US Army Corps of Engineers
Seattle District

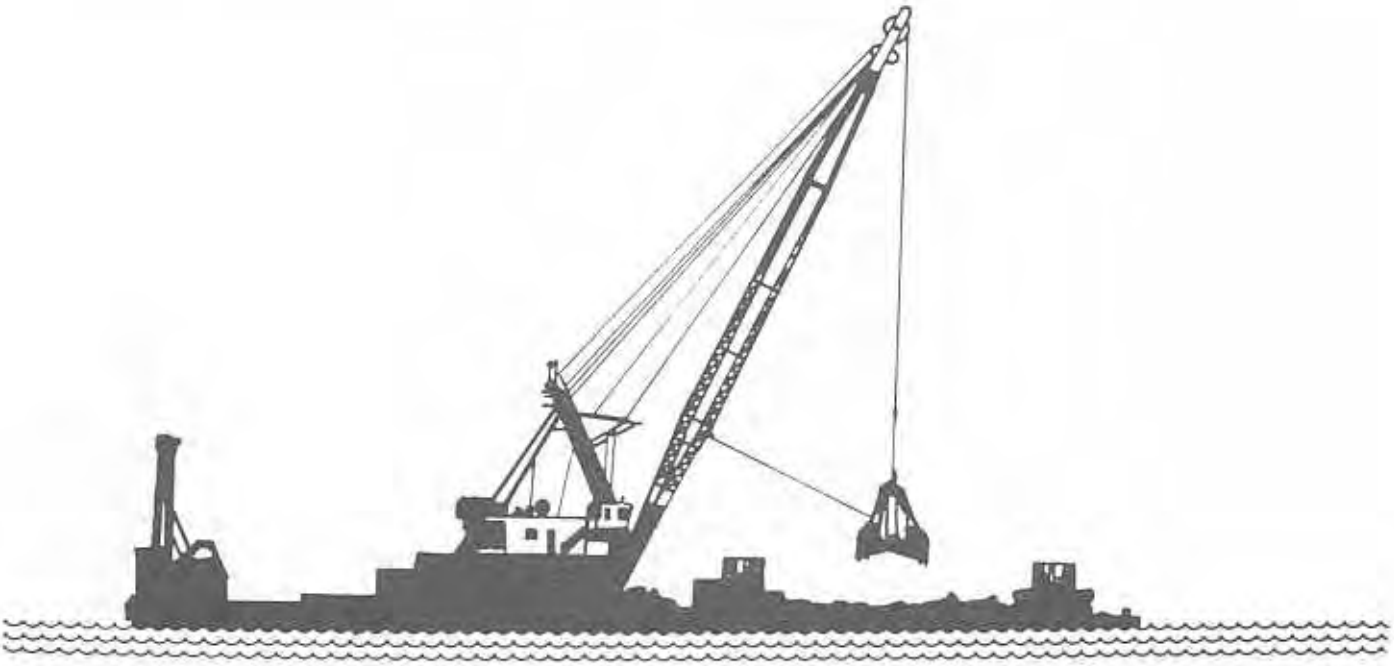
PSDDA Reports

Puget Sound Dredged Disposal Analysis

Washington State Dept. of Natural Resources

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

This files contains the executive summary, introduction, and Parts I and II.



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EPA Region 10

ECOLOGY

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.

ACKNOWLEDGEMENTS

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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.

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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.

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.

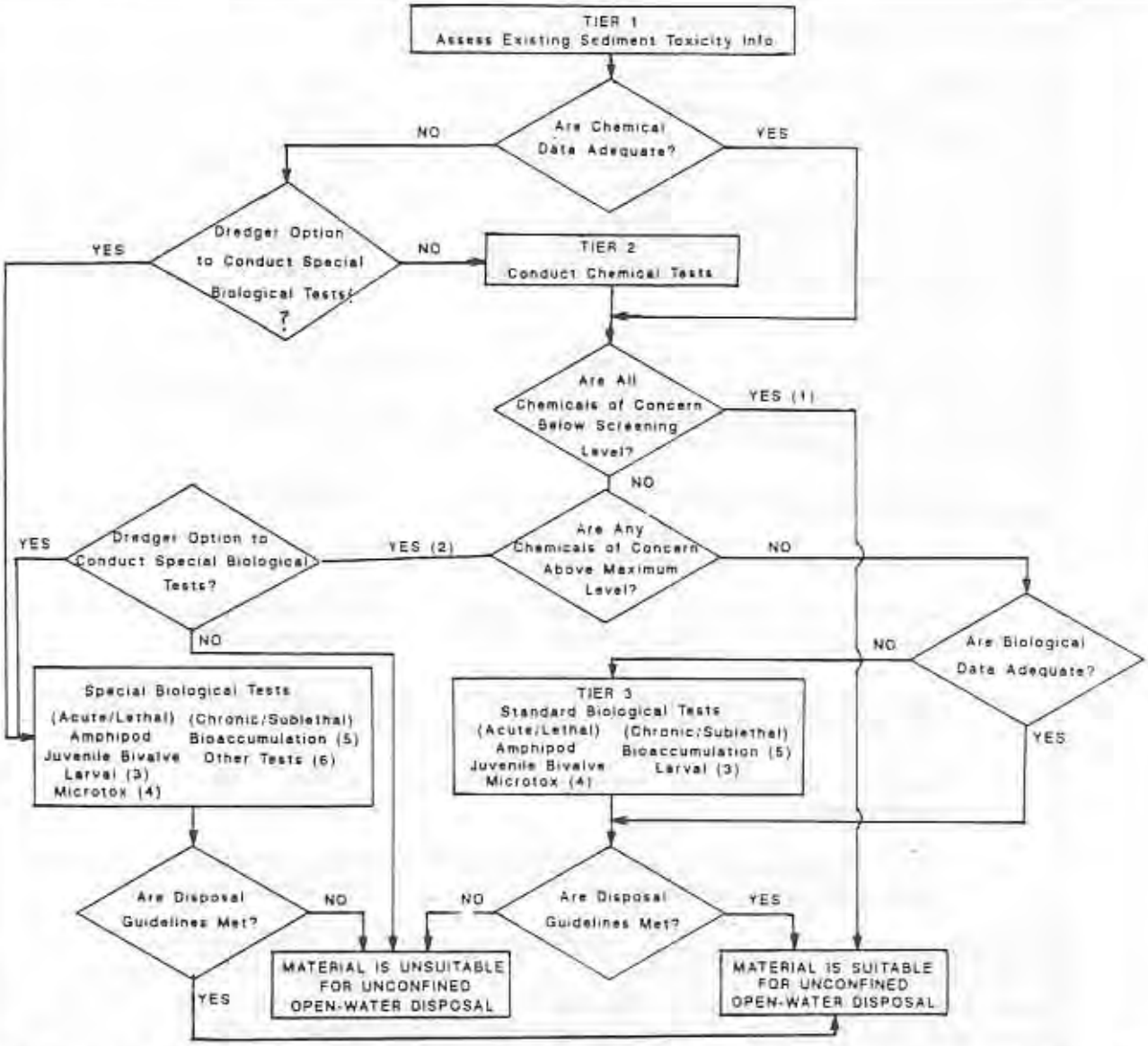
The evaluation procedures assessment sequence for unconfined open-water disposal includes three tiers:

- 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 biclogical 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:

- A demonstrated or suspected effect on ecology or human health.
- A widespread distribution or high concentration relative to natural conditions.
- A potential for remaining toxic for along time in the environment.
- 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 Guidelines
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:

- Unconfined, open-water disposal

- Confined aquatic disposal (capped to restrict contact with, or loss of, chemicals of concern)

- Confined nearshore disposal (intertidal diking, with some restrictions for chemicals of concern)

- Upland, intermediate secure disposal (using some special technology to restrict chemical losses)

- 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.

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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:

- Identify acceptable unconfined, open-water disposal sites.
- Define consistent and objective evaluation procedures for the dredged material to be discharged at those sites.
- 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:

- Disposal Site Work Group (DSWG)
- Evaluation Procedures Work Group (EPWG)
- 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

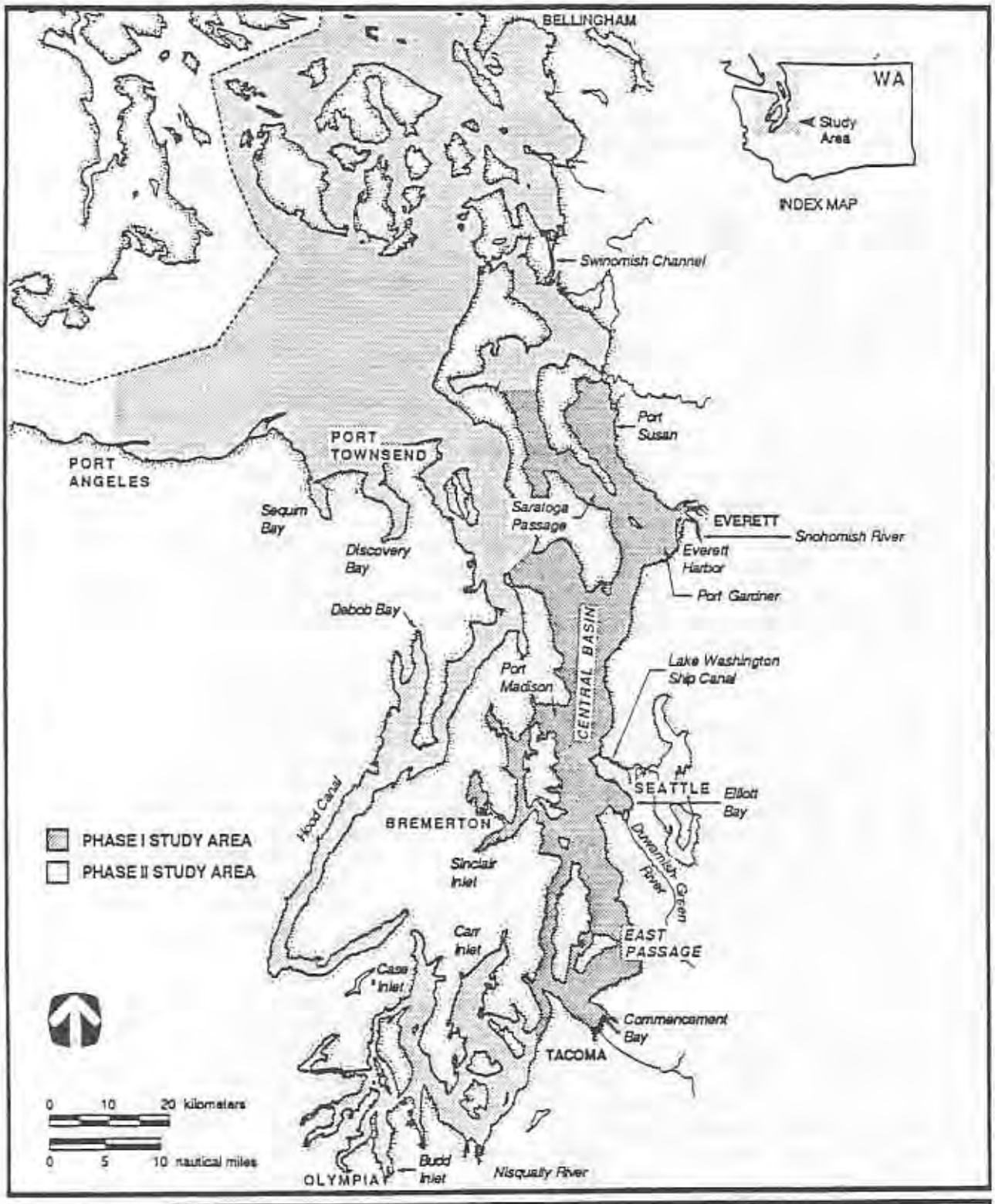


Figure I.1-1. PSDDA study areas.

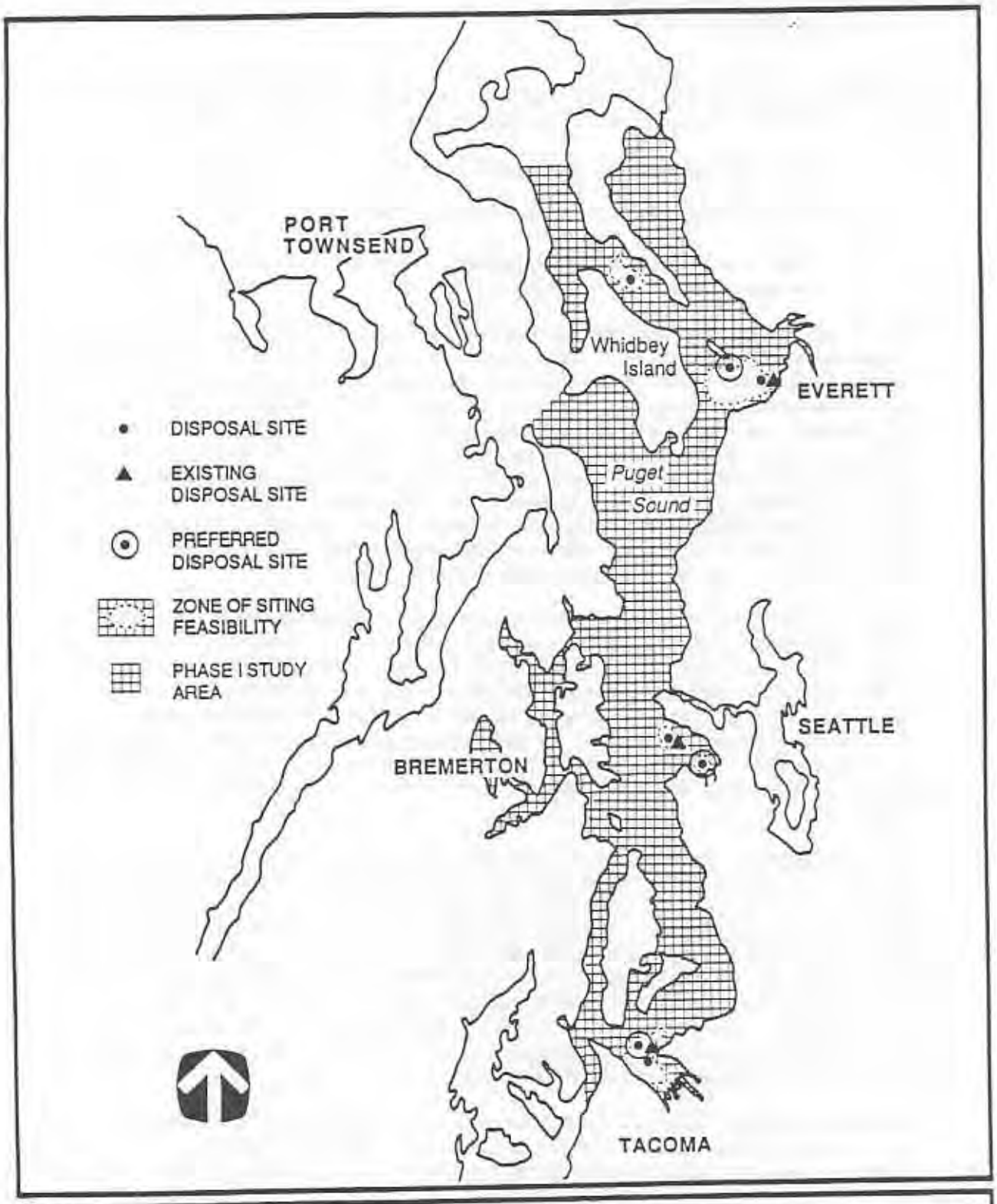


Figure I.I-2 PSDDA Phase I study area.

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

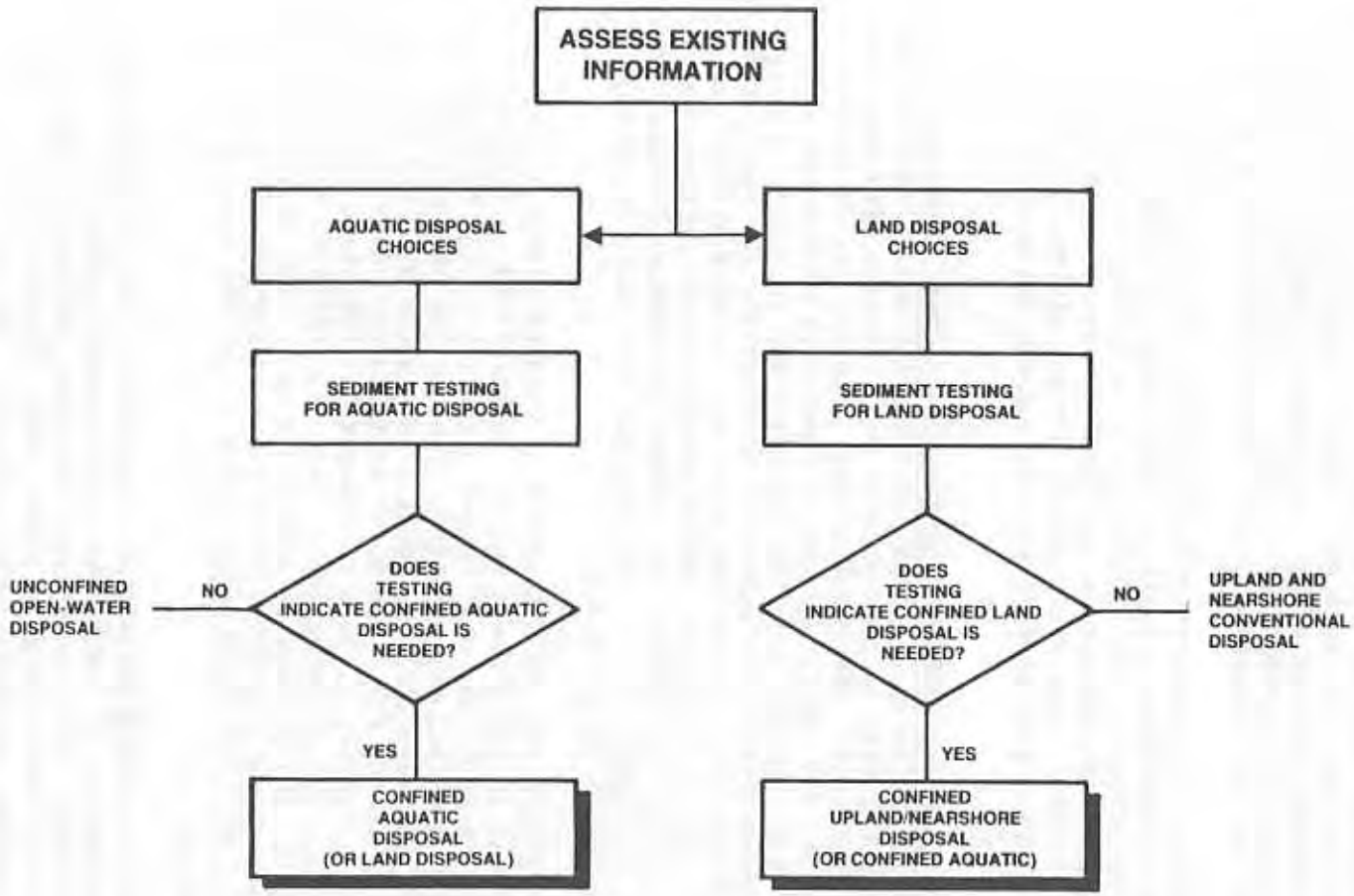


Figure I.1-3. Basic decision process for dredged material disposal.

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.

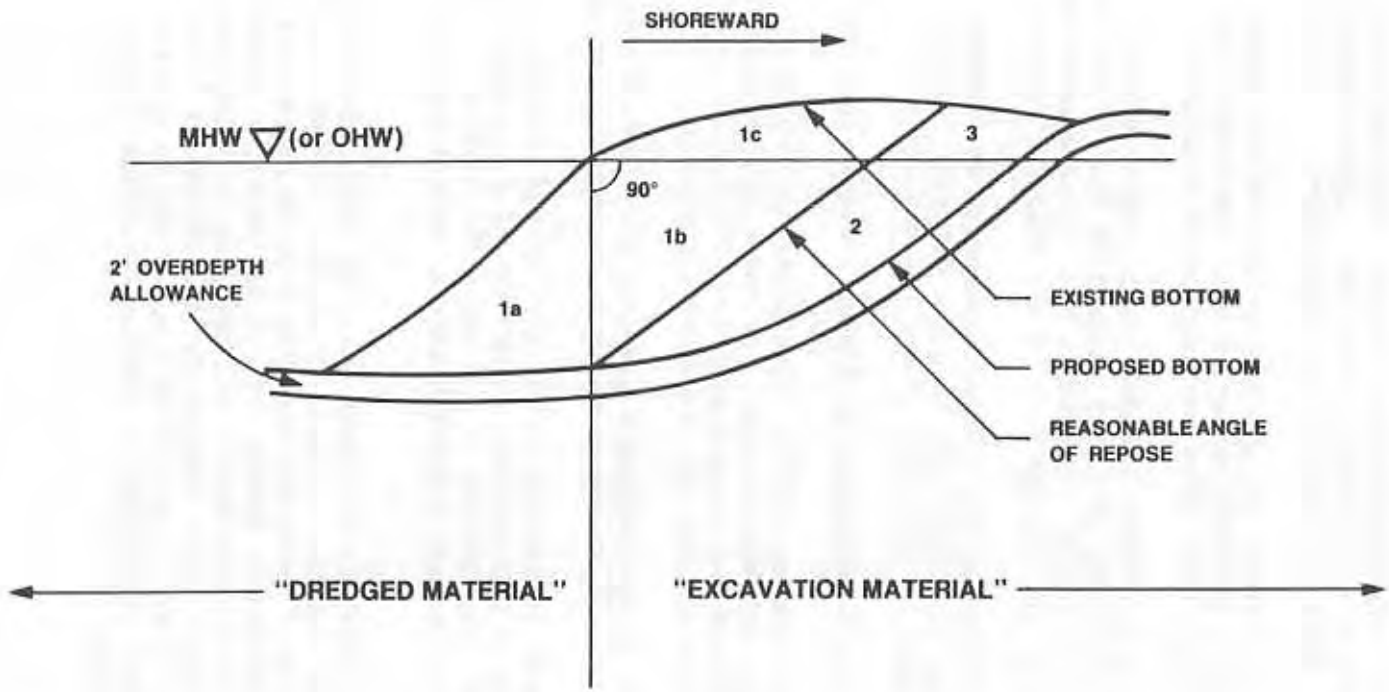


Figure I.2-1. Cross section of a dredging prism.

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:

- Accountable -- Any required tests as part of the permitting process must be justifiable to the individual permittee and to the public.
- Adaptable -- The requirements must be flexible enough to allow for project and site-specific concerns and be adaptable to projects of any size.
- 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.
- Cost effective -- The most cost-effective means of achieving the required technical adequacy must be applied.
- 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.
- Revisable -- Because scientific uncertainties exist, the procedures must be able to be updated to incorporate best current information and judgment.
- 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:

- 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.

- 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.

- 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.

- 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.

- 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:

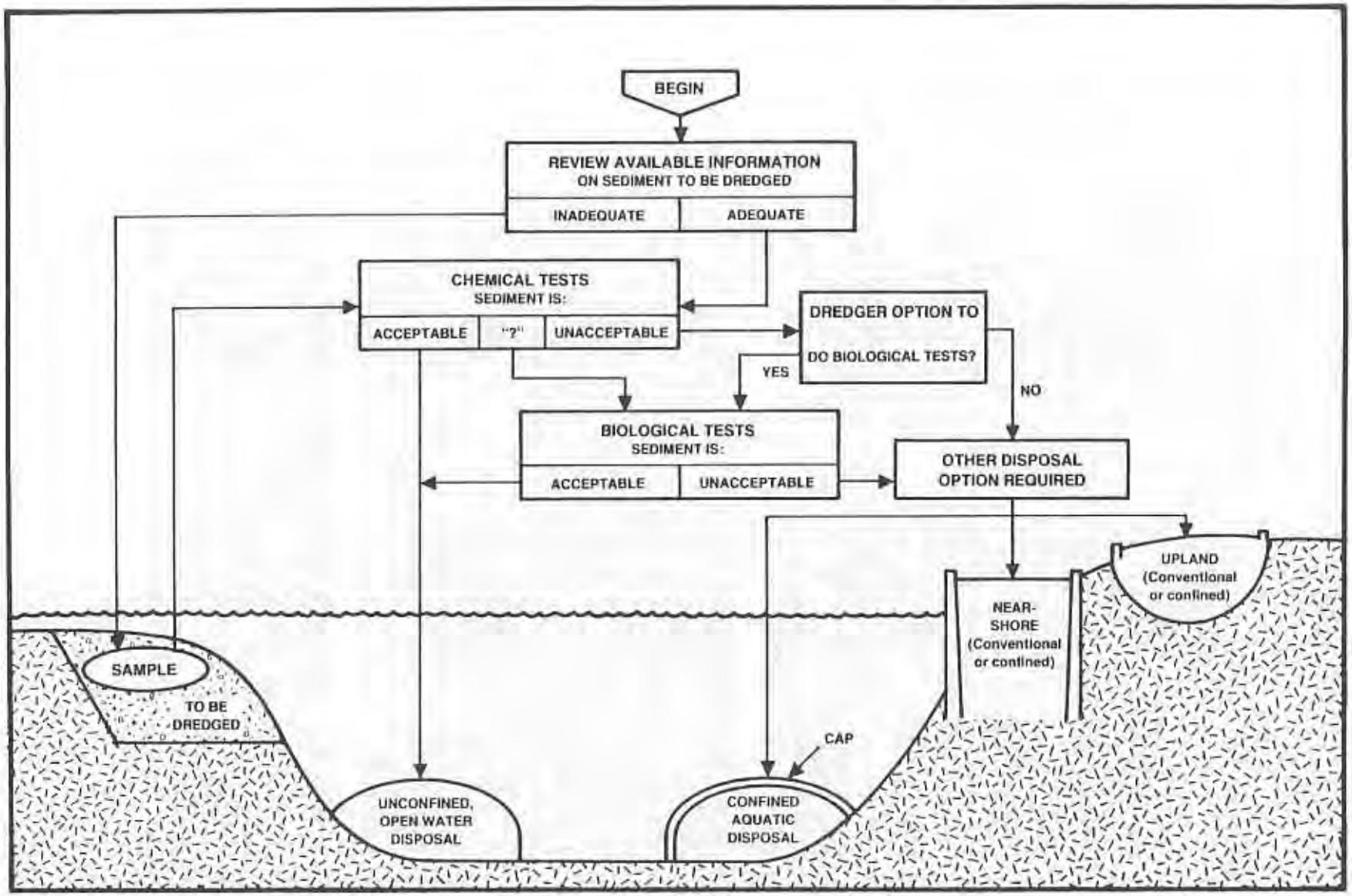


Figure I.3-1. Disposal testing strategy for unconfined, open water disposal.

- 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).

- 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).

- 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

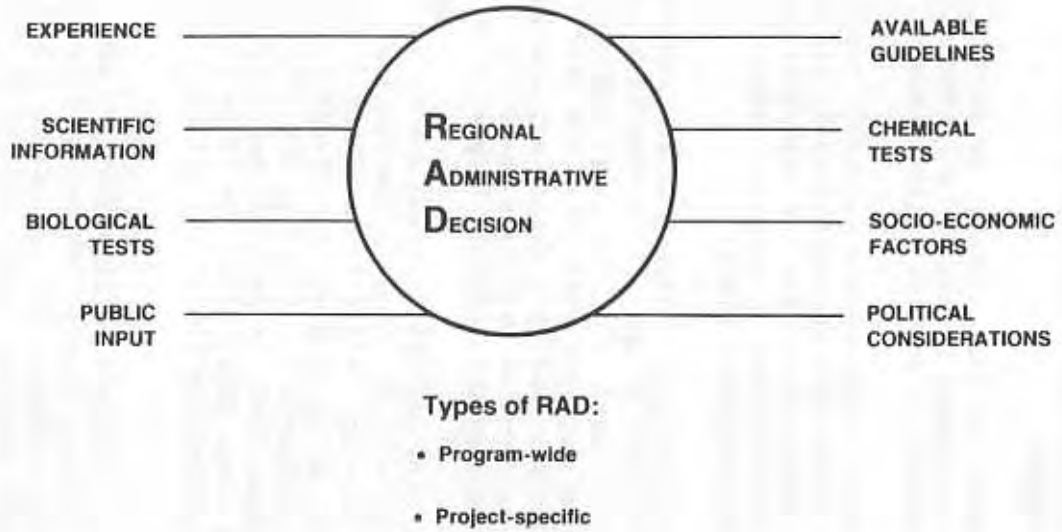


Figure I.3-2. Factors in Regional Administrative Decisions.

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 inhibiting 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).

- 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).

- 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:

- 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.

- 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

- 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

- 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."

- 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:

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

- 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.

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

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

- 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.

- 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.

- 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.

- 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:

- substrate,

- particulates/turbidity,

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

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

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

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

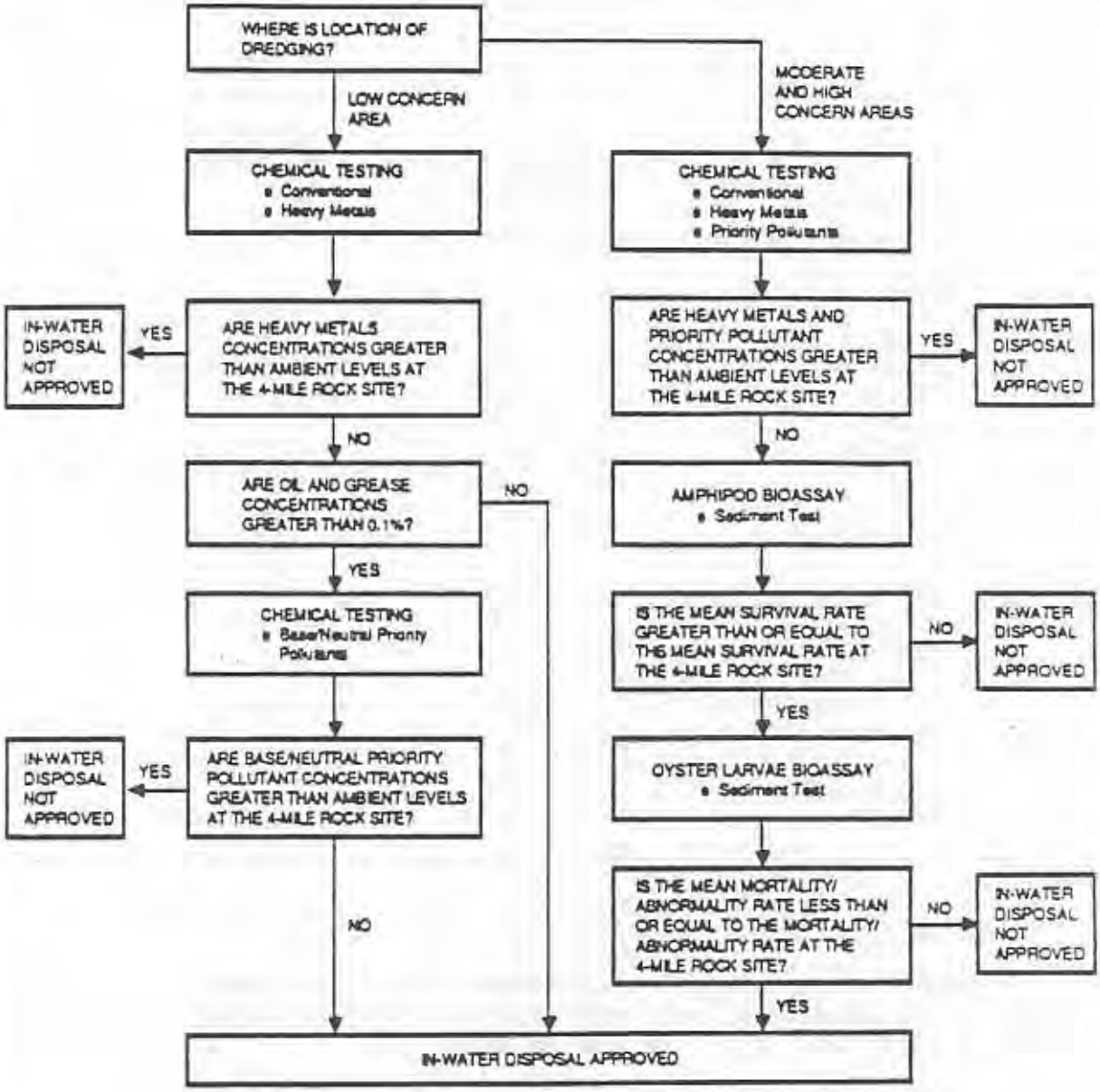


Figure II.1-1. Decision flow chart for Fourmile Rock interim dredged material disposal criteria.

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:

- 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.

- 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.

- 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.

- 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.

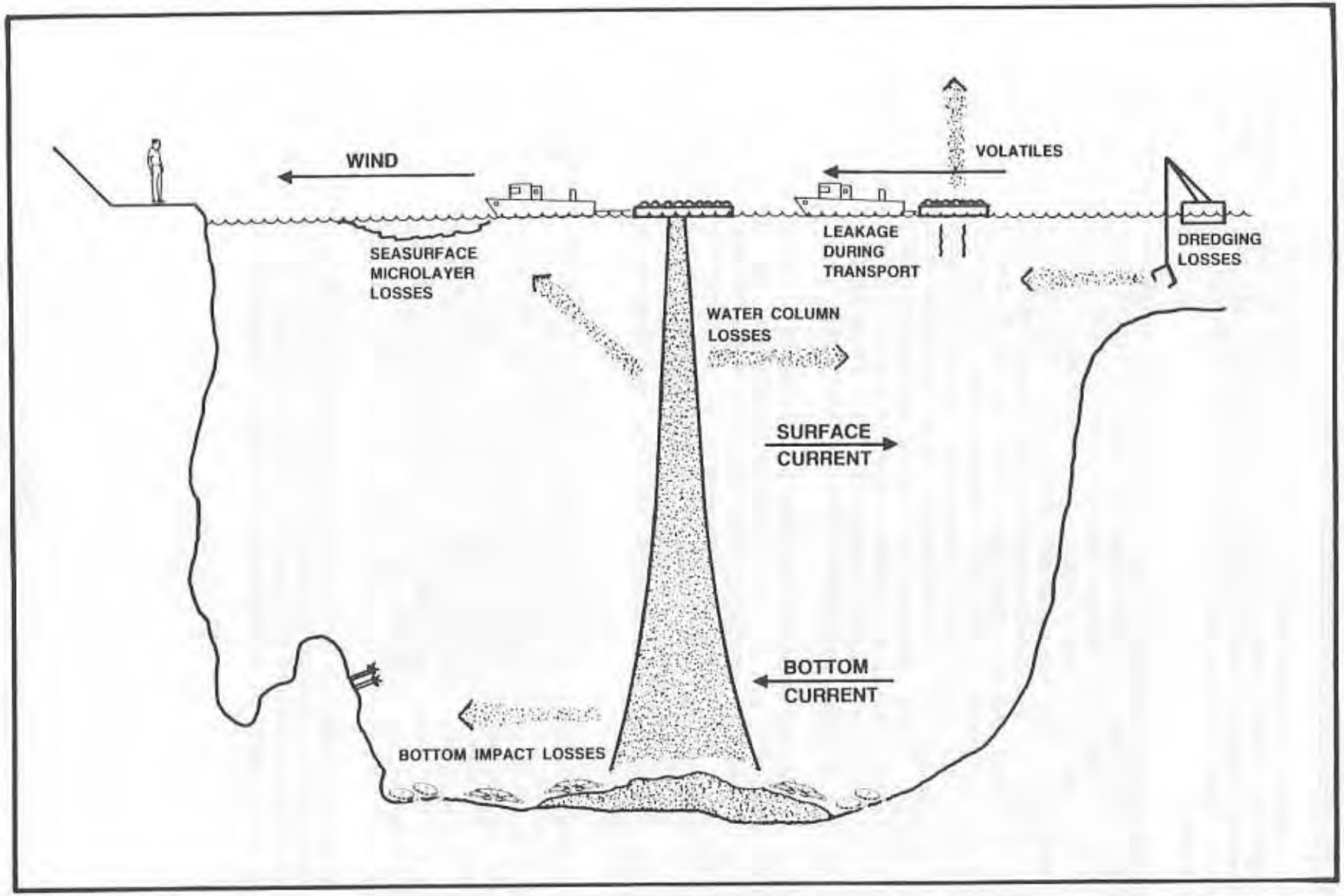


Figure II.2-1. Dredging and disposal processes.

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.

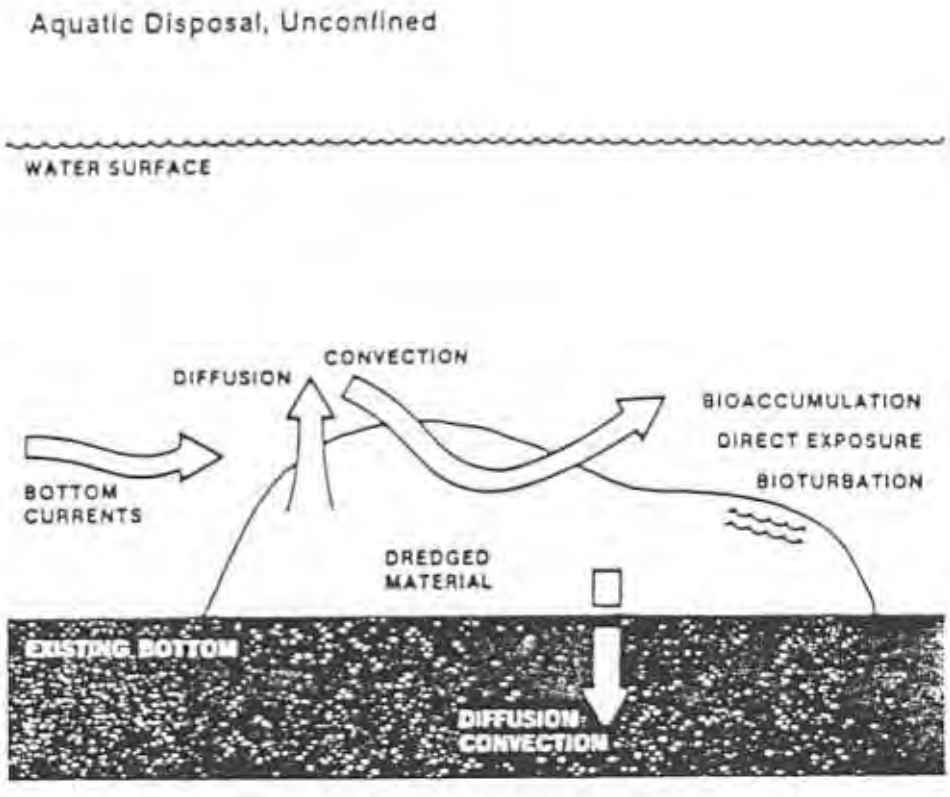


Figure II.2-2. Environmental pathways for unconfined open-water disposal.

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):

- 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).

- 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

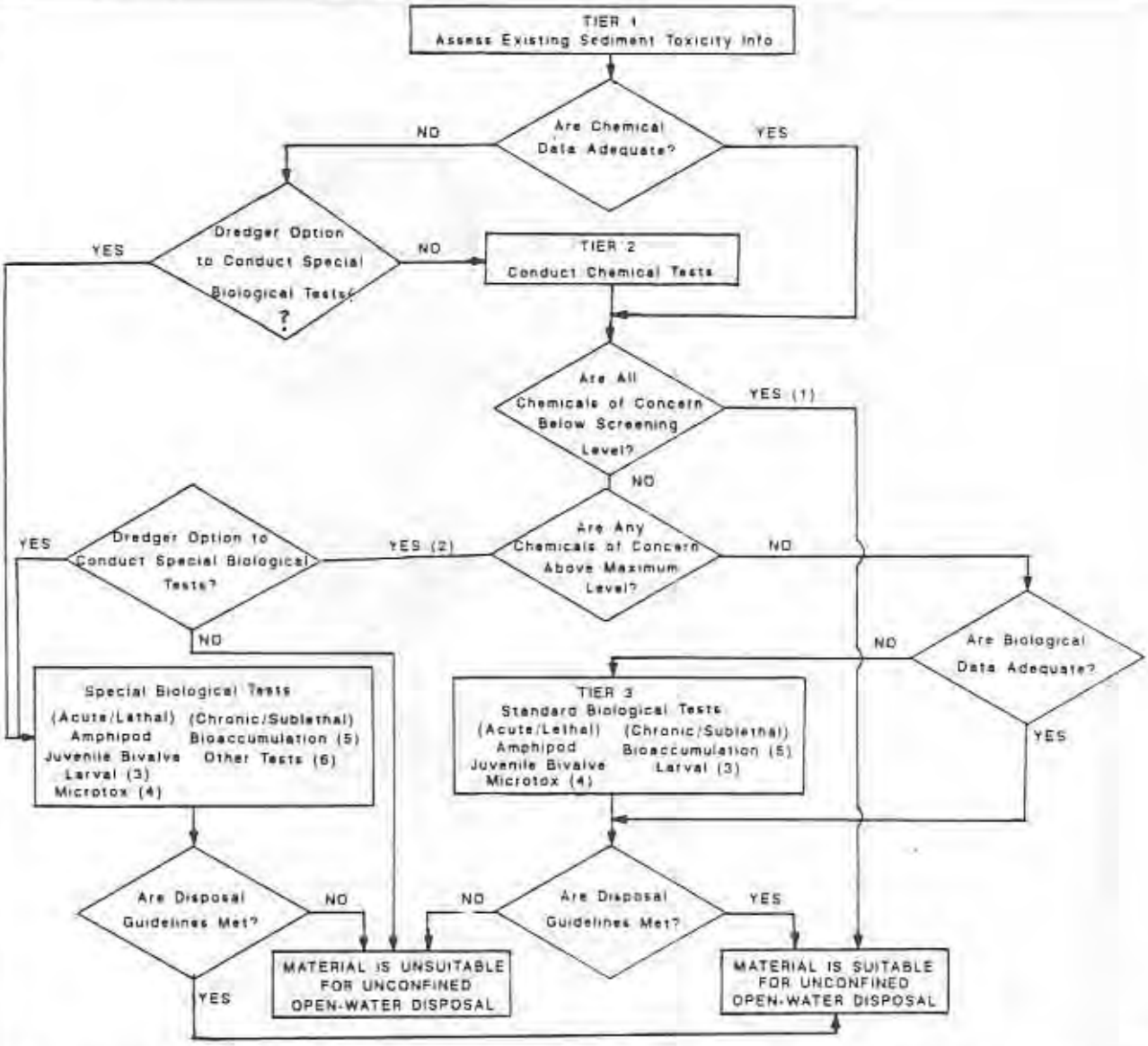
of chemical effects has shifted to sediment particles. Disposal models (dump models) are used to predict where discharges will land on the bottom and the amount of material that might be left in suspension after various time periods. In most cases, the models (and supporting field data) indicate that 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 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)

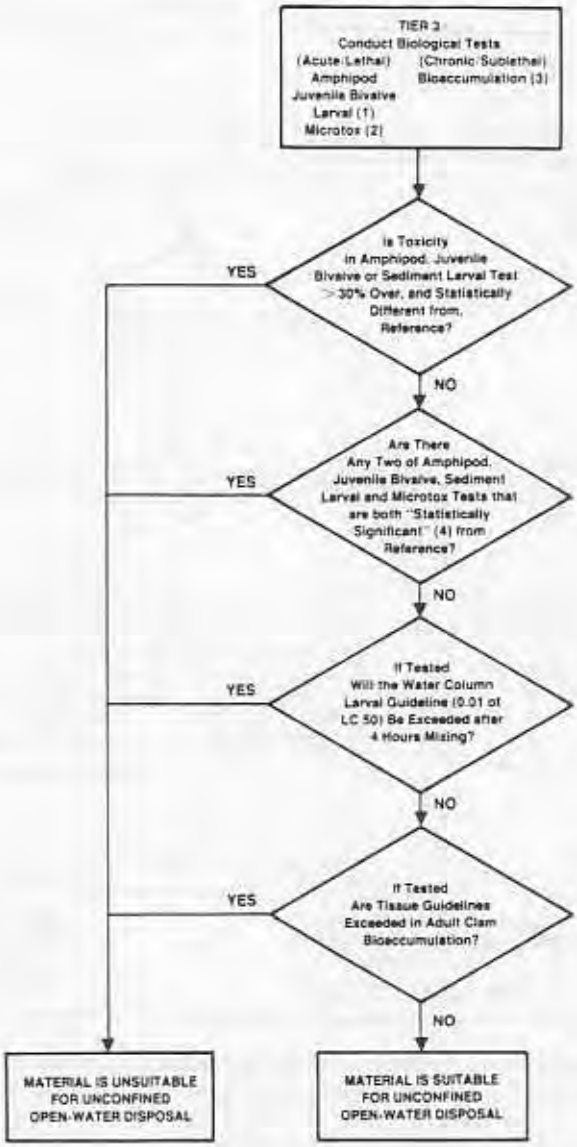
(3) The larval species can be used in either a sediment toxicity bioassy (for Section 401) and/or in a water column bioassy (for Section 404) The sediment larval test is required whenever biological testing is necessary, the water column larval test is only required when water column effects are of concern

(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 II2-3 PSDDA testing sequence.



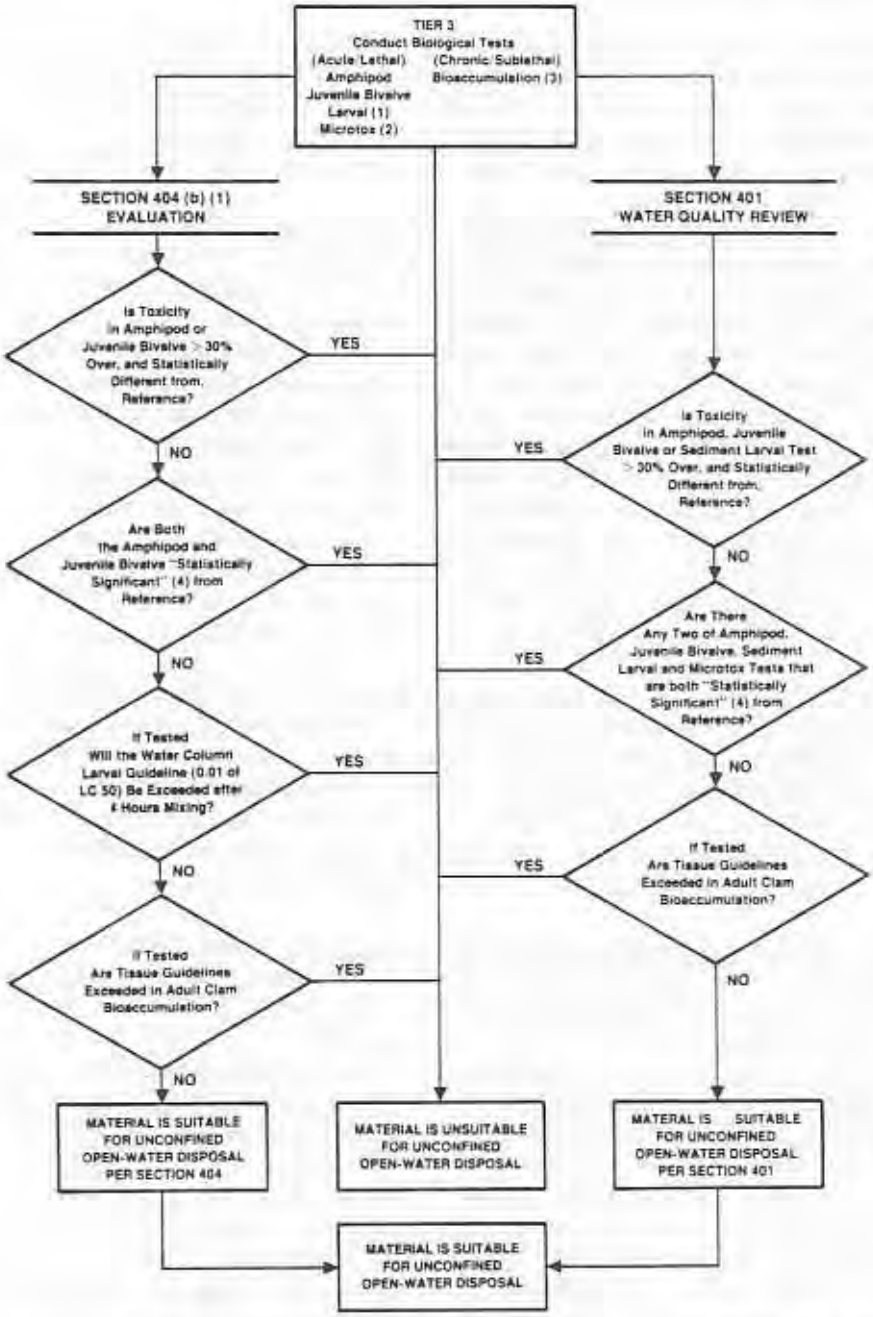
(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(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.

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

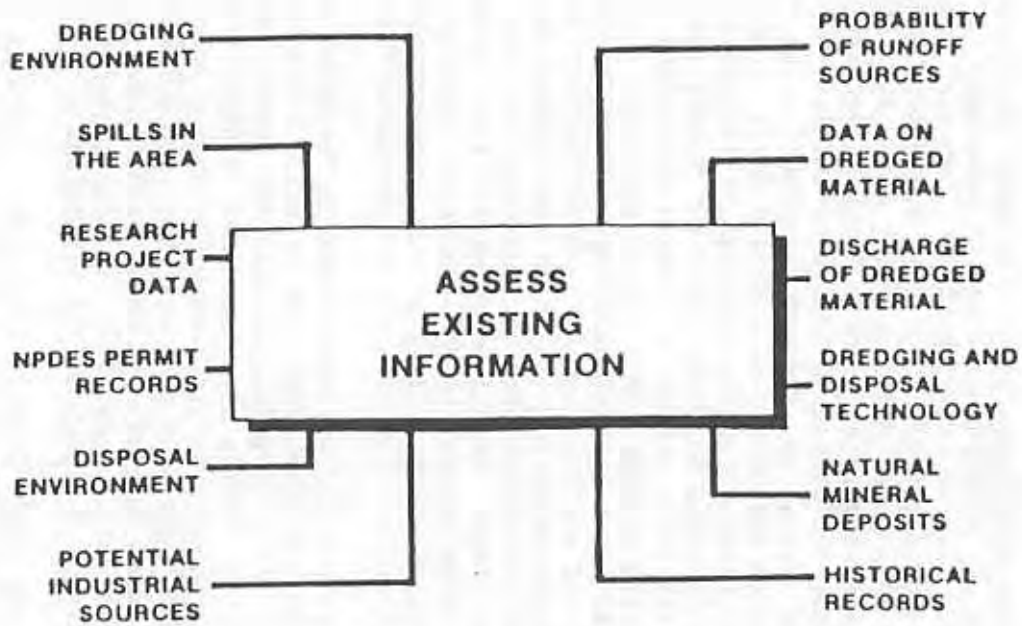


Figure II.3-1. Sources of existing information.

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:

- Sampling and analytical method (chemistry and bioassay results)
- Chemical detection limits
- Bioassay control sediment
- 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

	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	
Area Rank	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 1986i). 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 ± 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.

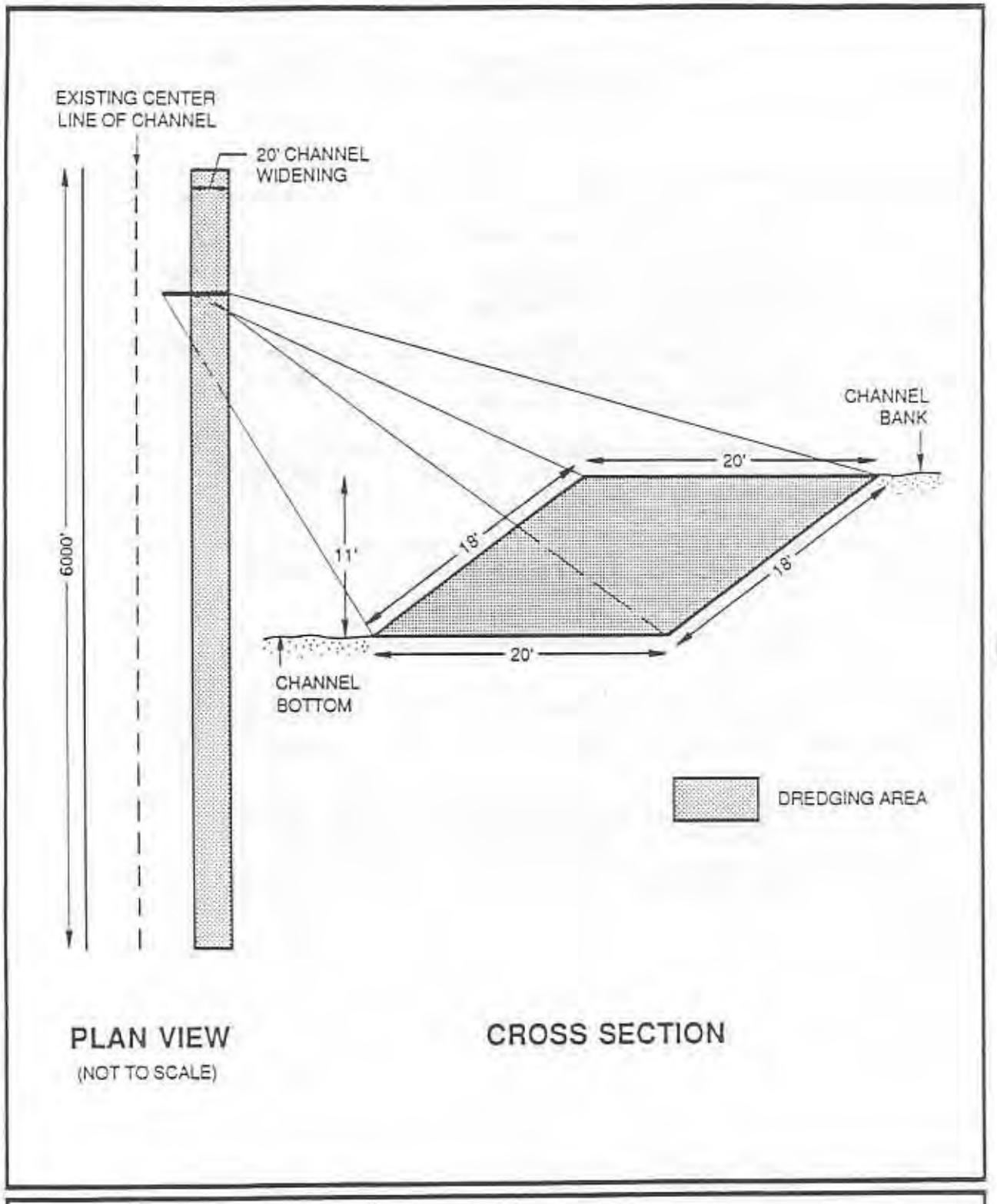


Figure II.4-1. Plan view and cross section of example dredging project.

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)

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

[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.:

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

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:

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

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:

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

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.

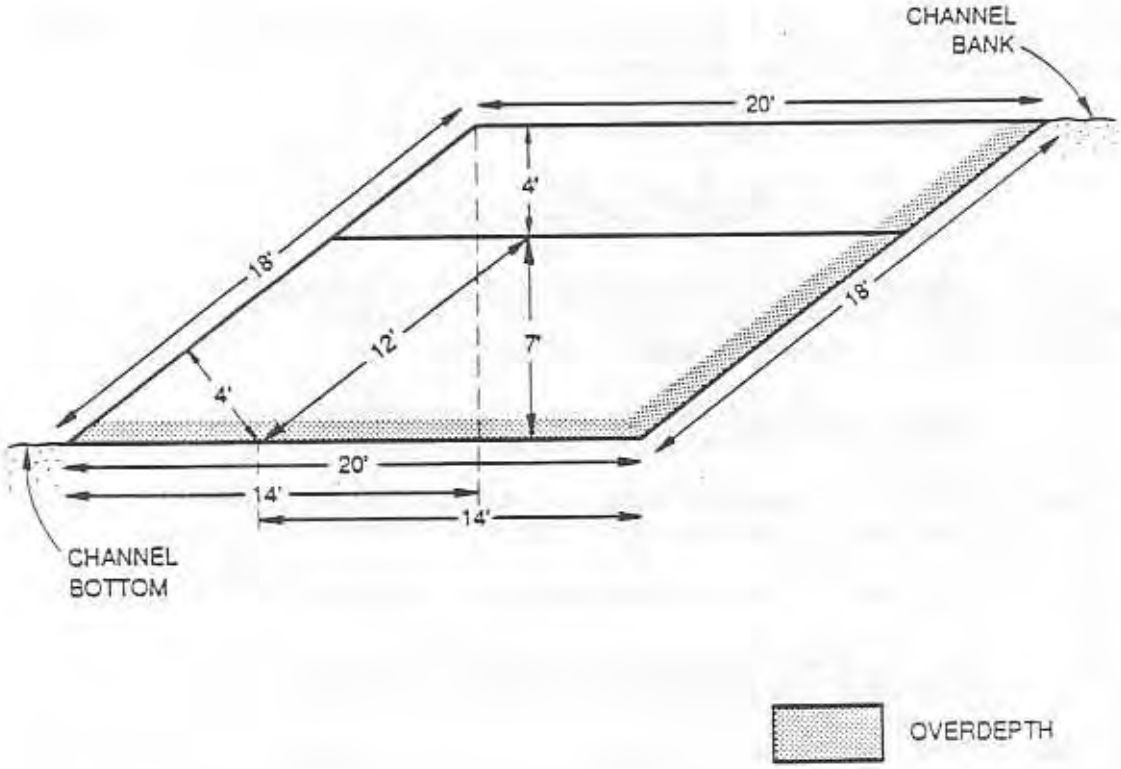
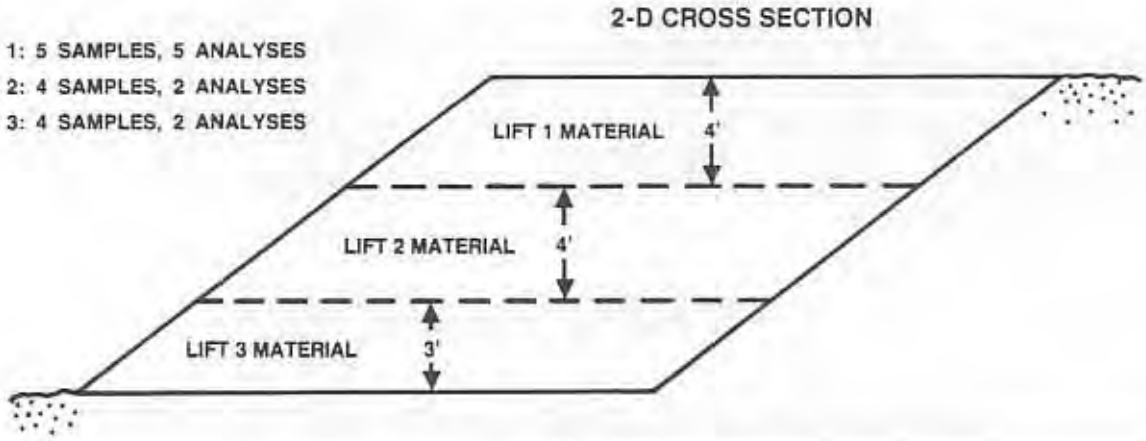


Figure II.4-2. Dimensions of example dredging prism used to estimate dredging volumes.

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

3-D CROSS SECTION

TOTAL: 9 CORING STATIONS

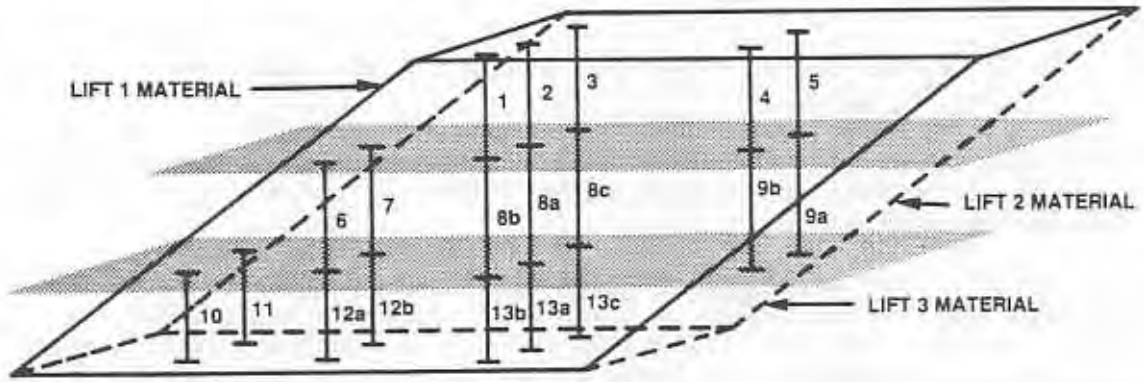


Figure II.4-3. Example of (A) vertical lifts in dredging prism, and (B) allocations of samples among lifts.

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:

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

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 II.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

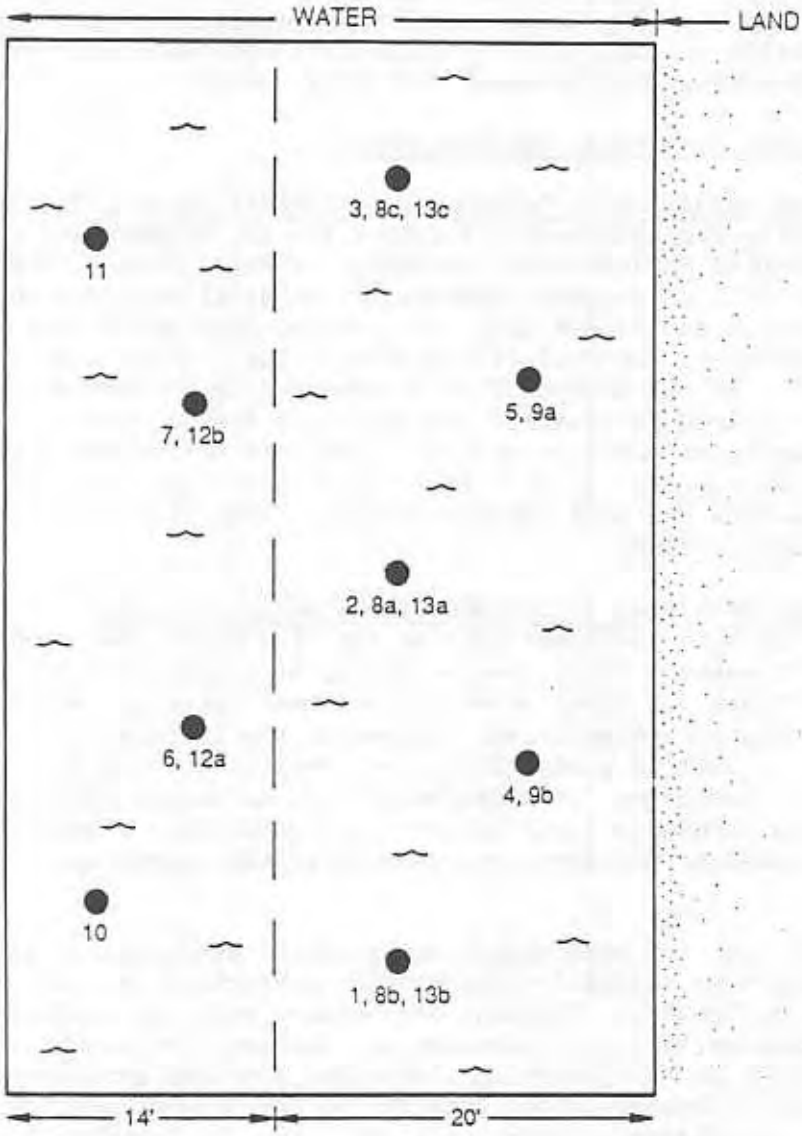


Figure II.4-4. Plan view of sampling stations in dredging prism.

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. 1986). 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. 1986).

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.

ERWG 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 gyrociliatus) 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.

- A demonstrated or suspected effect on ecology or human health (i.e., the focus of chemical concerns is ultimately unacceptable adverse biological effects).

- The chemical has a widespread distribution or high concentration relative to natural conditions (i.e., one or more present or historical sources).

- A potential for remaining toxic for a long time in the environment (biopersistent).

- 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:

- Cyanides
- Organotin complexes
- Chloroform
- 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.

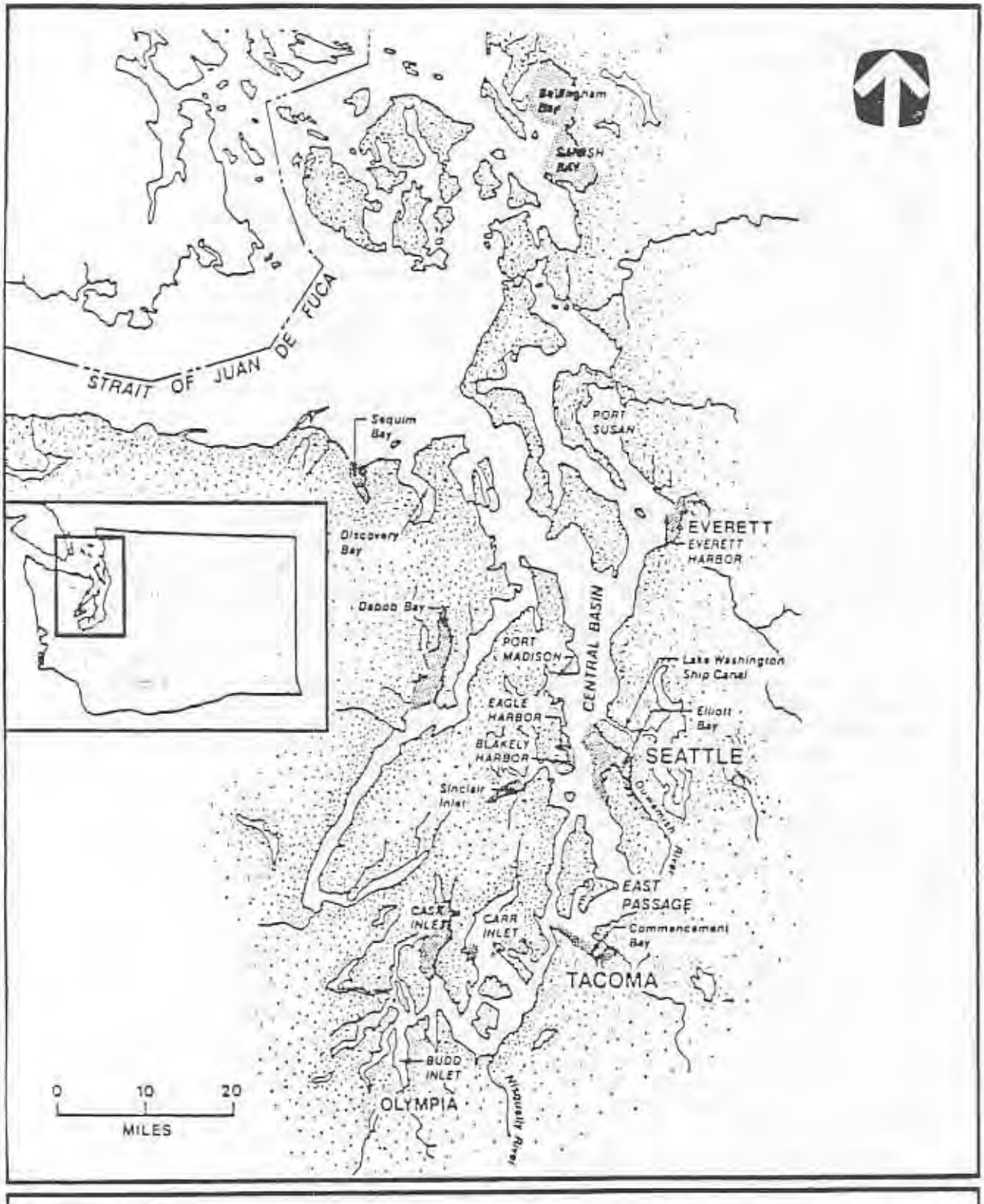


Figure II.7-1. Location of chemical and biological samples included in Puget Sound database.

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.

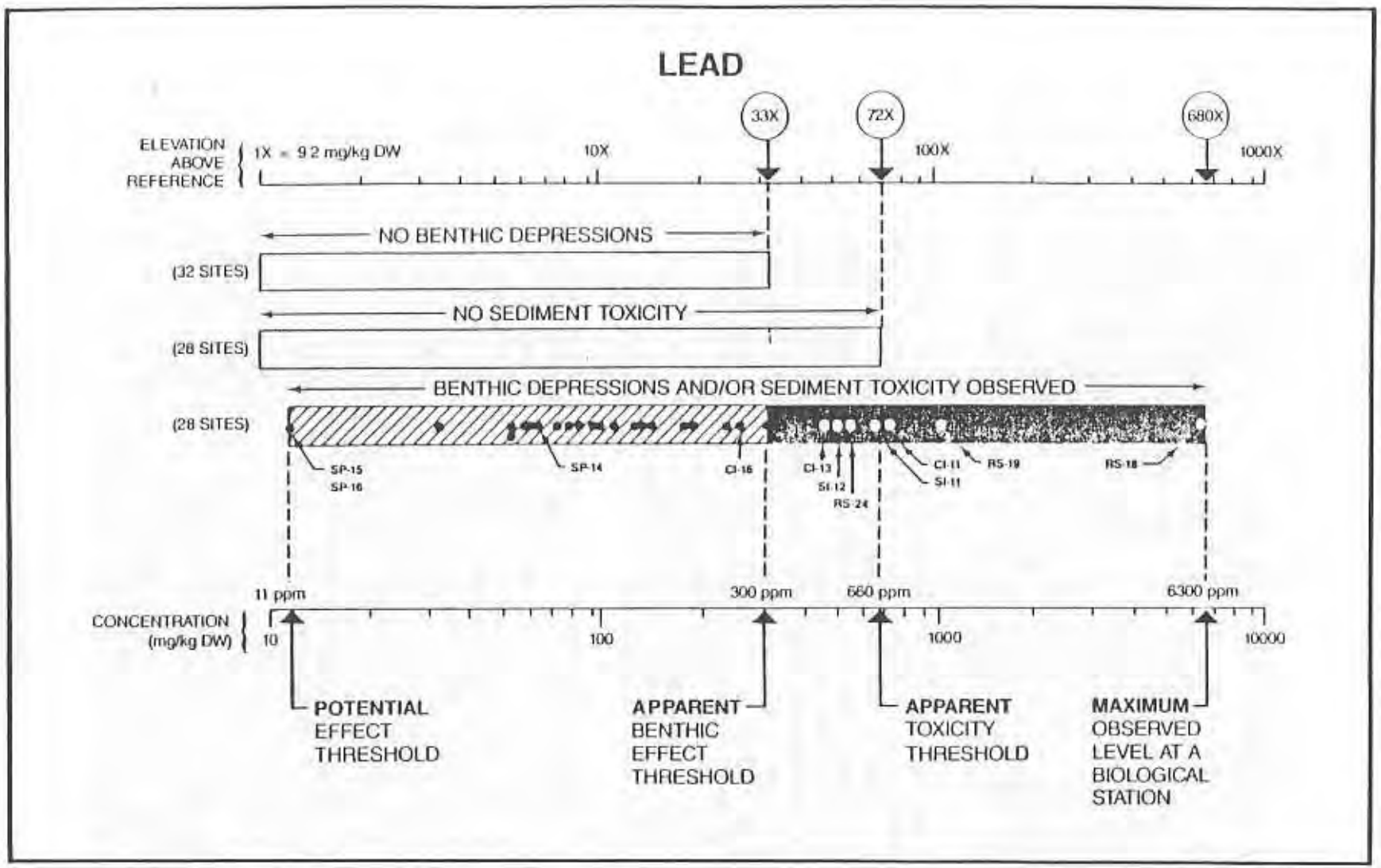


Figure II.7-2. The Apparent Effects Threshold (AET) approach applied for a single chemical (lead) [Data are taken from Tetra Tech (1985a)].

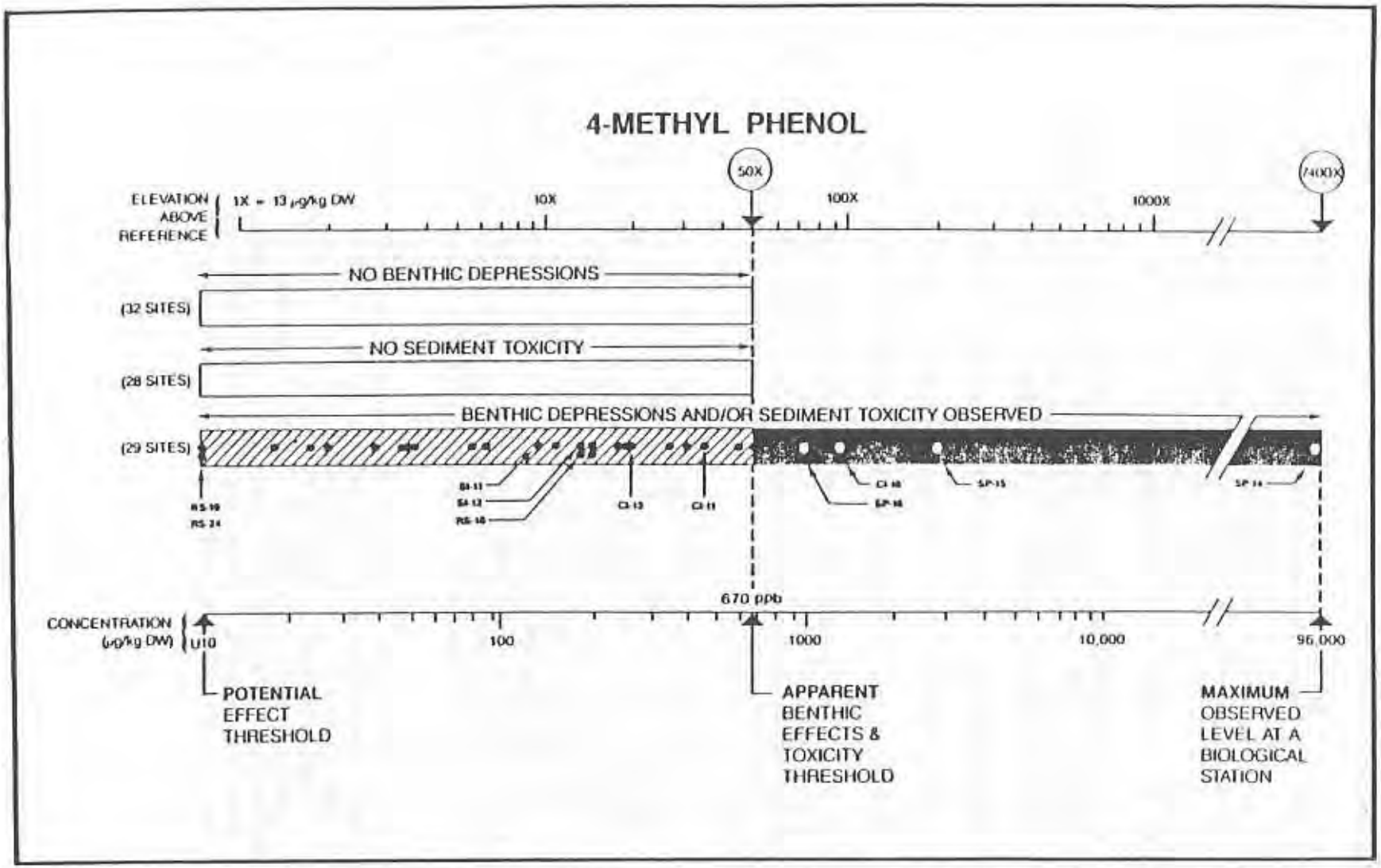


Figure II.7-3. The apparent effects threshold (AET) approach applied for a single chemical (4-methyl phenol) (from Tetra Tech, 1985a).

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:

- Sediments that did not exhibit significant infaunal depressions
- Sediments that did not exhibit significant toxicity
- 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 1986l).

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 1986l).

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:

- Total volatile solids.
- Grain size distribution (i.e., percent rocks, gravel, sand, silt, clay).
- Total organic carbon (TOC).
- Percent solids.
- Total sulfides.
- 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:

- 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.

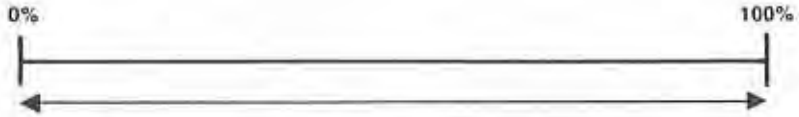
The maximum degree of potential biological effects (section II-8.2) and of chemicals of concern (section II-8.3) were defined for each of the three site conditions. Chemical "trigger" levels for the initiation of bioaccumulation tests in the characterization of dredged material were also defined (section 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:

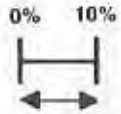
- Site Condition I: "No significant sublethal, chronic toxicity"
- Site Condition II: "No significant acute toxicity"
- Site Condition III: "No severe acute toxicity"

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.

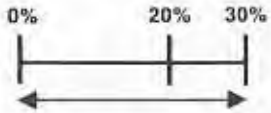
1. RANGE OF ABSOLUTE MORTALITY IN TEST RESULTS.



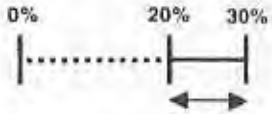
2. RANGE OF PERFORMANCE STANDARD FOR CONTROL RESULTS (≤ 10% ABSOLUTE MORTALITY).



3. RANGE OF ACCEPTABLE REFERENCE RESULTS (PERFORMANCE STANDARD RANGE IS ≤ 20% OVER CONTROL).



4. RANGE OF LOWER LIMIT OF "STATISTICALLY SIGNIFICANT MORTALITY" IN DREDGED MATERIAL RESULTS (≥ 20% OVER CONTROL).



5. RANGE OF SINGLE-SPECIES (AMPHIPOD, JUVENILE BIVALVE OR SEDIMENT OYSTER) UPPER LIMIT OF "NO SIGNIFICANT ACUTE TOXICITY" (≤ 30% OVER REFERENCE).

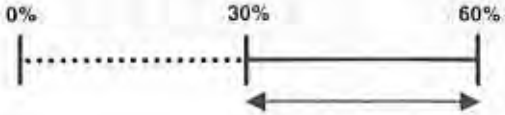


Figure II.8-1. Relationship of control, reference, and test treatment bioassay results in determining significant acute toxicity in sediment toxicity tests for dredged material.

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/1, 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.

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:

- Human exposure route is primarily through consumption of fish that could be directly exposed to bottom sediments at the disposal site (i.e., flatfish)

- All human exposure (consumption of flatfish) comes from a single population of fish having a home range that includes the disposal site

- Exposure of the flatfish population is directly proportional to the area of the home range covered by the disposal site

- Tissue concentrations of flatfish are directly proportional to exposure at the site (assumes 100 percent assimilation of chemicals of concern)

- 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 =

$$\frac{395 \text{ ac}}{2{,}334 \text{ ac}} \times 100 = 17 \text{ percent}$$

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.).

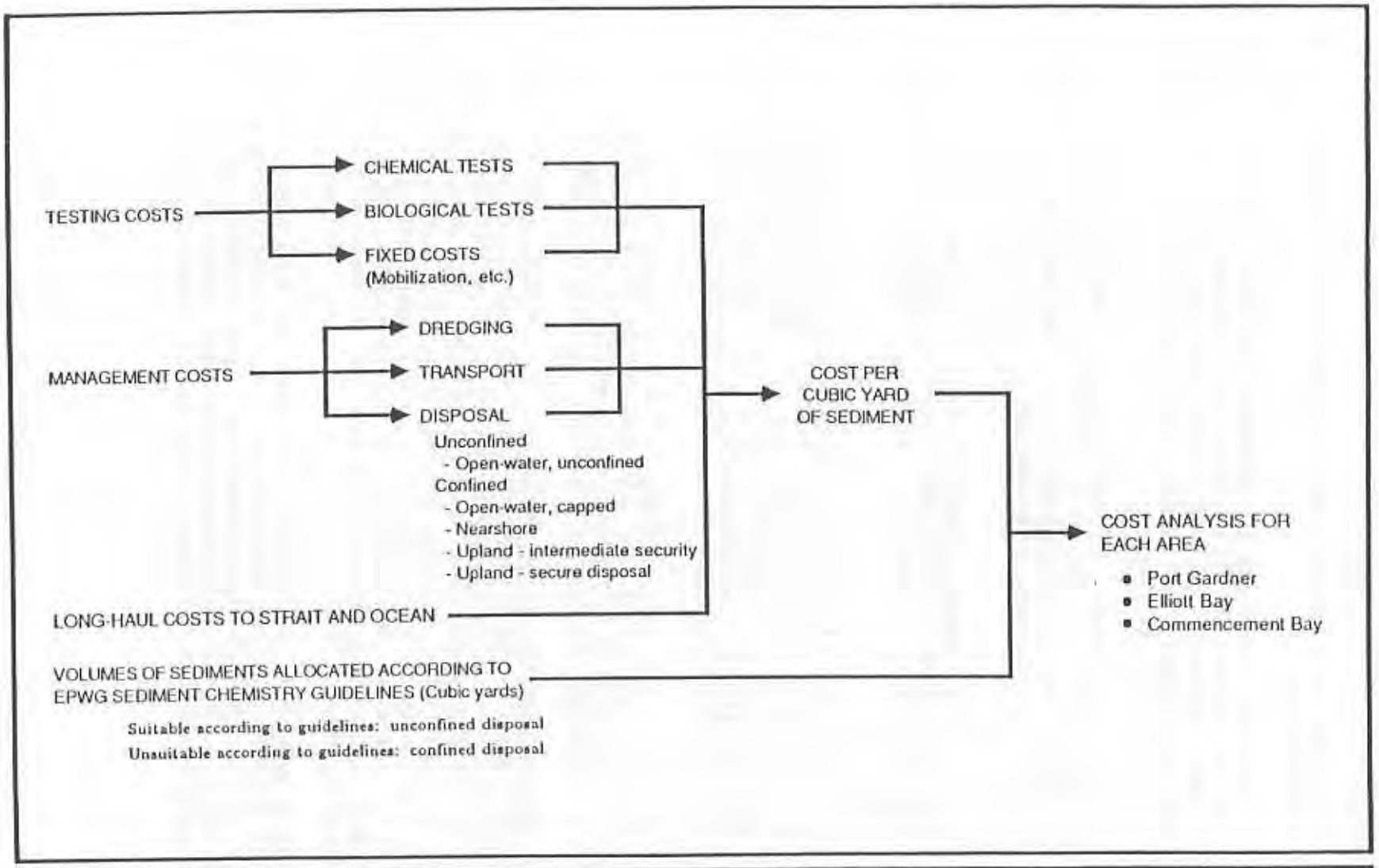


Figure II.10-1. Relationship of testing and dredged material management analyses to the overall cost analysis for dredging areas.

- All costs were adjusted to mid-1986 costs based on a 6 percent annual inflation rate.

- 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.

- 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.

- 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.

- 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.

- 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

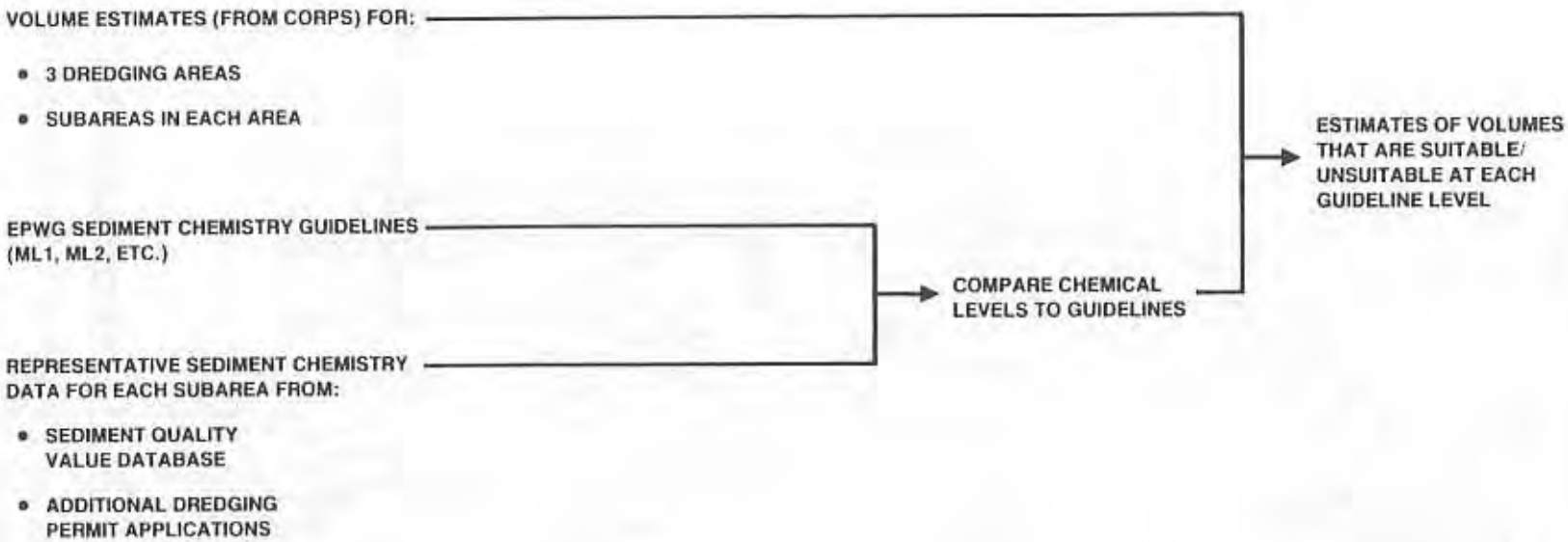


Figure II.10-2. Methods for quantifying dredged material volumes according to each EPWG site condition.

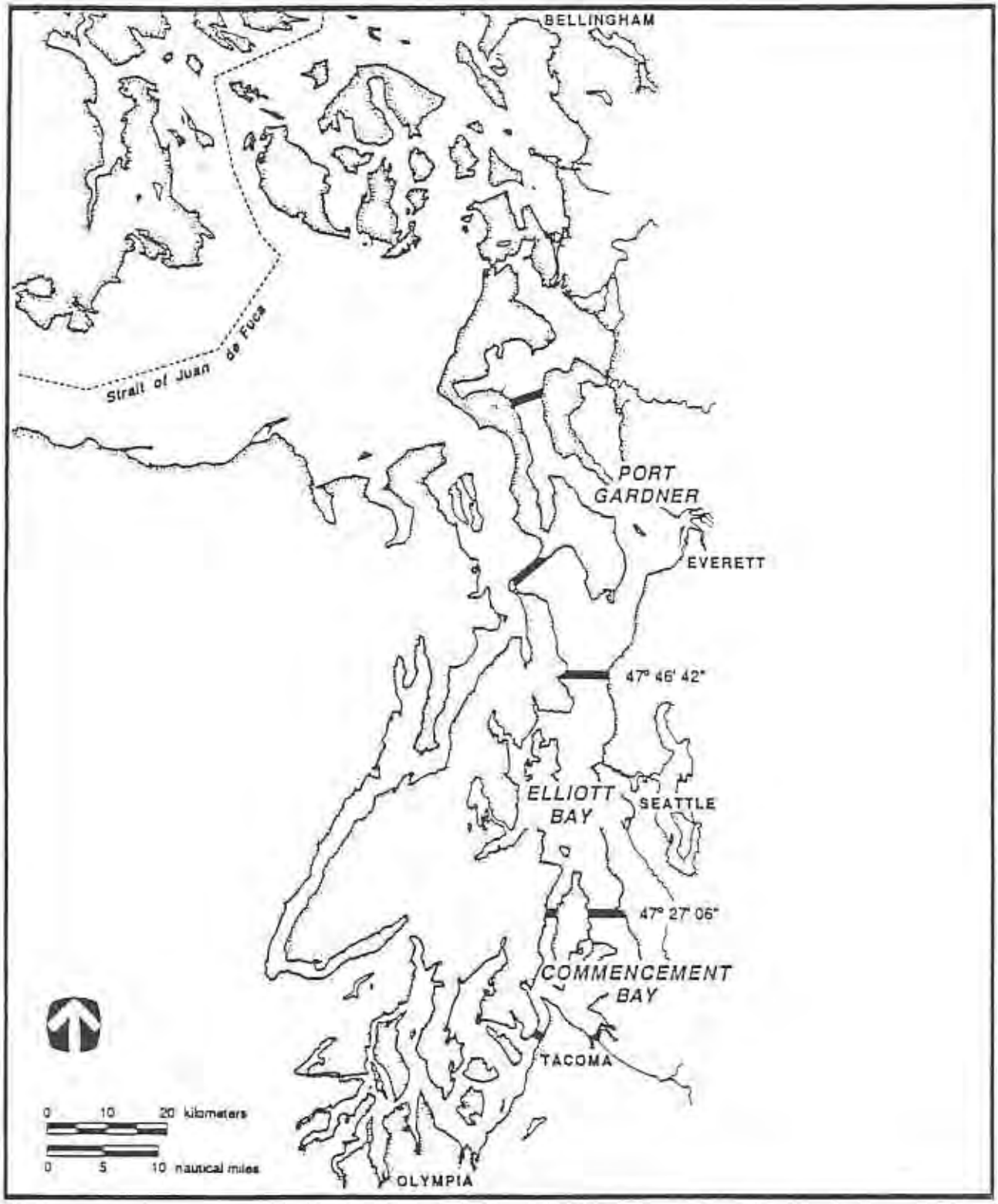


Figure II.10-3. Locations of the three Phase I dredging areas in central Puget Sound.

(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	PSDLA 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	6800	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.

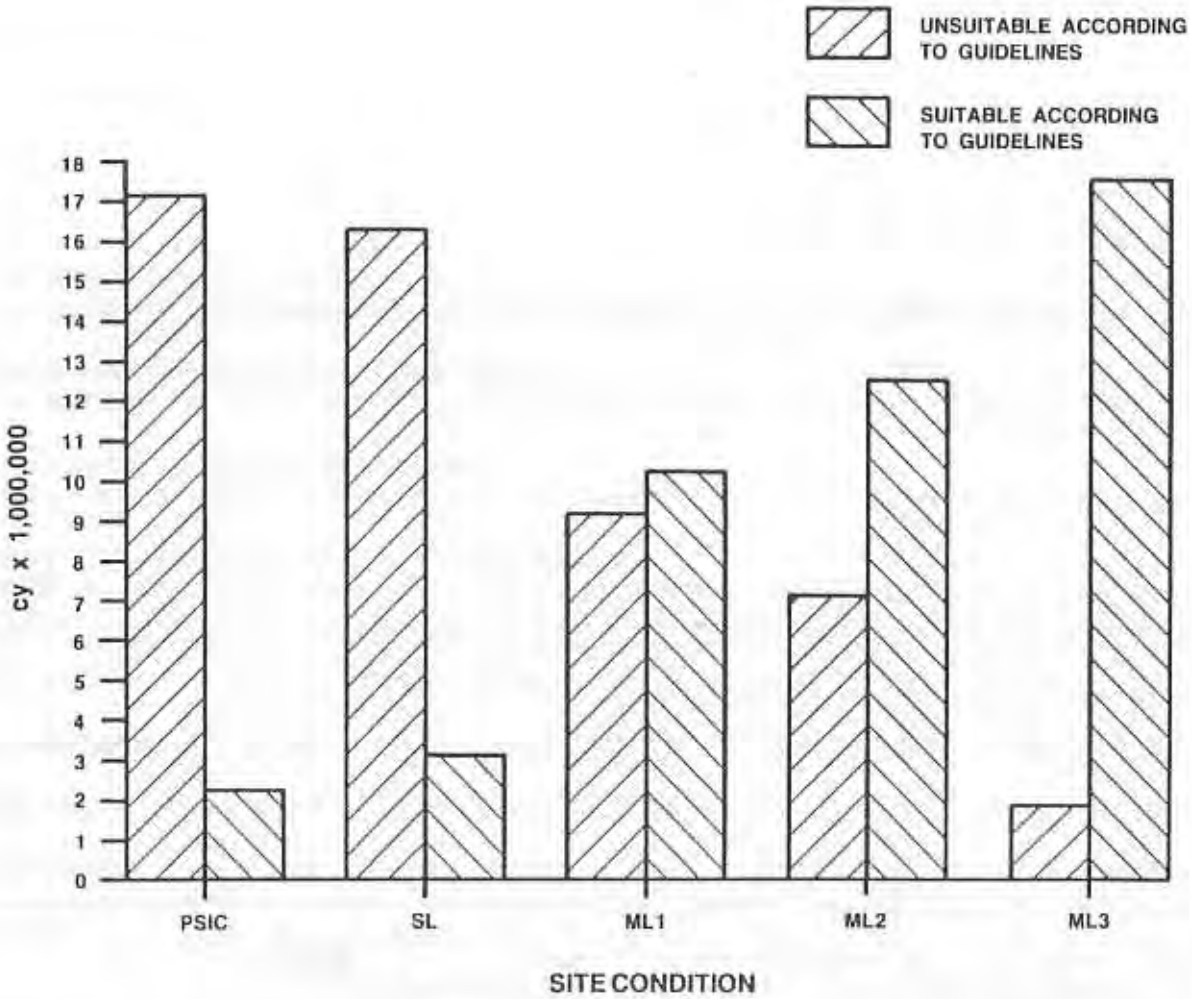


Figure II.10-4. Total sediment allocation for each sediment chemistry guideline level (see Table II.10-4).

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:

- Dredging and placement of sediments in a conveyance (barge or pipeline)
- Transport of the sediment from the project site to the disposal site
- 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 = (-0.5logN+3) x 11.25 x 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.

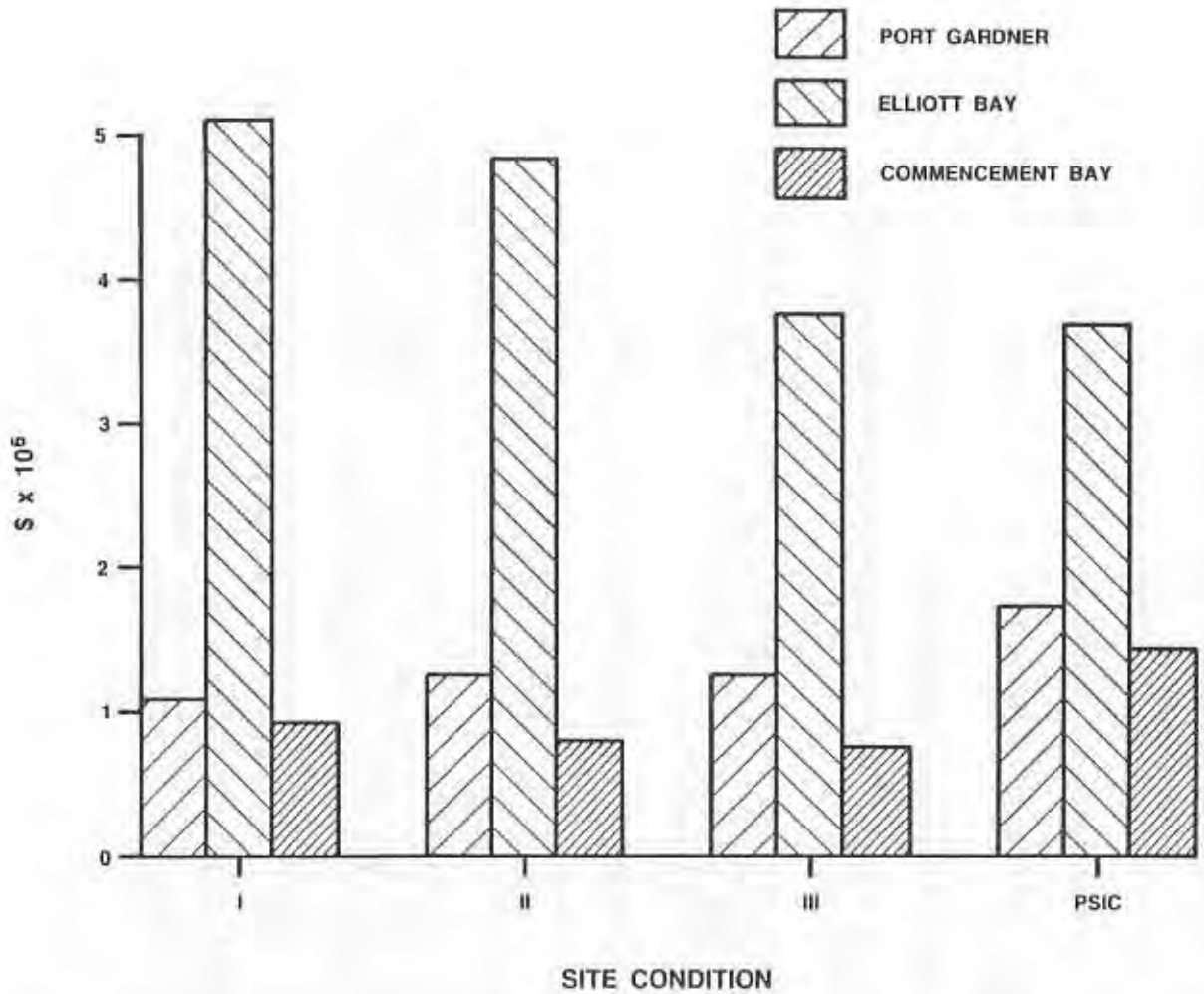


Figure II.10-5. Comparison of sampling and testing costs for each dredging area. (see Table II.10-9).

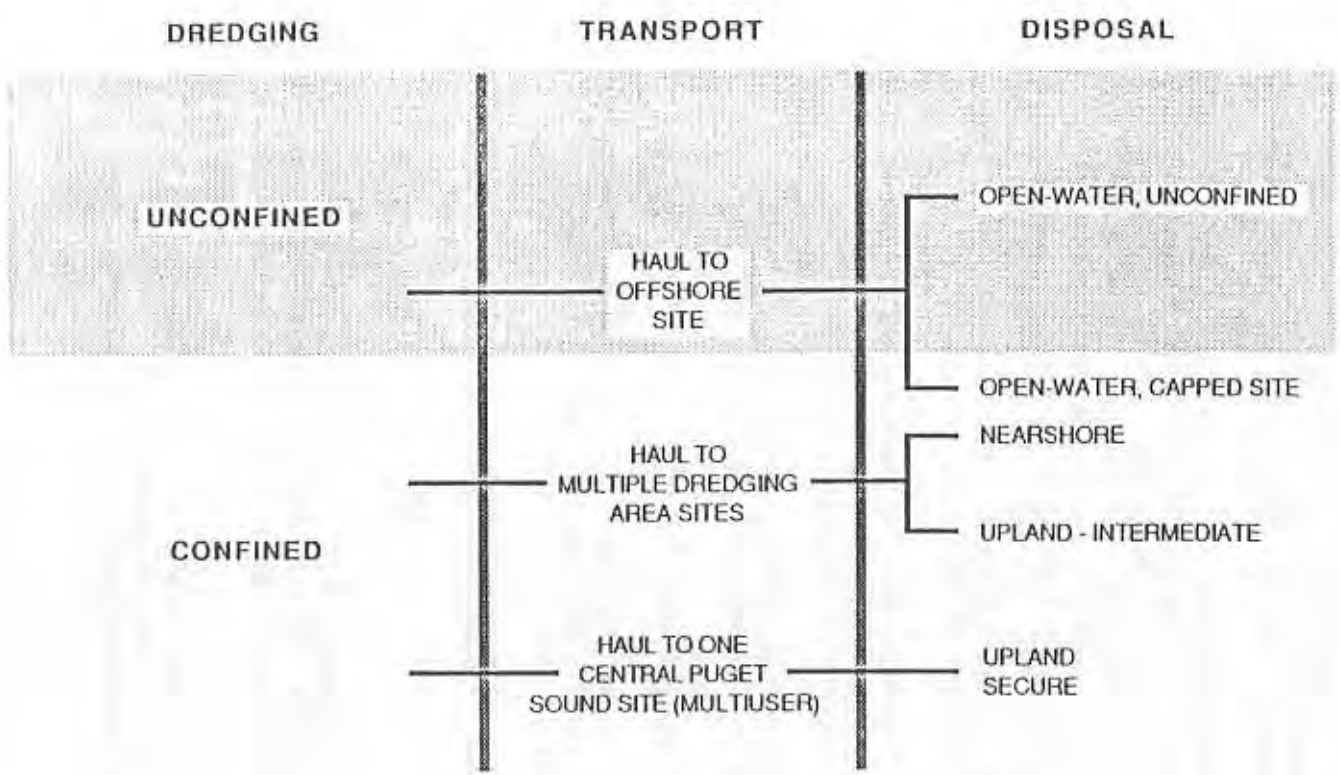


Figure II.10-6. Structure of the cost model for dredged material management, including costs of dredging, transport, and disposal.

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):

- An open-water disposal site (for the calculation of distances to both unconfined and capped sites)
- A nearshore disposal area
- A restricted upland disposal area (upland - intermediate security
- 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)	360 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°1'10" 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°33'50" 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 sit 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 Commencemen Bay for transport dis tance calculation 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 t 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 Facili 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 state 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 ($/c.y.)	Including Secure Site	
		Percent of Sediment Going To Each Technology	Prorated Cost ($/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.

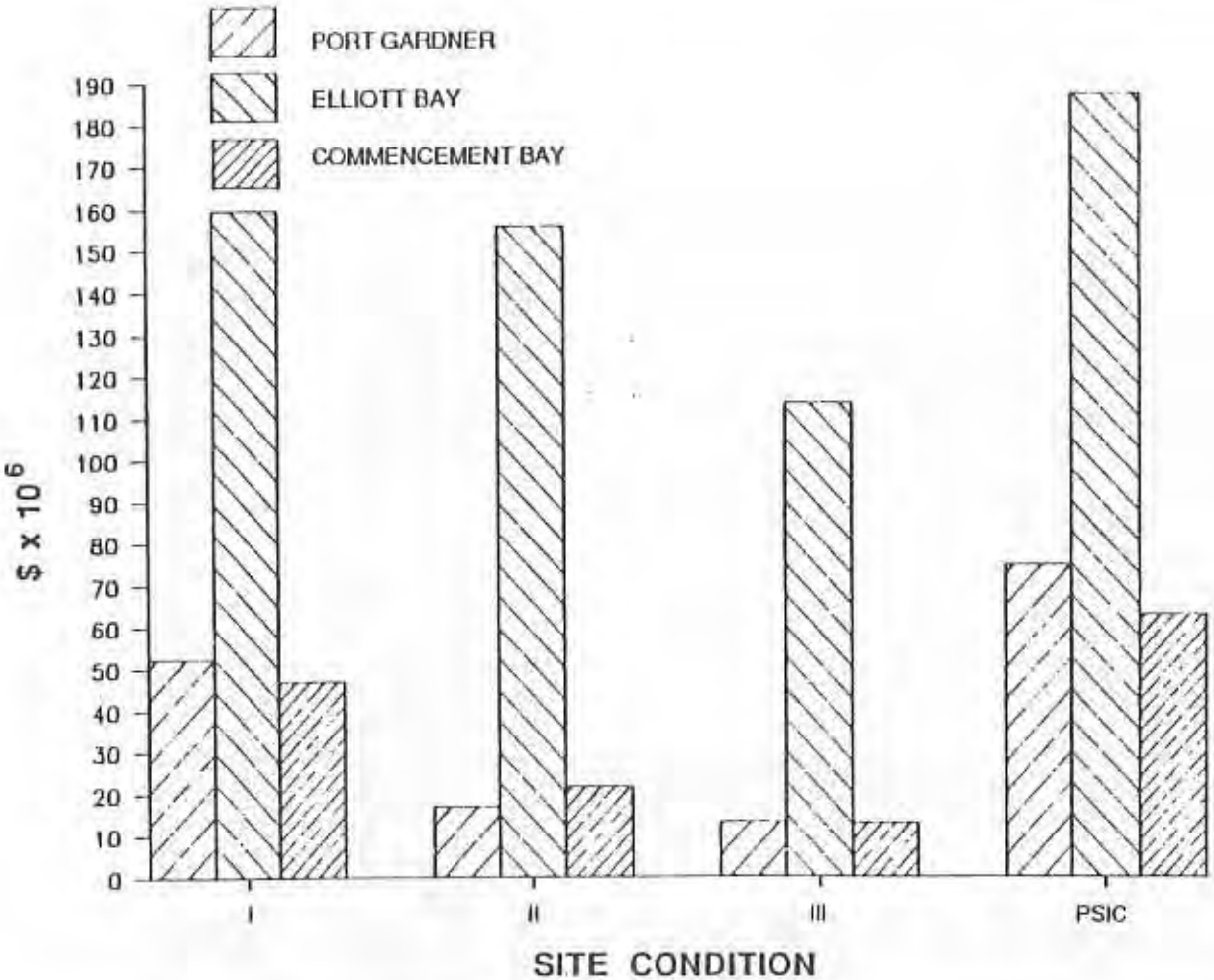


Figure II.10-7. Dredging, hauling, and disposal costs for each area.

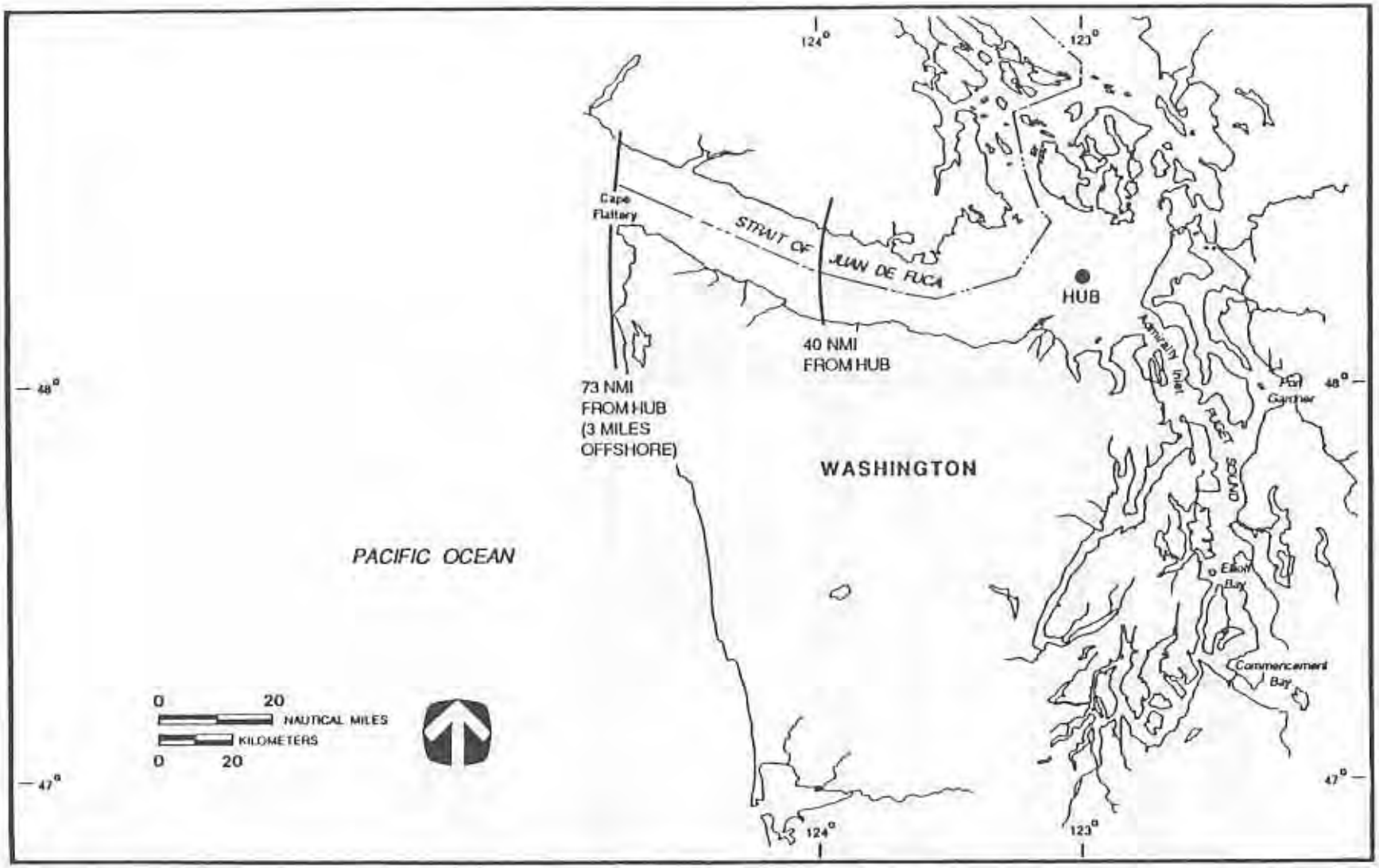


Figure II.10-8. General location of Puget Sound area dredged material sources and the material transport routes and distances to the Strait of Juan de Fuca and the Pacific Ocean. All material transported from the three Phase I dredging areas is assumed to pass through the point labeled HUB.

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.

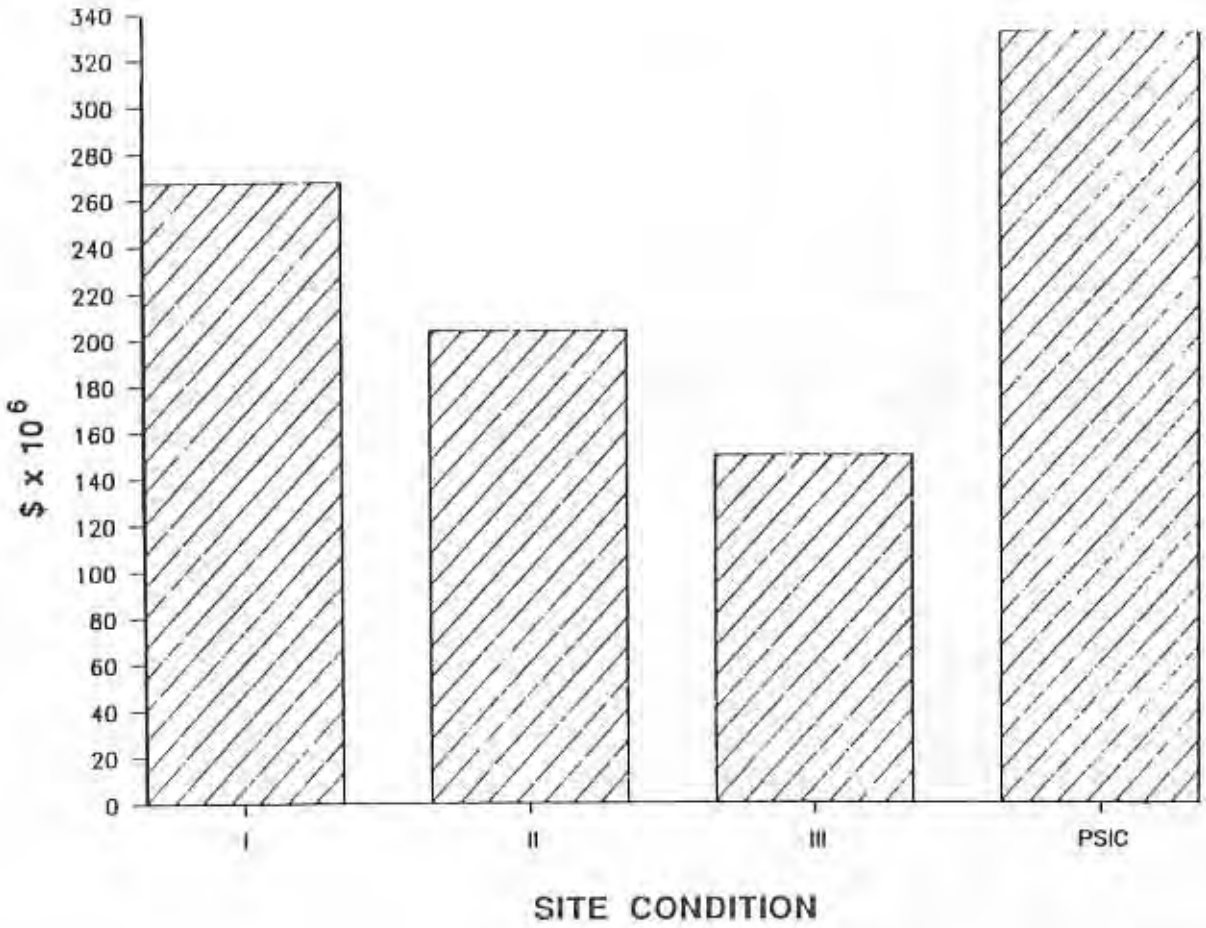


Figure II.10-9. Comparison of total costs for PSDDA and PSIC Program alternatives.

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:

- 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.

- 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.

- 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.

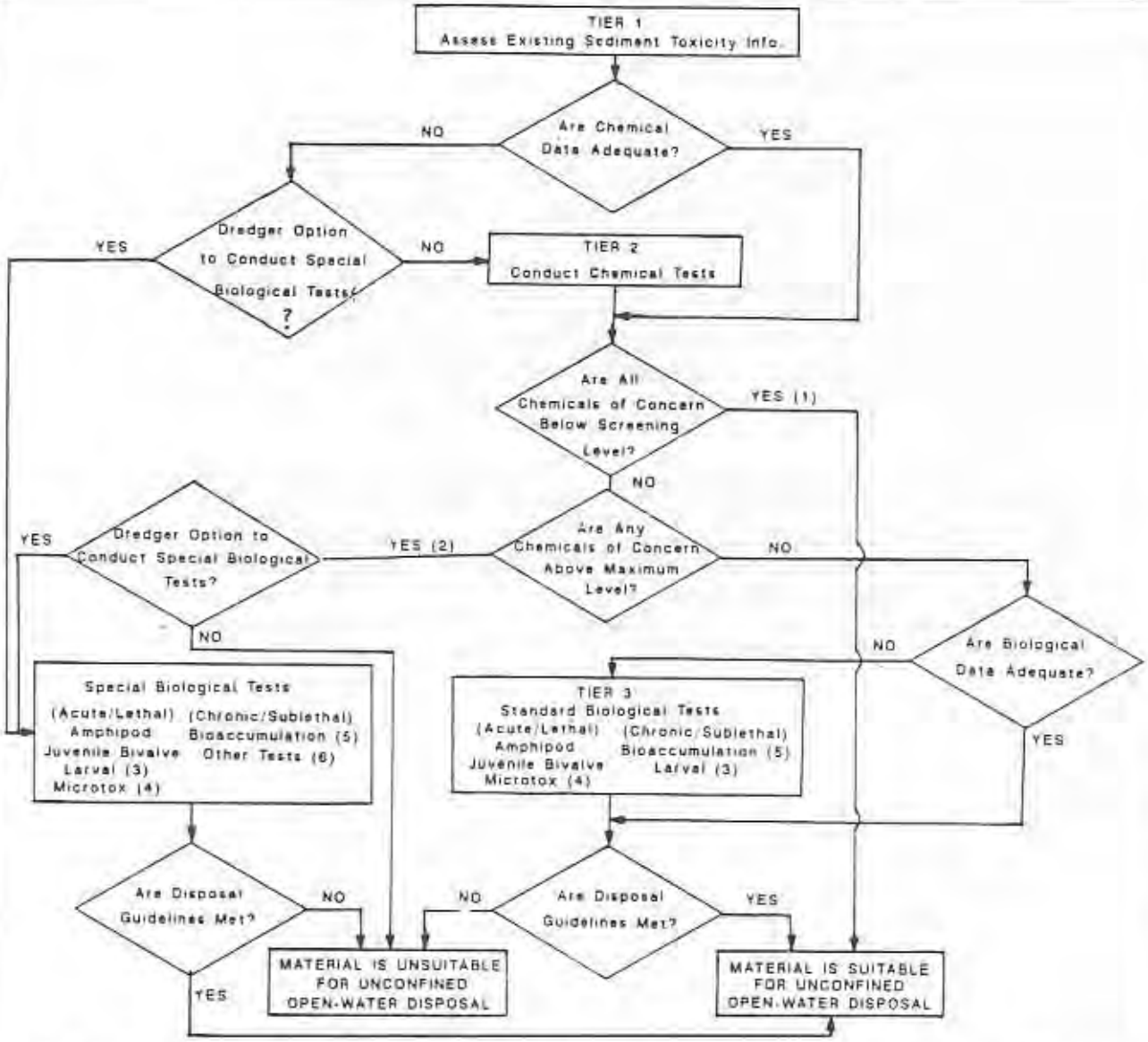
The expected volumes of dredged material acceptable under Site Condition II guidelines are expected to produce no more than minor effects at the disposal site. The total estimated management costs associated with Site Condition II allowable effects are lower than those estimated using existing Puget 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

- 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.

- 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.

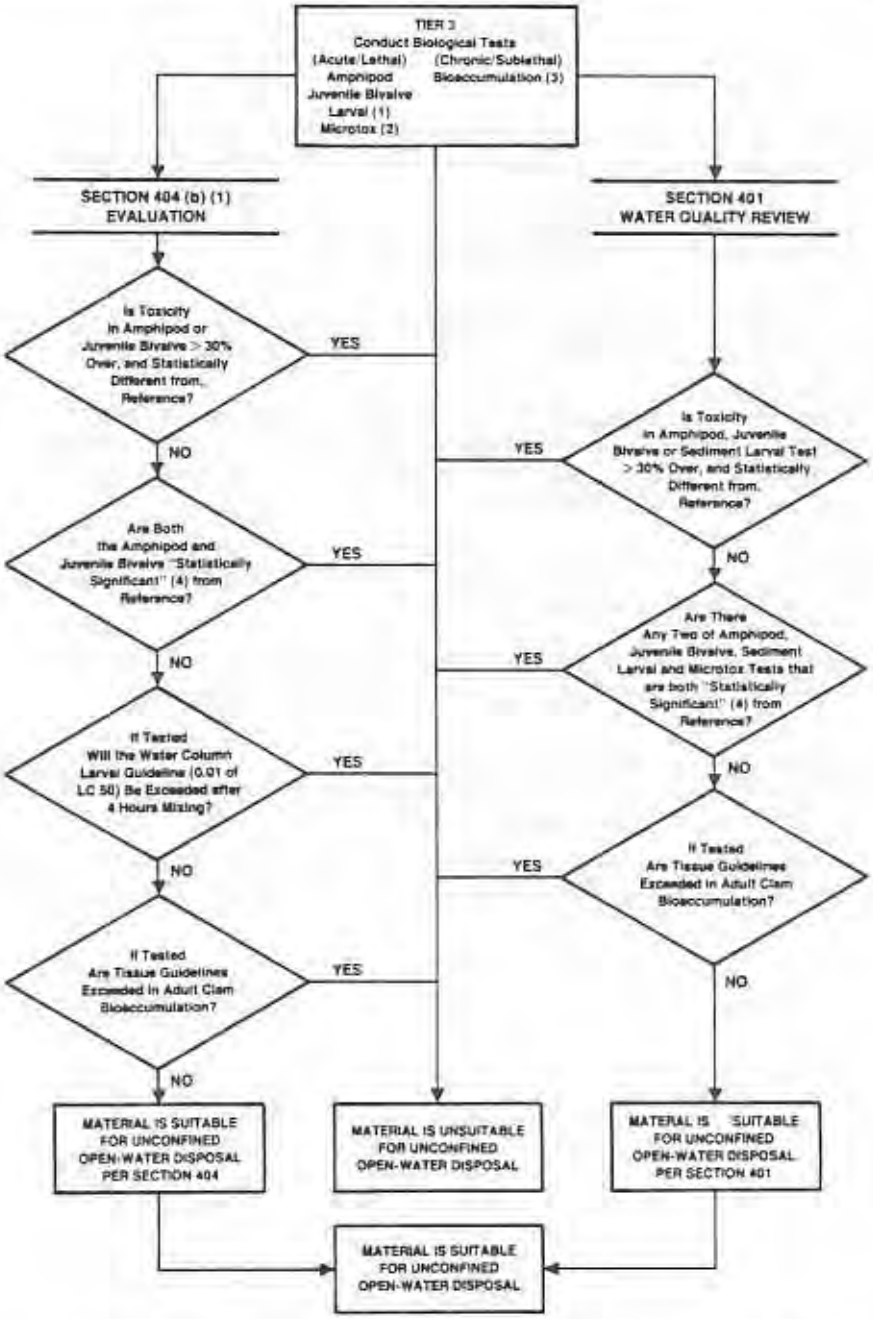
(c) For these compounds, the reference concentration was higher than the calculated value of SL so SL was set at the reference value.

(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.



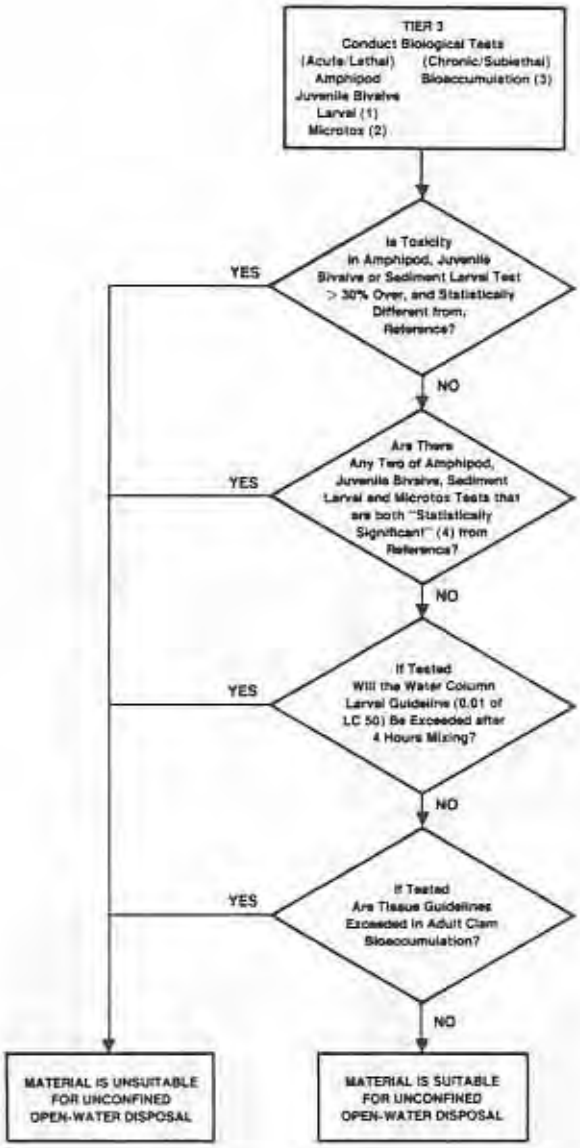
(1) The sediment larval test (for Section 401 reviews) is conducted whenever biological testing is required. The water column larval test (for Section 404 evaluations) is done only when water column effects are of concern.

(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.

1. RANGE OF ABSOLUTE MORTALITY IN TEST RESULTS.

2. RANGE OF PERFORMANCE STANDARD FOR CONTROL RESULTS (≤ 10% ABSOLUTE MORTALITY).

3. RANGE OF ACCEPTABLE REFERENCE RESULTS (PERFORMANCE STANDARD RANGE IS ≤ 20% OVER CONTROL).

4. RANGE OF LOWER LIMIT OF "STATISTICALLY SIGNIFICANT MORTALITY" IN DREDGED MATERIAL RESULTS (≥ 20% OVER CONTROL).

5. RANGE OF SINGLE-SPECIES (AMPHIPOD, JUVENILE BIVALVE OR SEDIMENT OYSTER) UPPER LIMIT OF "NO SIGNIFICANT ACUTE TOXICITY" (≤ 30% OVER REFERENCE).

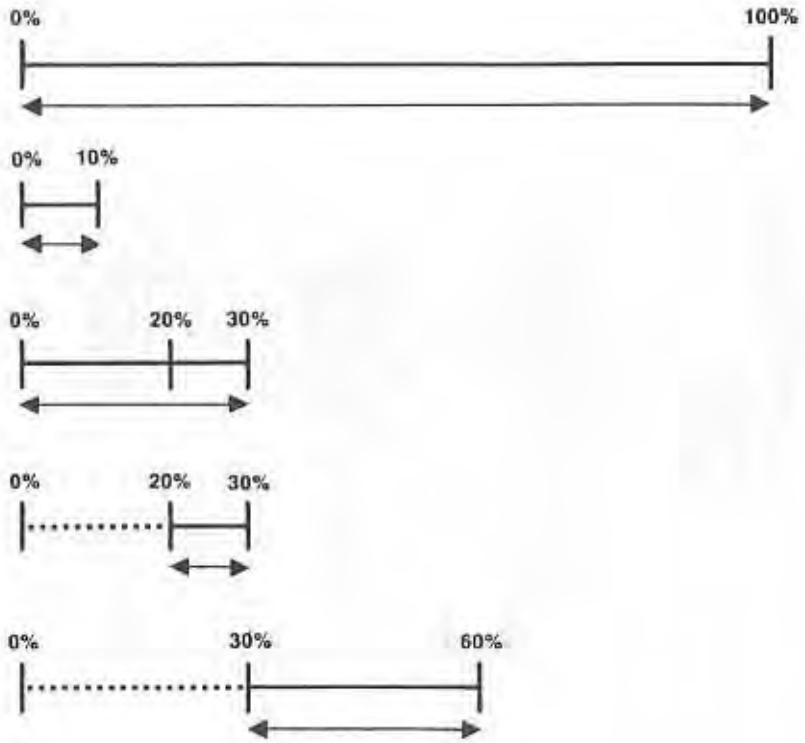


Figure II.11-4. Relationship of control, reference, and test treatment bioassay results in determining significant acute toxicity in sediment toxicity tests for dredged material.

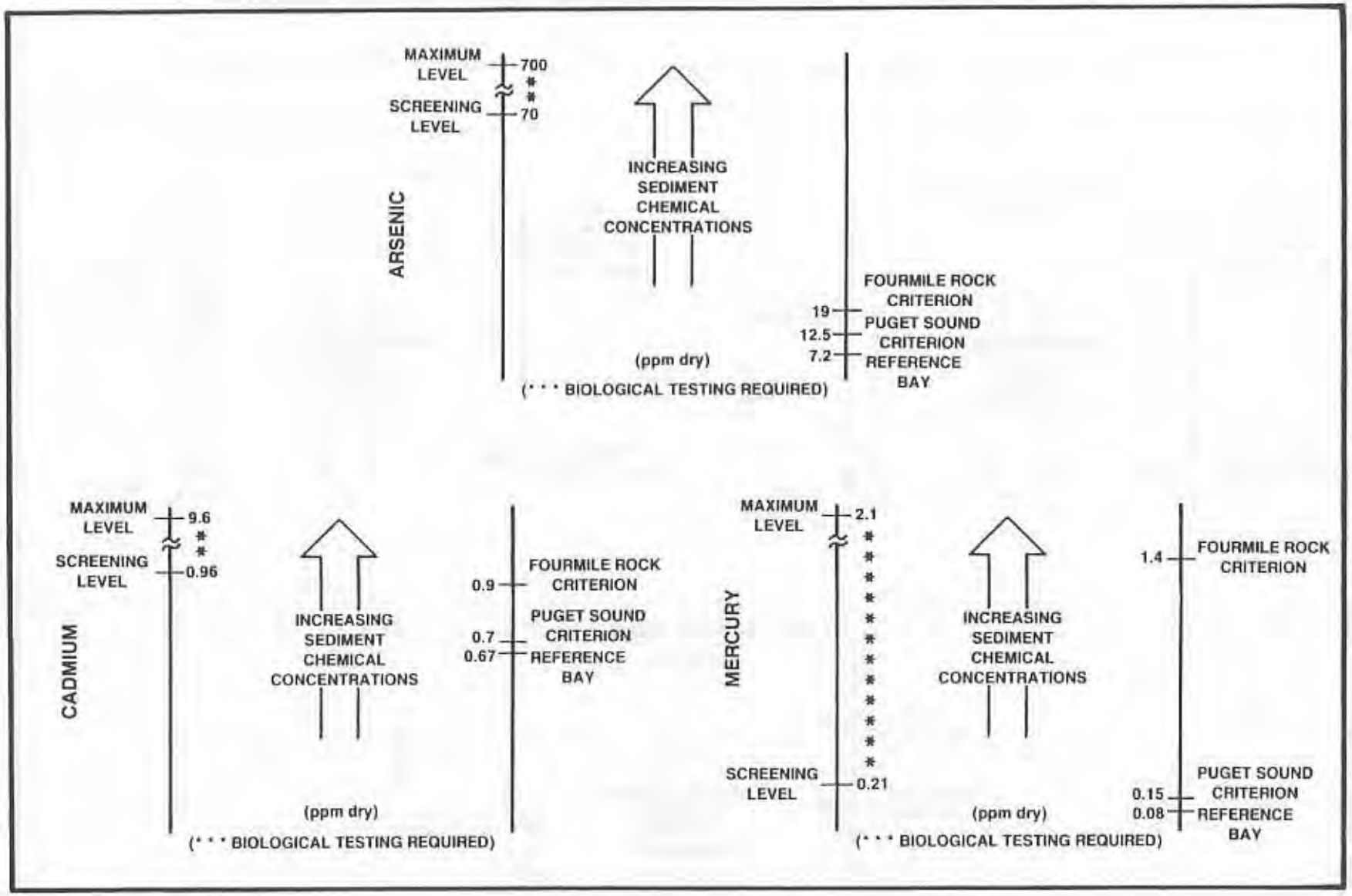


Figure II.11-5 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

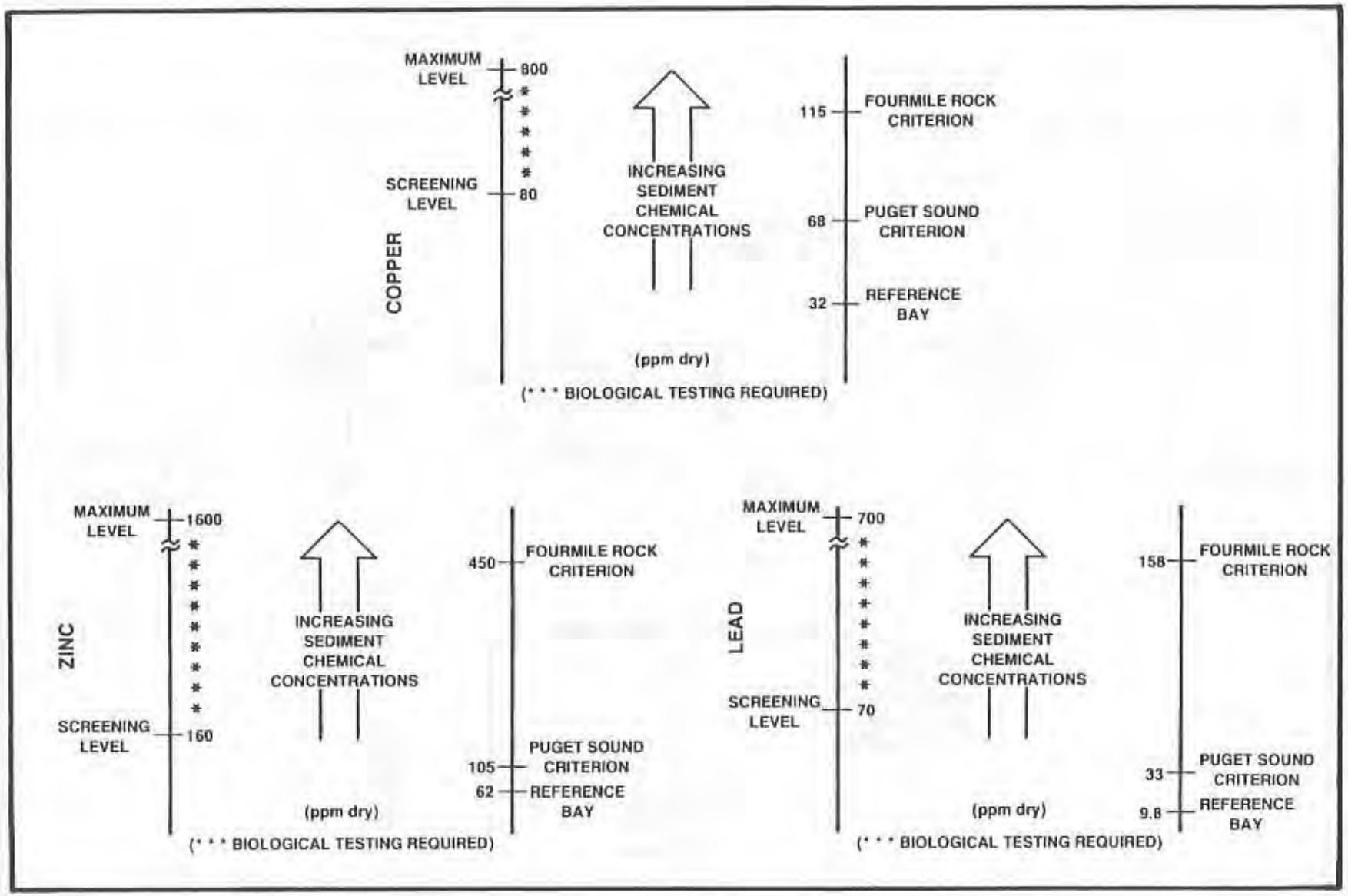


Figure II.11-6 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

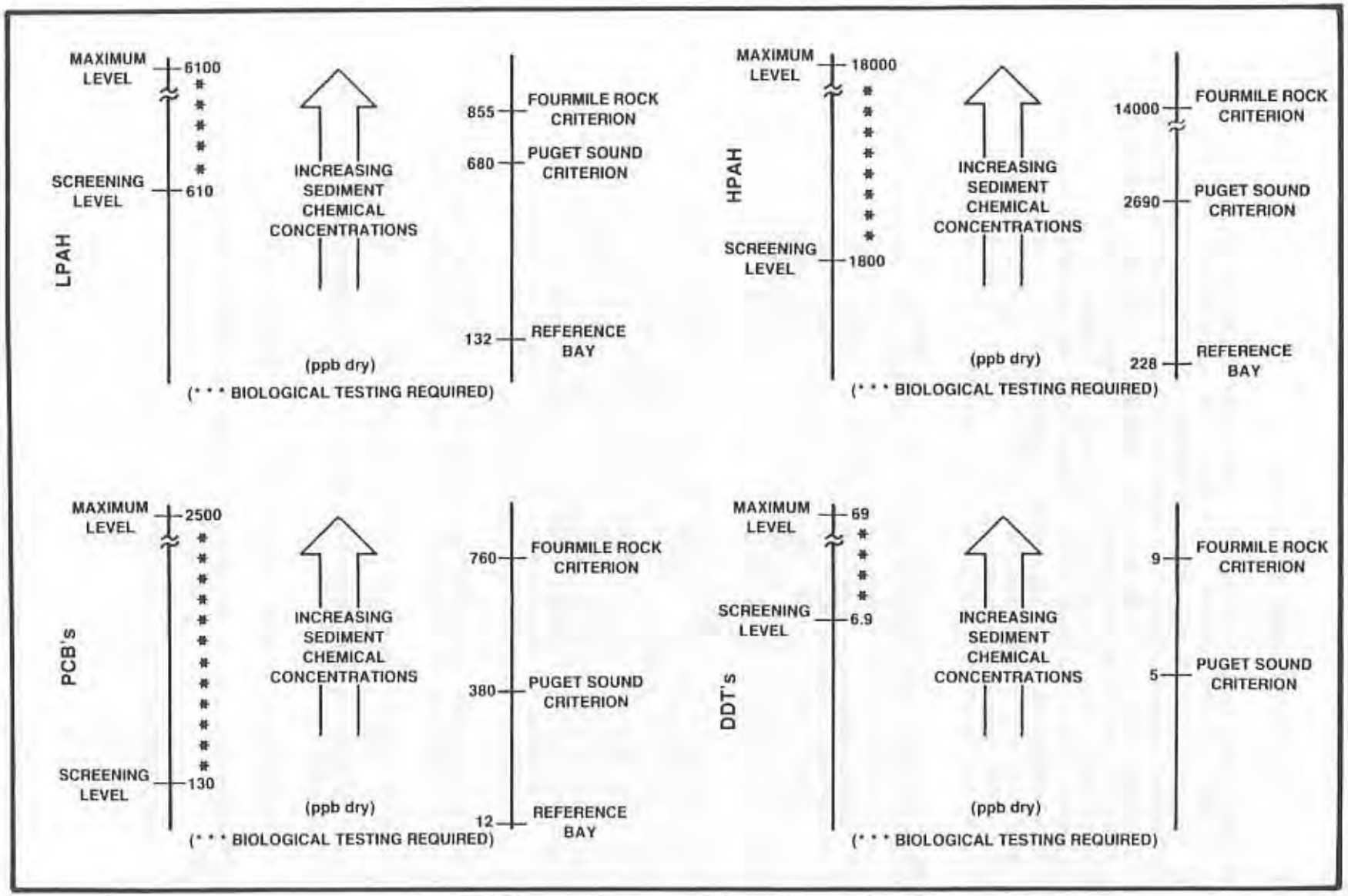


Figure II.11-7 Illustrated example of the differences between interim criteria and proposed PSDDA sediment quality values.

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

- Sediment quality values (both the ML and SL values)
- Results of monitoring relative to the predictions of the lab tests (what do the lab tests indicate about the field?)
- 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:

- 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.
- The evaluation procedures were developed by experienced managers and regulators; these individuals must continue to be involved in the interpretation of PSDDA guidelines.
- The evaluation procedures should be documented in a loose-leaf notebook to facilitate changes. All pages should be dated to indicate any revisions.
- 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):

- Changes must be procedurally logical, allowing the managed system to adjust over time
- Monitoring will likely provide the necessary evidence that will enable changes to AET
- 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
- 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.