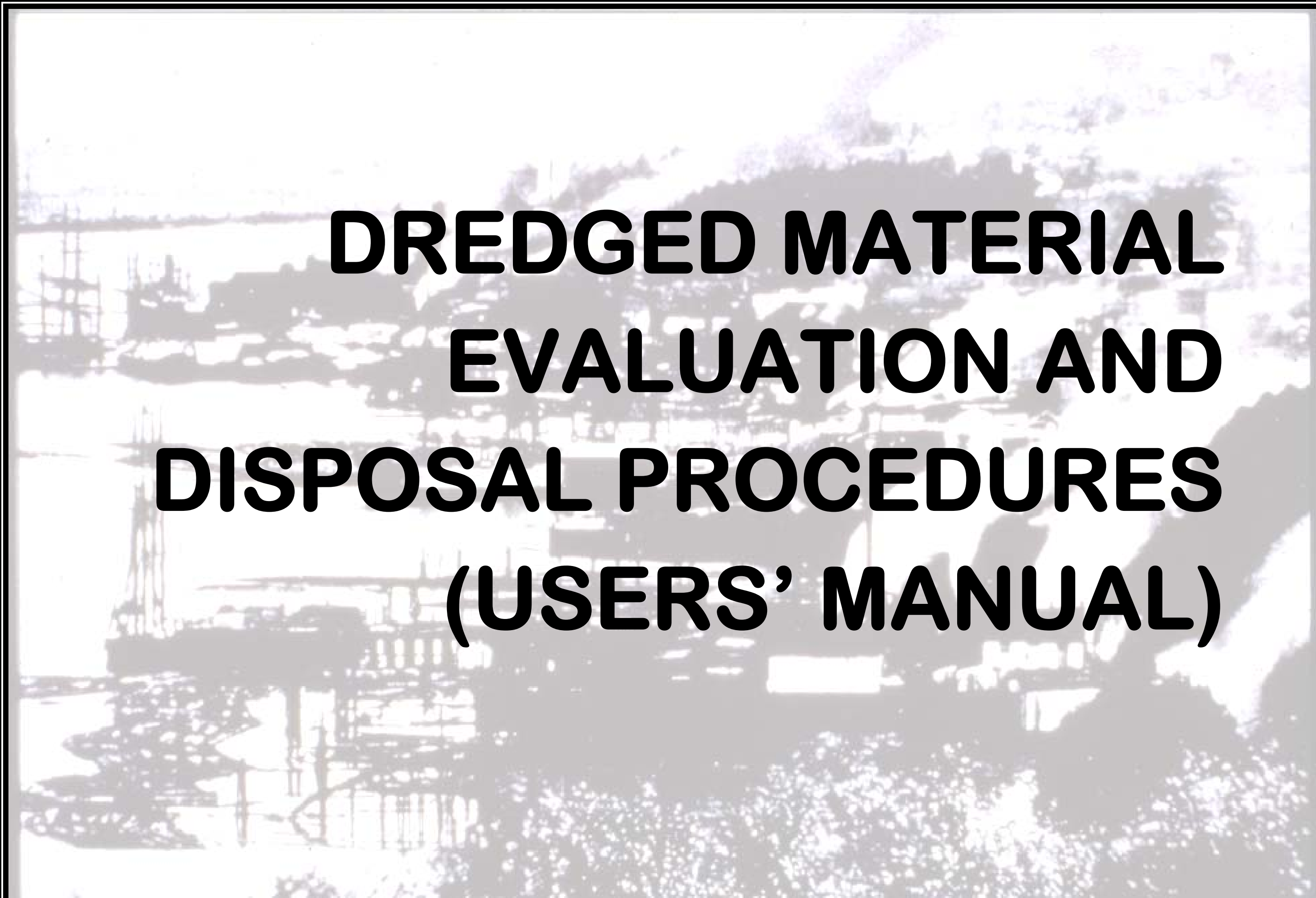


DREDGED MATERIAL EVALUATION AND DISPOSAL PROCEDURES (USERS' MANUAL)

Dredged Material Management Program

Corps of Engineers, Seattle District
Environmental Protection Agency, Region 10
Washington State Department of Natural Resources
Washington State Department of Ecology

July 2008

Prepared by:
Dredged Material Management Office
US Army Corps of Engineers
Seattle District

TABLE OF CONTENTS

TABLES

FIGURES

DEFINITIONS

Acute toxicity: Short-term toxicity to organism(s) that have been affected by the properties of a substance, such as contaminated sediment. The acute toxicity of a sediment is generally determined by quantifying the mortality of appropriately sensitive organisms that are exposed to the sediment, under either field or laboratory conditions, for a specified period.

Adjacent: Bordering, contiguous or neighboring. Wetlands separated from other waters of the United States by man-made dikes or barriers, natural river berms, beach dunes and the like are adjacent wetlands.

Advance Dredging/Advance Maintenance. Advance maintenance is dredging to a specified depth and/or width beyond the authorized channel dimensions in critical and fast shoaling areas to avoid frequent re-dredging and ensure the reliability and least overall cost of operating and maintaining the project authorized dimensions (USACE 2006).

Apparent Effects Threshold (AET): The sediment concentration of various chemicals of concern above which statistically significant ($p<0.05$) adverse biological effects (relative to an appropriate reference condition) are always expected. Theoretically, an AET can be calculated for any chemical and biological indicator.

Aquatic disposal: Placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline or surface release from hopper dredges or barges.

Aquatic environment: The geochemical environment in which dredged material is submerged under water and remains water-saturated after disposal is completed.

Aquatic ecosystem: Bodies of water, including wetlands, which serve as the habitat for interrelated and interacting communities and populations of plants and animals.

Beneficial use: Placement or use of dredged material for some productive purpose.

Bioaccumulation: The accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.

Bioaccumulation Trigger (BT): For bioaccumulative chemicals of concern, the sediment concentration that constitutes a “reason to believe" level that the chemical would accumulate in the tissues of target organisms. Sediments with chemical concentrations above the calculated BT require bioaccumulation testing before suitability for open-water disposal can be determined.

Bioassay: A bioassay is a test using a biological system. It involves exposing an organism to a test material and determining a response. There are two major types of bioassays differentiated by response: toxicity tests which measure an effect (e.g., acute toxicity, sublethal/chronic toxicity) and bioaccumulation tests which measure a phenomenon (e.g., the uptake of contaminants into tissues).

Biomagnification: Bioaccumulation up the food chain, e.g., the route of accumulation is solely through food. Organisms at higher trophic levels will have higher body burdens than those at lower trophic levels.

Capping: The controlled, accurate placement of a covering or cap of clean material over contaminated material to isolate the contamination from the aquatic environment.

Chemical of concern: A chemical present in a given sediment thought to have the potential for unacceptable adverse environmental impact due to a proposed discharge.

Chronic: Involving a stimulus that is lingering or which continues for a long time.

Clay: Soil particle having a grain size of less than 3.9 micrometers.

Coastal zone: Includes coastal waters and the adjacent shorelands designated by a State as being included within its approved coastal zone management program. The coastal zone may include open waters, estuaries, bays, inlets, lagoons, marshes, swamps, mangroves, beaches, dunes, bluffs, and coastal uplands. Coastal-zone uses can include housing, recreation, wildlife habitat, resource extraction, fishing, aquaculture, transportation, energy generation, commercial development, and waste disposal.

Comparability: The confidence with which one data set can be compared to others and the expression of results consistent with other organizations reporting similar data. Comparability of procedures also implies using methodologies that produce results comparable in terms of precision and bias.

Confined disposal: A disposal method that isolates the dredged material from the environment.

Confined disposal facility (CDF): An engineered structure for containment of dredged material consisting of dikes or other structures that enclose a disposal area above any adjacent water surface, isolating the dredged material from water during placement. Other terms used for CDFs that appear in the literature include confined disposal area, confined disposal site, and dredged material containment area.

Constituents: Chemical substances, solids, liquids, organic matter, and organisms associated with or contained in or on dredged material.

Contained aquatic disposal: Form of capping which includes the added provision of some form of lateral containment (for example, placement of the contaminated and capping materials in bottom depressions or behind subaqueous berms) to minimize spread of the materials on the bottom.

Contaminant: Chemical or biological substance in a form that can be incorporated into, onto, or be ingested by and is harmful to aquatic organisms, consumers of aquatic organisms, or users of the aquatic environment.

Contaminated sediment: Sediment that has been demonstrated to cause an unacceptable adverse effect on human health or the environment.

Control sediment: A sediment essentially free of contaminants and which is used routinely to assess the acceptability of a test. Control sediment is typically the sediment from which the test organisms are collected. Test procedures are conducted with the control sediment in the same way as the reference sediment and dredged material. The purpose of the control sediment is to confirm the biological acceptability of the test conditions and to help verify the health of the organisms during the test. Excessive mortality in the control sediment indicates a problem with the test conditions or organisms, and can invalidate the results of the corresponding dredged material test.

Data quality indicators: Quantitative statistics and qualitative descriptors which are used to interpret the degree of acceptability or utility of data to the user; include bias (systematic error), precision, accuracy, comparability, completeness, representativeness and statistical confidence.

Disposal site: That portion of the waters of the United States where specific disposal activities are permitted and consist of a bottom surface area and any overlying volume of water.

Dredged material: Material excavated from inland or ocean waters.

EC_{50}: The median effective concentration. The concentration of a substance that causes a specified effect (generally sublethal rather than acutely lethal) in 50% of the organisms tested in a laboratory toxicity test of specified duration.

Ecosystem: A system made up of a community of animals, plants, and bacteria and its interrelated physical and chemical environment.

Effluent: Water that is discharged from a confined disposal facility during and as a result of the filling or placement of dredged material.

Elutriate: Material prepared from the sediment dilution water and used for chemical analyses and toxicity testing. Different types of elutriates are prepared for two different procedures as noted in this manual.

Emergency: In the context of dredging operations, emergency is defined in 33 CFR Part 335.7 as a "situation which would result in an unacceptable hazard to life or navigation, a significant loss of property, or an immediate and unforeseen significant economic hardship if corrective action Is not taken within a time period of less than the normal time needed under standard procedures."

Evaluation: The process of judging data in order to reach a decision.

Factual determination: A determination in writing of the potential short-term or long-term effects of a proposed discharge of dredged or fill material on the physical, chemical and biological components of the aquatic environment.

Frequency: The repeated dredging of a given area within a specified period of time without the need for further sampling and testing.

Grain-size effects: Mortality or other effects in laboratory toxicity tests due to sediment granulometry, not chemical toxicity.

Gravel: A loose mixture of pebbles and rock fragments coarser than sand.

Habitat: The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for the maintenance of life. Typical coastal habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.

Heterogeneous Sediment: Sediment layers that have potentially different characteristics or levels of chemicals of concern. Heterogenous sediments are typically sampled with a coring device that allows for separate sampling and analysis for surface and subsurface sediment layers.

Homogeneous Sediment: Sediment that is well-mixed and deposited over a short time-frame. Homogenous sediments are often found in settling basins or some navigation channels where river flow slows down abruptly. A dredge prism made up of homogenous sediment can be represented with grab samples.

K_{OW}: The octanol-water partition coefficient (K_{ow}) is a measure of the equilibrium concentration of a compound between octanol and water that indicates the potential for partitioning into soil organic matter (i.e., a high K_{ow} indicates a compound which will preferentially partition into soil organic matter rather than water). K_{ow} is inversely related to the solubility of a compound in water.

LC_{50}: The median lethal concentration. The concentration of a substance that kills 50% of the organisms tested in a laboratory toxicity test of specified duration.

Leachate: Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through a confined disposal facility and picks up dissolved contaminants is considered leachate.

Loading density: The ratio of organism biomass or numbers to the volume of test solution in an exposure chamber.

Management actions: Those actions considered necessary to rapidly render harmless the material proposed for discharge (e.g., non-toxic, non-bioaccumulative) and which may include containment in or out of the waters of the US (see 40 CFR Subpart H). Management actions are employed to reduce adverse impacts of proposed discharges of dredged material.

Management unit: A manageable, dredgeable unit of sediment which can be differentiated by sampling and which can be separately dredged and disposed within a larger dredging area. Management units are not differentiated solely on physical or other measures or tests but are also based on site and project-specific considerations.

Maximum Level (ML): A guideline value derived for each chemical of concern which represents the highest Apparent Effects Threshold (AET) – a chemical concentration at which biological indicators show significant effects.

Method detection limit (MDL): The minimum concentration of a substance which can be identified, measured, and reported with 99% confidence that the analyte concentration is greater than zero.

Overdepth:. Paid allowable overdepth dredging (depth and/or width) is a construction design method for dredging that occurs outside the required authorized dimensions and advance maintenance (as applicable) prism to compensate for physical conditions and inaccuracies in the dredging process and allow for efficient dredging practices.

Pathway: In the case of bioavailable contaminants, the route of exposure (e.g., water, food).

Practicable: Available and capable of being done after taking into consideration cost, existing-technology, and logistics in light of overall project purposes.

QA: Quality assurance, the total integrated program for assuring the reliability of data. A system for integrating the quality planning, quality control, quality assessment, and quality improvement efforts to meet user requirements and defined standards of quality with a stated level of confidence.

QC: Quality control, the overall system of technical activities for obtaining prescribed standards of performance in the monitoring and measurement process to meet user requirements.

Reason to believe: Subpart G of the CWA 404(b) (1) guidelines requires the use of available information to make a preliminary determination concerning the need for testing of the material proposed for dredging. This principle is commonly known as “reason to believe” and is used in Tier I evaluations to determine acceptability of the material for discharge without testing. The decision to not perform additional testing based on prior information must be documented, in order to provide a reasonable assurance that the proposed discharge material is not a carrier of contaminants.

Recency: The duration of time for which chemical and biological characterization of a given dredge prism remains adequate and valid for decision making without further testing.

Reference sediment: A whole sediment used to assess sediment conditions exclusive of the material(s) of interest, that is as similar as practicable to the grain size and total organic carbon (TOC) of the dredged material. The reference sediment serves as a point of comparison to identify potential effects of contaminants in the dredged material.

Reference site: The location from which reference sediment is obtained.

Representativeness: The degree to which sample data depict an existing environmental condition; a measure of the total variability associated with sampling and measuring that includes the two major error components: systematic error (bias) and random error. Sampling representativeness is accomplished through proper selection of sampling locations and sampling techniques, collection of sufficient number of samples, and use of appropriate subsampling and handling techniques.

Salinity: Salt content, usually expressed in grams of salt per kilogram of water.

Sand: Soil particles having a grain size ranging between about 62.5 micrometers and 2,000 micrometers.

Screening Level (SL): A guideline value defined for each DMMP chemical of concern that identifies concentrations at or below which there is no reason to believe that dredged material disposal would result in unacceptable adverse effects.

Sediment: Material, such as sand, silt, or clay, suspended in or settled on the bottom of a water body. Sediment input to a body of water comes from natural sources, such as erosion of soils and weathering of rock, or as the result of anthropogenic activities such as forest or agricultural practices, or construction activities. The term dredged material refers to material which has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.

Silt: soil having a grain size ranging between 3.9 micrometers and 62.5 micrometers.

Sublethal (chronic) toxicity: Biological tests which use such factors as abnormal development, growth and reproduction, rather than solely lethality, as end-points. These tests involve all or at least an important, sensitive portion of an organism's life-history. A sublethal endpoint may result either from short-term or long-term (chronic) exposures.

Suspended solids: Organic or inorganic particles that are suspended in water. The term includes sand, silt, and clay particles as well as other solids, such as biological material, suspended in the water column.

Tiered approach: A structured, hierarchical procedure for determining data needs relative to decision-making, which involves a series of tiers or levels of intensity of investigation. Typically, tiered testing involves decreased uncertainty and increased available information with increasing tiers. This approach is intended to ensure the maintenance and protection of environmental quality, as well as the optimal use of resources. Specifically, least effort is required in situations where clear determinations can be made of whether (or not) unacceptable adverse impacts are likely to occur based on available information. Most effort is required where clear determinations cannot be made with available information.

Toxicity: Level of mortality or other end point demonstrated by a group of organisms that have been affected by the properties of a substance, such as contaminated water, sediment, or dredged material.

Toxicity test: A bioassay which measures an effect (e.g., acute toxicity, sublethal/chronic toxicity). Not a bioaccumulation test (see definition of bioassay).

Turbidity: An optical measure of the amount of material suspended in the water. Increasing the turbidity of the water decreases the amount of light that penetrates the water column. Very high levels of turbidity can be harmful to aquatic life.

Upland environment: The geochemical environment in which dredged material may become unsaturated, dried out, and oxidized.

Water quality certification: A state certification, pursuant to Section 401 of the Clean Water Act, which states that the proposed discharge of dredged material will comply with the applicable provisions of the Clean Water Act and relevant State laws. Typically this certification is provided by the affected State. In instances where the State lacks jurisdiction (e.g., Tribal Lands), such certification is provided by EPA or the Tribe.

Waters of the US: In general, all waters landward of the baseline of the territorial sea and the territorial sea. Specifically, all waters defined in the CWA 404(b)(1) guidelines.

Whole sediment: The sediment and interstitial waters of the proposed dredged material or reference sediment that have had minimal manipulation. For purposes of this manual, press-sieving to remove organisms from test sediments, homogenization of test sediments, compositing of sediment samples, and additions of small amounts of water to facilitate homogenizing or compositing sediments may be necessary to conducting bioassay tests. These procedures are considered unlikely to substantially alter chemical or toxicological properties of the respective whole sediments except in the case of AVS (acid volatile sulfide) measurements (EPA, 1991a) which are not presently required. Alternatively, wet sieving, elutriation, or freezing and thawing of sediments may alter chemical and/or toxicological properties, and sediment so processed should not be considered as whole sediment for bioassay purposes.

“Z” sample: A sample from the first foot below the dredging overdepth, which must be collected during sampling of heterogeneous sediments, to characterize the surface exposed after dredging.

LIST OF ACRONYMS

AET	Apparent Effects Threshold
ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BT	Bioaccumulation Trigger
CAS	Chemical Abstract Service
CFR	Code of Federal Regulations
COC	Chemical of Concern
CSL	Cleanup Screening Level
CSO	Combined Sewer Overflow
CWA	Clean Water Act
CY	Cubic Yard
DAIS	Dredged Analysis Information System
WDFW	Washington Department of Fish and Wildlife
DMMO	Dredged Material Management Office
DMMP	Dredged Material Management Program
DMMU	Dredged Material Management Unit
DNR	Department of Natural Resources
DY	Dredging Year
EC50	Effective Concentration (affecting 50% of test organisms)
EIM	Environmental Information Management (Ecology database)
EPA	Environmental Protection Agency
EPTA	Evaluation Procedures Technical Appendix
ESA	Endangered Species Act
FC	Full Characterization
FDA	Food and Drug Administration
GIS	Geographic Information System
GPS	Global Positioning System
HPA	Hydraulic Project Approval
HPAH	High-molecular-weight PAH
JARPA	Joint Aquatic Resource Permits Application
K_{OW}	Octanol-water partition coefficient
LC50	Lethal Concentration (affecting 50% of test organisms)
LPAH	Low-molecular-weight PAH
ML	Maximum Level
MLLW	Mean Lower Low Water
MPR	Management Plan Report
NAD	North American Datum
NPDES	National Pollution Discharge Elimination System
PAH	Polynuclear Aromatic Hydrocarbon
PC	Partial Characterization
PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzodioxins
PCDFs	Polychlorinated Dibenzofurans
PSDDA	Puget Sound Dredged Disposal Analysis
PSEP	Puget Sound Estuary Program
QA/QC	Quality Assurance/Quality Control
SAP	Sampling and Analysis Plan
SEDQUAL	Sediment Quality Database
SMS	Sediment Management Standards

SL	Screening Level
TBT	Tributyltin
TEC	Toxic Equivalent Concentration
TEF	Toxicity Equivalency Factor
TEQ	Toxicity Equivalent
TOC	Total Organic Carbon
TVS	Total Volatile Solids
USCG	United States Coast Guard
VTS	Vessel Traffic Service
WGS	World Geodetic System

1 INTRODUCTION

The Dredged Material Management Program (DMMP) represents an interagency approach to the management of dredged material in the State of Washington. Two federal and two state agencies, all with roles in the oversight of dredging and disposal, cooperate to streamline dredged material evaluation and regulation. The Seattle District of the U.S. Army Corps of Engineers (Corps) acts as the lead agency. Cooperating agencies are Region 10 of the U.S. Environmental Protection Agency (EPA), the Washington Department of Ecology (Ecology); and the Washington Department of Natural Resources (DNR).

The DMMP interagency approach to dredged material management began in 1985 after studies surfaced concerns about environmentally degraded sediment and water quality in Puget Sound. Plunging public confidence in agency management of dredged material in Puget Sound led to the loss of shoreline permits for the Elliott Bay disposal site and a halt to much local dredging. This crisis led to the Puget Sound Dredged Disposal Analysis (PSDDA) study, a 4.5 year initiative meant to restore confidence in agency regulation of unconfined open-water dredged material disposal. PSDDA was implemented in two phases, first in June 1988 for central Puget Sound and second in September 1989 for north and south Puget Sound.

The PSDDA program provided publicly acceptable and environmentally safe management plans for regulation of unconfined open-water dredged material disposal, but only for Puget Sound. In 1995 a long-term interagency management strategy patterned after the PSDDA model was developed and implemented for the coastal estuaries of Grays Harbor and Willapa Bay. In 1998, a long-term interagency dredged material management strategy was also developed and implemented for the lower Columbia River. With the expansion of PSDDA oversight into Washington water bodies beyond Puget Sound, the program name changed from PSDDA to DMMP.

In this edition of the DMMP Users' Manual, dredged material evaluation and disposal procedures for both Puget Sound and the coastal estuaries (Grays Harbor and Willapa Bay) have been combined into one document. The evaluation procedures address sediment sampling, chemical and biological testing and test interpretation for determining the suitability of dredged material for unconfined, open-water disposal for both areas. Disposal procedures incorporate such topics as barge positioning, debris management and restrictions on site use.

The procedures in this Users' Manual replace guidance previously furnished in the 2000 PSDDA Users' Manual, the *Evaluation Procedures Technical Appendix - Phase I* (PSDDA, 1988) the *Management Plan Report - Phase II* (PSDDA, 1989) and the Grays Harbor/Willapa Bay Users' manual (*Dredged Material Evaluation Procedures and Disposal Site Management Manual: Grays Harbor and Willapa Bay, Washington,* 1995).

Guidance described in this edition of the DMMP Users' Manual reflects technical and policy updates that have occurred through the sediment management review meeting process and public workshops. The Users' Manual is considered to be a living document and will be revised periodically as needed to reflect changes made through the public review process.

2 PROCESS OVERVIEW

This chapter describes the process of obtaining Section 10/404 and Section 103 permits and getting the necessary sediment evaluation performed. It includes information on the overall regulatory process (Section 2.1), the dredged material evaluation process (Section 2.2), the development of the sampling and analysis plan (Section 2.3), the DNR site-use authorization (Section 2.4), the dredging quality control plan (Section 2.5), and the role of the Corps' Dredged Material Management Office (DMMO) (Section 2.6). Appropriate flow diagrams are included to illustrate the processes.

2.1 The Regulatory Process

New dredging will always require new permits. For maintenance dredging, the dredging proponent needs to determine whether new permits will be required. To do this, check the expiration date on any existing permits. Unless all projected dredging can be completed before permit expiration, new permits (or extensions on existing permits) will be required. For federal navigation project maintenance dredging, a determination is made whether a new Public Notice is required and whether an extension of the Water Quality Certification is needed.

Figure 2-1 illustrates the regulatory process when a new permit is required. In this case, two separate, but intertwined, processes occur. The first is the regulatory permitting process that consists of the following steps:

1. Submission of a complete permit application to the appropriate agencies, including the Regulatory Branch of the Corps of Engineers.
2. Preparation and distribution of a Public Notice by the Corps with a 30-day comment period.
3. Review and incorporation of comments from other agencies by the Corps.
4. Issuance of a Water Quality Certification (or Modification) and Hydraulic Project Approval by the State of Washington.
5. Permit decision for a Section 10/404 permit for inland waterways and a Section 103 permit for Coastal work.

The second process consists of the evaluation of the sediments proposed for dredging. The dredged material evaluation process is required for every dredging cycle and is intertwined with the regulatory process as shown in Figure 2-1. The dredged material evaluation process contains the following steps:

1. Contact the Seattle District DMMO (see Section 2.6).
2. Test sediment if necessary (see Section 2.2).
3. DMMO prepares a suitability determination, which is signed by the agencies.

It is recommended that the dredging proponent contact both the Corps' Regulatory Branch and the DMMO at the beginning of the process. While the JARPA can be submitted at any time, it is recommended that the dredging proponent wait until the DMMP agencies have finalized the suitability determination.

Figure 2-2 illustrates the regulatory process when a new permit is not required. In this case, the dredging proponent should contact the DMMO to determine the testing needs for the upcoming cycle of dredging. As in the preceding case, whether or not testing is required, a suitability determination will be drafted by the DMMO and signed by the agencies. Once the suitability determination is signed, the dredging proponent can proceed to obtain a DNR site-use authorization and then dredge.

For those dredging cycles in which sediment testing is not required, the suitability determination will include:

1. the volume to be dredged;
2. the disposal site to be used;
3. the last sampling and testing dates;
4. an indication of how the recency and frequency guidelines apply to the current dredging cycle;
5. summary of previous testing data as necessary; and
6. any new pollution sources or known incidents (i.e., a spill) that have occurred which might impact the quality of sediment to be dredged.

Applicants considering beneficial-use projects are encouraged to coordinate with the DMMO and with other resource agencies early in the dredged material evaluation process. A user's manual for beneficial use projects is being developed for this region; a more general beneficial use manual has been published by EPA (EPA, 2007).

For all dredging proposed to occur on State Owned Aquatic Land managed by DNR, the dredging proponent must receive DNR permission prior to beginning work. It is advisable to initiate this process at the same time that coordination with the Corps begins.

2.2 The Dredged Material Evaluation Process

Figure 2-3 illustrates the dredged material evaluation process; it is an expansion of the simple hexagonal block from Figures 2-1 and 2-2. The following steps comprise this process:

1. Dredging proponent (with consultant assistance as needed) determines project-specific sampling and analysis requirements. DMMO may be contacted for assistance.
2. Dredging proponent develops a sampling and analysis plan (SAP) for sediment evaluation (see Section 2.3 for more detailed information).
3. Dredging proponent submits SAP to the DMMO.
4. DMMO coordinates review of the SAP by the other regulatory agencies.
5. DMMO sends a SAP approval letter to the dredging proponent.

6. Dredging proponent conducts field sampling and laboratory testing.
7. Dredging proponent submits a final report to the agencies.
8. DMMO coordinates review of the testing data with the regulatory agencies.
9. DMMO drafts and the agencies sign a suitability determination for disposal.

Figure 2-4 presents the tiered testing decision diagram that will be followed for dredged material evaluations. Time can be saved by compressing tiers II and III; that is, by conducting concurrent chemical and biological testing. If Tier IV testing is needed, it will need to be specially designed with or by the regulatory agencies.

2.3 Development of the Sampling and Analysis Plan

A well-designed sampling and analysis plan (SAP) is essential when evaluating the potential impact of dredged material discharge upon the aquatic environment. The SAP is submitted to the DMMO for coordinated review and approval by regulatory agencies before any sampling is initiated, as shown on Figure 2-3. This coordination, including full and open disclosure of information, can reduce the chance of having to repeat costly procedures and can assist in keeping projects on schedule. The SAP should contain the following information in enough detail to allow the regulatory agencies to determine the adequacy of the SAP:

1. Tier I (see Chapter 3) information, including site history, existing data, current site use, identification of sources of contamination, and past permitting (including NPDES permits as well as dredging).
2. Project description, including a plan view of the site, recent bathymetric survey data, one or more cross-sections of the dredging prism, type and volume of sediment.
3. Personnel involved with the project and their respective responsibilities, including project planning and coordination, field sampling, chemical and biological testing labs, QA management and final report preparation.
4. Computation of sampling and analysis requirements, formulation of a conceptual dredging plan, identification and rationale for dredged material management units, allocation of field samples and development of a compositing plan.
5. Sampling procedures, including field sampling schedule, sampling technology, positioning methodology, decontamination of equipment, sample collection and handling protocols, core logging, sample extrusion, sample compositing and subsampling, sample transport and chain of custody.
6. Physical and chemical laboratory testing, including grain-size analysis, sediment conventionals, chemicals-of-concern, extraction/digestion methods, analysis methods, holding time requirements and quality assurance requirements.
7. Biological testing, including holding time requirements, proposed testing sequence, bioassay protocols and quality assurance requirements.
8. Reporting requirements, including the sediment characterization report, DAIS-ready data, QA2 data for Ecology and cost data.

The DMMO can provide any additional assistance needed in the development of a SAP.

2.4 The DNR Disposal Site Use Authorization

A disposal site use authorization (SUA) must be obtained from Washington State Department of Natural Resources (DNR) prior to disposal of dredged material in any Puget Sound, Grays Harbor or Willapa Bay disposal site. Some Columbia River sites may be managed under Washington DNR; the agency should be consulted to determine appropriate jurisdiction early in the planning process.

Before DNR will begin processing an SUA application, the applicant must provide a COMPLETE application package. A typical application package includes a completed Site Use Application, and copies of all other agency permits required for dredging and dredged material disposal. DNR will not process an incomplete application package.

Typical dredging projects require the following permits:

- U.S. Army Corps of Engineers Permit
- Washington Department of Ecology Water Quality Certification
- Washington Department of Fish and Wildlife Hydraulic Project Approval
- Shoreline Substantial Development Permit or Exemption Letter

Application packages must be mailed to DNR's DMMP office at:

Department of Natural Resources
Aquatic Resources Division
ATTN: DMMP Manager
1111 Washington Street S.E.
P.O. Box 47027
Olympia, WA 98504-7027

Once DNR's DMMP office receives a completed Site Use Application and all required permits, it will take approximately two to three weeks to process the application and produce an unsigned SUA. Dredging proponents are encouraged to contact DNR early in the process to avoid delays after other permits and/or a suitability determination have been obtained. DNR maintains updated information on all SUA requirements, including application forms, on its DMMP office web page.

2.5 The Dredging Quality Control Plan and Pre-Dredge Conference

Proponents of regulated projects that are evaluated using this manual are required to submit a dredging quality control plan and attend a pre-dredge conference with the regulatory agencies prior to the initiation of dredging.

Prior to the pre-dredge conference, a dredging quality control plan must be submitted to the Seattle District Regulatory Office, which will coordinate review of this document with the DMMP. **The plan must be submitted no fewer than seven days prior to the pre-dredge conference, otherwise the conference will be cancelled**. Some projects require additional review time but any requirement for extended review will be stipulated in the SDM. The dredging quality control plan provides the following information (see Section 9.1 for details):

1. Project schedule.
2. Dredging and disposal procedures.
3. Water quality monitoring plan.
4. Coordination procedures.

The pre-dredge conference will be coordinated by the Enforcement Section, Regulatory Branch, US Army Corps of Engineers and will include, at minimum, the applicant, the dredging contractor, and representatives from the Corps, DNR, Ecology and EPA. The conference will be used to review disposal locations, water quality certification, the dredging quality control plan, the DNR site use authorization and any other permit conditions. Completion of the pre-dredge conference will be documented as part of the Regulatory Branch enforcement file.

2.6 Role of the Dredged Material Management Office

The Corps' Dredged Material Management Office (DMMO) provides a "one-stop" location for dredged material evaluations. The staff is available to answer questions, assist in the development of sampling and analysis plans, and help troubleshoot during sediment sampling and testing (see DMMO on Figures 2-1, 2-2, and 2-3). The DMMO coordinates SAP and data reviews with the other DMMP agencies (EPA Region 10, Ecology and DNR), prepares the SAP approval letter and drafts suitability determinations. The DMMO also interfaces with the Corps' Regulatory Branch and provides them assistance on dredged material management issues. **Any questions, problems or issues related to dredged material management should be directed to the DMMO:**

	Department of Army Seattle District, CENWS-OP-TS
Physical Address:	4735 East Marginal Way South Seattle, WA 98134-2385
Mailing Address:	P.O. Box 3755 Seattle, WA 98124-3755
Fax:	206-764-6602

DMMO Staff Members:

David Kendall (206) 764-3768
david.r.kendall@usace.army.mil

David Fox (206) 764-6083
david.f.fox@usace.army.mil

Stephanie Stirling (206) 764-6945
stephanie.k.stirling@usace.army.mil

Sandy Lemlich (206) 764-6930
sandra.k.lemlich@usace.army.mil

Lauran Cole Warner (206) 764-6550
lauran.c.warner@usace.army.mil

The DMMO homepage is also a useful source of information. For links, contacts, news, program updates and more visit:
http://www.nws.usace.army.mil/PublicMenu/Menu.cfm?sitename=dmmo&pagename=home

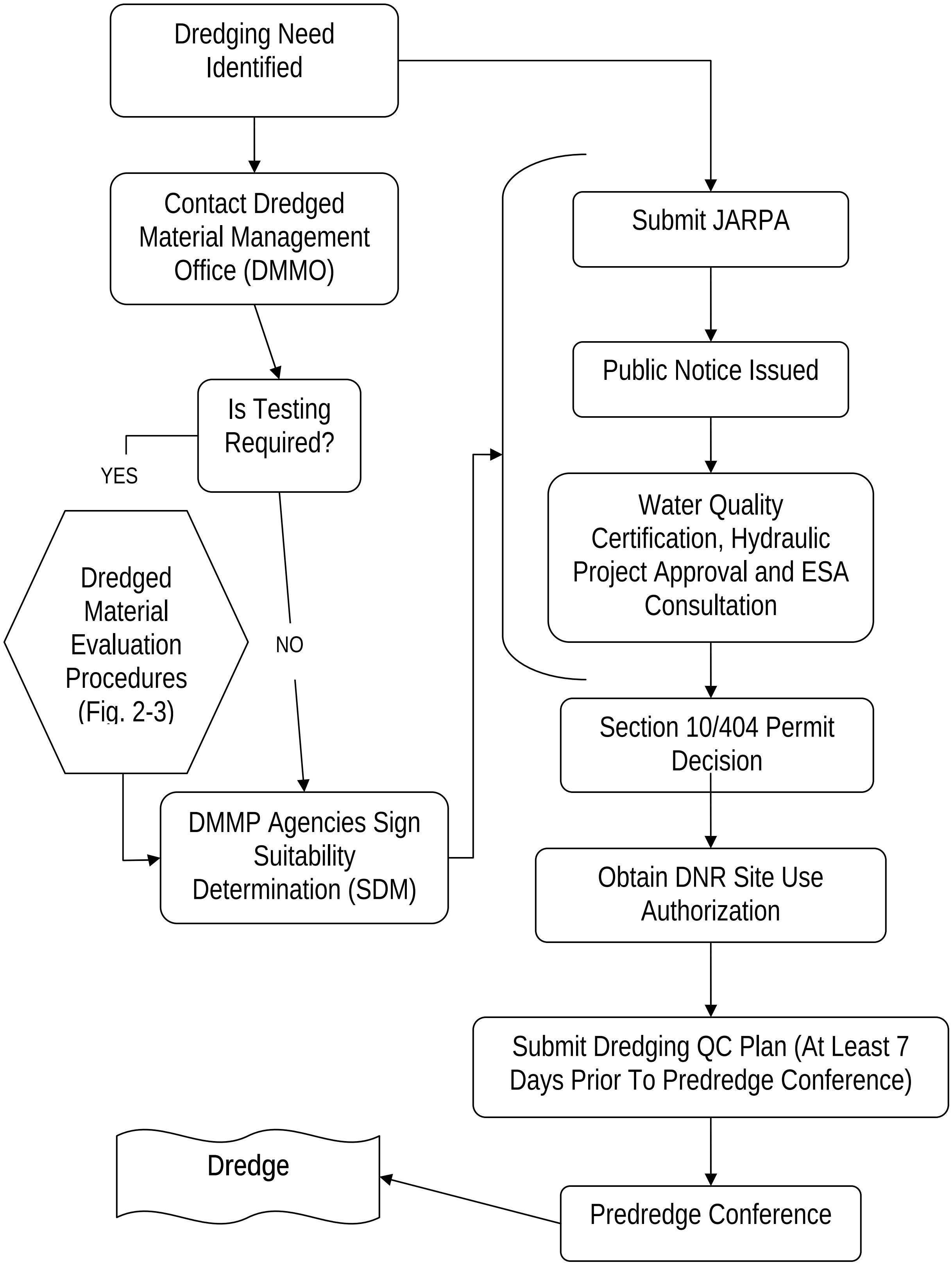


Figure 2-1. Section 10/404 Regulatory Process (New Permit Required)

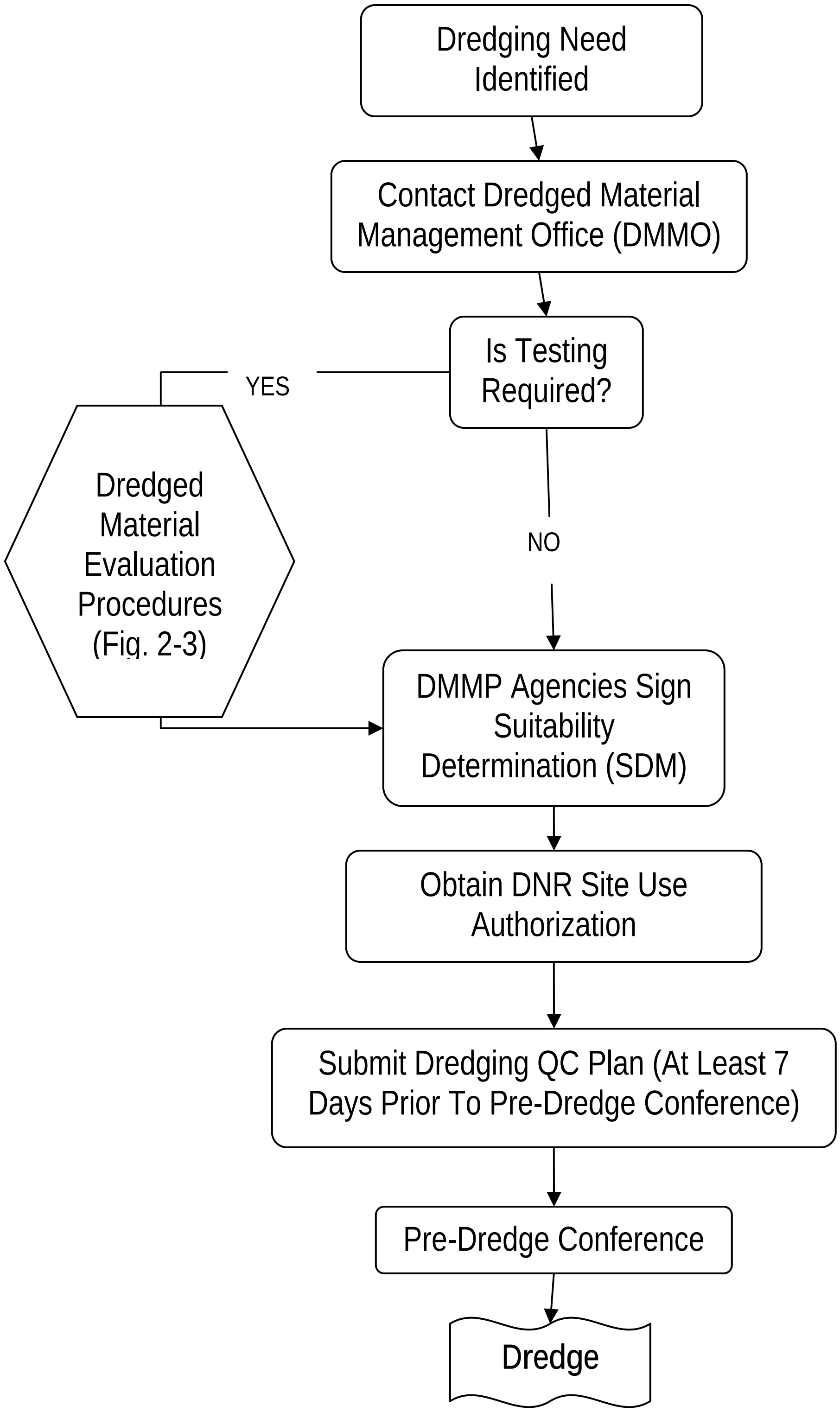


Figure 2-2. Section 10/404 Regulatory Process (New Permit NOT Required).

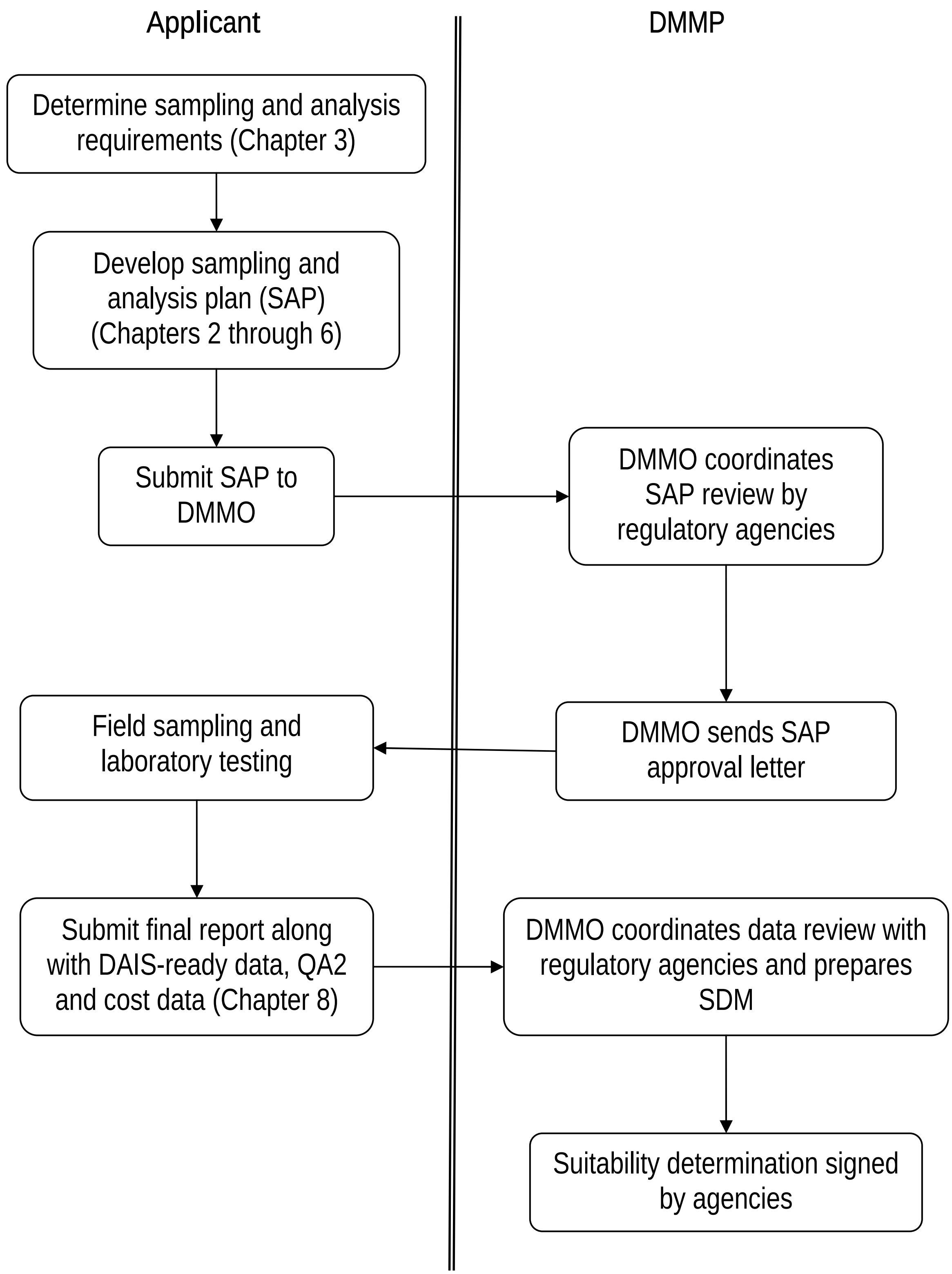


Figure 2-3. Dredged Material Evaluation Process.

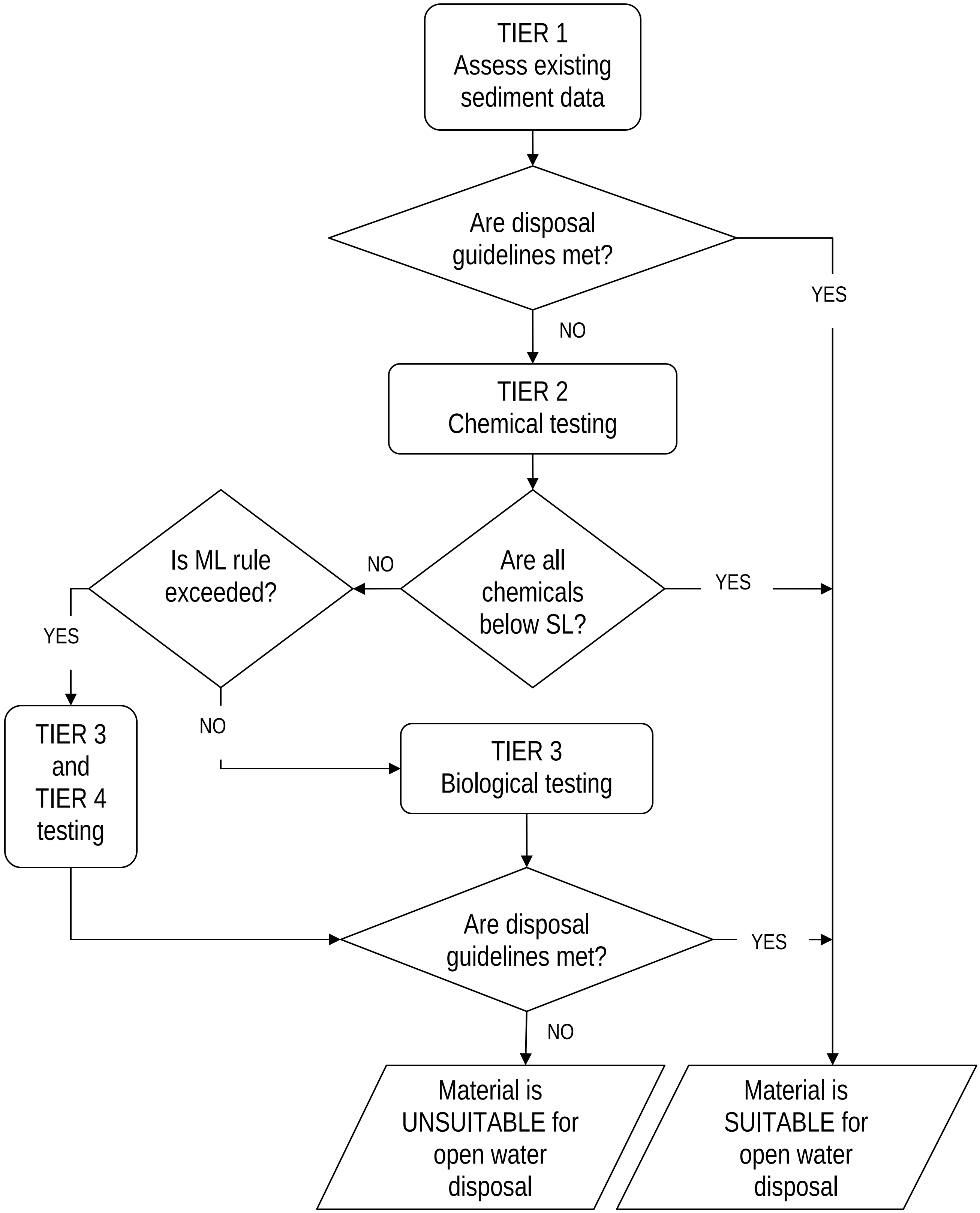


Figure 2-4. Tiered Testing Decision Diagram.

3 TIER I: EVALUATION/SITE HISTORY

A Tier I evaluation of existing information should be included in the sampling and analysis plan (SAP). Tier I is a comprehensive analysis of all readily available existing information on the proposed dredging project, including a site history and all previously collected physical, chemical and biological data. The type and amount of information required for a Tier I evaluation will vary according to the size and complexity of the project and the history of the dredging site.

3.1 Site Histories

The history of a project area plays a pivotal role in project evaluation and sampling plan development. The purpose of the site history is to document past and present sources of potential contamination to dredged material proposed for open-water disposal. A site history characterizes known activity at the dredging site, in near-shore areas, and on adjacent properties. It identifies past activities, and describes the type of contamination that may have resulted from those activities.

The following outline identifies the type of information that may be necessary in a site history for a large, complicated site. Smaller projects in areas of lower concern will require less information. For most projects, site histories do not need to extend beyond two to three pages. A reasonable effort should be made to obtain data. It is recognized that certain types of data may not be readily available but the effort to obtain it should be documented. Information available in agency files does not need to be re-gathered, but should be referenced and summarized.

Emphasis should be placed on those activities that took place since the last dredging cycle, and any previous sampling data is crucial to the site history and should be summarized in the sampling and analysis plan. It is important to identify whether the proposed dredging project is within, or adjacent to, an EPA or Ecology-listed MTCA, CERCLA or SMS site, and who the appropriate site manager is (if known). This will facilitate the coordination process among agencies.

The site history should include all the following information that is applicable to the specific project:

1. A map showing the site's location, layout, storm drainage, outfalls, and special aquatic sites such as eelgrass or wetlands.
2. Current site use.
3. Industrial processes at or near the site (and hazardous substances used/generated).
4. Outfall information, such as type, volume, NPDES data.
5. MTCA-, CERCLA- or SMS-listed site information (including site manager if known).
6. Spill events.
7. History of site ownership and land uses.
8. Adjacent property use, especially those up-gradient or up-current/upstream.

9. Site characteristics that could affect movement of contaminants (e.g. prop wash, ferry traffic).
10. Results of any previous sampling and testing.
11. Any dredging activity and data/information from that activity.

3.2 Sources of Information

There are a wide variety of information sources for site histories. Potential sources include:

- Current and previous property owners.
- Aerial photographs (past and present).
- Real estate and Sanborn fire insurance maps.
- Zoning, topographic, water resource, and soil maps.
- Agency records, such as NPDES permit files, contaminated site lists (state and federal), aquatic leases, previous permits, databases, etc.
- Land use records.
- Knowledgeable persons at or near the site (managers, employees, adjacent property owners).
- City atlases (Kroll and Metsker).

Not all sources are needed for all projects, and the type and extent of sources consulted will vary. Smaller projects and those with less complicated source histories will generally require less documentation but should always include enough information to enable the agencies to adequately address sampling and testing issues. Dredging proponents can contact the Dredged Material Management Office to determine the level of effort required for their specific project. The DMMO will coordinate with the other agencies as necessary to determine project-specific requirements

4 DEVELOPING THE SAMPLING AND ANALYSIS PLAN

The following steps are followed in the development of a sampling plan for the full characterization of project sediments:

1. determine the rank for the project
2. determine the volume of material to be dredged
3. determine the required number of dredged material management units (DMMUs) and field samples based on the volume and rank
4. develop a conceptual dredging plan
5. develop a sampling plan which distributes the DMMUs to reflect the conceptual dredging plan, allocates the required number of field samples, and presents a compositing plan.

These steps must be documented in the sampling and analysis plan developed for review by the agencies. Details are provided in the following sections.

4.1 Determining the Rank for the Project

A dredging area, or a specific project, may be assigned to one of four possible ranks: *high*, *moderate*, *low-moderate*, or *low*. These ranks represent a best professional judgment of concern or potential risk *by the agencies*, typically reflective of a scale of potential for adverse biological effects or elevated concentrations of chemicals of concern. The lower the rank, the less the concern, and the less intense the sampling and testing requirements needed to adequately characterize the dredged material. The ranking system is based on two factors:

1. The available information on chemical and biological-response characteristics of the sediments.
2. The number, kinds, and proximity of chemical sources (existing and historical).

For those dredging projects with sufficient historical data, the assigned ranking is based on the available chemical and biological data for project sediments. For those projects lacking sufficient historical data, the number, kinds and proximity of chemical sources are the major factors driving the assigned rank. Table 4-1 defines the ranking guidelines.

4.1.1 General Rankings

Certain areas or use activities are assigned a general rank based upon the nature and extent of possible sources of chemicals of concern that could impact sediments needing to be dredged. In the absence of sediment quality data to the contrary, urban and industrialized areas are initially ranked *high*. Marinas, fueling and ship berthing facilities, construction facilities, and sediments located close to moderate-sized sewer outfalls are initially ranked *moderate*. High energy areas that are characterized by coarse-grained material (sand and gravel) and are geographically removed from potential sources of chemicals of concern are initially ranked *low-moderate* or *low*.

Table 4-1. Dredged Material Ranking Guidelines.

RANK	GUIDELINES
Low	Few or no sources of chemicals of concern. Data are available to verify low chemical concentrations (below DMMP screening levels) and no significant response in biological tests.
Low-Moderate	Available information indicates a "low" rank, but there are insufficient data to confirm the ranking.
Moderate	Sources exist in the vicinity of the project, or there are present or historical uses of the project site, with the potential for producing chemical concentrations within a range associated historically with some potential for causing adverse biological impacts.
High	Many known chemical sources, high concentrations of chemicals of concern, and/or biological testing failures in one or both of the two most recent cycles of testing.

4.1.2 Area-Specific and Project-Specific Rankings

To facilitate the determination of sampling requirements, initial rankings for dredging projects in specific geographic areas, associated with certain activities, or with adequate historical testing data were determined using the ranking guidelines in Table 4-1. Current rankings for the Puget Sound area are shown in Table 4-2 and for Grays Harbor and Willapa Bay in Table 4-3.

4.1.3 Re-Ranking of Areas/Projects/Project Reaches

Modifications of the initial rankings can occur as the result of additional testing. A project area can be ranked higher (e.g., from low-moderate to moderate) based on the results of a single testing period. However, consistent results from two testing periods are required before a ranking can be lowered (e.g., from high to moderate). Projects may be ranked lower for a one-time dredging event based on the results of a partial characterization (see Section 4.6). However, two testing cycles will be required to lower the rank on a longer-term basis.

Table 4-2. Current general and project-specific rankings for Puget Sound.

RANK	WATERWAY/AREA
High	▪ Bellingham Harbor (from the cement plant to the old disposal site and from the I&J Waterway to Post Point) ▪ East Waterway, Everett Harbor ▪ Intertidal Areas of the Snohomish River (up to the upper turning basin) ▪ Mukilteo ▪ Edmonds ▪ Salmon Bay ▪ Lake Washington Ship Canal ▪ Lake Union ▪ Kenmore ▪ Elliott Bay ▪ Duwamish River (downstream of station 254+00) ▪ Outer Eagle Harbor (south of the former creosote plant) ▪ Sinclair Inlet ▪ Commencement Bay (except as specifically mentioned) ▪ Olympia Harbor (except parts of the navigation improvement project) ▪ Lower Budd Inlet (including East Bay Marina) ▪ Shelton ▪ Port Townsend (south side of point and south of marina) ▪ Port Angeles (inside the harbor)
Moderate	▪ Squalicum Boat Harbor ▪ Cap Sante Waterway ▪ Anacortes waterways, marinas and Guemes Channel ▪ Subtidal areas of the Snohomish River (through the upper settling basin) ▪ West Port Susan (near Cavelero Beach) ▪ Port Madison ▪ Lake Washington (except Kenmore) ▪ Dyes Inlet ▪ Upper portion of Quartermaster Harbor ▪ Gig Harbor ▪ Port Townsend Marina ▪ All existing fueling and ship berthing or construction facilities ▪ All existing marinas except those listed individually ▪ All ferry terminals with the exception of Keystone
Low-Moderate	▪ Inner Eagle Harbor (west of former creosote plant) ▪ Port Orchard ▪ Duwamish River (upstream of station 254+00) ▪ Outer Quartermaster Harbor ▪ Keystone Ferry Terminal ▪ All other unidentified areas
Low	▪ Blaine (except marina) ▪ Swinomish Channel ▪ Blair Waterway (Commencement Bay) – navigation channel only; rank of cutback areas dependent on source review ▪ Sitcum Waterway (Commencement Bay) ▪ Oak Bay Channel ▪ LaConner Marina

Table 4-3. Current rankings for Grays Harbor and Willapa Bay.

RANK	GRAYS HARBOR	WILLAPA BAY
High	▪ Urban and Industrialized Areas	▪ Urban and Industrialized Areas
Moderate	▪ Marinas ▪ Fueling and Berthing Facilities ▪ Construction Facilities ▪ Located near moderate-sized sewer outfalls	▪ Other Marinas ▪ Fueling and Berthing Facilities ▪ Construction Facilities ▪ Located near moderate-sized sewer outfalls
Low-Moderate	▪ Rayonier Dock [1] ▪ Port of Grays Harbor Terminals 2, 3, 4 [2] ▪ Citifor Dock [2] ▪ Weyerhaeuser Bay City Dock	▪ None
Low	▪ Port of Grays Harbor Terminal 1 ▪ Bar Reach ▪ Entrance Reach ▪ South Reach ▪ Crossover Reach ▪ North Reach ▪ Hoquiam Reach ▪ Cow Point Reach ▪ Aberdeen Reach ▪ South Aberdeen Reach	▪ Bay Center ▪ Bay Center Entrance Channel ▪ Bay Center Entrance Channel Bar ▪ Willapa Bar ▪ Toke Point Channel

[1] Data from the most recent testing cycle indicates that this project could potentially be ranked low. An additional testing cycle is needed to confirm the low rank.
[2] Chemical testing conducted in 1989, 1991 and 2001 indicates that these areas could potentially be ranked low. Safety-net biological testing is needed to confirm the low rank.

4.2 Determining the Volume of Material to be Dredged

Where possible, the physical geometry and volume of sediments proposed for dredging should be determined from a pre-sampling bathymetric survey. The dredging volume calculation should include side slopes, overdepth and sediments anticipated to slough from under piers and wharves. For dredging projects that occur infrequently, the dredging prism should be divided between a "surface" layer (generally four feet in depth) and a "subsurface" layer consisting of everything below the surface layer. The volumes comprising each of these layers should be calculated. For projects that are dredged more frequently, the entire dredging prism may be considered homogeneous and the volume need not distinguish between surface and subsurface layers.

Dredging contracts routinely include "overdepth" material that is often one to three feet below the required dredging depth (except for very small projects where it may be decided to minimize overdepth volume for cost control). Overdepth volume will be included in the calculation of the requirements for sampling and analysis and disposal site use fees.

Volume estimates, including overdepth material, are incorporated into the associated site permit, water quality certification and site use authorization. Exceedances of permitted volumes may result in fines or work stoppages. Therefore, it is important to develop an accurate volume estimate of material to be dredged. To reduce the incidence of permit violations, the following guidelines should be followed:

1. Pre-sampling surveys should be taken as close in time as possible to the sampling event to get the best possible bathymetric data for volume estimates.
2. Pre-sampling volume estimates must include allowable overdepth for the entire dredging prism, including sideslopes. Technical justification for the selected angle of repose for the sideslopes must be included in the sampling and analysis plan.
3. When a box cut is proposed along a pier face, it is recommended that sloughing from under the pier be anticipated in all cases. Technical justification for the selected angle of repose for sideslopes under piers must be included in the sampling and analysis plan. The dredging proponent should ensure that all necessary geotechnical or under-pier survey data be provided to the contractor estimating the dredged material volume.
4. It is highly recommended that presampling estimates of in-situ volume be increased by an uncertainty factor to account for the error inherent in the estimation process and to include reasonable "non-pay" volume. Sampling and testing requirements will be based on this adjusted volume. The uncertainty factor must be identified in the sampling and analysis plan along with a technical justification for its selection. It should be noted that the uncertainty factor applies only to estimates of in-situ volume and is not meant to address bulking of sediments during dredging.

Some areas, particularly channels and settling basins, are characterized by rapid shoaling during winter storm events. Since sampling and testing are required to be conducted prior to dredging, not all of the sediments to be dredged will have been deposited at the time of sampling. In such instances, presampling bathymetric surveys, records from previous dredging events and best professional judgment will be used to estimate the volume of sediments likely to be dredged. Sampling and testing requirements will be based on this estimated volume.

4.3 Determining the Number of DMMUs and Field Samples

The number of field samples to be taken and the number of laboratory analyses conducted to fully characterize the sediments for any given project must be sufficient to allow for an adequate assessment. The following guidelines specify a maximum volume of dredged material that can be represented by a single field sample and by a single laboratory analysis. They are considered "minimum" requirements in that the dredger may opt, or regulatory agencies may require, additional samples or analyses if warranted.

4.3.1 Dredged Material Management Units

A "dredged material management unit" (DMMU) is the smallest volume of dredged material that is truly dredgeable (i.e., capable of being dredged independently from adjacent sediments) and also for which a separate disposal decision can be made by the agencies. Though "dredgeability" often defines the minimum volume in a given DMMU, the maximum volume is based on the project rank, dredging depth, and extent of mixing in the dredge prism. Thus, a given volume of sediment can only be considered a DMMU if it is capable of being dredged, evaluated and managed separately from all other sediment in the project.

Each DMMU is independently evaluated for suitability for unconfined, open-water disposal. Samples representing the sediment in a given DMMU are composited for a single laboratory analysis, with results applicable to the entire DMMU.

4.3.2 How Many DMMUs?

Sediment in any given project is considered either "heterogeneous" or "homogeneous." Heterogeneous sediment is divided into "surface" (0 to 4 feet of the dredging prism) and "subsurface" (greater than 4 feet below the sediment surface. Heterogeneous sediment is that in which there is presumed, or known, to be a difference in contamination levels in the surface and subsurface sediments. To characterize heterogeneous sediments, different sampling intensities are used for the surface and subsurface portions of the dredge prism (Table 4-4). For example, in a moderate-ranked area with 32,000 cubic yards (CY) of surface material (less than a 4-foot cut depth) and 24,000 CY of subsurface material (greater than a 4-foot cut depth), a total of three DMMUs are required (two from the surface volume and one from the subsurface volume).

This approach assumes that the surface material is more contaminated than the underlying material. If it is known, or suspected, that this scenario does not hold for a particular dredging project, then best professional judgment must be applied in determining volume limits for DMMUs.

For projects which are dredged frequently due to rapid or routine shoaling, the sediments are expected to be relatively homogeneous and the distinction between surface and subsurface sediments becomes less important. In this case, DMMU volumes may be based on the average of surface and subsurface maximum allowable volumes. The proposed dredging volume may be divided by this average volume to determine the number of DMMUs. Grab samples are considered adequate to characterize homogeneous sediments.

Table 4-4. Maximum sediment volume represented by each dredged material management unit (DMMU).

PROJECT RANK	HETEROGENEOUS SEDIMENT (contamination level varies with depth)		HOMOGENEOUS SEDIMENT (well mixed)
	SURFACE	SUBSURFACE	
Low	48,000 CY	72,000 CY	60,000 CY
Low-moderate	32,000 CY	48,000 CY	40,000 CY
Moderate	16,000 CY	24,000 CY	20,000 CY
High	4,000 CY	12,000 CY	8,000 CY

4.3.3 Sampling Intensity

The maximum volume of sediment that may be represented by a single field sample (typically a 4-foot core) varies with project rank and is presented in Table 4-5. A single core (e.g., 12 feet in length) may be divided into several samples (e.g., three samples each 4 feet in length). For projects in areas ranked low or low-moderate, a single sediment sample should be taken for every 8,000 CY of material to be dredged. For projects in areas ranked high or moderate, a single sediment sample should be taken for every 4,000 CY. Unlike the maximum volume represented by each DMMU, the maximum volume represented by each field sample does not vary with sediment depth. Continuing with the example presented in the previous section, a moderate-ranked project with 32,000 CY of surface sediment and

24,000 CY of subsurface sediment would require a total of 14 field samples: eight from the surface volume and six from the subsurface volume, which would be composited respectively to generate two analyses/DMMUs for the surface material and a single analysis/DMMu for the subsurface material

Table 4-5. Maximum sediment volume represented by a single field sample.

PROJECT RANK	SURFACE	SUBSURFACE
Low	8,000	8,000
Low-moderate	8,000	8,000
Moderate	4,000	4,000
High	4,000	4,000

4.3.4 Reduced Sampling and Testing for Small Projects

For small projects, the cost of testing must be balanced against the environmental risks posed by disposal of a very small volume of dredged material. Small projects in low, low-moderate and moderate ranked areas represent low potential risk that unacceptable adverse effects will result at the disposal site from the discharge of project material. As a result, with the exception of high-ranked areas, a small volume of sediment to be removed at a dredging site may require no testing or reduced testing.

To clearly define what constitutes a small project, there are two key qualifiers. 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, project volumes are defined in as large a context as possible. One example of this latter qualifier is recurring maintenance dredging of a small marina where "project volume" will be the projected dredging volume over 5 years. Another example is multiple-project dredging contracts where a single dredging contractor conducts dredging for several projects under a single contract or contract effort. Again, the "project volume" will be summed across all projects (as will any sampling and compositing efforts prior to testing).

4.3.5 "No-Test" Volumes for Small Projects

For projects in low, low-moderate, or moderate-ranked areas, volumes for which no testing need be conducted are shown in Table 4-6. In the absence of specific, conclusive evidence of unacceptable material, most projects with these or lesser volumes will be categorically considered suitable for unconfined, open-water disposal. For low-ranked areas, the "no test" volume is equal to the maximum volume represented by a single field sample (i.e., 8,000 CY). For low-moderate and moderate rankings, the "no test" volume of 1,000 CY is representative of the capacity of medium-sized barges. For high-ranked areas there is not a "no test" volume and some testing is always required.

Table 4-6. "No Test" volumes for small projects.

PROJECT RANK	"NO-TEST" VOLUME
Low	Less than 8,000 CY
Low-moderate and Moderate	Less than 1,000 CY
High	Some testing is always required

Some small dredging projects consist of the removal of sediment discharged from an outfall, or located directly adjacent to an outfall, yet fall within a general geographic area ranked low, low-moderate or moderate. However, it is possible that these sediments contain chemicals at a level of concern far greater than the area in general. Therefore, such dredging projects may be given a "high" rank by the agencies regardless of the rank of the general area. This decision will be made on a case-by-case basis, with consideration given to the type and size of the outfall, the shoaling pattern relative to the outfall, and any other relevant information available to the project proponent, such as catch basin and particulate data associated with the outfall.

4.3.6 Reduced Testing for Small Projects Exceeding the "No-Test" Volume

For projects of less than 500 CY located in high-ranked areas, some testing will always be required. The dredger will have the option to conduct either a single chemical analysis for all chemicals of concern (without the required QA/QC replication), or to conduct bioassays (amphipod and one additional bioassay) on a single sample (without chemistry, but with appropriate bioassay replicates). For the chemistry option, the "maximum levels (ML)" will be used as "acceptable/unacceptable" values. The dredger will still have the additional option to conduct standard and Tier IV biological testing if the material exceeds the ML values. (A single ML exceedance of less than 100% will require standard biological testing only).

For low-moderate and moderate-ranked projects between 1,000-4,000 cubic yards and high-ranked projects between 500-4,000 cubic yards, standard chemical testing must be conducted, but if biological testing is needed only two bioassays will be required (Table 4-7). These will include the 10-day amphipod test and one other bioassay from the standard suite.

For projects in low-ranked areas that exceed 8,000 CY and require biological testing based on chemical test results, the full biological testing suite will be conducted. This is because low-ranked areas are not expected to exceed the chemical screening levels (SLs), which is one of the reasons why the "no test" volume is set so high relative to other area rankings.

Table 4-7. Reduced testing requirements for small projects above the "no test" volume.

PROJECT RANK	VOLUME	REQUIRED BIOLOGICAL TESTS[1]
Low-moderate and Moderate	1,000-4,000 CY	amphipod and one other bioassay
High	0-500 CY	see narrative
High	500-4,000 CY	amphipod and one other bioassay

[1]Chemical tests are required of all such projects, with the exception of high-ranked projects less than 500 cubic yards. Biological tests as listed are required if chemical results indicate that the dredged material contains chemical concentrations above the screening levels.

4.3.7 Reduced Sampling and Testing for Native Material

Projects that involve dredging of native material that has not been exposed to contaminated groundwater may require less sampling and testing than the requirements identified in Tables 4-4 and 4-5. The agencies will make this determination using best professional judgment on a case-by-case basis using site-specific information.

4.3.8 Other Exclusions from Testing

High Energy Areas. Dredged material that may be excluded from testing, and circumstances when this may be allowed, are described in the regulations for both the Marine Protection, Research, and Sanctuaries Act (MPRSA) (40 CFR 227.13) and Clean Water Act (40 CFR 230.60). Generally, relatively larger grained material (e.g., sand and gravel) from high energy environments that are geographically removed from contaminant sources meet the exclusion criteria. The DMMP agencies will apply the exclusion criteria on a case-by-case basis.

4.4 Developing a Conceptual Dredging Plan

Prior to determining a sampling plan, a project-specific conceptual dredging plan needs to be prepared. This plan takes into consideration the depth and physical characteristics of the sediment, side slopes, practicable dredge cut widths and depths, dredging along pier faces, other physical and logistical constraints, available dredging methods and equipment, and conventional construction practices at similar dredging projects.

While construction-level detail is not required at this point in the process, a realistic conceptual dredging plan will aid in the delineation of DMMUs and avoid the situation in which a regulatory determination could negatively impact the ability to dredge the project and properly dispose of the material.

4.5 Full Characterization Sampling Plan Development

Once the required numbers of DMMUs and field samples have been calculated and a dredging plan conceived, a sampling plan must be developed which delineates the DMMUs, proposes locations for the collection of field samples, and identifies which field samples will be composited to represent each of the DMMUs. The DMMUs and field samples are distributed to the actual dredging prism in a manner consistent with the definition of a DMMU and any project-specific constraints. Ideally, the maximum volumes from Table 4-4 and Table 4-5 will be carried through to the actual field situation but this will not always be possible. It is not necessary or always desirable to restrict the volumes characterized by each individual sample or DMMU in the field to the maximums found in Table 4-4 and Table 4-5. Best professional judgment is necessary in the allocation of DMMUs and the development of a sampling and compositing plan.

In dividing the proposed dredging volume into DMMUs, it is important to ensure that the DMMUs be fully reflective of the dredging plan, i.e., *that the management units be truly "dredgeable."* If an individual DMMU (represented by one or more field samples) is found unsuitable for unconfined open-water disposal, then that DMMU must be capable of being dredged independently from adjacent sediment. Additional DMMUs, beyond the minimum number, may be required to achieve an appropriate dredging plan (e.g., where different sediment types or physically separated areas warrant separate DMMUs).

It is also important to note that the 4-foot cut (for heterogeneous sediments) need not be carried through to the actual dredging plan. The 4-foot cut is used solely as a guideline to establish the minimum number of required analyses. The actual dredging cuts will depend on the geometry of the dredging prism and project-specific physical, environmental and logistical constraints.

All of the field samples taken within a DMMU are composited to provide a single sediment sample for laboratory analysis that is representative of that DMMU. Therefore, the selection of sampling locations and the development of a compositing scheme must provide an accurate representation of the condition of each DMMU. In general, samples should be uniformly distributed across the dredging prism. However, special circumstances, such as the presence of sources of contamination, may dictate otherwise. The location of point sources in the vicinity of the project must be taken into consideration when locating field samples, but "worst-case" sampling should *not* be the goal of full characterization (it *is* the goal of partial characterization sampling; see Section 4.6). Tier I information, including the location of point sources, should be included in the sampling and analysis plan and should support the sampling locations selected to ensure representative sampling of the proposed dredged sediments.

4.6 Partial Characterization for Down-Ranking

A dredging proponent may choose to do a partial characterization (PC) of project sediments. A PC is most frequently done on larger projects and is based on the chemical analysis of a limited number of samples. If the PC data indicate that the project has been over-ranked, then down-ranking may be permitted for a subsequent full characterization (FC). Down-ranking may substantially reduce the overall cost of sampling and testing for a large project.

A PC is designed to be simple and economical. A PC is not a substitute for a full characterization, but is only a means for establishing a "reason to believe" that a lower ranking is appropriate. A PC must provide sufficient information to support a decision to re-rank a project. PC results are used to downrank a project on a one-time basis only. Two cycles of testing are required for longer-term downranking.

4.6.1 Development of a PC Sampling and Analysis Plan

A sampling and analysis plan must be developed for a PC. The PC plan must be submitted to the DMMO, who in turn will coordinate agency review with EPA, Ecology and DNR representatives.

The following PC guidelines are appropriate for most dredging projects. However, because anomalies may exist for a given project, the agencies reserve the right to 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 dredged material evaluation process, professional judgment will be an important factor in the decision-making process. The dredger should coordinate with the DMMO in the development of an adequate PC plan.

4.6.2 Sampling Requirements for Down-Ranking

The number of samples required for down-ranking is based on a percentage of the number of samples that would be required for a full characterization. A dredger may elect to down-rank up to two levels by increasing the sampling intensity. No compositing of samples for a PC is allowed. PC sampling station delineation must be approved in advance by the agencies and should represent "worst-case" sampling relative to the location of local point sources.

For the option of lowering a rank one level, ten percent of the FC minimum surface sample requirement must be analyzed for a PC. A minimum of two samples must be analyzed for this option. For the option of lowering a ranking two levels, 20 percent of the FC minimum surface sample requirement must be analyzed for a PC. At least three samples must be analyzed for this option. A dredger has the option of performing a PC on subareas of a dredging project. Subareas must be selected with the approval of the agencies. A minimum of two samples is required for each subarea. Although a PC is most frequently done on surface sediments, a dredger may be required to perform subsurface sampling and analysis during a PC if there is reason to believe that subsurface sediments are contaminated relative to sediments in the upper four feet of the dredging prism.

Partial characterization data for a given sampling station may also be used, in some limited cases, in partial fulfillment of FC requirements. The strategy for doing so must be clearly stated in the PC sampling and analysis plan and approved by the agencies.

4.6.3 Ranking Guidelines Based on PC Data

The down-ranking of a project (or subarea) will be based on the results of the sample having the highest level of chemicals of concern (see also Section 6.4, which discusses special COC's). Ranking guidelines based on PC data are shown in Table 4-8.

PC samples must be analyzed for the full list of chemicals of concern (see Table 5-1) and sediment conventionals. PC data may also be used as a "reason to believe" test to screen out certain chemicals of concern. If a chemical is not found in the PC and is not available from nearby sources, it may be deleted from the full characterization.

Table 4-8. Ranking guidelines based on partial characterization data.

RANK	PC GUIDELINE
High	At least one chemical > ML
Moderate	At least one chemical > (SL +ML)/2 and < ML
Low-moderate	At least one chemical > SL and < (SL + ML)/2
Low	All chemicals < SL

4.7 Recency Guidelines

Recency guidelines apply to material that has been sampled and tested for open-water disposal but not yet dredged. A key consideration in determining whether available data are still representative is the recency of the information. "Recency" guidelines for existing information refer to the duration of time for which chemical and biological characterization of project-specific sediment remains adequate and valid for decision making without further testing. These guidelines are based on the number and operating status of chemical sources near the area to be dredged, on whether the sediment is close to the sediment-water interface or not, and on how well previous samples describe the current conditions at the project site. With older data there is increased potential for a "changed condition" that could alter its validity. Data must be sufficiently recent to be considered representative of the material to be dredged.

The ranking system for dredging projects takes into consideration both the sources of contamination and historical chemical and biological testing data (which are considered an integrated reflection of the effects of sources on the project area). Therefore, the recency guidelines are based on the project rank. For high-ranked projects, the recency guidelines allow characterization data to be valid for a period of 2 years. The recency guideline for moderate, low-moderate and low-ranked projects is a period of 5, 6 and 7 years respectively.

When other permitting requirements prevent a project from being dredged during the recency period, extension of the recency period will be considered on a case-by-case basis. When considering whether existing data continue to adequately characterize sediment from a specific project, the agencies will review previous characterization data, any new data from the dredge site or vicinity, and site use and character. Based on this review, the agencies may extend the recency determination, typically for one year. This extension may be allowed with no additional testing, or may require some level of additional testing, from confirmatory to full characterization.

The recency guidelines never apply when a known "changed" condition (e.g., accidental spills or new discharges) has occurred since the most recent samples were obtained. For subsurface sediments, the potential for contamination from groundwater sources must be considered.

Project proponents should contact the DMMO if recency guidelines are likely to be exceeded at their project site prior to dredging. Depending on the project area and site complexity, a written proposal to extend the recency period will likely be requested. The proposal should thoroughly evaluate the above variables and suggest a course of action. The DMMP will respond in writing to the request, and provide a recency determination addendum to the original Suitability Determination when results from the analysis and characterization events have been evaluated. For further clarification on recency extensions and guidelines, see SMARM updates Recency Guidelines: Program Considerations (2002) and Recency Guideline Exceedances: Guidelines for Retesting in High Ranked Areas (2003).

4.8 Frequency Guidelines

Frequency guidelines refer to the extent of time a given dredging project can be maintained with repeated dredging without further testing. Once the sampled and tested material has been dredged, frequency guidelines apply. Time durations for the frequency guidelines are the same as for the recency guidelines: two years for high-ranked areas; and 5 to 7 years for moderate, low-moderate, and low-ranked areas. Sediment dredged within the frequency guidelines will not generally require full testing. However, two cycles of sampling and testing for a project are required before the frequency guidelines take effect. A biological testing failure during any testing cycle will negate the applicability of the frequency guidelines and automatically result in a need to conduct testing every dredging cycle.

To avoid the possibility of “surprises” in dredging cycles to which frequency guidelines apply, a minimum of one bulk chemical analysis (project composite) may be required as a “safety net” against unexpected chemical concentrations not indicated by historical data. Chemical data resulting from this analysis will be compared to screening level values and historical data to determine if there is reason to believe that biological testing is warranted. Safety-net testing will be required on a case-by-case basis using best professional judgment.

For the maintenance dredging of the Federal navigation project at Grays Harbor (a low-ranked area), a complete testing cycle will be conducted every 6 years. To avoid large annual fluctuations in testing costs for a project of this magnitude, testing within three different sub-areas will be rotated sequentially on a two-year cycle. This provides predictable, manageable and level biennial operating budgets for testing.

4.9 Safety-net Biological Testing

To avoid a situation where a chemical-of-concern not on the standard list is present at a concentration high enough to cause biological effects, "safety-net" biological testing may be required of a limited number of DMMUs for low-ranked areas. Biological testing will consist of the 10-day amphipod test and one other bioassay from the standard suite. Twenty percent of project DMMUs, representing the finest-grained material, should be tested (minimum of one DMMU). If there are exceedances of the screening levels for any DMMUs, triggering biological testing, these DMMUs will fulfill the requirement for safety-net testing as long as the twenty-percent guideline is followed. The frequency of safety-net testing for low-ranked projects is 6 years.

If all chemicals-of-concern are below the screening level, yet the safety-net biological testing indicates a potential for adverse biological effects, best professional judgment will need to be applied in resolving the apparent conflict between the chemical and biological testing data. Additional chemical or biological testing may be needed to determine the nature of the problem.

4.10 New Sediment Exposed by Dredging (Z Sample)

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. The exposed sediment must meet the State of Washington Sediment Management Standards (SMS). A “Z sample” is a sample from the first foot below the dredging overdepth and must be collected during sampling of heterogeneous sediments. Z-sample collection and analysis guidance is as follows:

- Z-samples will be collected and archived for every core sampling location for all projects, regardless of rank. Archived sediment must be maintained at -18° C.
- If TBT testing is required for the project, interstitial water from an unfrozen sediment subsample must be extracted within seven days of field collection. The porewater extract must be maintained at -18°C.
- It is likely that the holding time for mercury will be exceeded prior to any testing of archived sediment. The results should be flagged as having exceeded the holding time.
- Archived sediment cannot be tested for volatile organics. Therefore, the requirement to test for the DMMP volatiles is waived unless these chemicals are anticipated to be a problem at the project site.
- If a surface DMMU is found to be contaminated (e.g., unsuitable for unconfined-open-water disposal), and the underlying DMMU is also contaminated or has not been adequately characterized, then archived Z-samples must be analyzed to verify the sediment quality of the Z-horizon.
- Z-sample analyses will initially consist of sediment conventional and chemical analyses. If the results of these analyses indicate exceedances of SMS Sediment Quality Standards, the dredging applicant may be required to remobilize and resample those given Z-sample locations in order to perform required biological testing (bioassays and/or bioaccumulation testing). This must occur prior to dredging.
- The post-dredged sediment surface (top 10 cm) may be subject to sediment quality evaluation at the discretion of the DMMP or the Department of Ecology for any project

where overlying surface or subsurface DMMUs were found to be unsuitable for unconfined open-water disposal.

For further discussion of Z-sample and post-dredge sediment surface guidelines, see the full updates from the 2001 and 2008 SMARMs.

5 SAMPLING

5.1 Timing of Sampling

When required, sampling and testing must be coordinated with the DMMP in advance of dredging to allow time for testing and data review. Sampling and analysis prior to dredging prevents a situation in which the testing data show sediments to be unacceptable for open-water disposal after disposal occurs.

Areas that receive large volumes of material due to shoaling during winter storm events also need to be sampled prior to dredging. Because these projects are typically dredged within a short time after deposition by winter storms, insufficient time is available to completely characterize all the material that will eventually be dredged. Instead, material that is already in place prior to the winter storm season is sampled and tested. This sampling strategy assumes that sediments deposited by winter storms will have a chemical composition very similar to the sediments that are in place at the time sampling and testing is conducted. This strategy is a compromise that includes consideration of the need to provide representative sampling and the need to provide an evaluation process adaptable to the fast shoaling pattern found in these areas. This compromise will also help avoid reliance on “emergency dredging” whereby sediment sampling and testing is not possible prior to dredging. Accordingly, the number of DMMUs and field samples will be based on pre-sampling bathymetric surveys, records from previous dredging events and best professional judgment.

5.2 Sampling Approach

If full characterization sampling and analysis are required for a project, the applicant will be required to sample the sediment for chemical and, if necessary, biological analyses. There are three sampling approaches that the dredging proponent may take:

1. **Concurrent Testing:** Collect sufficient sediment for all chemical and biological tests potentially required. Run these tests concurrently.

2. **Tiered Testing:** Collect sufficient sediment as above, but archive adequate sediment for biological testing pending the results of the chemical analysis.

3. **Tiered Testing/Resampling:** Collect only enough sediment to conduct the chemical analyses and, if biological testing is required, re-sample the site.

The proposed sampling approach should be clearly documented in the sampling and analysis plan. The selection of either option 1 or 2 is encouraged because these alternatives provide chemical and biological data on sub-samples of a single homogenized sediment. These alternatives are also advantageous because they both preclude the cost involved with collection of additional sediment. Concurrent testing is the least time consuming, and is likely the most economical when the need for biological testing is expected. For tiered testing, the biological samples must be stored at 4 degrees C with zero headspace (or with headspace purged with nitrogen) while chemical tests are completed. Maximum holding time for biological testing is 56 days

Tiered testing with resampling should only be considered if biological testing is not expected. If it does occur, biological analysis can proceed without re-analysis of sediment chemistry, unless bioaccumulation testing will also be conducted. Biological samples must be taken from the same stations as the previous sediment chemistry samples.

In general, a minimum of 6 liters of homogenized sediment will be needed to provide adequate volume for physical, chemical and standard biological analysis. Bioassay analysis requires approximately four (4) liters and chemical analysis requires approximately one (1) liter of sediment. The additional liter should be archived for contingencies such as bioassay retests. Bioaccumulation testing requires a minimum of 15-20 liters of sediment beyond the 6 liters identified here.

For all projects where samples were taken with coring devices, sediment that will be exposed by dredging must also be sampled. Please refer to Section 4.10 (Z samples).

5.3 Positioning Methods

A precision navigation system should be used to record all sediment sampling locations to a geodetic accuracy of ± 2 meters. In most cases, samples should be obtained as near as possible to the target locations provided in the project sampling plan. Such accuracy can be obtained with a range of positioning hardware, such as microwave trisponders, differential GPS, electronic measuring devices, etc. The exact positioning system to be used and associated QA/QC procedures should be documented in the project sampling plan.

Sampling location data will be entered into the Dredged Analysis Information System (DAIS) in the form of latitudes and longitudes referenced to North American Datum of 1983 (NAD 83) which is considered equivalent to the World Geodetic System 1984 (WGS 84). If sampling locations are referenced to a local coordinate grid, the local grid should be tied to NAD to allow conversion to latitudes and longitudes. Latitudes and longitudes referenced to the North American Datum of 1927 (NAD 27) should be transformed to NAD 83.

5.4 Sampling Methods

The goal of sediment sampling for characterization of each individual DMMU is to collect a sample (or a number of composited samples) which will be representative of the DMMU. The accuracy of this representation can be increased vertically by taking core samples from the sediment/water interface down to the maximum proposed depth of dredging and horizontally by increasing the number of samples taken. The agencies have established minimum sampling requirements (see Chapter 4) based on volumetric measurements. The type of sampling required, however, depends on the type of project. The sampling methodology to be used should be presented in the sampling and analysis plan along with the rationale for its use.

5.4.1 Core Sampling

For projects which are dredged infrequently (less than once every 5-7 years) and for new-work dredging, the proponent will be required to take core samples from the sediment/water interface down to the maximum depth of dredging, including overdepth and Z-samples.

There are numerous gear options available for obtaining core samples. These include impact corers, hydraulic push corers, vibracorers, augers with split spoons or Shelby tubes, jet samplers, etc. The methodology chosen will depend on availability, cost, efficacy, and anticipated sediment recoveries.

5.4.2 Grab Sampling

Sediments in frequently dredged areas (e.g. Grays Harbor navigation channel) are assumed to be relatively homogeneous. Therefore, for frequently dredged projects not in high-ranked areas, grab samples will be considered adequate to represent the dredged material, even if shoaling results in sediment accumulation greater than four feet. The minimum number of grab samples required can be calculated from the tables in Chapter 4.

5.5 Sample Collection and Handling Procedures

Proper sample collection and handling procedures are vital for maintaining the integrity of the sample. If the integrity of the sample is compromised, the analysis results may be skewed or otherwise unacceptable. Procedures for decontamination, sampler deployment, sample logging, sample extrusion, compositing, sample transport, chain of custody, archiving and storage all need to be discussed in the sampling and analysis plan.

The remainder of this chapter provides general guidance on sample handling procedures. For further guidance please refer to the Puget Sound Protocols and Guidelines (PSEP, 1997a). The protocols describe field collection and processing methods, bioassay-specific QA/QC, and data reporting procedures. Also, general protocols are provided for field collection of surficial test sediments and for general QA/QC procedures that apply to all sediment bioassays.

5.5.1 Decontamination Procedures

It is recommended that sampling containers be decontaminated by the laboratory or manufacturer prior to use. All sampling equipment and utensils such as spoons, mixing bowls, extrusion devices, sampling tubes and cutter heads, etc., should be made of non-contaminating materials and be thoroughly cleaned prior to use. The intention of these procedures is to avoid contaminating the sediments to be tested, since this could possibly result in dredged material, which would otherwise be found acceptable for open-water disposal, being found unacceptable. While not strictly required, an adequate decontamination procedure is highly recommended. The dredging proponent assumes a higher risk of sample contamination by not following an established protocol. The Puget Sound Protocols and Guidelines should be consulted for specific guidance.

After decontamination, sampling equipment should be protected from recontamination. Any sampling equipment suspected of contamination should be decontaminated again or rejected. During core sampling, extra sampling tubes should be available on-site to prevent interruption of operations should a sampling tube become contaminated. Sampling utensils should be decontaminated again after all sampling has been conducted for a given DMMU to prevent cross-contamination. Disposable gloves are typically used and decontaminated or disposed of between DMMUs.

5.5.2 Sample Collection

Sampling procedures and protocols will vary depending on the sampling methodology chosen. Whatever sampling method is used, measures should be taken to prevent contamination from contact with sources of contamination such as the sampling platform, grease from winches, engine exhaust, etc. Core sampling methodology should include the means for determining when the core sampler has penetrated to the required depth. If the core is driven beyond the proposed dredging depth, the core logging must be adequate to allow the proper core section to be taken post-sampling for inclusion in the sample composite. The sampling location must be referenced to the actual deployment location of the sampler, not to another part of the sampling platform such as the bridge of a sampling vessel.

5.5.3 Volatiles and Sulfides Sub-sampling

The volatiles and sulfides sub-samples should be taken immediately upon extrusion of cores or immediately after accepting a grab sample for use. For composited samples, one core section or grab sample should be randomly selected for the volatiles and sulfides sampling. Sediments which are directly in contact with core liners or the sides of the grab sampler should not be used.

Two separate 4-ounce containers should be completely filled with sample sediment for volatiles analysis. No headspace should be allowed to remain in either container. Two samples are collected to ensure that an acceptable sample with no headspace is submitted to the laboratory for analysis. The containers, screw caps, and cap septa (silicone vapor barriers) should be washed with detergent, rinsed once with tap water, rinsed at least twice with distilled water, and dried at >105 degrees C. A solvent rinse should not be used because it may interfere with the analysis.

To avoid leaving headspace in the containers, sample containers can be filled in one of two ways. If there is adequate water in the sediment, the vial should be filled to overflowing so that a convex meniscus forms at the top. Once sealed, the bottle should be inverted to verify the seal by demonstrating the absence of air bubbles. If there is little or no water in the sediment, jars should be filled as tightly as possible, eliminating obvious air pockets. With the cap liner's PTFE side down, the cap should be carefully placed on the opening of the vial, displacing any excess material.

For sulfides sampling, 5 mls of 2 Normal zinc acetate per 30-g of sediment should be placed in a 4-ounce sampling jar. The sulfides sample should be placed in the jar, covered, and shaken vigorously to completely expose the sediment to the zinc acetate.

The volatiles and sulfides sampling jars should be clearly labeled with the project name, sample/composite identification, type of analysis to be performed, date and time, and initials of person(s) preparing the sample, and referenced by entry into the log book. The sulfides sampling jars should indicate that zinc acetate has been added as a preservative.

5.5.4 Sampling Logs

As samples are collected, and after the volatiles and sulfides subsamples have been taken, logs and field notes of all samples should be taken and correlated to the sampling location map. The following should be included in this log:

1. Date and time of collection of each sediment sample.
2. Names of field supervisors and person(s) collecting and logging in the sample.
3. Weather conditions.
4. The sample station number and individual designation numbers assigned for individual core sections.
5. Notation of any resistance of sediment column to coring.

6. The water depth at each sampling station. This depth should then be referenced to mean lower low water (MLLW NAVD 88) through the use of an on-site tide gage.

7. Length, depth interval (referenced to the sediment/water interface) and percent recovery of core sections.

8. Physical sediment description, including type, density, color, consistency, odor, stratification, vegetation, debris, biological activity, presence of an oil sheen or any other distinguishing characteristics or features.

9. Any deviation from the approved sampling plan.

5.5.5 Extrusion, Compositing and Sub-sampling

Depending on the sampling methodology and procedure proposed, sample extrusion, compositing and subsampling may take place at different times and locations. If core sampling is conducted, these activities can either occur at the sampling site (e.g., on board the sampling vessel) or at a remote facility. Grab samples are processed immediately upon sampling. If cores are to be transported to a remote facility for processing, they should be stored on ice onboard the sampling vessel and during transport. The cores should be sealed in such a way as to prevent leakage and contamination. If the cores will be sectioned at a later time, thought needs to be given to core integrity during transport and storage to prevent loss of stratification. For cores or split-spoon sampling, the extrusion method should include procedures to prevent contamination.

For composited samples, representative volumes of sediment should be removed from each core section or grab sample comprising a composite. The composited sediment should be mixed until homogenized to a uniform color and consistency, and should occasionally be stirred while individual samples are taken of the homogenate. This will ensure that the mixture remains homogenous and that settling of coarse-grained sediments does not occur.

At least 6 liters of homogenized sample needs to be prepared to provide adequate volume for physical, chemical and biological laboratory analyses. Bioassays require approximately four (4) liters while chemical testing requires approximately one (1) liter of sediment. Physical, chemistry and bioassay samples should be taken from the same homogenate. Portions of each composite sample will be placed in appropriate containers obtained from the testing laboratories (Table 5-1).

After compositing and subsampling are performed, the sample containers should be refrigerated or stored on ice until delivered to the analytical laboratory. The samples reserved for bioassays should be stored in the dark at 4 degrees C in containers with zero headspace, or with headspace purged with nitrogen, for **up to 56 days** pending initiation of any required biological testing. Each sample container should be clearly labeled with the project name, sample/composite identification, type of analysis to be performed, date and time, and initials of person(s) preparing the sample, and referenced by entry into the log book.

Table 5-1. Sample storage criteria.

<table>
<tr><th>SAMPLE TYPE</th><th>HOLDING TIME</th><th>SAMPLE SIZE (1)</th><th>TEMPERATURE (2)</th><th>CONTAINER</th><th>ARCHIVE(3)</th></tr>
<tr><td>Particle Size</td><td>6 Months</td><td>100-200 g
(75-150 ml)</td><td>4 degrees C</td><td rowspan="5">1-liter
Glass
(combined)</td><td rowspan="8">X</td></tr>
<tr><td>Total Solids</td><td>14 Days</td><td>125 g
(100 ml)</td><td>4 degrees C</td></tr>
<tr><td>Total Volatile Solids</td><td>14 Days</td><td>125 g
(100 ml)</td><td>4 degrees C</td></tr>
<tr><td>Total Organic Carbon</td><td>14 Days</td><td>125 g
(100 ml)</td><td>4 degrees C</td></tr>
<tr><td>Ammonia</td><td>7 Days</td><td>25 g
(20 ml)</td><td>4 degrees C</td></tr>
<tr><td rowspan="2">Metals (except Mercury)</td><td>6 Months</td><td rowspan="2">50 g
(40 ml)</td><td>4 degrees C</td><td rowspan="2">4 oz. glass jars</td></tr>
<tr><td>2 years</td><td>-18 degrees C</td></tr>
<tr><td>Semi-volatiles,
Pesticides
And PCBs</td><td>14 Days until extraction

1 Year until extraction

40 Days after extraction</td><td>150 g
(120 ml)</td><td>4 degrees C

-18 degrees C

4 degrees C</td><td></td></tr>
<tr><td>Total Sulfides</td><td>7 Days</td><td>50 g
(40 ml)</td><td>4 degrees C (4)</td><td>125 ml Glass or polyethylene</td><td></td></tr>
<tr><td>Mercury</td><td>28 Days</td><td>50 g
(40 ml)</td><td>-18 degrees C</td><td>125 ml Teflon or polyethylene</td><td></td></tr>
<tr><td>Tributyltin (porewater)</td><td>7 Days</td><td>Sediment sufficient to collect 200-500 ml of porewater</td><td>4 degrees C (5)</td><td>Field: Polycarbonate, glass, or steel
Lab (post extraction): Polycarbonate</td><td></td></tr>
<tr><td>Volatile Organics</td><td>14 Days</td><td>100 g
(2-40 ml jars)</td><td>4 degrees C</td><td>2-40 ml Glass</td><td></td></tr>
<tr><td>Bioassay</td><td>8 Weeks</td><td>5 liters</td><td>4 degrees C (5)</td><td>5-1 liter Glass or polyethylene</td><td></td></tr>
<tr><td>Bioaccumulation</td><td>8 Weeks</td><td>variable (6)</td><td>4 degrees C (5)</td><td>Glass or Polyethylene</td><td></td></tr>
</table>

(1) Recommended minimum field sample sizes for one laboratory analysis. Actual volumes to be collected have been increased to provide a margin of error and allow for retests.
(2) During transport to the lab, samples will be stored on ice. The mercury and archived samples will be frozen immediately upon receipt at the lab.
(3) For every DMMU, a 250 ml container is filled and frozen to run any or all of the analyses indicated.
(4) The sulfides sample will be preserved with 5 ml of 2 Normal zinc acetate for every 30 g of sediment.
(5) Headspace purged with nitrogen.
(6) See Table 8-3.

5.5.6 Sample Transport and Chain of Custody Procedures

Sample transport and chain-of-custody procedures should follow the PSEP protocols, which include the following guidelines:

1. If sediment cores are taken in the field and transported to a remote site for extrusion and compositing, chain-of-custody procedures should commence in the field for the core sections and should track the compositing and subsequent transfer of composited samples to the analytical laboratory. If compositing occurs in the field, chain-of-custody procedures should commence in the field for the composites and should track transfer of the composited samples to the analytical laboratory.

2. Samples should be packaged and shipped in accordance with U.S. Department of Transportation regulations as specified in 49 CFR 173.6 and 49 CFR 173.24.

3. Individual sample containers should be packed to prevent breakage and transported in a sealed ice chest or other suitable container.

4. Ice should be placed in separate plastic bags and sealed, or blue ice used.

5. Each cooler or container containing sediment samples for analysis should be delivered to the laboratory within 24 hours of being sealed.

6. A sealed envelope containing chain-of-custody forms should be enclosed in a plastic bag and taped to the inside lid of the cooler.

7. Signed and dated chain-of-custody seals should be placed on all coolers prior to shipping.

8. The shipping containers should be clearly labeled with sufficient information (name of project, time and date container was sealed, person sealing the container and consultant's office name and address) to enable positive identification.

9. Upon transfer of sample possession to the analytical laboratory, the chain-of-custody form should be signed by the persons transferring custody of the sample containers. The shipping container seal should be broken and the condition of the samples should be recorded by the receiver.

10. Chain-of-custody forms should be used internally in the lab to track sample handling and final disposition.

6 TIER II: CHEMICAL TESTING

Following an assessment of existing information in Tier 1, chemical testing of the dredged material is usually required. Chemical analysis includes both the measurement of "conventional" parameters and the measurement of concentrations of chemicals which have been identified by DMMP as chemicals of concern (COCs).

6.1 Sediment Conventional Parameters

"Conventional" parameters are required to be measured to further characterize the sediment in the DMMU and to provide information to aid in interpreting chemical and biological tests. Conventionals required are:

- Total volatile solids (TVS)
- Grain size
- Total organic carbon (TOC)
- Percent solids (Total solids)
- Total sulfides
- Ammonia

6.2 Sediment Conventional Testing Protocols

Analysis of total solids, TVS and total sulfides under the DMMP testing program must follow the *Recommended Protocols for Measuring Conventional Sediment Variables in Puget Sound* (PSEP, 1986). Ammonia analysis should be conducted according to standard EPA/Corps procedures (Plumb, 1981). Appendix D of *Recommended Guidelines for Measuring Organic Compounds in Puget Sound Water, Sediment and Tissue Samples* (PSEP, 1997b) must be consulted for analysis of TOC.

Particle size may be determined using either PSEP (1986) or ASTM Method D-422, which subdivide the silt-clay fraction by pipette and hydrometer respectively. One of the following sieve series must be used: 1) Modified EPA - sieve numbers 4, 10, 18, 35, 60, 120, 230 or 2) Modified ASTM - sieve numbers 4, 10, 20, 40, 60, 140, 230. The fine-grained fraction must be classified by phi size (+5, +6, +7, +8, >8).

6.3 Standard List of Chemicals of Concern

Chemical testing, when required, will involve analysis for DMMP COCs. Table 6-1 lists these chemicals and presents the most current marine guideline values for each chemical. The COC list was developed using historical data and existing activities information from Puget Sound, Grays Harbor and Willapa Bay. The chemicals of concern generally have the following characteristics:

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

- One or more present or historical sources of sufficient magnitude to be of concern (i.e., relatively widespread distribution and high concentration when compared to natural conditions).
- A potential for remaining in a toxic form for long periods in the environment (persistence).
- A potential for entering the food web (bioavailability).

Table 6-1. Screening Level (SL), Bioaccumulation Trigger (BT) and Maximum Level (ML) Marine Guideline Chemistry Values

CHEMICAL	CAS[1] NUMBER	SL	BT	ML
METALS (mg/kg)				
Antimony	7440-36-0	150	---	200
Arsenic	7440-38-2	57	507.1	700
Cadmium	7440-43-9	5.1	11.3	14
Chromium[2]	7440-47-3	---	267	---
Copper	7440-50-8	390	1,027	1,300
Lead	7439-92-1	450	975	1,200
Mercury	7439-97-6	0.41	1.5	2.3
Nickel	7440-02-0	140	370	370
Selenium[2]	7782-49-2	---	3	---
Silver	7440-22-4	6.1	6.1	8.4
Zinc	7440-66-6	410	2,783	3,800
ORGANOMETALLIC COMPOUNDS (µg/L)				
Tributyltin (interstitial water)	56573-85-4	0.15	0.15	---
ORGANICS (µg/kg)				
PAHs				
Total LPAH	---	5,200	---	29,000
Naphthalene	91-20-3	2,100	---	2,400
Acenaphthylene	208-96-8	560	---	1,300
Acenaphthene	83-32-9	500	---	2,000
Fluorene	86-73-7	540	---	3,600
Phenanthrene	85-01-8	1,500	---	21,000
Anthracene	120-12-7	960	---	13,000
2-Methylnaphthalene[3]	91-57-6	670	---	1,900
Total HPAH	---	12,000	---	69,000

CHEMICAL	CAS[1] NUMBER	SL	BT	ML
Fluoranthene	206-44-0	1,700	4,600	30,000
Pyrene	129-00-0	2,600	11,980	16,000
Benz(a)anthracene	56-55-3	1,300	---	5,100
Chrysene	218-01-9	1,400	---	21,000
Benzofluoranthenes (b, j ,k)[7]	205-99-2 205-82-3 207-08-9	3,200	---	9,900
Benzo(a)pyrene	50-32-8	1,600	---	3,600
Indeno(1,2,3-c,d)pyrene	193-39-5	600	---	4,400
Dibenz(a,h)anthracene	53-70-3	230	---	1,900
Benzo(g,h,i)perylene	191-24-2	670	---	3,200
CHLORINATED HYDROCARBONS				
1,3-Dichlorobenzene	541-73-1	170	---	---
1,4-Dichlorobenzene	106-46-7	110	---	120
1,2-Dichlorobenzene	95-50-1	35	---	110
1,2,4-Trichlorobenzene	120-82-1	31	---	64
Hexachlorobenzene (HCB)	118-74-1	22	168	230
PHTHALATES [4]				
Dimethyl phthalate	131-11-3	71	---	1,400
Diethyl phthalate	84-66-2	200	---	1,200
Di-n-butyl phthalate	84-74-2	1,400	---	5,100
Butyl benzyl phthalate	85-68-7	63	---	970
Bis(2-ethylhexyl) phthalate	117-81-7	1,300	---	8,300
Di-n-octyl phthalate	117-84-0	6,200	---	6,200
PHENOLS				
Phenol	108-95-2	420	---	1,200
2-Methylphenol	95-48-7	63	---	77
4-Methylphenol	106-44-5	670	---	3,600
2,4-Dimethylphenol	105-67-9	29	---	210
Pentachlorophenol	87-86-5	400	504	690
MISCELLANEOUS EXTRACTABLES				
Benzyl alcohol	100-51-6	57	---	870
Benzoic acid	65-85-0	650	---	760

Dibenzofuran	132-64-9	540	---	1,700
CHEMICAL	**CAS[1] NUMBER**	**SL**	**BT**	**ML**
Hexachloroethane	67-72-1	1,400	---	14,000
Hexachlorobutadiene	87-68-3	29	---	270
N-Nitrosodiphenylamine	86-30-6	28	---	130
VOLATILE ORGANICS[5]				
Trichloroethene	79-01-6	160	---	1,600
Tetrachloroethene	127-18-4	57	---	210
Ethylbenzene	100-41-4	10	---	50
Total Xylene (sum of o-, m-, p-)	95-47-6 108-38-3 106-42-3	40	---	160
PESTICIDES & PCBs				
Total DDT (sum of 4,4'-DDD, 4,4'-DDE and 4,4'-DDT)	72-54-8 72-55-9 50-29-3	6.9	50	69
Aldrin	309-00-2	10	---	---
Total Chlordane [7] (sum of cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, oxychlordane)	5103-71-9 5103-74-2 5103-73-1 39765-80-5 27304-13-8	10	37	---
Dieldrin	60-57-1	10	---	---
Heptachlor	76-44-8	10	---	---
Gamma-BHC (Lindane)	58-89-9	10	---	---
Total PCBs	---	130	38 [6]	3,100

(1) Chemical Abstract Service Registry Number
(2) As no SL value exists to trigger toxicity testing, this chemical will only be evaluated for its bioaccumulative potential.
(3) 2-Methylnaphthalene is not included in the summation for total LPAH.
(4) Based on 1998 LAET/HAET's; see http://www.nws.usace.army.mil/PublicMenu/Doc_list.cfm?sitename=dmmo&pagename=17th_ARM_MAy_5_2004
(5) Volatile organics are not required to be analyzed for dredging projects in Grays Harbor and Willapa Bay.
(6) This value is normalized to total organic carbon, and is expressed in mg/kg carbon.
(7) Components of benzofluoranthenes and chlordane were clarified at the 2007 SMARM.

6.4 Chemicals of Concern for Freshwater Areas

This manual has historically focused on marine evaluations, but recently the DMMP has reviewed greater numbers of projects that are within freshwater systems. The DMMP will be adopting the Regional Sediment Evaluation Team's (RSET) freshwater chemical screening values, as well as the freshwater bioassay and freshwater bioaccumulation guidance. As the RSET is still developing their manual, projects that are within freshwater will use the interim guidance (available on the DMMO website) for evaluation of material proposed for freshwater in-water disposal, as well as for Z-sample evaluation of sediments exposed by dredging.

6.5 Chemicals of Concern for Limited Areas

In addition to the standard list of standard chemicals of concern, there are COCs that may need to be measured for dredging projects in limited areas. These chemicals include those from the following list, which are further discussed below.

- Guaiacol (2-methoxyphenol) and chlorinated guaiacols (3,4,5-trichloroguaiacol; 4,5,6-trichloroguaiacol; tetrachloroguaiacol)
- Tri-, tetra-, and pentachlorobutadienes
- Polychlorinated dibenzodioxins and dibenzofurans
- Tributyltin

6.5.1 Guaiacol and Chlorinated Guaiacols

Guaiacol and chlorinated guaiacols are measured in areas where kraft pulp mills are located. Only guaiacol will be measured near sulfite pulp mills (chlorinated guaiacols are not expected in processes that do not involve bleaching). These chemicals are of particular concern in Grays Harbor.

6.5.2 Tri-, Tetra-, and Pentachlorobutadienes

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). They are recommended for analysis only where chlorinated butadienes are suspected to have a major source.

6.5.3 Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs)

Polychlorinated dibenzo-dioxins (PCDDs) and polychlorinated dibenzo-furans (PCDFs) are commonly referred to together as "dioxins." Dioxins are a group of chlorinated organic compounds with similar chemical structures, or congeners. The most studied and most toxic dioxin congener is 2,3,7,8- tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). 2,3,7,8-TCDD has been identified as a "known human carcinogen" (IARC 1997) and a probable human carcinogen by USEPA (Group B2 carcinogen). Other dioxins may cause cancer, disrupt the endocrine system, and cause reproduction and developmental effects. Dioxins are toxic to humans and other mammals at very low concentrations. They are persistent in the environment and may bioaccumulate in animal tissues.

Dioxins are produced by natural events and are also unintentional byproducts of certain industrial processes. Natural events include forest fires or volcanic activity. Industrial processes include incomplete combustion of materials in the presence of chloride, such as burning of fuels, municipal and domestic waste incineration, as well as chlorine bleaching of pulp and paper, and creosote and chlorinated pesticide manufacturing.

6.5.3.1 Dioxin Concern Levels

Testing for dioxins and furans is required on a case-by-case basis in areas where there is reason to suspect presence of these chemicals. Significant factors which can trigger a "reason-to-believe" that dioxin may be present and thus result in the requirement for dioxin testing include the following:

- Proximity to current or historical sources (chlor-oxide bleach process pulp mills; chlor-alkali or chlorinated solvent manufacturing plants, former wood treatment sites; phenoxy herbicide manufacture and/or use and handling)
- Areas with high PCB concentrations
- Areas previously sampled that showed elevated levels of dioxin, regardless of known sources

6.5.3.2 Interim Approach to Dioxin Evaluation in Dredged Material

In the past, the DMMP utilized a dioxin concern level of 5 ng/kg 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and a total toxic equivalency (TEQ) of 15 ng/kg in making suitability determinations for sediments containing PCDD/PCDFs. These concern levels were derived from a dioxin risk assessment performed by the COE for Grays Harbor in 1991. However, these values are not sediment concentrations associated with "acceptable" or minor effects and were never considered regulatory standards. The DMMP agencies have recognized that an updated approach is needed and are in the process of conducting a series of stakeholder workshops as part of an ongoing process to develop dioxin interpretive guidelines.

Pending development of programmatic guidelines, reviews of dioxin data will be done on a project-specific basis using interim guidelines. These interim guidelines were adopted by the DMMP Agency directors in March 2007 to serve as a clear and consistent process for making suitability determinations until programmatic revisions are completed. Interim guidelines, as well as any updates or other dioxin news, can be found on the Dioxin Information page of the DMMO website and can be summarized as follows:

For non-dispersive sites in Puget Sound:
- Approach based on a comparison of dioxin in test sediments to disposal-site background.
- "Background" is defined using disposal-site sediment dioxin data generated as part of DMMP site monitoring.
- Dioxin concentrations in any given dredged material management unit may not exceed site maximum (Table 6-2).
- Average dioxin concentrations (weighted to the volume of each dredged material management unit) cannot exceed mean site concentration.

For dispersive sites in Puget Sound:
- Approach based on a comparison of dioxin in test sediments to reference background.
- "Background" is defined using sediment dioxin data from nearest reference site.
- Presently, he available reference site dioxin data are limited to Carr Inlet and Sequim Bay. As more data are collected this information will be available on the DMMO website. It is dredger's responsibility to sample nearest reference site if data are not available.

Bioaccumulation testing for dioxin is currently not used to determine suitability for either dispersive or non-dispersive sites in Puget Sound.

For dispersive sites in Grays Harbor, the 5 ng/kg 2,3,7,8-TCDD concentration or 15 ng/kg TEQ will be used as a trigger for the requirement to perform bioaccumulation testing.

Table 6-2. Disposal site sediment dioxin toxic equivalence.

Disposal Site Sediment Dioxin Toxic Equivalence (ng/kg-dry weight)		
Disposal Site	**Mean**	**Maximum**
Port Gardner	4.1	5.2
Anderson Ketron	3.6	6.8
Bellingham Bay	6.9	10.5
Elliott Bay	8.0	10.6
Commencement Bay	2.1	4.1

6.5.3.3 Dioxin Analysis and Reporting

Specifying data analysis procedures for PCDD/F is considerably more difficult than for other chemicals in the DMMP list, due to the analytical complexity. The DMMP clarified preferred data analysis methods at the 2007 SMARM, in *Polychlorinated Dioxins and Furans (PCDD/F): Clarification of Procedures for Acquiring Sediment Data* (DMMP 2007a) and *Supplemental Information on Polychlorinated Dioxins and Furans (PCDD/F) for use in Preparing a Quality Assurance Project Plan (QAPP)* (DMMP 2007b). **Please refer to the full documents, available on the DMMO website, for complete guidance.** In summary, for dioxin analysis, the DMMP requires:

a) Sediment sampling and holding. These procedures are generally similar to semivolatile chemicals in the DMMP. Frozen samples may be held for one year prior to extraction.

b) Analytical methods. Three solid-phase EPA methods are available for PCDD/F analysis. The identification of PCDD/F congeners at low concentrations is difficult, and there is significant possibility of interfering compounds (such as diphenyl ethers) causing the reporting of artificially elevated values. The DMMP agencies recommend EPA Method 1613B: Tetra- Through Octa-Chlorinated Dioxins and Furans by Isotope Dilution High Resolution Gas Chromatography/High Resolution Mass Spectrometry as the most suitable method for sediment.

c) Data evaluation/validation methods. Because of the complexity of the method, the extremely low reporting limits, and the high potential for interfering compounds such as chloro diphenyl ethers, it is strongly suggested that dioxin raw data be validated. If the applicant chooses not to validate the data, the primary method of data evaluation will consist of analysis of a traceable sediment reference material. Based upon review of precision, accuracy, representativeness, and completeness measures as well as the SRM, further validation of the dioxin raw data may be required. The DMMP will review the primary results against the Method 1613B acceptance limits or those in the QAPP, and against the sediment reference material. Should the DMMP request validation, the project must provide it, using a person with demonstrated experience accomplishing validation for PCDD/F.

d) Data Reporting. The laboratory should report each of the 2,3,7,8-chlorine substituted PCDD/F congeners on a dry-weight basis as well as the summation of each homolog group (e.g., all HxCDDs). (This latter is standard practice, but the homologs are not used in calculating TEQ.) The 17 congeners of interest should be tabulated as TEQ, both with nondetected values (U) = ½ detection limit and with U = 0. (The difference between these values gives data reviewers an idea of how much the detection limit substitution affects the TEQ summation.) See Table 6-3 for the TEFs for various dioxins and furans.

Table 6-3. Toxicity Equivalency Factors (TEFs) for PCDDs and PCDFs[1].

	CONGENERS / ISOMERS	TOXIC EQUIVALENCY FACTOR (TEF)
Dioxins	2,3,7,8-TCDD	1
	1,2,3,7,8-PeCDD	1
	1,2,3,4,7,8-HxCDD	0.1
	1,2,3,6,7,8-HxCCD	0.1
	1,2,3,7,8,9-HxCDD	0.1
	1,2,3,4,6,7,8-HpCDD	0.01
	OCDD	0.0003
Furans	2,3,7,8-TCDF	0.1
	1,2,3,7,8-PeCDF	0.03
	2,3,4,7,8-PeCDF	0.3
	1,2,3,4,7,8-HxCDF	0.1
	1,2,3,6,7,8-HxCDF	0.1
	2,3,4,6,7,8-HxCDF	0.1
	1,2,3.7,8,9-HxCDF	0.1
	1,2,3,4,6,7,8-HpCDF	0.01
	1,2,3,4,7,8,9-HpCDF	0.01
	OCDF	0.0003

[1] World Health Organization Human and Mammalian TEFs, from van den Berg et (2006)

6.5.4 Tributyltin

Tributyltin (TBT) testing is indicated in areas near marinas, boatyards, shipyards, CSOs, treatment plant outfalls and in urban areas, especially Commencement Bay, Elliott Bay, Duwamish River, Lake Washington ship canal, Salmon Bay and Lake Union.

The available evidence indicates that neither sediment chemistry screening levels nor the existing DMMP bioassays may be as useful in predicting environmental effects as measurement of TBT concentrations in interstitial water and tissues. Therefore, the standard tiered testing approach utilizing bulk sediment chemistry and short-term bioassays is not considered appropriate for evaluating the potential adverse effects of TBT.

Measurement of TBT in interstitial water may provide a more direct measure of potential bioavailability, and hence toxicity, than bulk sediment concentrations. Therefore, interstitial water analysis replaces bulk sediment analysis as the initial step in a tiered assessment of TBT toxicity for DMMP projects. Centrifugation is preferred for collecting sediment interstitial water (for detailed guidance on interstitial water collection and sample handling refer to SMARM update paper Tributyltin Analysis: Clarification of Interstitial Water Extraction and Analysis Methods - Interim (1998)). Alternative interstitial water extraction methods may be used in cases where centrifugation is not an effective technique, (e.g., for very sandy sediments) and will be decided on a case-by-case basis by the DMMP agencies. Measurement of TBT in interstitial water may provide a more direct measure of potential bioavailability, and hence toxicity, than bulk sediment concentrations.

Acceptable methods for measuring TBT involve tropolone/methylene chloride extraction, followed by Grignard derivitization and analysis by GC/MS (e.g., Krone *et al*., 1989), GC/MS SIM (e.g., PSEP, 1997), or GC/FPD (e.g., Unger *et al*., 1986).

6.6 Laboratory Accreditation

Laboratories are required to be accredited by the Department of Ecology for sediment methods used to generate chemical and biological data for DMMP projects. For information on accreditation application and renewal, contact Ecology's Laboratory Accreditation Program at (360) 895-6144.

6.7 Quality Control

Chemical data submitted to characterize dredged material proposed for open-water disposal at a DMMP site must be quality-assured before it may be used for regulatory decision-making. This section provides general quality assurance (QA) guidelines, as well as guidelines specific to the analysis of tributyltin.

6.7.1 General Quality Assurance Guidelines

Most laboratories performing DMMP chemical analysis use modified EPA Contract Lab Program (EPA CLP) methods. These methods have their own QA "control" limits for precision, matrix spike recovery and surrogate spike recovery, which have been established through interlaboratory testing. Laboratories rely on the CLP control limits to determine when data quality may be inadequate and corrective action is necessary.

In addition to the CLP limits in common use, the Puget Sound Estuary Program (PSEP) has established both "warning" limits and "action" limits for these same QA parameters. PSEP defines warning limits as "numerical criteria that serve to alert data reviewers and users to possible problems within the analytical system. When a warning limit is exceeded, the laboratory is not obligated to halt analyses, but the reported data may be qualified during subsequent QA/QC review." Action limits are defined as "numerical criteria that, when exceeded, require specific action by the laboratory before data may be reported. Action limits are intended to serve as contractual controls on laboratory performance." The terms "action limit" and "control limit" are similar and used interchangeably.

Table 6-3 includes QA limits which are as consistent as possible with both PSEP and CLP. A system of warning and action limits, similar to PSEP, is used. In most cases, PSEP quantitative levels have been adopted as well. The warning and action limits listed in the table were adopted by the DMMP agencies for use in QA1 evaluations.

Table 6-4. DMMP Warning and Action Limits.

QA Element	Warning Limits	Action Limits
Precision		
Metals:	none	20% RPD or COV
Organics:	35% RPD or COV	50% COV or a factor of 2 for duplicates
Matrix Spikes		
Metals:	none	75-125% recovery
Organics:		none (zero percent recovery may be cause for data rejection however)[1]
Volatiles:	70-150%	
Semivolatiles and Pesticides:	50-150%	
Reference Materials		
Metals:	none	95% CI if specified for a particular CRM; 80-120% recovery if not.
Organics:	none	95% CI for CRMs. No action limit for uncertified RMs.
Surrogate Spikes		
Organics:		EPA CLP chemical-specific recovery limits
Volatiles:	85% minimum recovery	
Pesticides:	60% minimum recovery	
Semi-volatiles:	50% minimum recovery	

[1] Rigorous control limits are not recommended due to possible matrix effects and interferences.

For matrix spike and surrogate spike recoveries, independent warning limits were established for volatiles, semivolatiles and pesticides. These limits meet the PSEP definition of warning limits and screen data effectively relative to the EPA CLP control limits. The chemical-specific EPA CLP control limits were adopted for use as action limits for surrogate spike recoveries and for a basis of evaluation in the application of best professional judgment for matrix spike recoveries. Where certified reference materials are available for either metals or organics, the interlaboratory-derived 95% confidence interval should be used as an objective evaluation tool. This alternative is endorsed by PSEP.

6.7.2 TBT QC Performance Criteria: Sample Collection/Interstitial Water Analysis

The DMMP agencies recommend QC performance criteria rather than providing a step-by-step protocol for the extraction, derivitization, and analysis of TBT. The criteria presented in Table 6-4 must be met in order to verify that sample cleanup, extraction and derivitization methods are being performed correctly. Laboratories will be required to meet these performance criteria as well as take the specified corrective action if performance criteria are not met. Deviations from the specified performance criteria will be considered by the DMMP agencies on a project-specific basis. Justification for alternative performance criteria must be submitted in writing and receive agency approval prior to the initiation of testing. As discussed in earlier guidance (Michelsen, *et al*., 1996), TBT analytical results should be reported as the TBT ion.

If the TBT concentration in the interstitial water is quantitated above 0.15 ug TBT/L, bioaccumulation testing of project sediments must be conducted using the DMMP bioaccumulation guidelines. Acute bioassay testing will not be required unless other chemicals of concern exceed screening levels. If unacceptable tissue concentrations are measured at the end of the bioaccumulation test, the sediment will be found unsuitable for open-water disposal. For additional information, see the SMARM issue paper Testing, Reporting, and Evaluation of Tributyltin Data in PSDDA and SMS Programs (1996).

Table 6-4. Summary of Quality Control Procedures for TBT in Interstitial Water.

QC CHECK	MINIMUM FREQUENCY	ACCEPTANCE CRITERIA	CORRECTIVE ACTION
Laboratory Control Sample (LCS) [1]	1 per analytical batch (≤ 20 samples)	Recovery 50 – 150%	1. Check calculations 2. Reanalyze (matrix or injection problems) 3. If still out, re-extract and reanalyze LCS and assoc. samples (if available); If not available flag data.
Matrix spike (MS) and matrix spike duplicate (MSD) [1]	1 MS/MSD pair per analytical batch (≤ 20 samples)	Recovery 50 – 150% and relative percent difference (RPD) ≤ 30%	1. Evaluate for supportable matrix effect. 2. If no interference, re-extract and reanalyze MS/MSD once (if available). 3. If still out, report both sets of data.
Surrogate spike [1] (Tripentyltin recommended)	1 per sample	Recovery 50 – 150%	1. Check calculations. 2. Evaluate for supportable matrix effect 3. If no interference is evident, re-extract and reanalyze affected sample(s) (if available) and flag any outliers.
Method blank[2]	1 per analytical batch (≤ 20 samples)	Target analyte < 3x the reporting limit (RL)	1. Flag if target > 3x RL but less than 0.075 ppb.[3] 2. Rerun batch and ID contamination source if target >0.075 ppb.

[1]All QC samples should be run using the same sample handling as is used on the environmental samples.
[2] Method blank can include centrifugation step or, alternatively a centrifugation blank can be run separately from the analytical method blank.
[3] 0.075 ppb TBT is used here as a benchmark for evaluating blank performance because it represents a concentration that is one-half the interstitial water screening level (0.15 ppb) that is being used by the DMMP agencies to determine the need for bioaccumulation testing. Note that a minimum interstitial water volume of 200-500 ml will be needed to attain reporting limits less than 0.075 ppb TBT.

6.8 Chemical Evaluation Guidelines

Chemical concentrations will be compared to two chemical guideline values presented in Table 6-1. First, a "screening level" (SL) has been defined for each chemical as a guideline to identify chemical concentrations at or below which there is no reason to believe that dredged material disposal would result in unacceptable adverse effects. Second, a "maximum level" (ML) has been derived for each chemical of concern which represents the highest Apparent Effects Threshold (AET) – a chemical concentration at which all four biological indicators show significant effects.

For dredged material with chemical concentrations at or below the SL values, biological testing is not required to determine material suitability for unconfined, open-water disposal. Chemical concentrations present at levels between the SL and ML require additional biological information for decision-making. For each DMMU, the SL and ML guideline values will be used to determine whether biological testing is needed before a decision is made on the suitability for unconfined, open-water disposal. The following potential scenarios are possible:

1. All chemicals are **at or below their SLs**; no biological testing is needed; the DMMU is considered suitable for unconfined, open-water disposal at any DMMP site and for all open-water beneficial uses.

2. One or more chemicals are present at levels **between SL and ML**; standard biological testing is needed (see Chapters 7 and 8).

3. One or more chemicals are present at levels above the ML. Standard biological testing may still be pursued but there is a high probability that the dredged material will fail Tier III testing.

The DMMP agencies have increasingly come to regard the ML values as a more valuable screen for project proponents rather than as a useful regulatory tool for “testing.” While some sediments with more than one ML exceedance have passed biological testing, the majority have failed. By comparing sediment chemical data to the MLs, a dredging proponent can better judge how to proceed with the project, i.e., whether to invest more into testing for unconfined, open-water disposal, or to rechannel that effort into other disposal options and testing for those options (e.g., leachate tests).

Chemical concentrations in the Z-samples are compared to the sediment quality standards (SQS), a subset of the State of Washington Sediment Management Standards. Marine sediments proposed for beneficial use are also compared against SQS.

6.9 Summing of PCB Aroclors

Total PCB aroclors includes the sum of the following aroclors: 1016, 1221, 1232, 1242, 1248, 1254, and 1260. If present, Aroclor-1262 and 1268 should be reported but not included in the total PCB summation.

For summing PCB Aroclor results for comparison to SL, BT and ML values, a group summation is performed using all detected concentrations. Undetected results are considered zero values and are not included in the sum. The estimated values between the MDL and the laboratory reporting limit (*i.e.,* J-flagged values) are included in the summation at face value. If all constituents of a group are undetected, the group sum is reported as undetected, and the highest laboratory reporting limit (or SQL) of all the constituents is reported as the SQL for the group sum.

6.10 Bioaccumulation Triggers

In addition to comparisons to SL and ML and subsequent determinations outlined above, bioaccumulation trigger (BT) values are used as guidelines to determine when bioaccumulation testing is required. These values are found in Table 6-1. If any chemical of concern exceeds the bioaccumulation trigger guideline value, additional information gained via bioaccumulation testing will be required in order to determine whether dredged material is suitable for unconfined, open-water disposal. Discussion on bioaccumulation testing is presented in Chapter 8.

6.11 Detection And Reporting Limits

In the case of undetected chemicals of concern, sample detection limits will be used to determine biological testing requirements. If undetected chemicals of concern have sample detection limits greater than the chemical guidelines presented in Table 6.1, then further testing may be necessary.

The following guidelines must be followed when reporting results of chemical analysis (see http://www.nws.usace.army.mil/PublicMenu/documents/DMMO/Sediment_detection_levels_SMARM_05).

1. Laboratories must report estimated concentrations that fall between the method detection limit and reporting limit. Such estimated concentrations should be accompanied by a “J” qualifier.

2. Laboratories must report both the reporting limit and the sample detection limit for any COC that is accompanied by a “U” flag.

3. Biological testing will be required when one or more COCs have sample detection limits above the screening levels.

4. For mixtures of chemicals, such as Total PCBs, the reported values of detected constituents - including “J” values falling between the sample detection limit and the reporting limit - will be summed. In the event that all constituents are undetected, the single highest detection limit will be used as the value for the mixture and will be accompanied by a “U” qualifier.

The following scenarios are possible and need to be understood and handled appropriately:

1. One or more chemicals-of-concern (COC) have sample detection limits exceeding screening levels while all other COCs are quantitated or have sample detection limits at or below the screening levels: the requirement to conduct biological testing will be triggered solely by sample detection limits. In this case the chemical testing subcontractor should do everything possible to bring sample detection limits down to or below the screening levels, including additional cleanup steps, re-extraction, etc. This is the only way to prevent unnecessary biological testing. If problems or questions arise, the chemical testing subcontractor should be directed to contact the Dredged Material Management Office.

2. One or more COCs have sample detection limits exceeding screening levels for a lab sample, but below respective bioaccumulation triggers (BT), and other COCs have quantitated concentrations above screening levels: The need to do bioassays is based on the detected exceedances of SLs and the sample detection limits above SL become irrelevant. No further action on the part of the chemical testing subcontractor is necessary.

3. One or more COCs have sample detection limits exceeding SL and BT, and other COCs have quantitated concentrations above screening levels: the need to do bioassays is based on the detected exceedances of SLs but all other sample detection limits must be brought below BTs to avoid the requirement to do bioaccumulation testing. As in scenario "1" above, everything possible should be done to lower the sample detection limits.

In all cases, to avoid potential problems and leave open the option for retesting, sediments or extracts should be kept under proper storage conditions until the chemistry data are deemed acceptable by the regulatory agencies.

6.12 Wood Waste Management

Wood waste can range in size from intact logs down to fine bark and sawdust. The DMMP program requires logs and large debris to be removed prior to disposal. No debris greater than 24 inches in any dimension is allowed at the open-water disposal sites. Sediments with large pieces of wood debris may require debris removal by passing the dredged material through a 24" X 24" steel screen. The quantity of wood debris that would pass through a 24" X 24" screen must be visually assessed during field collection of sediments. If the sediment contains a significant quantity of smaller wood debris, the sediments must be analyzed in the laboratory to quantify the wood fraction as described below.

Wood debris can be quantified in the laboratory on either a volume or a weight-specific basis. While quantifying wood debris in sediments on a volumetric basis may be more ecologically meaningful, it is much more difficult and less accurate than quantifying it on a weight-specific basis. Therefore, dredged material assessment of wood debris will be accomplished on a dry-weight basis, then converted to a volumetric basis by multiplying the weight-based number by two[1] (example: 25% by weight ≅ 50% by volume). The dry-weight fraction of debris is estimated by quantifying the organic fraction[2]. Dredged material containing an organic fraction greater than 25% dry weight will be required to undergo biological testing to assess the suitability of the material for unconfined open-water disposal. Likewise, dredged material containing an organic fraction less than 25% dry weight will be considered suitable for unconfined open-water disposal without further testing unless one or more chemicals of concern exceed chemical screening levels.

Sediment grain size is an important consideration when selecting the species to be used in the amphipod test and choosing appropriate reference sediments. Therefore, in addition to conventional grain size analysis, applicants should analyze the residue left from the modified Total Volatile Solids analysis for grain size. This organic-free particle size distribution should be used in conjunction with the conventional particle size distribution in selecting the appropriate amphipod species and reference sediment.

For additional information see *Management of Wood Waste under DMMP and SMS Cleanup Program* at http://www.nws.usace.army.mil/dmmo/9th_arm/wood_97.htm

[1] Observed ratio from Port of Everett/South Terminal Dredging Project reported in Floyd & Snider and Pentec (1997).
[2] One method recently applied to a dredging project involved a weight based method: quantification by modified Total Volatile Solids (TVS) analysis (ASTM D-2974C. Method A) protocol, where the sample size was increased to 100-300 grams of sample. Other methods may be proposed by the applicant in lieu of this approach, but must be approved by the agencies with jurisdiction over dredging and disposal.

7 TIER III BIOLOGICAL TESTING: BIOASSAYS

Tier III biological testing of dredged material is required when chemical testing results indicate the potential for unacceptable adverse environmental or human health effects. Biological testing could include:

- **Bioassays**– used to evaluate potential toxicity effects on benthic invertebrates – discussed in this chapter.
- **Bioaccumulation tests--**used to evaluate the effect of certain chemicals which bioaccumulate and are known or suspected agents affecting human or ecological health in the marine environment– discussed in Chapter 8.

7.1 Acute and Chronic Bioassays

The standard suite of bioassays in tier III sediment evaluations is triggered by **exceeding** one or more screening levels for chemicals of concern in the dredged material (see Table 6-1). The suite of three bioassays used in the DMMP program includes both acute and chronic tests to characterize toxicity of whole sediment. Bioassays used for marine evaluations are:

1. 10-day amphipod mortality test (acute toxicity)
2. 20-day juvenile infaunal growth test (chronic toxicity)
3. Sediment larval test (acute toxicity)

The protocols for the required bioassays can be found in the Puget Sound Protocols and Guidelines (PSEP, 1995). The protocols describe field collection and processing methods, bioassay specific QA/QC, and data reporting procedures. Also, general protocols are provided for field collection of surficial test sediments and for general QA/QC procedures that apply to all sediment bioassays. Protocols for freshwater bioassays can be found in the RSET Sediment Evaluation Framework, Interim Final, Section 8.2.2.

As described in Section 6.5 for chemical data, laboratories providing biological effects data for DMMP projects must be accredited by the Department of Ecology for the analytical methods used to produce the data. Additional information related to bioassay testing under the DMMP and SMS programs can be found at the DMMO website.

7.2 Bioassay Species

The DMMP recommends the following listed species for marine bioassay testing. Further information on species selection is provided in test-specific information below. **If recommended species are not available, please contact the DMMO prior to initiating testing with a non-recommended species.**

1. 10-day amphipod mortality test.
   - *Eohaustorius estuarius* – most commonly used species; can be considered for use over grain size distributions ranging from 100% sand to 0.6% sand, as long as the clay fraction <20%; and in interstitial salinities ranging from 2 ppt to 28 ppt.
   - *Ampelisca abdita* – recommended if test sediment contains greater than 20% clay.
   - *Rhepoxynius abronius* – alternative species for use in coarser-grained sediments (i.e. fines <60%)

2. <u>20-day juvenile infaunal growth test.</u>
   - *Neanthes arenaceodentata* (Los Angeles karyotype)

3. <u>Sediment larval test</u>.
   - Bivalve: *Mytilus galloprovincialis*
   - Echinoderm: *Dendraster excentricus*

7.3 10-day Amphipod Mortality Test

This bioassay is an acute test that looks at survival of interstitial amphipods to evaluate the potential toxicity of sample sediments.

7.3.1 Amphipod Species Selection

Rhepoxynius abronius has shown sensitivity to high percent fines in sediments, particularly high clay content sediments, and has exhibited mortalities greater than 20 percent in clean, reference area sediments (DeWitt *et al*., 1988; Fox, 1993). Applicants may wish to consider use of *Ampelisca abdita* or *Eohaustorius estuarius* when fines exceed 60 percent. *Ampelisca* is relatively grain-size-insensitive to concentrations of fines greater than 60 percent. When testing fine-grained sediments (> 60 percent) where interstitial salinities are substantially below 25 ppt, dredging applicants may prefer to use *Eohaustorius estuarius*. This species is relatively insensitive to salinity changes and effects of grain size, except for high clay (>20%) content. Proposed species must be coordinated through the Dredged Material Management Office, and the rationale for species selection must be documented in the sampling and analysis plan for the proposed dredging project. Appropriate negative control sediment must be used for the test species selected. More information on amphipod species selection can be found in a clarification paper from the 1999 SMARM.

7.3.2 Ammonia Considerations for Amphipod Bioassay

Ammonia toxicity is a potential non-treatment factor that may affect the results of the larval and amphipod bioassays (Fox 1993). In some cases, ammonia can interfere with bioassay results, providing stress to test animals that is not related to stress caused by the chemicals of concern (e.g. anoxic sediments with elevated TOC). In other cases, the effects of ammonia are considered important to the toxicity of the sediment, and are a contaminant of concern (e.g., for wood waste). To reduce ammonia levels, purging of test sediments may be appropriate, as discussed below. In any test where elevated ammonia levels may be a consideration, the proponent may wish to run water-only LC50 tests. Considerations for both these approaches are discussed below.

7.3.2.1 Purging during amphipod bioassay testing

The DMMP needs to consider the project-specific bulk sediment interstitial ammonia values before deciding whether to commence purging prior to testing, and to allow each purging program to be tailored to the project under consideration. As a rule, the DMMP would like to minimize purging due to the unknown effects of purging on the integrity of sediment samples.

US EPA 1994 lists species-specific no-effect interstitial ammonia concentrations. The DMMP proposes using the total ammonia values (Table 7-1) as the threshold for considering purging of test sediments. Accordingly, prior to initiation of testing, project proponents concerned that ammonia may be an issue in their sediments must check the bulk sediment interstitial total ammonia levels. Should the levels approach the values in Table 7-1, **coordination with DMMO should occur** prior to test initiation. In consultation with the project proponent, a determination will be made as to whether purging should occur prior to initiation of the tests. For further information on purging methods and test initiation, please see the clarification paper Ammonia and Amphipod Toxicity Testing from the 2002 SMARM.

Table 7-1. Thresholds for consideration of purging for amphipod bioassay.

PARAMETER	*Ampelisca abdita*	*Eohaustorius estuarius*	*Rhepoxynius abronius*
Ammonia (interstitial total mg/L, pH 7.7)	>30	>60	>30

From US EPA 1994

7.3.2.2 Water-only LC50 testing

To assess the role of ammonia on any expressed toxicity project proponents may elect to run a water-only ammonia LC50 experiment to quantify the sensitivity of the amphipod population being used to ammonia levels occurring in the test sediment. Ammonia LC50 data will allow the DMMP and project proponents to determine the extent of ammonia-related toxicity while minimizing the need to purge sediments. As a general guideline, if interstitial ammonia is found at one-half the threshold value for consideration of purging (Table 7-2) project proponents should consider running an ammonia reference toxicant (LC50) test.

Table 7-2. Thresholds for running amphipod ammonia reference toxicant (LC50) Test.

PARAMETER	*Ampelisca abdita*	*Eohaustorius estuarius*	*Rhepoxynius abronius*
Ammonia (interstitial total mg/L, pH 7.7)	>15	>30	>15
Ammonia (interstitial unionized mg/L, pH 7.7)	>0.2	>0.4	>0.2

Ammonia tests must be run on animals collected and delivered at the same time and place as the test animals, and be run concurrently with the bioassays. The agencies will use information from the water-only tests to consider whether ammonia is contributing to or largely responsible for the observed toxicity in a given test. Test methods and guidelines for interpreting LC50 data should be arranged in consultation with the DMMP agencies prior to the initiation of any testing.

Ammonia LC50 tests will not be appropriate for many bioassays. Elevated ammonia levels can be expected primarily from very deep sediments or those with substantial amounts of organics such as wood waste. However, ammonia LC50 data will be required to support any contentions that ammonia, and not other chemicals of concern, was the primary cause of any expressed toxicity in the amphipod bioassay.

7.3.2.3 Reporting Ammonia Data

Once the bulk sediment interstitial water ammonia values have been measured and determined to be near or above the threshold values in Table 7-1, an appropriate interstitial water testing regime must be planned. If purging is determined to be appropriate, reference and control containers must be carefully planned. The following information should be tracked and reported for all project sediments (including control and reference) where bulk sediment interstitial water ammonia values have been measured and determined to be near or above the threshold values, whether or not purging occurs (DMMP 2001).

- Initial bulk sediment interstitial ammonia
- Total and unionized interstitial ammonia at test initiation (day 0) and day 10. Overlying water ammonia should also be reported as part of regular daily water quality measurements.
- LC50 water only experiment data

For those projects ultimately requiring purging, total and unionized interstitial ammonia (mg/L) should also be tracked and reported for each day testing of water occurs during purging.

7.4 20-day juvenile infaunal growth test (*Neanthes*)

This bioassay is a sublethal bioassay, testing for chronic rather than acute (fatal) toxicity to the nereid worm *Neanthes arenaceodentata.* The growth of this worm is used as an indication of sublethal toxicity. Protocols for running this test can be found on the Puget Sound Protocols and Guidelines website.

7.4.1 Ammonia Considerations for Neanthes Bioassay

Ammonia can also interfere with *Neanthes* bioassay results at the threshold values in Table 7-3. To reduce ammonia levels, purging of test sediments may be appropriate as discussed above. In any test where elevated ammonia levels may be a consideration, the proponent may wish to run water-only LC50 tests. For more information, see Ammonia and Sulfide Guidance Relative to *Neanthes* Growth Bioassay from the 2004 SMARM.

With the standard ammonia data, synoptic ammonia LC50 data help the DMMP agencies and project proponents determine the potential extent of ammonia-related toxicity and reduce the need to purge sediment samples. Labs should already be experienced in running reference toxicant tests, however, project sampling and analysis plans (SAPs) should include a specific discussion including the lab's protocol for ammonia testing and calculating an LC50, should the ammonia reference toxicant test be required.

The total ammonia no-effects concentrations presented in Table 7-3 can be used as thresholds above which project proponents should conduct water-only ammonia reference toxicant (LC50) tests.

Table 7-3. Thresholds of concern for *Neanthes* 20-day Chronic Test[1].

Parameter	No effects (0% mortality; no effect on growth)	Minor effects (~20% mortality; growth reduced 31-35% relative to control)	Major effects (~100% mortality, no growth)
Bulk Ammonia	< 115 mg/Kg	> 230 mg/Kg	>400 mg/Kg
Total Interstitial Ammonia (overlying water)	< 10 mg/L	> 20 mg/L	> 40 mg/L
Unionized Interstitial Ammonia (overlying water)	< 0.46 mg/L	> 0.68 mg/L	> 1.25 mg/L
Total Sulfide (overlying water)	< 3.4 mg/L	> 5.5 mg/L	>15 mg/L

7.5 Sediment Larval Test

The sediment larval test uses the planktonic larval form of a benthic invertebrate to test for acute toxicity to this life stage. Larvae are introduced into chambers of test sediment and overlying water directly after fertilization. Development and survival are tracked for the 48 to 60 hours of larval growth.

7.5.1 Larval Species Selection

This test uses larvae of either an echinoderm or bivalve species. Typically, *Dendraster excentricus* is the recommended echinoderm species and *Mytilus galloprovincialis* is the recommended bivalve species. If either of these species in unavailable, applicants and/or laboratories may propose use of alternative species, including echinoderms *Stronglyocentrotus droebachiensis* and *S. purpuratus* or bivalve *Crassostrea gigas.* **Use of these species should proceed only after DMMP coordination and approval.**

7.5.2 Special Considerations for Sediment Larval Bioassay

Because the larval stage is a sensitive one, care must be taken during the test to insure that non-treatment factors for larval survival and development are optimized. The PSEP Protocols should be followed carefully to insure that useable data are collected.

For the sediment larval test, adults must be collected in spawning condition or must be induced to spawn in the laboratory. Therefore, seasonality plays a role in selecting a test organism for this bioassay. Viable test organisms are most difficult to obtain in the fall and early winter and the probability of performance problems increases during that time. The DMMP agencies recommend that biological testing be avoided late in the calendar year if at all possible.

[1] Total ammonia, unionized ammonia, and total sulfide concentrations from Dillon et al. (1993).

7.6 Quality Assurance/Quality Control in Bioassays

The following QA/QC guidelines apply to the standard suite of solid phase (sediment) bioassays:

7.6.1 Negative Control and Reference Samples

For the amphipod and the juvenile infaunal species biological tests, a negative control sediment is run with each test batch. The negative control sediment for the amphipod test is taken from the test organism collection site (see additional information in 7.6.2). The juvenile infaunal growth test, using laboratory-cultured *Neanthes arenaceodentata*, requires collection of negative control sediment from an appropriate area such as West Beach, Whidbey Island. For the sediment larval test, a negative seawater control is required. The negative control provides an estimate of test organism general health during the test exposure period.

In addition to the negative control, a reference sediment must be run with each test batch, for all three bioassays. The reference sediment is collected from one of the reference sediment collection sites in Puget Sound or Grays Harbor and should be compatible on a physical and grain size basis with the dredged material. The primary purpose of the reference sediment is to determine the response of the test organisms to sediments of physical characteristics similar to the proposed dredged material. The reference sediment must be run in-batch. For dredged material with relatively coarse-grained sediments (> 80 % sand), the dredger can opt to rely solely on a control sediment[2] (see guidance below on when it is appropriate to use control sediments as a reference).

7.6.2 Selection of Negative Control Sediments

An appropriate negative control sediment must be used for the amphipod mortality and *Neanthes* growth tests. PSEP (1995) provides the following description of native habitat for various amphipods: "*Rhepoxynius abronius* and *Eohaustorius estuarius* typically inhabit well-sorted, fine sand while *Ampelisca abdita* is a tube-dwelling amphipod found mainly in protected areas and is often abundant in sediments with a high organic content. It generally inhabits sediments from fine sand to mud and silt without shell, although it can also be found in relatively coarser sediments with a sizable fine component." The best way to ensure a good negative control is to collect the control sediment from the same location at which the test organisms are collected.

Neanthes arenaceodentata is cultured in the lab rather than field-collected. However, PSEP (1995) states that, "For the *Neanthes* bioassay, sand should be used as the control sediment." West Beach of Whidbey Island is most often used as a collection site for clean control sediment. From PSEP (1995), "*Neanthes* maintained in West Beach sand exhibited low mortality and high percentage increases in biomass during the exposure period, indicating that West Beach sand is a suitable material for a control sediment."

PSEP (1995) also states that, "All bioassays must be conducted using well-established negative (clean) controls. Such controls are clean, nontoxic seawater and/or sediment samples taken from outside each study area." For dredged material management programs in the State of Washington or for comparison to SMS, sediments proposed for use as

[2] for *Rhepoxynius abronius* and *Neanthes arenaceodentata*.

negative controls must be approved before bioassays commence. If an area without a proven track record is proposed for collection of negative control sediment, sufficient data (such as grain size, organic carbon content, chemical data, bioassay results) must be submitted before its use can be approved by the regulatory agencies.

7.6.3 Use of control sediments as reference sediments

When a reference sediment fails to meet its performance standard, and more than one reference has been collected, Michelsen and Shaw (1996) provide procedures for statistical comparisons. If no reference sediments meet performance standards, or if the control sediment is closer in grain size and TOC to one or more stations being evaluated than any of the remaining reference sediments, the control sediment should be evaluated for use as a reference sediment. If the control sediment is similar in grain size and TOC to the site sediments and/or a reference sediment that failed to meet performance standards, it will be considered an acceptable substitute for the reference sediment and the data will be interpreted accordingly.

If a control sediment is substantially dissimilar to the site stations and a failed reference sediment in its physical characteristics (e.g., >25% difference in fines and a difference of 1% TOC), it may still be used as a substitute for the reference station if both the agencies/site manager and the project proponent agree that this is appropriate. Otherwise, the data will be considered unusable and the bioassay(s) in question will need to be rerun.

7.6.4 Quality control limits for the negative control treatment

All three bioassays have negative control performance standards that must be met (see Table 7-4). In the amphipod and juvenile infaunal bioassay tests, control mortality over the exposure period should be less than or equal to 10 percent. This represents a generally accepted level of mortality of test organisms under control conditions, where the bioassay (in terms of test organism health) is still considered a valid measure of effects of the test treatments. If control mortality is greater than 10 percent, the bioassay test will generally have to be repeated, although that determination must be made in consultation with the agencies through the DMMO. For the sediment larval test, the performance standard for the seawater negative control combined endpoint (mortality + abnormality) is 30 percent.

7.6.5 Quality control limits for the reference sediment

Performance guidelines for reference sediments are listed in Table 7-4. The mean amphipod test mortality for the reference sediment must not exceed 20 percent absolute over the mean control sediment mortality. For the juvenile infaunal growth test, the reference sediment mean mortality must be less than or equal to 20 percent at the end of the exposure period, while the mean growth rate must be greater than or equal to 80 percent of the control sediment's mean growth rate. The seawater-normalized combined endpoint (mortality + abnormality) observed in the reference sediment for the sediment larval test must not exceed 35 percent. Failure to meet the reference sediment performance standard for a bioassay may require that the bioassay be rerun with a new reference sediment. If a performance guideline is not met for a reference sediment, the Corps' Dredged Material Management Office should be contacted as soon as possible to coordinate with the agencies regarding a retest. Additional information regarding reference sediment performance can be found at http://www.nws.usace.army.mil/dmmo/by_topic.htm

7.6.6 Positive control - Reference toxicant

An appropriate reference toxicant must be run with each batch of test sediments as a positive control to assess the test organism sensitivity. The LC_{50} or EC_{50} must be within the 95 percent confidence interval of responses expected for the toxicant used.

7.6.7 Water quality monitoring

Temperature, aqueous salinity, pH, and dissolved oxygen should be monitored on a daily basis for the amphipod and sediment larval tests, and every three days for the 20-day *Neanthes* growth test. Total sulfides and ammonia should be measured at test initiation and termination for all three tests. Interstitial salinity should be measured prior to test initiation. The test protocols for each of these bioassays specify acceptable ranges for these parameters. Water quality data can be critical in the interpretation of bioassay results.

7.7 Bioassay Interpretive Criteria

The response of bioassay organisms exposed to the tested dredged material representing each DMMU will be compared to the response of these organisms in both control and reference treatments. This comparison will determine whether the material is suitable for unconfined, open-water disposal relative to the Clean Water Act (CWA) Section 404(b)(1) Guidelines (see Table 7-4).

The determination of an environmentally significant response involves two conditions: first, that the response in the tested DMMU must be greater than 20 percent different from the control response; and, second, that a comparison between mean test and mean reference responses be statistically significant. For the latter determination, the following guidelines are to be followed:

1. Multiple comparison tests (e.g., ANOVA, Dunnett's) are not to be used.

2. A null hypothesis shall be selected that reflects the one-tailed t-test approach and the type of endpoint being evaluated.

3. Bioassay data expressed in percent should be transformed, if necessary, prior to statistical testing using the arcsine-square root transform to stabilize the variances and improve the normality of the data. *Neanthes* growth data may require a square root or log transformation.

4. Bioassay data should then be tested for normality and homogeneity of variances, using the Shapiro-Wilk test (W test) and Levene's test, respectively.

5. Bioassay data passing both tests should be tested for statistical difference using a one-tailed Student's t-test.

6. Data passing the W test but failing Levene's test should be tested for statistical difference using the approximate t-test.

7. Data failing the W test but passing Levene's test should be tested for statistical difference using the non-parametric Mann-Whitney test.

8. Data failing both the W test and Levene's test should be converted to rankits and tested with a t-test.

Seattle District has developed statistical analysis software called BIOSTAT to facilitate bioassay statistical comparisons with appropriate reference sediments.

7.7.1 Single-hit failure

When **<u>any one</u>** biological test exhibits a test sediment response that exceeds the bioassay-specific guidelines relative to the negative control and reference, and which is statistically significant in comparison to the reference, the DMMU is judged to be unsuitable for unconfined open-water disposal (see Table 7-4).

<u>Amphipod Bioassay</u>. For the amphipod bioassay, mean test mortality greater than 20 percent absolute over the mean negative control response, and greater than 10 percent (dispersive) or 30 percent (nondispersive) absolute over the mean reference sediment response, and statistically significant compared to reference (alpha = 0.05), is considered a "hit" under the "single-hit" guidelines.

<u>Juvenile Infaunal Growth Test</u>. Juvenile *Neanthes* growth test results that show a mean individual growth rate less than 80 percent of the mean negative control growth rate, and less than 70 percent (dispersive) or 50 percent (nondispersive) of the mean reference sediment growth rate, and statistically significant compared to reference (alpha = 0.05), is a hit under the single-hit rule.

<u>Sediment Larval Bioassay</u>. For the sediment larval bioassay, test and reference sediment responses are normalized to the negative seawater control response. This normalization is performed by dividing the number of normal larvae from the test or reference treatment at the end of the exposure period by the number of normal larvae in the seawater control at the end of the exposure period, and multiplying by 100 to convert to percent. The normalized combined mortality and abnormality (NCMA) is then 100 minus this number. If the mean NCMA for a test sediment is greater than 20 percent, and is 15 percent (dispersive) or 30 percent (nondispersive) absolute over the mean reference sediment NCMA, and statistically significant compared to reference (alpha = 0.10), it is considered a hit under the single-hit rule.

7.7.2 Double-hit failure

When **<u>any two</u>** biological tests (amphipod, juvenile infaunal growth or sediment larval) exhibit test sediment responses which are less than the bioassay-specific reference-comparison guidelines noted above for a single-hit failure, but are significantly significant compared to the reference sediment (and less than 70 percent of the mean reference sediment growth rate for the *Neanthes* bioassay for nondispersive sites), the DMMU is judged to be unsuitable for unconfined open-water disposal.

Table 7-4. Solid Phase Bioassay Performance Standards and Evaluation Guidelines.

Bioassay	Negative Control Performance Standard	Reference Sediment Performance Standard	Dispersive Disposal Site Interpretation Guidelines		Nondispersive Disposal Site Interpretation Guidelines	
			1-hit rule	2-hit rule	1-hit rule	2-hit rule
Amphipod	$M_C \leq 10\%$	$M_R - M_C \leq 20\%$	$M_T - M_C > 20\%$ and M_T vs. M_R SS (p=.05) and		$M_T - M_C > 20\%$ and M_T vs. M_R SS (p=.05) and	
			$M_T - M_R > 10\%$	NOCN	$M_T - M_R > 30\%$	NOCN
Larval	$N_C \div I \geq 0.70$	$N_R \div N_C \geq 0.65$	$N_T \div N_C < 0.80$ and N_T/N_C vs. N_R/N_C SS (p=.10) and		$N_T \div N_C < 0.80$ and N_T/N_C vs. N_R/N_C SS (p=.10) and	
			$N_R/N_C - N_T/N_C > 0.15$	NOCN	$N_R/N_C - N_T/N_C > 0.30$	NOCN
Neanthes growth	$M_C \leq 10\%$ and $MIG_C \geq 0.38$	$M_R \leq 20\%$ and $MIG_R \div MIG_C \geq 0.80$	$MIG_T \div MIG_C < 0.80$ and MIG_T vs. MIG_R SS (p=.05) and		$MIG_T \div MIG_C < 0.80$ and MIG_T vs. MIG_R SS (p=.05) and	
			$MIG_T/MIG_R < 0.70$	NOCN	$MIG_T/MIG_R < 0.50$	$MIG_T/MIG_R < 0.70$

M = mortality, N = normal larvae, I = initial count, MIG = mean individual growth rate (mg/individual/day)
SS = statistically significant, NOCN = no other conditions necessary, N/A = not applicable
Subscripts: R = reference sediment, C = negative control, T = test sediment

7.8 Water Column Bioassay Testing

The Tier III evaluation of dredged material may include an evaluation of potential water column effects using echinoderm or bivalve larvae, when warranted. Water column testing for biological effects is not routinely required for regulated or federal dredging projects evaluated under CWA Section 404 for DMMP disposal. This test will need to be conducted only when the Washington Department of Ecology requires for water quality certification an assessment of potential water column toxicity effects relative to a particular chemical of concern.

In the event that water column testing is required, the echinoderm/bivalve larval test will be conducted to evaluate water column effects. The appropriate assessment is described in the *Inland Testing Manual* (EPA/USACE, 1994). The protocol found in PSEP (1995) may be followed to the extent that it conforms to test specifications described in the *Inland Testing Manual* (Appendix E). The following species may be used for the larval water column bioassay test:

- Echinoderm: *Dendraster excentricus*
- Bivalve: *Mytilus galloprovincialis*

7.9 Reference Sediment Collection Sites

Bioassays must be run with a reference sediment which is well-matched to the test sediments for grain-size and other sediment conventionals (such as total organic carbon). Table 7-8 contains information about each of the Puget Sound sites that are recommended for use. Table 7-9 contains information about reference sites for Grays Harbor and Willapa Bay. Other reference areas may be utilized if:

- biological tests are initially run using the proposed reference area along with an already recognized reference area

- chemical (DMMP contaminants of concern) analysis is performed for the proposed area.

Table 7-8. Reference Sediment Collection Areas for Puget Sound.

	CARR INLET	SAMISH BAY	HOLMES HARBOR	SEQUIM BAY
Fines (%):	5-85	11-96	3-96	19-85
TOC (%):	0.2-11.8	0.4-29.0	0.2-31.0	2.3-2.7
Reference:	PTI, 1991; SAIC, 2001	PTI, 1991; SAIC, 2001	PTI, 1991; SAIC, 2001	DAIS

The sampling protocol used for the collection of reference sediment can affect its performance during biological testing. The following guidelines should be followed when collecting reference sediments:

- Use experienced personnel.
- Follow PSEP protocols.
- Sample from biologically active zone.
- Avoid anoxic sediment below the Redox Potential Discontinuity (RPD) horizon.
- Use wet-sieving method.
- Fix sulfides sample with zinc acetate.

TABLE 7-9. Reference Sediment Collection Sites for Grays Harbor and Willapa Bay.[1]

PARAMETER	STATION					
	3.9 MILE ODMDS	WBS5	WBS7	GHS4	GHS6	GHS7
Location	SE of 3.9 Mile Site[2]	Grassy Point	Bay Center	Stearns Bluff	Elk River	North Bay
GPS Latitude (WGS84)	46^o 51.00'	46^o 38.04'	46^o 37.90'	46^o 55.73'	46^o 52.52'	47^o 00.35'
GPS Longitude (WGS84)	124^o 13.73	124^o 01.78'	123^o 56.80'	123^o 59.03'	124^o 04.78'	124^o 05.79'
Fines (%)	10	0	35-52	12	2	7-59
TOC (%)	0.10	0.02	0.51-1.0	0.25	0.06	0.15-1.1

[1]Adapted from The *Grays Harbor and Willapa Bay Dredged Material Management Study: Expanded Reference Area Sediments* final report (SAIC, 1993)
[2]Station4 from the 3.9-Mile ODMDS site.
[3]Location of the sample with the highest fines content.

Wet-sieving is imperative in finding a good grain-size match with the test sediment. Wet-sieving is accomplished using a 63-micron (#230) sieve and a graduated cylinder; 100 ml of sediment is placed in the sieve and washed thoroughly until the water runs clear. The volume of sand and gravel remaining in the sieve is then washed into the graduated cylinder and measured. This represents the coarse fraction; the fines content is determined by subtracting this number from 100. Because of the wide heterogeneity of grain size in the reference areas, it may be necessary to perform wet-sieving in several places before a reference sediment with the proper grain size is found.

It should be noted that wet-sieving results will not perfectly match the dry-weight-normalized grain size results from the laboratory analysis, but should be relatively close. It is requested that wet-sieving results be submitted along with the laboratory data so that a regression line for each embayment can be developed which more accurately predicts the dry-weight fines fraction from the wet-sieving results found in the field. Reference station coordinates should also be reported, with an accuracy of $\pm$ 3 meters.

In addition to wet-sieving in the field, reference sediments must be analyzed in the laboratory for total solids, total volatile solids, total organic carbon, grain size, ammonia and sulfides. The methods and QA guidelines used for analysis of sediment conventionals in test sediments should also be used for reference sediments.

8 TIER III BIOLOGICAL TESTING: BIOACCUMULATION

Bioaccumulation is the accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material. Tier III bioaccumulation testing of dredged material is required when results of sediment chemical analysis for bioaccumulative chemicals of concern (BCOCs) indicate the potential for unacceptable adverse environmental or human health effects. The tissue residues derived from bioaccumulation tests are compared to the DMMP's target tissue levels (TTLs) and reference values to assess the potential for both human- and ecological-health related effects. Important elements of this testing process are described below.

8.1 Bioaccumulative Contaminants of Concern (BCOCs) and Triggers for Bioaccumulation Testing

In 2003, the DMMP adopted a revised list of Bioaccumulative Contaminants of Concern (see April 24, 2003 Issue Paper and January 2007 Technical Basis document) using a systematic approach that considered multiple lines of evidence for determining the bioaccumulative risk posed by a particular chemical. Revising the DMMP's BCOC list involved creation of four separate BCOC lists. List 1 is the primary list of bioaccumulative contaminants of concern. Analysis for these 17 chemicals in sediments (and potentially in tissues) is required to determine dredged material suitability. Analysis of PCDDs/PCDFs and TBT are required only on a case-by-case basis. Lists 2 and 3 define chemicals of potential concern for bioaccumulative effects but for which definitive data are still lacking – analysis of these chemicals is not routinely required. List 4 chemicals are those which the DMMP does not consider to be bioaccumulative.

When measured sediment concentrations of the List 1 contaminants exceed the bioaccumulation trigger (BT) values presented in Table 8-1, bioaccumulation testing must be performed before suitability of the test sediment for open-water disposal can be determined. The BT is set at a sediment concentration that constitutes a "reason to believe" that the chemical would accumulate in the tissues of target organisms. Originally, BTs were established for human health COCs at concentrations in the upper 30th percentile of the concentrations allowable for unconfined, open-water disposal (i.e., 70 percent of the difference between the SL and ML) (EPTA, 1988). The 2003 revisions to the BCOC list did not involve revisions to existing BT values. Interim BT values were developed for six of the new List 1 chemicals using the same algorithm used in EPTA (PSDDA 1988). The interim BT for selenium was developed in consideration of sediment concentrations reported in the literature to be associated with adverse ecological effects from bioaccumulation. These values are designated as "interim" pending a reexamination of the BT derivation approach, planned for the near future as part of the RSET process.

Updated regional bioaccumulation guidance is presently being developed by RSET with participation of DMMP and will be adopted by the DMMP after appropriate public review and comment. Until that time, the approach and guidelines outlined in this section are those that will be used by the DMMP. However, modifications proposed by applicants, based on RSET guidelines, may be considered on a case-by-case basis.

Table 8-1. List 1 Bioaccumulative Chemicals of Concern

CHEMICAL	METHOD INFORMATION	LOG K_{ow}[1]	BT (dry wt basis[2])
METALS			
Arsenic	SW846 M.6020	N/A	507.1 mg/kg
Cadmium	SW846 M.7131	N/A	*11.3 mg/kg*
Chromium	SW846 M.6020	N/A	*267 mg/kg*
Copper	SW846 M.6020	N/A	*1027 mg/kg*
Lead	SW846 M.7421	N/A	*975 mg/kg*
Mercury	SW846 M.7421	N/A	1.5 mg/kg
Nickel	SW846 M.6020	N/A	370 mg/kg
Selenium	SW846 M.7740	N/A	*3 mg/kg*[3]
Silver	SW846 M.7761	N/A	6.1 ug/kg
Zinc	SW846 M.6010	N/A	*2783 ug/kg*
ORGANOMETALLIC COMPOUNDS			
Tributyltin (interstitial water)	Krone/Unger	3.7-4.4	0.15 ug/L
ORGANICS			
Fluoranthene	SW846 M.8270	5.12	4,600 ug/kg
Pyrene	SW846 M.8270	5.11	*11,980 ug/kg*
CHLORINATED HYDROCARBONS			
Hexachlorobenzene (HCB)	SW846 M.8081	5.89	168 ug/kg
PHENOLS			
Pentachlorophenol	SW846 M.8270	5.09	504 ug/kg
PESTICIDES/PCBs			
Total DDT (sum of 4,4'-DDD, 4,4'-DDE and 4,4'-DDT)	SW846 M.8081	(5.7 - 6.0)[4]	50 ug/kg
Chlordane[5]	SW846 M.8081	6.32	37 ug/kg
Dioxin/Furans	EPA 1613	5.5-13.9	TBD[6]
Total Aroclor PCBs	SW846 M.8081/2	(3.6-11)[7]	38 mg/kg OC

Italics indicate interim BTs

1 Octanol/Water Partitioning Coefficients (log K_{OW}) for organic chemicals of concern for bioaccumulation in Puget Sound.

2 Except where noted otherwise

3 Based on review of sediment effect values from the literature and best professional judgment.

4 Range of individual chemicals making up the total.

5 Chlordane includes cis-Chlordane, trans-Chlordane, cis-Nonachlor, trans-Nonachlor, and oxychlordane. Components of chlordane were clarified at the 2007 SMARM.

6 To Be Determined: interpretive guidelines for PCDD/PCDF are currently in development. The interim approach to determine suitability of dioxin in sediments does not involve bioaccumulation testing and is discussed in Section 6.4.3

7 Range of individual congeners making up the total.

8.2 Bioaccumulation Test Species Selection

Selection of appropriate species is an important consideration for an appropriate Tier III bioaccumulation test. Studies have shown that the time required for any given species to achieve a steady-state tissue concentration of a chemical of concern may vary (see Table 8-2), or are not well known (Windom and Kendall, 1979; Rubenstein, Lores, and Gregory, 1983). As such, for a given chemical triggering a Tier III bioaccumulation test, the applicant should consider selecting species that will assimilate the target chemical near its steady-state concentration (if known) within the exposure period or consider extending the exposure period. The Inland Testing Manual requires bioaccumulation testing with species from two different trophic niches, including: 1) a suspension-feeding/filter-feeding organism and 2) a burrowing deposit-feeding organism. The Tier III marine bioaccumulation test is usually conducted with both an adult bivalve (*Macoma nasuta*) and an adult polychaete (*Nephtys caecoides, Nereis virens,* or *Arenicola marina*). For recommended freshwater species, consult the RSET SEF, Section 9.4.

8.3 Bioaccumulation Test Protocol

The standard Tier III bioaccumulation test utilizes the EPA protocol (Lee *et al*. 1989) and a 28-day exposure period (exceptions are PCBs, TBT and DDT for which a 45-day exposure time has been required by the DMMP - see recent protocol updates below), after which a chemical analysis is conducted of the tissues to determine the concentration of bioaccumulative chemicals of concern identified in the original sediments. Protocols for tissue digestion and chemical analysis will follow the PSEP-recommended procedures for metals and organic chemicals.

For many chemicals in Table 8-1, it is assumed that a 28-day exposure is sufficient for a steady-state tissue concentration to be reached. For other chemicals, particularly those with octanol/water partitioning coefficients (K_{OW}) greater than 5.5, it is unlikely that steady state will have been reached after 28 days. However, even for these highly hydrophobic chemicals, tissue concentrations should be detectable following a 28-day exposure period. It will be necessary to extrapolate the measured tissue concentrations to “steady-state” concentrations for these chemicals (using chemical-specific information from published studies) prior to using this data to judge sediment suitability. Extrapolation to steady-state would not be required for tissue data resulting from 45-day exposure periods.

Given holding time limitations (see Table 5-1), it may be necessary to resample project sediments in order to obtain samples for bioaccumulation testing. Under these circumstances, it is necessary to analyze the bioaccumulation sediment for the chemicals of concern that triggered the requirement for bioaccumulation testing. If the chemical concentration(s) found in the bioaccumulation test sediment are less than that measured in the original sediment analyzed, the DMMP will require that the measured tissue concentrations of that chemical be mathematically adjusted. The resulting adjusted tissue concentration reflects the bioaccumulation of a given chemical that would have been expected from exposure to the original sediment sample.

Recent bioaccumulation protocol updates that have been adopted by the DMMP:

- Use a 45-day exposure time when conducting bioaccumulation testing for specific chemicals of concern for bioaccumulation (PCBs, TBT, DDT) to ensure steady-state chemical concentrations in the tissues of the test species (*Macoma nasuta* and *Nephtys caecoides*). Increasing the exposure to 45 days will require once weekly supplemental additions of 175-mL of test or control/reference sediment to each replicate10-gallon aquaria/test chamber.

- Wet-weight biomass (of a subset of 10 individual organisms/replicates) should be measured at the beginning and end of the bioaccumulation exposure period for test, control and reference samples. This estimate of net individual growth during the exposure period will be used as an additional metric to evaluate the health of the test animals, and to build a database that may support establishing a benthic effects-based target-tissue level.

- Use an alpha level of 0.1 (rather than 0.05) when making statistical comparisons between tissue concentrations in test and reference samples to reflect higher likelihood for within-sample variability, and to increase the power of the test to discriminate between reference and test tissue concentrations. Note that an alpha level of 0.05 should be used when making comparisons between test tissues and target tissue levels (TTLs).

- Consider testing compatible polychaete and bivalve species in the same test container. A considerable volume of sediment is required for testing each of the test species (Table 8-3). To conserve laboratory space and reduce the sediment volume required, applicants may test *Macoma nasuta* and *Nephtys caecoides* together in the same test chambers. The total sediment requirement for co-testing is 20 liters. In practice, this approach has been adopted by all applicants doing bioaccumulation testing over the past 10 years.

Table 8-2. Percent of Steady-State Tissue Residues of Selected Metals and Neutral Organics from 10 and 28 day Exposures to Bedded Sediment[1]

COMPOUND	% OF STEADY STATE[2] TISSUE RESIDUE		SPECIES	ESTIMATED BY	REFERENCES[3]
	10-DAY	28-DAY			
METALS					
Copper	75	100	*Macoma nasuta*	G[5]	Lee (unpublished)
Lead	81	100	*Macoma nasuta*	G	Lee (unpublished)
Cadmium	17	50	*Callianassa australiensis*	G	Ahsanulla et al., 1984
Mercury	ND[4]	ND[4]	*Neanthes succinea*	G	Kendall, 1978
ORGANICS					
PCBs					
Aroclor 1242	18	87	*Nereis virens*	G	Langston, 1978
Aroclor 1254	12	82	*Macoma balthica*	G	Langston, 1978
Aroclor 1254	25	56	*Nereis virens*	K[6]	McLeese et al., 1980
Aroclor 1260	53	100	*Macoma balthica*	G	Langston, 1978
Total PCBs	21	54	*Nereis virens*	G	Pruell et al., 1986
Total PCBs	48	80	*Macoma nasuta*	G	Pruell et al., 1986
Total PCBs	23	71	*Macoma nasuta*	G	Boese (unpublished)
PAHs					
Benzo(a)pyrene	43	75	*Macoma inquinata*	G	Augenfield et al., 1982
Benzo(b,k)fluoranthene	71	100	*Macoma nasuta*	G	Lee (unpublished)
Chrysene	43	87	*Macoma inquinata*	G	Augenfield et al., 1982
Fluoranthene	100	100	*Macoma nasuta*	G	Lee (unpublished)
Phenanthrene	100	100	*Macoma inquinata*	G	Augenfield et al., 1981
Phenanthrene	100	100	*Macoma nasuta*	G	Lee (unpublished)
Pyrene	84	97	*Macoma nasuta*	G	Lee (unpublished)
TCDD/TCDF					
2,3,7,8-TCDD	6	22	*Nereis virens*	G	Pruell et al., 1990
2,3,7,8-TCDD	63	100	*Macoma nasuta*	G	Pruell et al., 1990
2,3,7,8-TCDF	43	62	*Nereis virens*	G	Pruell et al., 1990
2,3,7,8-TCDF	92	100	*Macoma nasuta*	G	Pruell et al., 1990
MISCELLANEOUS					
4,4-DDE	20	50	*Macoma nasuta*	G	Lee (unpublished)
2,4-DDD	31	56	*Macoma nasuta*	G	Lee (unpublished)
4,4-DDD	32	60	*Macoma nasuta*	G	Lee (unpublished)
4,4-DDT	17	10	*Macoma nasuta*	G	Lee (unpublished)

[1] Modified from Inland Testing Manual (Table C), using data updated from Boese and Lee (1992).
[2] Steady-state values are estimates, as steady-state is not rigorously documented in these studies.
[3] See Boese and Lee (1992) for complete citations.
[4] ND = Not Determined. Observed AFs (accumulation factors) for field tissue levels compared with sediment levels (normalized to dry weight) averaged 4 for this species, but ranged from 1.3 to 45 among other benthic macroinvertebrate species. Laboratory 28-day exposures to bedded sediment indicated uptake fit a linear regression model over the exposure period and experimental conditions. Tissue levels observed (*N. succinea)* at 28 days amounted to only 2.5 % of the total sediment-bound Hg potentially available.
[5] G = Steady-state residue estimated by visual inspection of graphs of tissue residue versus time.
[6] K = Steady-state residue estimated from a 1st-order kinetic uptake model.

Table 8-3. Species-specific sediment requirement for bioaccumulation testing.

SPECIES	MINIMUM SEDIMENT REQUIREMENT
Macoma nasuta	250-400 ml per beaker x 10 beakers per replicate x 5 replicates = **12.5-20 liters**
Nereis virens	200 ml per worm x 20 worms per replicate x 5 replicates = **20 liters**
Arenicola marina OR *Abarenicola spp.*	500 ml per beaker x 4 beakers per replicate x 5 replicates = **10 liters**
Co-testing: Macoma/Nephtys[3]	4 liters per replicate x 5 replicates = **20 liters**

This alternative has become the generally accepted protocol for bioaccumulation testing within DMMP.

8.4 Bioaccumulation Test Interpretation

The DMMP's numerical test interpretation guidelines, or target tissue levels, were mostly derived based on human health considerations. However, the potential for ecological effects of bioaccumulation have played an increasingly important role in the interpretation of bioassay results (e.g., for TBT).

8.4.1 Human Health Effects

Tissue residues from bioaccumulation testing are compared to the DMMP's target tissue levels (TTLs). TTLs are allowable tissue concentrations of BCOCs that were derived either from human-health risk assessments or from FDA action levels[1]. Most of the human risk-based TTLs were developed during the PSDDA study for deep-water disposal sites, using consumption rates of bottom fish by recreational anglers, the home range of bottom fish and the size of the Elliott Bay disposal site (EPTA, 1988). An exception is the TTL for Total PCBs which is based on a human-health risk assessment performed by the DMMP for the Elliott Bay disposal site (DMMP, 1999). For those chemicals with FDA action levels lower than the risk-based concentrations, the FDA action levels were adopted. Table 8-4 shows the current TTLs used by the DMMP for suitability determinations. DMMUs are compared to the values in this table using the approach described below.

Interpretation of test results requires a statistical comparison of the mean tissue concentration of contaminants in animals exposed to dredged material to the TTL. The statistic employed is the one-tailed one-sample t-test (alpha level of 0.05):

$$t = \frac{\bar{x} - TTL}{\sqrt{\frac{s^2}{n}}}$$

where "$\bar{x}$", "s^2", and "n" refer to the mean, variance, and number of replicates associated with a contaminant's tissue concentrations from bioaccumulation testing of the proposed dredged material. For undetected chemicals, a concentration equal to one-half the detection limit will be used in the statistical analysis.

[1]An exception is the TTL for TBT, which is an ecological effects-based value

Use of the one-sample t-test is necessary to allow experimental results for bioaccumulation testing to be compared to the TTLs, which are constants. A one-*tailed* t-test is appropriate since there is concern only if bioaccumulation from the dredged sediment is not significantly less than the TTL. The null hypothesis in this case is that the tissue concentration is greater than or equal to the TTL.

If the mean tissue concentration of one or more contaminants of concern is greater than or equal to the TTL, then no statistical testing is required. The conclusion is that the dredged material is not acceptable for open-water disposal. If the mean tissue concentration of a chemical of concern is less than the applicable TTL, a one-tailed one-sample t-test is conducted and the dredged material is considered acceptable for open-water disposal if the null hypothesis is rejected.

8.4.2 Ecological Effects

The results of a Tier III bioaccumulation test will be compared directly with reference results (or ecological TTLs once these become available) for statistical significance. Significant bioaccumulation of chemicals of concern in test species relative to reference areas may demonstrate the potential for food-web effects. For undetected chemicals, a concentration equal to one-half the detection limit will be used in the statistical analysis. If the results of a statistical comparison show that the tissue concentration of the chemical(s) of concern tested in sediments is statistically higher (one-tailed t-test, alpha level of 0.1) than the reference sediment, the dredged material will be evaluated further to determine the potential ecological significance of the measured tissue residues.

The four factors summarized below will be reviewed as part of the suitability determination process when bioaccumulation of contaminants in dredged material tests shows significantly higher accumulation of one or more chemicals of concern. In reviewing these factors, the best available regional guidance will be used to assess the relative importance of each factor to the regulatory decision.

1. How many contaminants demonstrate bioaccumulation from dredged material relative to reference sediments?

2. What is the magnitude of the bioaccumulation from dredged material compared to reference sediments?

3. What is the toxicological importance of the contaminants (e.g., do they biomagnify or have effects at low concentrations?). In assessing the toxicological importance, ecologically-based TTLs may be set on a project-specific basis by the regulatory agencies based on a review of the current residue-effects literature. A statistical comparison will be made to ecologically-based TTLs using the one-sample t-test described under human-health effects.

   One exception to the project-specific nature of ecologically-based TTLs is the TTL for TBT (Table 8-4), which was adopted from a CERCLA risk assessment (EPA, 1999) that used a weight-of-evidence approach. The TBT TTL represents a residue that is associated with reduced growth in a number of invertebrate species including polychaetes and crustaceans.

4. What is the magnitude by which contaminants found to bioaccumulate in laboratory test tissues exceed the tissue burdens of comparable species found at or in the vicinity of the disposal site?

If results of the bioaccumulation test in Tier III are found to be equivocal, or there is a concern that steady-state body burdens in test organisms were not achieved and/or cannot be estimated, further testing may be required in Tier IV before a regulatory decision can be made on the suitability of the dredged material for unconfined open-water disposal.

Table 8-4. Target Tissue Concentration Values for Chemicals of Concern

CHEMICAL	TTL mg/kg wet wt.
Arsenic	10.1
Cadmium	TBD
Chlordane [1]	0.3 *
Chromium	TBD
Copper	TBD
Dioxins/Furans	n/a[2]
Fluoranthene	8400
Hexachlorobenzene	180
Lead	TBD
Mercury	1.0 *
Nickel	20,000
Pentachlorophenol	900
Pyrene	TBD
Selenium	TBD
Silver	200
TBT	0.6 [3]
Total Aroclor PCBs	0.75 [4]
Total DDT [5]	5.0*
Zinc	TBD

* FDA Action Level
TBD = to be determined on a project-specific basis.
[1] Chlordane includes the chlordane isomers and metabolites cis-Chlordane, trans-Chlordane, cis-Nonachlor, trans-Nonachlor, and oxychlordane
[2] The DMMP is currently in the process of developing programmatic guidelines for dioxin/furans. In the interim, suitability determinations are being made using only sediment data and do not involve bioaccumulation testing.
[3] The target tissue level for TBT was derived from a CERCLA risk assessment and is based on site-specific considerations of ecological risk for benthos found in the Harbor Island/Elliott Bay area and may not be appropriate for all disposal sites.
[4] The target tissue level for PCBs is based on site-specific considerations of subsistence human exposure in Elliott Bay and may not be appropriate for all disposal sites.
[5] Total DDT is determined by summing the p,p'- isomers of DDT and its metabolites (DDD, and DDE).

9 TIER IV EVALUATIONS

If standard chemical and/or biological evaluations of dredged material are unable to determine suitability of dredged material, a Tier IV assessment may be required. A Tier IV assessment is considered a special, non-routine evaluation and will require discussions among the agencies and the dredging proponent to determine the specific testing or assessment requirements. If two or more chemicals of concern during a Tier II evaluation exceed the maximum level (ML) guidelines, or if any one chemical exceeds the ML by more than 100 percent, the material will be considered unsuitable for unconfined open-water disposal unless a Tier IV assessment is conducted. Alternative analyses that may be conducted in this tier may include any or all of the following.

9.1 Steady State Bioaccumulation Test

In a Tier IV evaluation, bioaccumulation testing may be necessary to determine, either by time-sequenced laboratory bioaccumulation testing (Lee *et al*., 1989) or by collection of field samples, the steady state concentrations of contaminants in organisms exposed to the dredged material as compared with organisms exposed to the reference material. Testing options may also include longer time-sequenced laboratory exposures (exposures longer than 28 days may be necessary to reach a steady state concentration). Tier IV evaluations of data collected would follow the interpretation guidance specified in Section 6-7.

9.1.1 Time-Sequenced Laboratory Testing

This test is designed to detect differences, if any, between steady-state bioaccumulation in organisms exposed to the dredged sediments and steady-state bioaccumulation in organisms exposed to the reference sediments. If organisms are exposed to biologically available contaminants under constant conditions for a sufficient period of time, bioaccumulation will eventually reach a steady-state in which maximum bioaccumulation has occurred, and the net exchange of contaminant between the sediment and organism is zero.

The necessary species, apparatus and test conditions for laboratory testing are the same as those utilized for the Tier III bioaccumulation test. Tissue sub-samples taken from separate containers during the exposure period provide the basis for determining the rate of uptake and elimination of contaminants. From these rate data, the steady state concentrations of contaminants in the tissues can be calculated, even though the steady state may not have been reached during the actual exposure. For the purposes of conducting this test, steady state is defined as "the concentration of contaminant that would occur in tissue after constant exposure conditions have been achieved."

An initial time-zero sample is collected for each species for tissue analysis. Additional tissue samples are then collected from each of the five replicate reference and dredged-material exposure chambers at intervals of 2, 4, 7, 10, 18, and 28 days. Alternative time intervals may be proposed by the agencies. It is critical that sufficient tissue is available to allow the interval body burden analyses at the specified detection limits for the chemical(s) of concern.

Based on the magnitude of bioaccumulation from the dredged material, a comparison is then made with current FDA action levels (or best professional judgment for chemicals with no FDA action levels, or future Human Health Guidelines promulgated by the Washington State Department of Ecology and Department of Health), and a statistical comparison of test sediment organisms with reference organisms at steady state body burdens.

Calculating steady-state concentrations following time-sequenced testing should follow data analysis procedures outlined in the Corps/EPA Inland Testing Manual (Appendix D, Paragraph D3.2.1, pages D-47 to D-51). Bioaccumulation data are very expensive to obtain, because of the extensive number of chemical analyses required, and the data should be carefully and correctly analyzed.

9.1.2 Field Assessment of Steady State Bioaccumulation

Measuring concentrations in field-collected organisms may be considered as an alternative to laboratory exposures. A field sampling program designed to compare dredging and reference tissue levels of the same species allows a direct comparison of steady state contaminant tissue levels. The assessment involves measurements of tissue concentrations from individuals of the same species collected within the boundaries of the dredging site and a suitable reference site. Collecting sufficient numbers of individuals of the same relative size ranges and biomass of the same species to enable tissue analyses at the reference and dredging site can make this type of assessment problematic. A determination is made based on a statistical comparison of the magnitude of contaminant tissue levels in organisms collected within the boundaries of the reference site, compared with organisms living within the area to be dredged.

9.2 Human Health/Ecological Risk Assessments

When deemed appropriate by the agencies, a human health and/or ecological risk assessment may be required to evaluate a particular chemical of concern, such as dioxin, mercury, PCBs, etc. In the case of chemicals like dioxin, national guidance is in a rapid state of flux, and project-specific risks to human health or ecological health should be evaluated using the best available technical information and risk assessment models.

9.3 Other Case-Specific Studies

Biological effects tests in Tier IV should only be used in situations that warrant special investigative procedures. To address unique concerns, special studies not formally approved for use may be recommended to evaluate a specific dredged material issue. The nature and details of these studies would have to be worked out on a case-by-case basis through a consensus process with the agencies and dredging proponent.

Tests considered may include chronic/sublethal tests, field studies such as benthic infaunal studies, experimental studies such as *in situ* toxicity tests or toxicity identification evaluations (TIE procedure; see Ankley *et al*, 1992), risk assessments and/or no effects levels for aquatic life. In such cases, test procedures have to be tailored for specific situations, and general guidance cannot be offered. Such studies, when conducted, require design and evaluation specific to the need arising, with the assistance of administrative and scientific expertise from the agencies and other sources as appropriate.

Prediction of the movement of contaminants from sediment into and through pelagic food webs is technically challenging and should only be dealt with in a Tier IV evaluation, if deemed necessary. General approaches may be explored which bracket likely concentrations of specific contaminants at different trophic levels based on an empirical model derived from a variety of marine food webs (Young, 1988). Other methods may be recommended, such as bioenergetic based toxicokinetic modeling, if deemed appropriate to address a particular concern.

As part of the annual review process, the agencies will continually evaluate new tests and evaluation procedures that have been peer reviewed and are deemed ready for use in the regulatory evaluation of dredged material. The agencies will subsequently make recommendations about their potential implementation and use in Puget Sound, Grays Harbor and Willapa Bay.

10 SUBMITTAL OF SAMPLING AND TESTING DATA

Upon completion of sampling and testing, data submittal is comprised of four elements. Each element is discussed below.

1. A sediment characterization report (submitted in both paper and electronic format)
2. Data in the format required for the Corps' dredged analysis information system (DAIS)
3. Data in the format required for Ecology's Environmental Information Management database (EIM) and
4. Sampling and testing cost data (optional).

10.1 Sediment Characterization Report

The sediment characterization report must be submitted in both electronic and paper format and should include the following items:

1. Quality assurance report documenting deviations from the sampling and analysis plan and the effects of quality assurance deviations on the testing results.

2. A plan view showing the actual sampling locations.

3. The sampling coordinates in latitude and longitude within an accuracy of ± 3 m.

4. Methods used to locate the sampling positions.

5. The compositing scheme.

6. The type of sampling equipment used, the protocols used during sampling and compositing and an explanation of any deviations from the sampling plan.

7. Sampling logs with sediment descriptions.

8. Chain-of-custody procedures and explanation of any deviations from the sampling plan.

9. Chemical and biological testing results, including quality assurance data (NOTE: QA2 data defined in Section 10.3 should not be included in this report). Chemical testing results shall be presented in the same order as the list of chemicals of concern presented in Table 6-1 to facilitate data entry into DAIS.

10. Explanation of deviations from the analysis plan.

11. Comparison to SMS for beneficial use projects or where "Z" samples have been analyzed.

10.2 Dredged Analysis Information System (DAIS)

The Dredged Analysis Information System (DAIS) was developed by Seattle District to manage data generated by the Dredged Material Management Program. This includes physical, chemical and biological testing data associated with dredged material characterization. A checklist of required DAIS data will be furnished to the dredging proponent as part of the sampling and analysis plan approval process.

The Corps performs a quality assurance evaluation of all sediment test data before it is entered in DAIS, including checks on completeness, accuracy, precision and laboratory contamination. This level of quality assurance is referred to as QA1.

10.3 Environmental Information Management Database (EIM)

The Department of Ecology uses the Environmental Information Management (EIM) database to manage a variety of environmental data, including from sediment characterization. Future plans for EIM include AET-calculation capability. Ecology requires additional quality assurance data to fully validate the chemical and biological testing data used to update the AETs. This includes information such as chromatograms, calibration curves, etc., and is referred to as QA2. Hardcopy QA2 data should be submitted directly to Ecology with a copy of the transmittal letter provided to the DMMO. Requirements for QA2 data can be furnished to the dredging proponent.

For assistance with submittal of EIM data, contact the Dept. of Ecology Data Coordinator at Email: eim_data_coordinator@ecy.wa.gov or call: (360) 407-6258 (Olympia, Washington).

10.4 Sampling and Testing Costs

The submittal of sampling and testing costs is encouraged for all DMMP projects. While voluntary, this data is vital in tracking trends in costs and will provide dredging proponents with information useful in planning future dredging. The Corps will report on sampling and testing costs in its biennial report. A cost data form can be furnished to the dredging proponent.

11 DREDGING AND DISPOSAL

11.1 Preparing to Dredge

Once all necessary permits are obtained, planning for dredging and disposal can proceed. Dredgers must coordinate as follows:

- At least 14 days prior to the beginning of dredging and disposal work, notify the Corps of Engineers Regulatory Branch, at (206)764-3495. Some permits may require additional notice.
- Submit Dredging and Disposal Quality Control Plan for distribution to agencies, including DMMP representatives, at least 7 days prior to scheduled pre-dredge conference
- Attend pre-dredge conference (see Section 11.3) at least 7 days prior to the start of dredging.

Please note that some permits may have additional requirements.

11.2 Dredging and Disposal Quality Control Plan (QCP)

This document helps contractor, agencies and dredging proponents to all know what to expect during the dredging process. It is submitted at least 7 days prior to the pre-dredge conference and reviewed carefully at the conference. The QCP should accurately describe all the following that are pertinent to the project:

1. Project description (including project and vicinity maps)
2. Schedule of dredging and disposal activities
3. Dredging contractor, personnel and equipment
4. Dredging method and procedures, including:
    a. measures to control or minimize potential water quality impacts
    b. separation of contaminated material from sediments suitable for open-water disposal
    c. decontamination of dredging equipment, if required
    d. plan for removal of floatable and non-floatable debris (see 11.4)
    e. horizontal and vertical controls during dredging (see 11.5)
    f. volume estimate and bulking factors (see 11.5)
5. Disposal method and procedures, including:
    a. accuracy of disposal within the specified surface disposal zone
    b. names, types (e.g. bottom dump) and capacities of barges and dump scows (see 11.5)
    c. identification of tow boats (by name and call letters)
    d. tug operator's name and telephone number
    e. disposal site coordinates and boundary
    f. navigation equipment and positioning protocol for disposal
    g. disposal data recording and reporting
6. Water quality monitoring
7. Hydrographic surveys
8. Telephone numbers of contractors and operators
9. Coordination procedures with the regulatory agencies, including contact information and notification requirements

The dredging and disposal quality control plan must be approved by the DMMP agencies prior to commencement of open-water disposal.

11.3 Pre-Dredge Conference

All regulated projects that are evaluated are required to have a pre-dredge conference with the regulatory agencies prior to the initiation of dredging. The meeting will be coordinated by the Regulatory Branch, US Army Corps of Engineers. Attendees will include, at a minimum, the applicant, the dredging contractor, and representatives from the Corps, DNR, Ecology and EPA. The meeting will be used to review the disposal locations, water quality certification, dredging QCP, DNR site use authorization and any other permit conditions. Completion of the pre-dredge conference will be documented as part of the Regulatory Branch enforcement file.

Modifications to the QCP that are made at the predisposal conference must be incorporated into a final control plan and submitted to the agencies for approval prior to dredging A predisposal dry run may be required by the Corps. At the discretion of the Corps, an enforcement project manager may ride out to the disposal site during the predisposal dry run or any disposal run to verify positioning accuracy.

11.4 Debris Management

In general, debris is not allowed to be disposed at the DMMP open-water sites. This includes all floatable debris and large non-floatable debris such as logs, piling, rip-rap and concrete. Occasionally it may include smaller non-floatable woody debris such as sawdust, bark or wood chips, if these occur in relatively large homogeneous volumes. Large woody debris is most often segregated from sediment using a clamshell bucket during the dredging operation. In cases where a heterogeneous mix of smaller woody debris and sediment exists, which otherwise meets DMMP disposal guidelines, open-water disposal may occur as long as none of the debris measures more than two feet in it longest dimension. Occasionally, a relatively small quantity of rip-rap may be approved for open-water disposal. However, a 2-ft by 2-ft steel mesh must be used during the dredging operation to remove larger pieces of rip-rap. Pre- and post-disposal monitoring may be required at the disposal site, on a case-by-case basis, to verify the absence of problem debris.

11.5 Dredged Material Volume Estimates

Exceedances of permitted dredging volumes may result in fines or work stoppages. In addition to the presampling guidance provided in Section 3.2 the following guidelines should be followed to reduce the potential for permit violations:

1. Up to two feet of additional shoaling is permitted under the DMMP guidelines between the time of sampling and dredging without the need for additional characterization. It is the project proponent's responsibility to identify the need for a volume adjustment as a result of post-sampling shoaling. Volume adjustments should be made prior to issuing the public notice. If significant shoaling occurs after the public notice has been issued, written requests for permit revisions must be made to the permitting agencies as early as possible and before dredging commences.

2. An estimate of the bulking factor, and a justification for its selection, must be included in the QCP.

3. A description of the barge measurement method for volume must be included in the QCP.

4. A description of the procedures to ensure vertical and horizontal dredging control must be included in the QCP. Such procedures prevent over-dredging and may reduce the need for confirmatory surveys in areas where suitable and unsuitable dredged materials are in close proximity.

5. Once dredging has begun, if the dredging proponent or contractor determines that significant dredging has occurred outside the permitted dredging prism, vertical and horizontal control must be re-established immediately and DNR and the Corps contacted as soon as possible.

6. When the daily barge estimates, corrected for bulking, tally to fifty percent of the permitted in-situ volume, the dredging contractor must confer with the Corps, DNR and the dredging proponent. Based on the experience of the dredging contractor during the first half of the project, a correction in the bulking factor will be made if necessary. Dredging progress (based on condition surveys or spatial coverage) will then be compared to the corrected barge measurements (using the revised bulking factor) as a check on the adequacy of the permitted in-situ volume. A decision will be made by the DMMP as to whether permit revisions for an increased volume will be necessary. Details of this coordination procedure must be included in the QCP.

7. As dredging proceeds, the contractor must closely monitor dredging progress and notify the agencies as soon as possible if an exceedance of the permitted volume appears likely. Revision of the permits may be made as necessary. Dredging must stop when the sum of the daily barge estimates, corrected for bulking using the revised bulking factor, reaches the permitted in-situ volume. DNR and the Corps must be notified at this time. If the dredging has not been completed, a determination will be made as to the cause of the impending volume exceedance and permit volumes revised as appropriate.

8. Post-dredge surveys will be reviewed by the agencies, as necessary, to ensure that the dredging plan has been followed.

11.6 Post Dredge Surface Guidelines

As part of each sediment characterization, the DMMP requires the collection and archiving of a sample (Z-sample) of the top one-foot of material extending beyond the proposed project dredging depth (Section 4-10). This sample reflects the new surface sediment quality that would be exposed following dredging (PSDDA, 1988, 1989).

Z-samples will be collected and archived for every core sampling location for all projects in areas ranked from low to high, unless there is recent sediment quality data (e.g., within recency guideline specifications) to verify that contaminants are restricted to the surficial sediment layer (< 4 feet, or less than the depth cut plus overdredge proposed for dredging) of the sediments proposed for dredging.

If a dredged material management unit (DMMU) is found to be contaminated (e.g., unsuitable for unconfined-open-water disposal), and the underlying DMMU either is contaminated also or has not been adequately characterized, then archived Z-samples must be analyzed to verify the sediment quality of the Z-horizon.

Z-sample analyses will initially consist of sediment conventional and chemical analyses. If the results of these analyses indicate exceedances of SMS-SQS or CSL chemicals of concern within the Z-sample horizon, the dredging applicant may be required to remobilize and resample those given Z-sample locations in order to perform required biological testing (bioassays and/or bioaccumulation testing). The evaluation standard for interpreting the Z-sample sediment quality data will be the Sediment Management Standards "Sediment Quality Standard" (Chapter 173-204 WAC).

The post-dredge sediment surface (top 10 cm) may be subject to sediment quality evaluation at the discretion of the DMMP and/or SMS programs for any project where either overlying surface or subsurface DMMUs were found to be unsuitable for unconfined open-water disposal.

11.7 Beneficial Uses Guidelines

"Beneficial use" is the placement or use of dredged material for some productive purpose. While the term "beneficial" indicates some "benefit" is gained by a particular use, the term has come to generally mean any "reuse" of dredged material. As part of overall sediment management in Washington, the regulatory agencies responsible for sediment management support the productive reuse of dredged material.

To ensure a beneficial uses project's viability, a chemical and physical evaluation of the proposed dredged material is required. Applicants considering potential beneficial uses projects should bring these projects to the attention of the DMMP agencies and other resource agencies, including but not limited to DNR's Sediment Quality Unit and Beneficial Use Workgroup (BUW), early in the evaluation process. Depending on the adequacy and recency of project testing information (including any DMMP testing), and the specifics of the beneficial uses project, some additional testing may or may not be required. The agencies will continue to make every effort to adequately coordinate these projects on a case by case basis.

11.7.1 Pre-application for Beneficial Use Material

When the DNR owns dredged material desired for reuse, the project proponent should contact the DNR and the Corps early in the project planning process. In this pre-application process, DNR and/or Corps agency representatives will present potential beneficial use projects at the DMMP monthly forum. The project proponent will be asked to provide either a brief written project description, or provide a presentation of the proposed project. In some dredging years conflicts among potential users of dredged material may arise. In these situations, an interagency subgroup and project proponents will likely have separate meetings to discuss potential projects, resolve conflicts and determine priority for use of the material.

When DNR is not the owner of the material, a project proponent should approach the material owner and negotiate for its use. If a beneficial use project is agreed upon and will be brought forward for permitting, the project should be coordinated via the Corps at the interagency DMMP monthly forum.

11.7.2 Sediment Characterization of Beneficial Use Material

Sediment characterization is required in order to determine whether a particular dredged material is suitable for a proposed reuse. Characterization may include determining physical characteristics (such as grain size) and chemical characteristics via sampling and testing. The amount of information already known about an area and its dredged material, as well as the proposed reuse, will dictate the amount and types of characterization required.

Unconfined aquatic projects (such as beach nourishment, habitat restoration, and in-situ capping) are projects where dredged material may come directly into contact with the surrounding aquatic environment. For these projects, results of chemical testing on dredged material is compared to existing numeric and narrative standards of the Washington State Sediment Management Standards (SMS) in Chapters 173-204-320 through 173-204-340 WAC. For most projects, detected chemicals of concern must fall below SQS (Sediment Quality Standards) levels and any bioassays must pass SQS criteria. Material that has levels of chemicals greater than SQS but lower than CSL (Cleanup Screening Level) may be appropriate for beneficial uses on a case-by –case basis due to site specific considerations.

11.8 Dredging and Disposal Closures

11.8.1 WDFW Closures

The Washington Department of Fish and Wildlife (WDFW) establishes closure periods in various parts of Puget Sound to protect aquatic resources. In-water work, including dredging and disposal, cannot be conducted during closed periods. WDFW Habitat Managers should be contacted directly to determine the closure periods for dredging and disposal of specific project.

11.8.2 Native American Fisheries

The following standard site use conditions will be specified by the Corps and DNR as part of the Federal/State permitting processes:

1. during periods of tribal fishing in the disposal site areas, disposal will only occur during daylight hours; and
2. during daylight hours, "navigation rules of the road" will apply to the dredger in the event Indian treaty fishing is occurring at the disposal site.

The dredger's permit will state that disposal is to occur when there is no treaty fishing occurring at the disposal site. The permittee must coordinate any nighttime disposal with the Enforcement Section, Regulatory Branch. Approval must be received from the District Engineer prior to conducting nighttime disposal.

11.8.3 Endangered Species Act

Under the Endangered Species Act (ESA), all in-water projects are evaluated for impacts to listed species. The Seattle District Corps of Engineers undergoes formal consultation under Section 7 of the ESA to address the potential use effects of the DMMP disposal sites on federally listed species. Current programmatic Biological Evaluations and concurrence letters are posted on the DMMP website. Every five years—or when a new species is listed—the Corps updates ESA coordination and documentation. Disposal windows or restrictions may be modified as part of that coordination.

11.9 Disposal Site Information

Tables 11-1 and 11-2 contain descriptive information about the DMMP disposal sites. Figure 11-1 is a schematic delineating the target area and disposal zone within a generic non-dispersive disposal site. In the non-dispersive sites the disposal barges should open within the target area to ensure dredged material is released within the disposal zone. The zone allows for some difficulties in maneuvering. For dispersive sites, the target area and the disposal zone are one and the same. Figures 11-2 through 11-9 show the disposal sites and are suitable drawings for public notices.

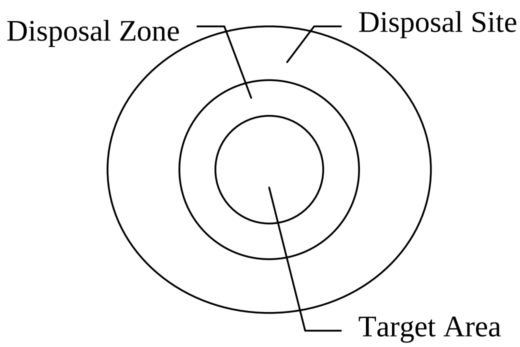


Figure 11-1. Disposal Zone vs. Target Area

11.10 Disposal Positioning

11.10.1 Coast Guard Notification and VTS Monitoring

The United States Coast Guard (USCG) must be notified 14 days prior to commencing dredging operations. Notification should be sent to Commander (DPW), Thirteenth Coast Guard District, 915 Second Avenue, Seattle, Washington 98174-1067 or faxed to (206) 220-7265 so that the information can be issued in the Local Notice to Mariners. Dredging operations north of a line between Bush Point on Whidbey Island and Nodule Point on Marrowstone Island must monitor VHF-FM Channels 13 and 5A. Dredging operations south of this line must monitor VHF-FM Channels 13 and 14. The USCG Puget Sound Vessel Traffic Service (VTS) also known as "Seattle Traffic" must be contacted by radio prior to each disposal for positioning and verification of location within the surface target disposal zone. Disposal may not commence until verification is received from the USCG. Information required by the USCG must be provided for recording of the dump.

11.10.2 Dump-Site Position Recording Equipment

For some projects, silent-inspector equipment that records disposal events is used. This equipment utilizes differential global positioning and a tracking system to provide a record of disposal events. If required, the permittee and the disposal contractor will be responsible for installation of the equipment on the tug and barges, protection and security of such equipment, and ensuring that equipment is operational.

Table 11-1. Puget Sound Disposal Site Descriptions

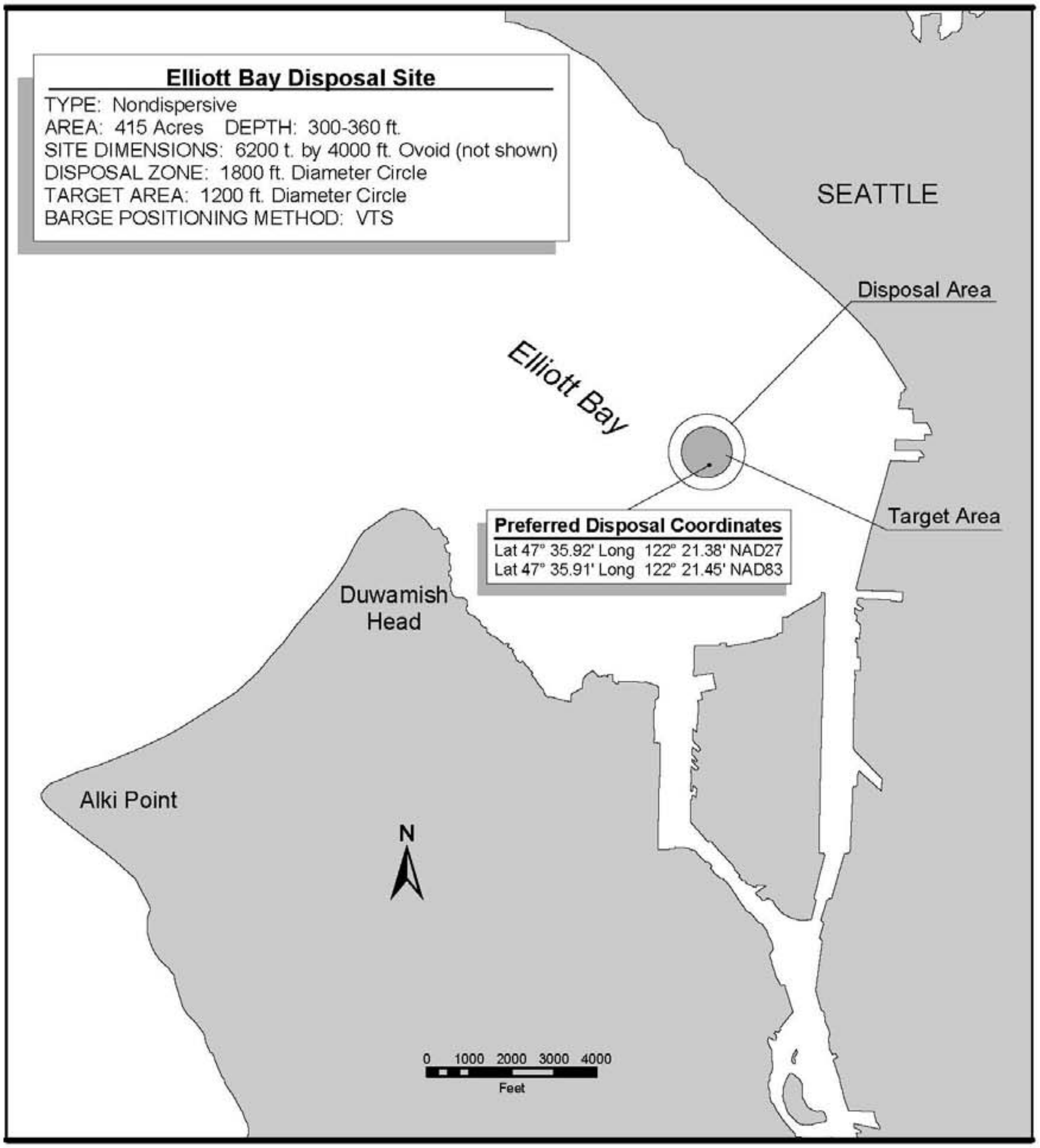
Site	Area (acres)	Depth (ft)	Disposal Zone diameter (ft)	Target Area diameter (ft)	Disposal Site Dimensions (ft)	Site Coordinates (NAD83: Lat/Long)	Positioning VTS/ DGPS
Anderson/Ketron Island (nondispersive site)	318	442	1,800 (circle)	1,200 (circle)	4,400 x 3,600 (ellipsoid)	Lat: 47° 09.42’ Long: 122° 39.47’	DGPS
Bellingham Bay (nondispersive site)	260	96	1,800 (circle)	1,200 (circle)	3,800 x 3,800 (circular)	Lat: 48° 42.82’ Long: 122° 33.11’	DGPS
Commencement Bay (nondispersive site)	310	540-560	1,800 (circle)	1,200 (circle)	4,600 x 3,800 (ellipsoid)	Lat: 47° 18.21’ Long: 122° 27.91’	VTS
Elliott Bay (nondispersive site)	415	300-360	1,800 (circle)	1,200 (circle)	6,200 x 4,000 (Tear drop shape)	Lat: 47° 35.91’ Long: 122° 21.45’	VTS
Port Gardner (nondispersive site)	318	420	1,800 (circle)	1,200 (circle)	4,200 x 4,200 (circular)	Lat: 47° 58.85’ Long: 122° 16.74’	DGPS
Port Angeles (dispersive site)	884	435	3,000 (circle)	none	7,000 x 7,000 (circular)	Lat: 48° 11.67’ Long: 123° 24.94’	VTS
Port Townsend (dispersive site)	884	361	3,000 (circle)	none	7,000 x 7,000 (circular)	Lat: 48° 13.61’ Long: 122° 59.03’	VTS
Rosario Strait (dispersive site)	650	97-142	3,000 (circle)	none	6,000 x 6,000 (circular)	Lat: 48° 30.87’ Long: 122° 43.56’	VTS

VTS = USCG Vessel Traffic Service; **DGPS** = Differential Global Positioning System

Table 11-2. Grays Harbor and Willapa Bay Disposal Site Descriptions

<table>
<tr><th>Area</th><th>Site (Dispersive)</th><th>Area (acres)</th><th>Depth (ft)</th><th>Disposal Zone</th><th>Disposal Site Dimensions (ft)</th><th colspan="2">Site Coordinates (NAD83) (Latitude/Longitude)</th><th>Positioning VTS/ DGPS</th></tr>
<tr><td rowspan="4">WILLAPA BAY</td><td>8.0 Mile Ocean Site</td><td>58.4</td><td>140-160 ft</td><td>1,800 ft diameter circle</td><td>1,800 ft diameter circle</td><td colspan="2">Site presently inactive</td><td>DGPS</td></tr>
<tr><td rowspan="2">Cape Shoalwater (Estuarine)</td><td rowspan="2">178.9</td><td rowspan="2">5-19 ft</td><td rowspan="2">USCG buoy G “13”</td><td rowspan="2">3,000 x 5,196 x 6,000 ft. triangle</td><td>46°42’05.34</td><td>124°01’21.50</td><td rowspan="2">USCG Buoy G13</td></tr>
<tr><td colspan="2">(coordinates for USCG buoy G “13”)</td></tr>
<tr><td>Goose Point (Estuarine)</td><td>58.4</td><td>30–48 ft</td><td>1,800 ft diameter circle</td><td>1,800 ft diameter circle</td><td>46°39’27.60</td><td>123°59’46.04</td><td>DGPS</td></tr>
</table>

Area	Site (Dispersive)	Area (acres)	Depth (ft)	Disposal Zone	Disposal Site Dimensions (ft)	Site Coordinates (NAD83) (Latitude/Longitude)		Positioning VTS/ DGPS
GRAYS HARBOR	Point Chehalis (Estuarine)	229.6	>50 ft	Within rectangle, partitioned into 3 cells (2,000 x 5,000 ft)	2,000 x 5,000 ft. (rectangle)	46°55’00.51 46°55’04.49 46°55’10.46 46°55’17.09 46°54’41.91 46°54’45.90 46°54’51.87 46°54’58.50	124°08’06.94 124°07’50.66 124° 07’26.23 124°06’59.10 124°07’57.26 124°07’40.98 124° 07’16.55 124°06’49.42	DGPS
						(Corners of 3 cells within rectangle)		
	South Jetty (Estuarine)	55.1	>50 ft	Within rectangle (800 X 3,000 ft)	800 X 3,000 ft. (rectangle)	46°54’34.82 46°54’32.06 46°54’26.96 46°54’24.20	124°09’30.67 124°08’47.65 124° 09’31.74 124°08’48.72	DGPS
						(4 corners of rectangle)		
	Half Moon Bay (beneficial use)	2.9 (1A) 52.6 (1) 37.3 (2)	15.5 ft (1A) 10-15 ft (1) 11-26 ft (2)	Variable within each subarea, see Figure	Variable within each subarea (Area 1A, Area 1, Area 2), see Figure	Variable within each subarea		DGPS
	South Beach (beneficial use)	1,223.4	17-46 ft	Within Quadrilateral (6,400 x 7,700 ft x 6,200 x 9,500 ft)	6,400 x 7,700 ft x 6,200 x 9,500 ft (Quadrilateral)	46°54’23.23 46°54’29.23 46°52’51.62 46°53’05.60	124°10’14.39 124°08’42.22 124° 09’41.30 124°08’14.60	DGPS
						(4 corners of Quadrilateral)		
	3.9-Mile SW Ocean Site	58.4 (circle) 1,056.6 (paralle-ogram.)	>120 ft	1,800 ft diameter circle within parallelogram	6,000 x 8,000 ft. (parallelogram)	46°51’55.68	124°14’40.53	DGPS
						(center of circle)		
						46°51’56.19 46°52’57.51 46°52’08.67 46°51’07.35	124°15’03.91 124°13’51.34 124° 13’02.50 124°14’15.06	
						(4 corners of parallelogram)		
						(center of circle)		



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:

(1)

(2)

IN

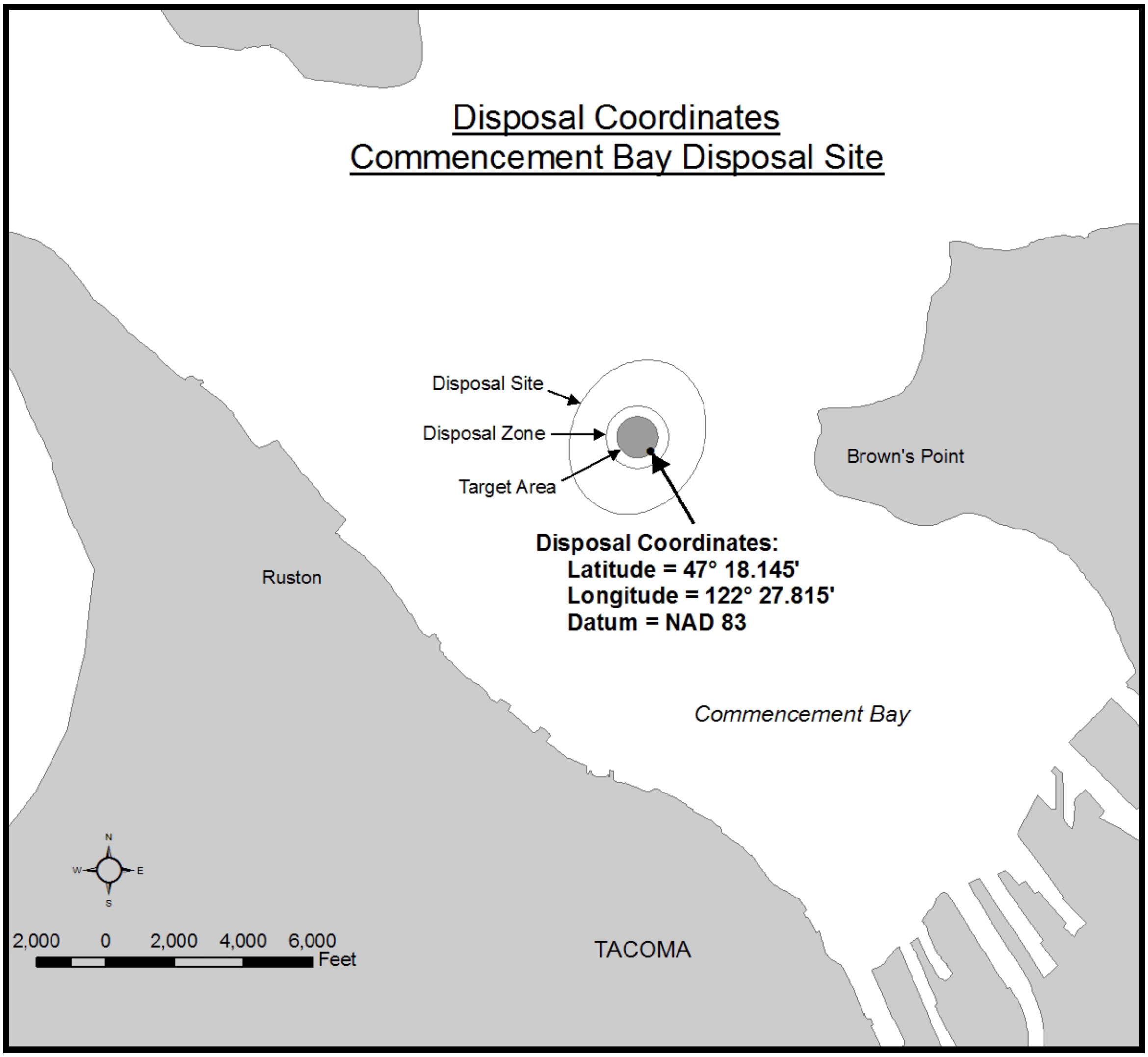
AT

COUNTY OF STATE

APPLICATION BY

SHEET OF DATE

Figure 11-2. Elliott Bay Disposal Site



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:
①
②

IN
AT
COUNTY OF **STATE**
APPLICATION BY

SHEET **OF** **DATE**

Figure 11-3. Commencement Bay Disposal Site

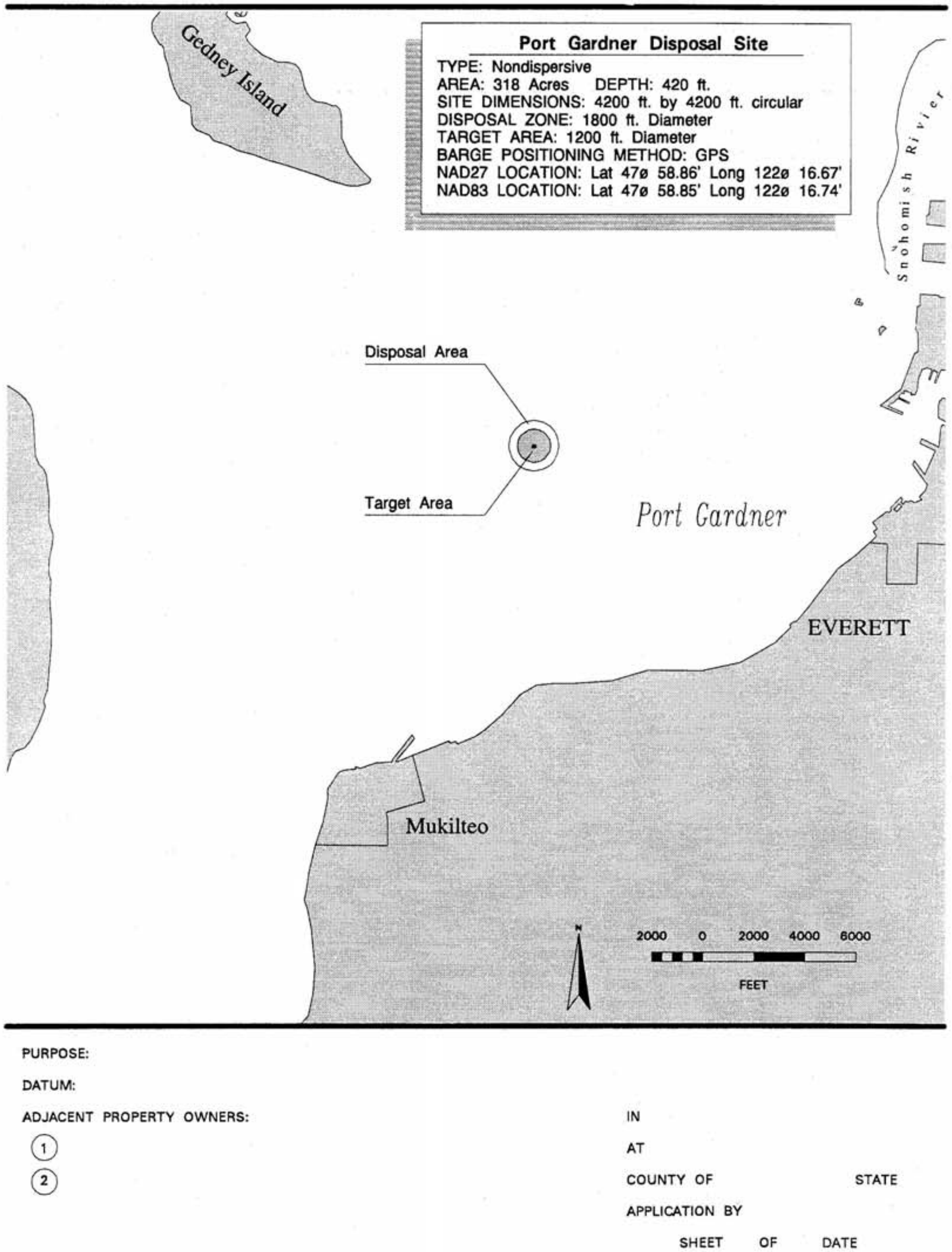
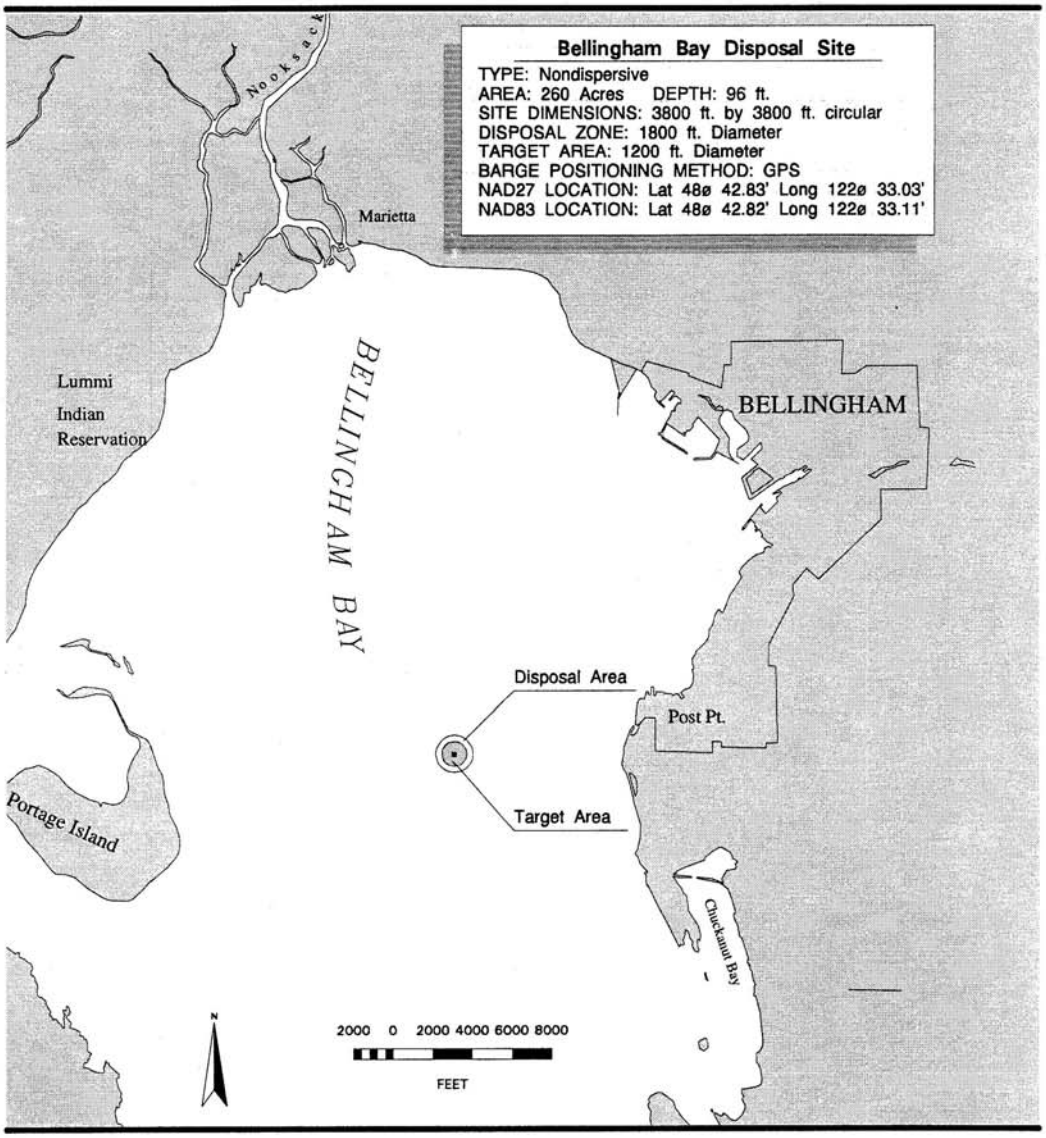


Figure 11-4. Port Gardner Disposal Site



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:

(1)

(2)

IN

AT

COUNTY OF STATE

APPLICATION BY

SHEET OF DATE

Figure 11-5. Bellingham Bay Disposal Site

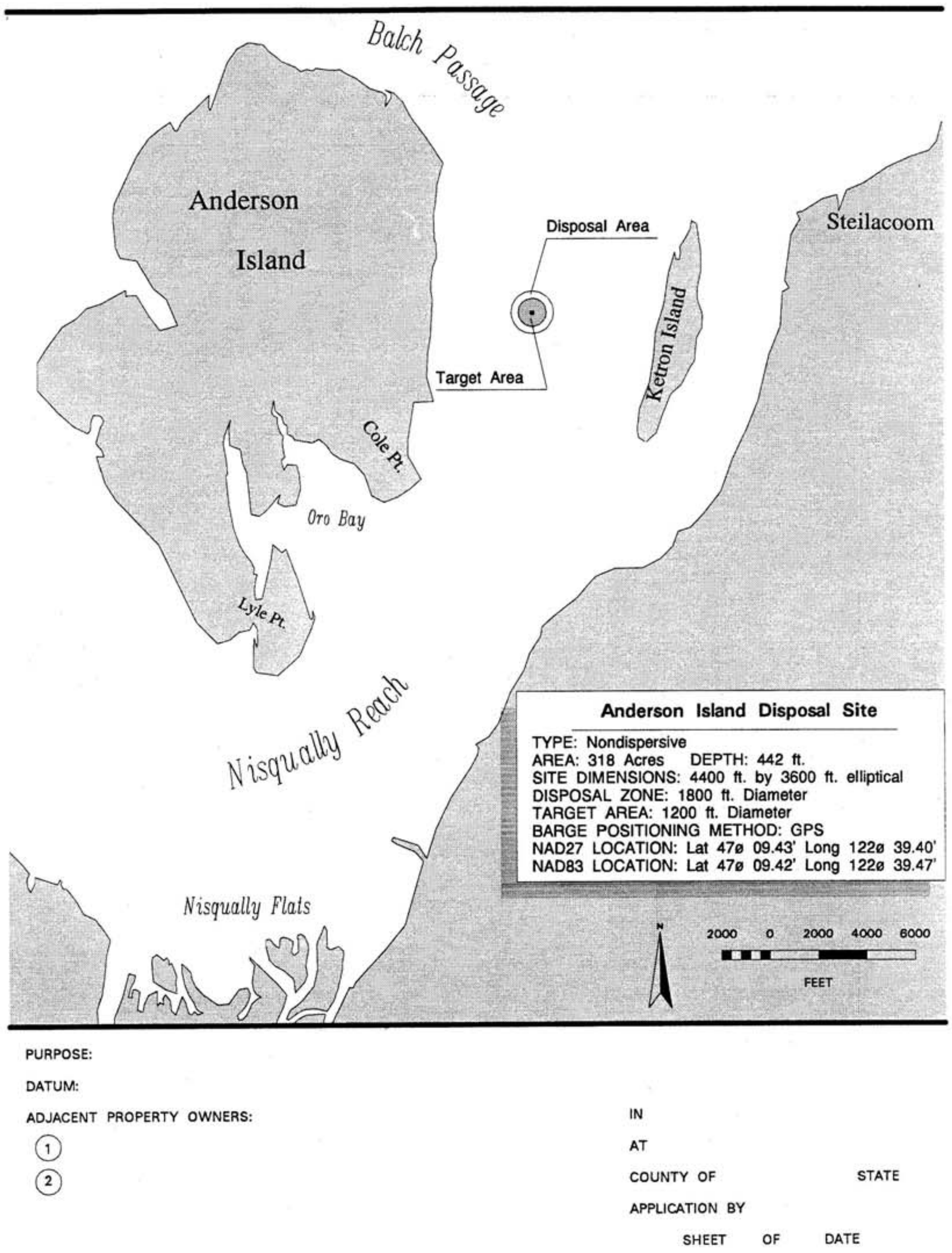
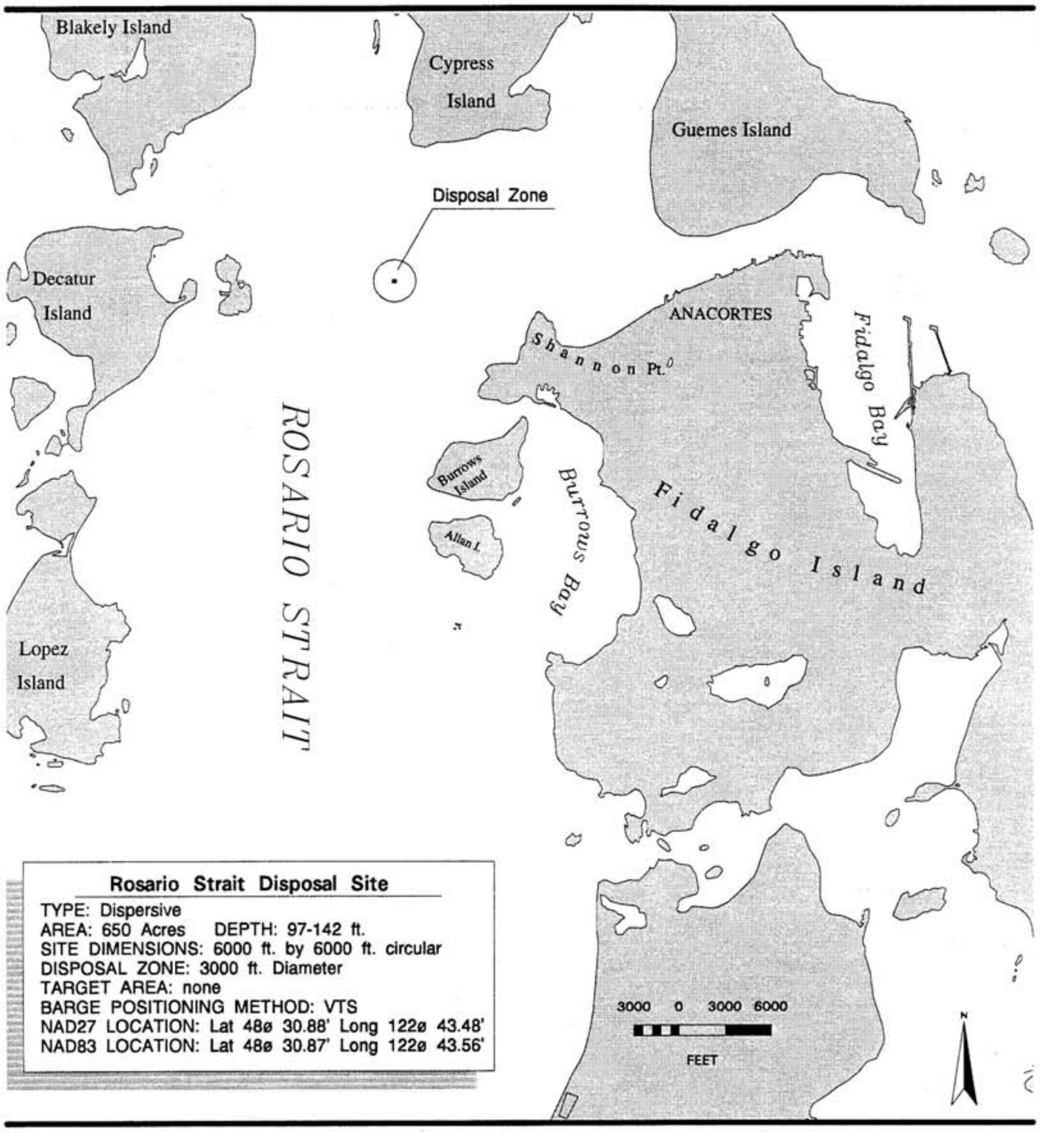


Figure 11-6. Anderson-Ketron Disposal Site



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:

(1)

(2)

IN

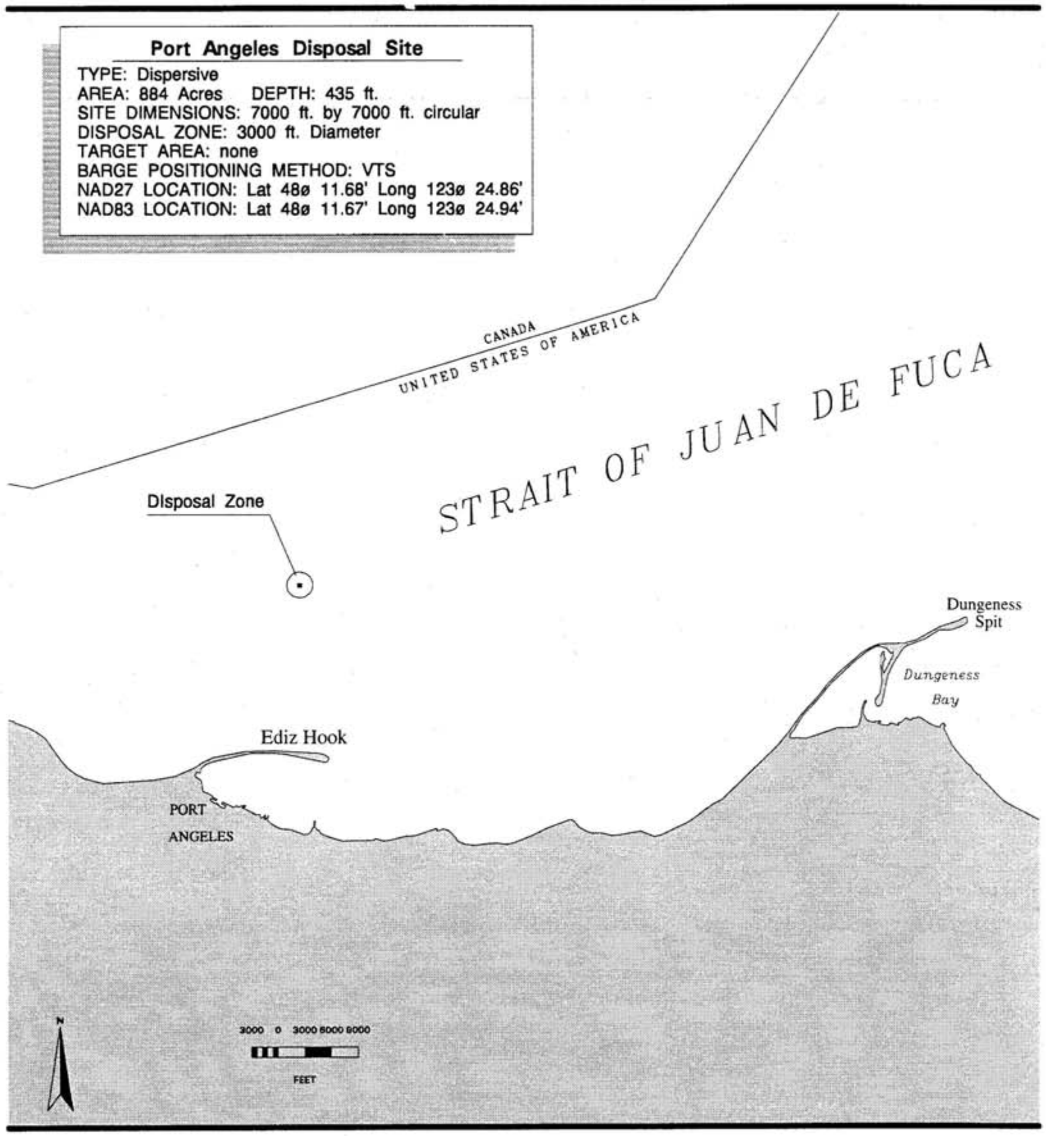
AT

COUNTY OF STATE

APPLICATION BY

SHEET OF DATE

Figure 11-7. Rosario Strait Disposal Site



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:

(1)

(2)

IN

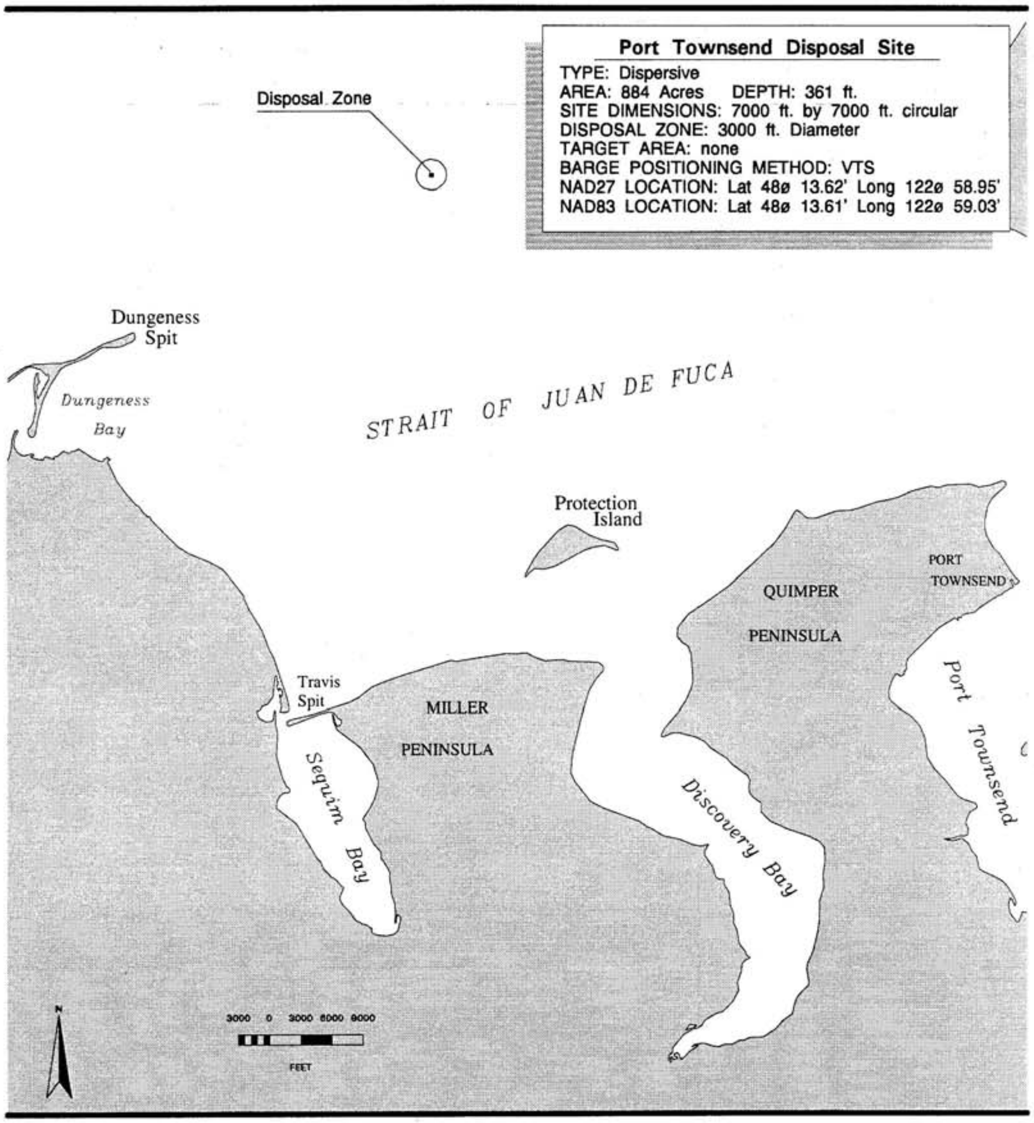
AT

COUNTY OF STATE

APPLICATION BY

SHEET OF DATE

Figure 11-8. Port Angeles Disposal Site



PURPOSE:

DATUM:

ADJACENT PROPERTY OWNERS:

(1)

(2)

IN

AT

COUNTY OF STATE

APPLICATION BY

SHEET OF DATE

Figure 11-9. Port Townsend Disposal Site

12 REFERENCES

Ankley, G.T., M.K. Schubauer-Berigan, and R.O. Hoke. 1992. Use of toxicity identification techniques to identify dredged material disposal options: a proposed approach. Environmental Management, 16, 1-6.

Boese, B.L., and D.T. Lee II. 1992. Synthesis of methods to predict bioaccumulation of sediment pollutants. U.S. Environmental Protection Agency, Environmental Research Laboratory - Narragansett, ERL - N, No. N232.

Dewitt, T.H., G.R. Ditsworth, and R.C. Schwartz. 1988. Effects of natural sediment features on survival of the phoxocepalid amphipod, *Rhepoxynius abronius*. Mar. Env. Res., 25, 99-124.

Dillon, T.M., D.W. Moore and A.B. Gibson. 1993. Development of a chronic sublethal bioassay for evaluating contaminated sediment with the marine polychaete worm *Nereis (Neanthes) arenaceodentata*. Environmental Toxicology and Chemistry. Vol. :589-605pp.

DMMP. 1995. Dredged Material Evaluation Procedures and Disposal Site Management Manual: Grays Harbor and Willapa Bay, Washington. US Army Corps of Engineers-Seattle District; US Environmental Protection Agency; Washington State Department of Ecology, and Washington State Department of Natural Resources. 125 pp.

DMMP. 1999. DMMP Interim total PCB Human Health TTL re-evaluation. December 1999

DMMP. 2001. Reporting ammonia LC50 data for larval and amphipod bioassays. DMMP clarification paper. Prepared by Lauran Cole Warner (US Army Corps of Engineers) for the DMMP agencies, Seattle, WA.

DMMP. 2007a. Polychlorinated Dioxins and Furans (PCDD/F): Clarification of procedures for acquiring sediment data. Prepared by Sandy Lemlich (U.S. Army Corps of Engineers); Erika Hoffman (U.S. Environmental Protection Agency); John Wakeman (U.S. Army Corps of Engineers).

DMMP. 2007 b.. Supplemental information on Polychlorinated Dioxins and Furans (PCDD/F) for use in preparing a Quality Assurance Project Plan (QAPP).

EPA. 2007. Identifying, Planning & Financing Beneficial Use Projects Using Dredged Material. October 2007.

EPA/USACE. 1994. Evaluation of dredged material proposed for discharge in inland and near coastal waters - inland testing manual. U.S. EPA and U.S. ACOE

Floyd & Snider and Pentec. 1997. Review of the significance of log handling and wood debris in the marine environment. Draft Report. Prepared for the Hylebos Wood Debris Group (Louisiana-Pacific Corp., Manke Lumber Company, and Weyerhaeuser Company), Tacoma, WA.

Fox, D.F. 1993. Reference sediment performance analysis. PSDDA Fifth Annual Review Meeting Minutes, Appendix A, overheads 9a-9aa.

IARC (Int'l Agency for Research on Cancer) 1997. Polychlorinated Dibenzo-para-dioxins and polychlorinated Dibenzofurans. IARC Monogr Eval Carcinog Risks Hum 69.

Krone, C.A., D.W. Brown, D.G. Burrows, S.L. Chan, and U. Varanasi. 1989. A method for analysis of butyltin species in measurement of butyltins in sediment and English sole livers from Puget Sound. Marine Environmental Research 27:1-18.

Lee, H., B.L. Boese, J. Pelliter, M. Winsor, D.T. Specht, and R.C. Randall. 1989. Guidance manual: Bedded sediment tests. EPA-600/x-89-302, U.S. Environmental Protection Agency, Pacific Ecosystems Branch, Bioaccumulation Team, Newport, OR.

Michelsen, T., T.C. Shaw, and S. Stirling. 1996. Testing, reporting and evaluation of tributyltin data in PSDDA and SMS programs. Final PSDDA Issue Paper/SMS Technical Information Memorandum, October 1996.

Michelsen, T. and T. C. Shaw, 1996, Statistical Evaluation of Bioassay Results, In: Sediment Management Annual Review Meeting Minutes, PSDDA/SMS agencies.

Northwestern Aquatic Sciences, SOP #6288. SOP for Purging Ammonia From Amphipod Sediments.

Plumb, Jr., R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Prepared for U.S. Environmental Protection Agency and U.S. Army Corps of Engineers.

PSDDA. 1988. Puget Sound dredged disposal analysis: Evaluation procedures technical appendix, Phase I. (EPTA) U.S. Army Corps of Engineers - Seattle District, U.S. Environmental Protection Agency - Region 10, Washington State Department of Natural Resources, Washington State Department of Ecology.

PSDDA. 1989. Puget Sound dredged disposal analysis: Management plan report, unconfined open-water disposal of dredged material, Phase II. U.S. Army Corps of Engineers - Seattle District, U.S. EPA - Region 10, Washington State DNR, Washington State Department of Ecology.

PTI Environmental Services. 1991. Reference Area Performance Standards for Puget Sound. Prepared for EPA Region 10. PTI Environmental Services, Bellevue, WA

Puget Sound Estuary Program (PSEP). 1986. Recommended protocols for measuring conventional sediment variables in Puget Sound, In: Puget Sound Protocols and Guidelines, Puget Sound Estuary Program.

Puget Sound Estuary Program (PSEP). 1997a. Recommended guidelines for sampling marine sediment, water column, and tissue in Puget Sound. U.S. Environmental Protection Agency, Region 10, Seattle, WA and Puget Sound Water Quality Authority, Olympia, WA.

Puget Sound Estuary Program (PSEP). 1997b. Recommended Guidelines for Measuring Organic Compounds in Puget Sound Water, Sediment and Tissue Samples

PSEP. 1995a. Recommended guidelines for conducting laboratory bioassays on Puget Sound sediments, In: Puget Sound Protocols and Guidelines, Puget Sound Estuary Program.

Rubenstein, N.I.; E. Lores, and N. Gregory. 1983. Accumulation of PCBs, mercury, and cadmium by *Nereis virens*, *Mercenaria mercenaria*, and *Palaemonetes pugio* from contaminated harbor sediments. Long-term Effects of Dredging Operations Program, Technical Report D-83-4, U.S. Environmental Protection Agency, Gulf Breeze, FL.

SAIC. 1993. Science Applications International Corporation (SAIC), 1993, “Grays Harbor and Willapa Bay Dredged Material Management Study, Expanded Reference Area Sediments.” Contact No. 010098-04-1344. SAIC Environmental Sciences Division, Bothell, Washington.

SAIC. 2001. Final *Eohaustorius estuaries* Clay Sensitivity Study. Prepared for Engineering Field Activity, Northwest, Naval Facilities Engineering Command, Poulsbo, WA by Science Application International Corporation, Bothell, WA.SMS. 1991. Sediment Management Standards, Chapter 173-204 WAC, Washington State Department of Ecology, Olympia, WA.

Unger, M.A., W.G. McIntyre, K. Greaves, and R.J. Huggett, 1986. GC Determination of butyltins in natural waters by flame photometric detection of hexyl derivatives with mass spectrometric confirmation. Chemosphere 15:461.

USACE. 2006. Memorandum for Commanders, Major Subordinate Commands, “Assuring the Adequacy of Environmental Documentation for Construction and Maintenance Dredging of Federal Navigation Projects.”

US EPA. 1994. Methods for assessing the toxicity of sediment-associated contaminants with estuarine and marine amphipods. EPA/600/R-94/025. Environmental Protection Agency Office of Research and Development, June 1994. Pp. 80-82 and errata.

Van den Berg, et al. 2006. The 2005 World Health Organization Re-evaluation of Human and Mammalian Toxic Equivalency Factors for Dioxins and Dioxin-like Compounds. Toxicol Sci, 93(2), 223–241.

Windom, H.L., and D.R. Kendall. 1979. *Accumulation and transformation of mercury in coastal and marine biota,* In: The Biogeochemistry of Mercury in the Environment, ed. by Nriagu, Elsevier/North-Holland Biomedical Press, 303-323.

Young, D. 1988. Report on the assessment and application of pollutant biomagnification potential in near coastal waters. EPA Report 600X-88/295, U.S. Environmental Protection Agency, ERL-Narragansett N-065.