Multiuser Confined Disposal Sites Program Study

ENVIRONMENTAL AND PUBLIC HEALTH ISSUES

FINAL

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TABLE OF CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

INTRODUCTION

Dredging and disposal of dredged material has been a longstanding practice in Puget Sound waters. Measurable levels of some chemicals of concern are found in all Puget Sound sediments. Contaminated sediments that exceed the guidelines established through the Puget Sound Dredged Disposal Analysis (PSDDA) studies for unconfined disposal may need to be disposed at a confined site.

Multiuser sites in three alternative environmental settings (aquatic, nearshore, upland) are being considered for the confined disposal of contaminated sediments. The environmental and public health issues associated with the disposal of contaminated sediments are, in general, similar for multiuser sites as for sites established on a project by project basis. The key difference of a multiuser site program is that operating larger sites over a long period (e.g. 20 years) minimizes the number of areas disrupted by site construction and operation. On the other hand, the potential impacts on areas where multiuser sites are located could be greater in magnitude than at single project sites. The environmental and public health issues associated with multiuser sites are identified in this Issue Paper. The three types of sites are treated as generic sites. A discussion about potential impacts can only occur when analyzing a specific site.

Mitigation measures can be implemented to prevent or minimize impacts, although some release of contaminants may be technically unavoidable. Siting is a key mitigation measure because sites should be located in areas where the impact of possible contaminant release on environmental resources and human health is minimized. Additional mitigation measures include application of technology to contain the dredged material, operations procedures, and regulatory controls. Mitigation measures can be applied during dredging, transport, and site operations and during the site closure and post-closure periods.

DREDGING AND TRANSPORT OF CONTAMINATED SEDIMENTS

Contaminants within the sediments can be released to the environment during dredging and transport activities. With the exception of the additional mode of truck transport associated with upland sites, the potential environmental and public health impacts that occur during dredging and transport would be similar regardless of the type of disposal site selected.

The principal impact of dredging is the loss or disruption of benthos and habitat in the dredge area. Other potential impacts of dredging are the exposure of benthic biota to contaminated sediments that may escape and settle on the floor of Puget Sound, short-term exposure of water column biota to released contaminants, and an increase in toxic contamination in the sea surface microlayer due to released contaminants. The dredging method (hydraulic or mechanical dredge) can influence contaminant losses at both the dredging and disposal sites.

The transport of dredged material could result in leakage and loss of contaminated sediments. The impacts associated with dredging could also occur with transport, but probably to a lesser extent. Potential additional impacts are volatilization, or escape of contaminants to the air, which can occur during barge or truck transport. Barge workers and nearby animals could inhale the toxic contaminants. In transporting dredged material from a shoreline transfer point to an upland disposal facility, soluble and particulate contaminants could leak from trucks onto roadways and result in the exposure of upland biota to toxic contaminants.

CONFINED AQUATIC DISPOSAL

At a confined aquatic disposal site, contaminated sediments would be dredged from multiple locations within Puget Sound and transported by barge for disposal at a different aquatic location. The key impact associated with the construction and operations of an aquatic site is the burial and smothering of benthic biota during discharge of the dredged material and any needed site construction. Additional potential impacts are: 1) effects on water column biota from turbidity; 2) exposure of benthic and water column biota to toxic contaminants and bioaccumulation of toxics in the food chain; 3) loss of aesthetics to boaters due to a localized turbidity plume, and; 4) exposure of humans to contaminated fish and shellfish through consumption.

Two key mitigation measures that could be implemented to minimize impacts at aquatic sites are capping the site and siting criteria. The placement of a cap of clean material over the dredged material upon completion of an individual project or group of projects (i.e., serial capping) isolates the contaminants from the environment and slows the migration of contaminants. Disposal site selection is critical since, although other impacts can be mitigated through technology or operations, the impact of burying benthic biota can only be mitigated by locating sites in non-critical habitat areas. However, benthic biota are expected to repopulate the site after placement of the cap. Siting is also important in minimizing construction requirements and the loss of contaminants during disposal and prior to and after capping, and in maintaining cap integrity. The impacts of contaminants that may be released and move off site even after mitigation measures are implemented can be monitored. Changes to the disposal requirements can be made if monitoring results indicate a problem.

NEARSHORE DISPOSAL

Nearshore disposal sites are confined disposal facilities located adjacent to land and within the area influenced by normal tidal fluctuations. The most significant impact of developing a nearshore site would be the destruction of marine and intertidal habitat. Other impacts could include: 1) exposure of marine and intertidal species to contaminants that may be released; and 2) exposure of humans to chemicals of concern through direct contact, inhalation of organic vapors or wind-blown dust, and consumption of contaminated fish and shellfish.

Environmental and public health impacts can be mitigated through various methods. The siting process can be instrumental in preventing the removal of habitat by selecting a site with no critical habitat. Habitat loss can also be mitigated by creating replacement habitat in another shoreline area. Detention ponds, infiltration basins, and run-on and run-off controls can minimize soil erosion and turbidity in marine waters from suspended solids. Interim cover of the diked cells can be used to control the escape of contaminants to the air and release of contaminants to surface water runoff. Placing a final cap on the site minimizes toxicity to land-based biota through biological uptake and creates the potential for beneficial use of the site. Monitoring for contaminant losses through operations and post-closure can be required to determine impacts and a contingency plan can be implemented in the event a problem is detected.

UPLAND DISPOSAL

Upland disposal involves the placement of dredged material in an environment that is not affected by tidal waters, although a site could be influenced by surface waters. The major consideration in developing an upland disposal site would be the protection of ground water resources and potable water supplies. Depending on flow velocities and direction, hydraulic gradients, and the permeability and porosity of subsurface strata, soluble contaminants can be transported by ground water. Recharge areas, such as wetlands, provide an interface between surface and ground waters and a possible pathway for transporting contaminants. Contaminants contained in surface runoff can be carried into streams and reservoirs, thereby entering drinking water supplies. Other impacts of developing an upland site could include: 1) effects of soil erosion and runoff on water quality, water column biota, and fisheries resources in any nearby surface waters; 2) exposure of plants to contaminated sediments and bioaccumulation in the food chain; 3) removal of vegetation and habitat, and; 4) human exposure to chemicals of concern through direct contact, inhalation of organic vapors or wind-blown dust, and drinking contaminated ground water.

Similar to confined aquatic and nearshore disposal, site selection is a critical mitigation measure. The impact of removing habitat can only be mitigated by locating sites in areas that contain no critical or sensitive habitats. The Siting process is also important in protecting ground and surface water resources. Design requirements of the disposal facility are also critical in preventing impacts. Design requirements can incorporate a double liner system, a leachate collection and treatment system, and stormwater runon and runoff controls. Interim cover consisting of clean material can be placed upon completion of each dredging project to minimize the time the contaminated sediments are exposed to the actions of wind and precipitation. A final cover could be placed once a cell reaches capacity. A monitoring program could be designed to track the effects of any contaminant losses both during operations and the post-closure period. Changes to the disposal operations can be made if the monitoring indicates any negative results. A contingency plan could be developed and implemented to correct any adverse effects that are detected through monitoring in the event of design or structural failure during the post-closure period.

COMPARISON OF ENVIRONMENTAL AND PUBLIC HEALTH ISSUES AMONG GENERIC SITES

The environmental and public health issues associated with disposal of contaminated sediments differ among the three types of disposal sites. The major differences pertain to receptors in the vicinity of the site, the number of pathways, and the degree of potential of contaminant release. Aquatic sites have the fewest number of pathways and receptors to affect, the lowest potential for release of contaminants. However, aquatic sites are more difficult to monitor and have limited mitigation options and remedial alternatives in the event of failure. Upland sites have the highest number of pathways for release, but have the most mitigation options and remedial alternatives in the event of failure. The siting process for upland disposal can be very effective in avoiding habitats of concern, and surface and ground water. Nearshore sites fall between aquatic and upland sites with respect to pathways, receptors, and mitigation. Sensitive habitat areas are more difficult to avoid and, therefore the impact of habitat loss can be more significant than for either aquatic or upland sites.

INTRODUCTION

The 1987 and 1989 Puget Sound Water Quality Management Plan contains several requirements for the Contaminated Sediments and Dredging Program implemented by the Washington Department of Ecology (Ecology). One of these requirements, the Multiuser Confined Disposal Sites Program, is a study to evaluate the utility and viability of establishing a system of multiuser confined disposal sites for contaminated sediments dredged from Puget Sound. Results of the study will be used by Ecology as the basis for a recommendation to the Puget Sound Water Quality for the establishment of a multiuser site program.

Over the past several years, various criteria have been established by regulatory agencies for determining the degree of contamination in sediments below which the sediments could be disposed of at designated open-water unconfined disposal sites. These interim criteria have now been replaced by disposal guidelines by the Puget Sound Dredged Disposal Analysis (PSDDA) study (PSDDA 1988). Disposal requirements are currently being addressed for contaminated sediments not allowed for open-water unconfined disposal.

Confined disposal involves the containment of dredged material so that migration of contaminants and effects on the environment and human health are minimized. Confined disposal standards are now under development to address the level of contamination above which the standards will apply; the required testing for determining application; and the design, operation, and closure/post-closure requirements of confined disposal sites.

Confined disposal will occur either in the upland environment similar to municipal landfills, in the nearshore environment, which generally involves the filling of intertidal and/or subtidal areas for the creation of usable land or intertidal habitat, or in the aquatic environment where confinement will occur in deeper waters.

Upland, nearshore, and confined aquatic disposal of dredged material generally occurs at sites established specifically for the project, especially for larger dredging projects. Although some current sites in the Puget Sound basin receive dredged material for disposal from more than one dredging project, these sites are limited to municipal landfills and a small number of other upland sites.

The concept of multiuser sites involves the establishment of one or more sites that would be available for use by all dredgers on a long-term basis for the disposal of dredged material requiring confinement.

The objectives of the Multiuser Confined Disposal Sites Program Study being conducted by the Department of Ecology are to identify the issues; make recommendations regarding the utility and viability of multiuser sites for the confined disposal of contaminated sediments in upland, nearshore, and aquatic areas; and to develop an action plan for implementing the recommendations. Contractor support for the study consists of developing issue papers addressing the following components:

- Assessment of needs
- Identification of potential environmental and public health concerns associated with establishing such sites, and possible methods of eliminating or minimizing those concerns through application of technology and/or site location selection

- Development of order-of-magnitude costs for siting, operation, and closure/post-closure; and development of funding alternatives

- Assessment of institutional options for siting, operation, and closure/post-closure of sites

- Development of alternative public involvement and public education plans.

A draft report will also be prepared incorporating response to comments on the issue papers, summarizing the issues, making recommendations for Ecology's consideration, and suggesting an action plan for implementation of the recommendations.

This issue paper addresses the potential environmental and public health concerns associated with the development of in-water, nearshore, and upland sites, and methods of reducing these concerns through application of siting, technology, and operational controls. More specifically, this issue paper includes the following objectives:

- Identify the generic environmental and public health issues associated with dredging, transport, and disposal of contaminated sediments, and with the site during the closure and post-closure periods

- Identify mitigation measures that would minimize potential impacts.

This issue paper identifies mitigation measures in three categories, including: siting the disposal facility;

application of technology, and site operations. The effectiveness of mitigation is discussed only generally. The ongoing effort to establish confined disposal standards will address the actual mitigation measures required. A determination of the significance of impacts associated with developing a multiuser site would need to be made on the basis of site-specific information. Prior to implementing any mitigation measure, each one would need to be evaluated according to a set of criteria. These criteria could include the following: 1) the necessity of mitigation based on the significance of the potential impact on the environment or public health; 2) expected effectiveness of reducing environmental impacts; 3) ease of implementation; 4) safety risks; 5) technical feasibility; 6) ability to meet any regulatory requirements; 7) cost, and; 8) public acceptance.

APPROACH AND METHODS

Generic environmental and public health issues associated with the development of the three types of multiuser sites were extracted from the literature. Literature was available through the library assembled on contaminated sediments as part of the ongoing effort by Ecology to establish confined disposal standards for contaminated sediments. The principal sources of environmental issues were the following:

1. Final Environmental Impact Statement - Unconfined Open-Water Disposal Sites For Dredged Material, Phase I (Central Puget Sound). Puget Sound Dredged Disposal Analysis (PSDDA). June 1988.

2. Draft Environmental Impact Statement - Unconfined Open-Water Disposal For Dredged Material, Phase II (North and South Puget Sound). PSDDA. March 1989.

3. Guidelines For Selecting Control and Treatment Options For Contaminated Dredged Material. Prepared by U.S. Army Corps of Engineers, Vicksburg, MS. PSDDA. September 1986.

4. Evaluation of Alternative Dredging Methods and Equipment, Disposal Methods and Sites, and Site Control and Treatment Practices for Contaminated Sediments. Prepared by U.S. Army Corps of Engineers, Seattle District. Commencement Bay Nearshore/Tideflats Superfund Site, Tacoma, WA Remedial Investigations. June 1985.

5. <u>Commencement Bay Nearshore/Tideflats Feasibility Study. Volume 1</u>. Prepared by Tetra Tech. December 1988.

6. <u>Final Supplemental to U.S. Navy Environmental Impact Statement, Carrier Battle Group, Puget Sound Region Ship Homeporting Project. Technical Appendices</u>. Prepared by U.S. Army Corps of Engineers, Seattle District. November 1986.

Although many of these documents focus more on the environmental issues associated with the disposal of contaminated sediments in open water unconfined (without cap) sites, they contain discussions on the issues of confined aquatic, nearshore, and upland sites as alternatives to the open water unconfined sites. The studies on Commencement Bay and Navy Homeporting projects, however, address confined disposal as alternatives, including nearshore and upland sites.

BACKGROUND INFORMATION

This section of the report presents the environmental context for assessing the potential impacts of developing confined multiuser sites. Five topics are addressed as part of the background information and listed below.

- Description of generic confined aquatic, nearshore, and upland sites

- Physical characteristics of dredged material in Puget Sound and the behavior of contaminants in sediments

- Chemicals of concern in Puget Sound and their sources

- Pathways and activities that result in the release of contaminants

- Activities associated with the dredging, transport and disposal of contaminated sediments at a multiuser site.

DESCRIPTION OF GENERIC MULTIUSER SITES

The three types of multiuser sites are described below.

Confined Aquatic Disposal

Confined aquatic sites are disposal facilities located in the subaqueous environment. In this alternative, contaminated sediments would be dredged from multiple locations and transported by barge for confined disposal at a different aquatic location. The disposal site would be of sufficient size to accommodate the material dredged from many projects. The disposal site would remain active for approximately 20 years. The contaminated dredged material would be placed in an excavated disposal facility, naturally occurring depression, or in a mound. Upon completion of an individual project or group of projects occurring within a limited timeframe (e.g. 1-2 months), the dredged sediments would be capped with clean material. Placement of a cap would minimize exposure of the surrounding biota to the contaminated sediments and the potential for contaminant migration.

Nearshore

Nearshore disposal sites are confined disposal facilities located adjacent to land and within the area influenced by normal tidal fluctuations. A site may contain a cluster of cells, each surrounded by dikes. Typically, dredged material is added to a diked area until the final elevation is above the high tide elevation. When the material is initially placed in the site, it is saturated. After the site is filled, the dredged material above high tide will dewater and dry, the material below high tide will remain saturated, and the intervening layer will be alternately unsaturated and saturated as the tide ebbs and floods. Nearshore sites are typically finished to grade to allow a beneficial use of the site after completion.

Upland

Upland disposal involves the placement of dredged material in an environment that is not influenced by tidal waters. Fresh surface waters could be an issue, however, at an upland site. An upland disposal site would be diked to confine the dredged material and capped at the completion of the fill. The site would likely be developed in stages or cells, and would be filled and closed serially over the 20 year life of the facility. The design standards would probably be comparable to the Minimum Functional Standards for sanitary landfills (Chapter 173-304 WAC), and would include liners, monitoring for the detection of liquids (leachate) seeping into underlying soils, groundwater monitoring, and collection and treatment of leachate.

CHARACTERISTICS OF DREDGED MATERIAL

Much of the material removed during harbor and channel maintenance dredging in Puget Sound is fine-grained with relatively high clay and organic content. Dredged material may contain significant concentrations of chemicals of concern if located in areas of historical or current discharge of contaminants. Often material to be dredged is devoid of oxygen (i.e. anoxic) and near neutral in pH (a measure to the degree to which the sediment is acidic, or basic). Anoxic conditions favor immobilization of many metals. The degree to which contaminants are bound to sediments also depends on the organic matter in and texture of the sediments. Coarse-grained sediments low in organic matter will not bind contaminants as tightly as fine-grained high clay and organic content sediments.

The behavior of contaminants in sediments is influenced by the conditions at the disposal site. Release or loss of contaminants from the sediments is more unlikely when the sediments remain saturated and in a low oxygen (anoxic) condition and neutral in pH. At a confined aquatic site, the contaminants in the sediments would remain close to the in situ saturated anoxic, neutral pH conditions. In contrast, sediments that are moved from a saturated anoxic, to an unsaturated, oxic environment, as in the cases of upland and possibly nearshore sites, the contaminants, particularly metals, could be released to the environment. In addition, pH may drop when the sediments dry, favoring the release of some contaminants. In general, leaving, or disposing of, contaminated sediments in a chemical environment as close as possible to their in situ state favors contaminant retention (especially metals).

DESCRIPTION OF CONTAMINATED SEDIMENTS TO BE DISPOSED AT MULTIUSER SITES

Dredging and disposal of dredged material has been a common and longstanding practice in Puget Sound waters. This practice is typically associated with the development of water-related commerce and recreational boating. In addition to new port and harbor construction, maintenance dredging to ensure safe water depths in existing shipping channels and berthing areas produces large volumes of dredged material.

Measurable levels of some chemicals of concern are found in all Puget Sound sediments. Relatively high concentrations of potentially harmful chemicals, however, have been recorded in urban and industrialized waterways and in areas adjacent to contamination sources. These contaminated areas have been associated with higher than normal frequencies of tumors, other biological abnormalities and bioaccumulation in certain fish and shellfish. Data indicate that chemicals that enter Puget Sound through various sources bind to particles and accumulate in the sediments in nearshore areas, including navigation channels and vessel berthing areas. In order to maintain the Sound's navigation system, dredging and disposal of these contaminated sediments is necessary.

The material dredged from Puget Sound may range from clean material to material classified by Ecology as dangerous waste. Clean material is defined as material that does not exceed disposal guidelines, standards, or any sediment criteria. Very little dredged material is expected to be contaminated at or near dangerous waste levels, as defined by Chapter 173-303 WAC (Amended 1986). The dredged material that would be disposed at a multiuser site may fall within a narrower range, which will be defined by the confined disposal standards. Disposal guidelines have been developed as part of the Puget Sound Dredged Disposal Analysis (PSDDA) study that identify material acceptable for disposal at unconfined open water sites. Material that exceeds the open water disposal guidelines but is not classified as dangerous waste is candidate material for multiuser sites.

PATHWAYS AND ACTIVITIES THAT TRANSPORT CONTAMINANTS

Three factors and their interaction influence the mobility or immobility of contaminants in the dredging and disposal of material. These factors are: 1) level and type of contaminants; 2) physical and chemical properties of the dredged material, and; 3) conditions at the proposed disposal site. An understanding of these three factors can facilitate the development of siting guidelines for multiuser sites and selection of mitigation measures to minimize potential contaminant release.

Contaminants

The type of contaminants and their concentration in the dredged sediments affect their mobilization, depending on the generic location of the disposal site (aquatic, nearshore, or upland). Chemicals of concern in Puget Sound sediments can be classified as metals or organic compounds. Organic compounds include organic acids, aromatic hydrocarbons, chlorinated aromatic hydrocarbons, pthalate esters, pesticides, volatile chlorinated hydrocarbons, and others.

The chemicals of concern generally have the following characteristics when present at significant levels in the sediments.

- A demonstrated or suspected effect on ecology or human health (i.e., the focus of chemical concerns is ultimately unacceptable adverse biological effects.)
- A potential for remaining toxic for a long time in the environment (biopersistent).
- A potential to bioaccumulate and enter the food web.

Activities and Release Pathways

Release and loss of contaminants can occur during dredging, transport and disposal of contaminated sediments. Losses can occur in the short term (e.g. during dredging and disposal) and in the long term (e.g. after disposal). Net contaminant loss from each phase must be evaluated with respect to their potential impacts and necessary mitigation. Losses of contaminants bound to particulates (solids), contaminants in water (soluble contaminants), and contaminants that escape into the air (volatile contaminants) can occur.

The losses will vary depending on the characteristics of the material to be dredged, the type and level of contamination, the method of dredging, transport and disposal, and the mitigation methods used to control the losses. The potential impacts of the losses will be very site-specific and depend on the type and level of contaminants lost, the form in which they are lost (i.e. solid, liquid, gas), the magnitude of the loss, and the surrounding environment and receptors.

The pathways and mechanisms for release of contaminants are listed below for dredging, transport and disposal activities.

- Dredging
  - Loss of soluble contaminants to the water column
  - Resuspension and resettling of the sediment

- Transport
  - Loss of contaminants from the barge or pipeline
  - Loss of contaminants to the air
  - Loss of contaminants to roadways (truck transport to upland site)

- Disposal at a Confined Aquatic Site
  - Loss of contaminated sediments during disposal
  - Resuspension and resettling of the sediment
  - Loss of contaminants after disposal through soluble diffusion and convection
  - Direct exposure of biota to the contaminants
  - Migration through the cap

- Disposal at a Nearshore Disposal Site
  - Leachate migration to ground water
  - Surface runoff from material placed in unsaturated zone to surface water
  - Discharge of slurry water (hydraulic dredge)
  - Discharge from dewatering (clamshell dredge)
  - Seepage through the dike as generally influenced by tidal pumping
  - Volatilization of organics from material in unsaturated zone

- Biological uptake through plants, depending on final use of site
- Direct exposure of marine biota to the contaminants

■ Disposal at an Upland Disposal Site
- Runoff to surface water
- Leachate migration to surface or ground water
- Biological uptake through plants
- Volatilization of organics
- Direct exposure of biota to the contaminants
- Discharge of slurry water (hydraulic dredge)
- Loss of effluent from dewatering (clamshell dredge)

Site Comparison

In general, confined aquatic sites have fewer transport mechanisms than nearshore or upland sites. Since the dredged material remains in a saturated state, the air pathway is absent and ground water is rarely a concern. In contrast to confined aquatic sites, nearshore sites are located in a very active environment. These sites have the transport mechanisms of an upland site and the addition of a much more active water exchange due to tidal activity than at confined aquatic sites. Upland sites are in an environment where precipitation and ground water infiltration are key transport mechanisms. Ground water can be a significant resource at an upland site. Nearshore sites typically do not have potable ground water nearby.

PHASES OF SITE DEVELOPMENT

For the purpose of presenting potential environmental and public health impacts and mitigation measures, multiuser sites have been categorized into six phases of development.

The six phases are:

- Dredging

  Removal of contaminated sediments by mechanical or hydraulic dredge

- Transportation

  Movement of material from dredge site to disposal site (aquatic, nearshore) or transfer point (upland) by barge

  Movement from transfer point to disposal site by truck (upland)

- Site Construction

  Excavation or use of natural depression depending on bathymetry (aquatic)

  Construction of cells, and dikes for containment

  Installment of liners, leachate collection and treatment, monitoring for the detection of leachate, groundwater monitoring (upland)

- Site Operations

  Disposal of contaminated sediments at site over a 20 year period

  Operational controls (e.g. runon/runoff of storm water, monitoring)

  Intermediate cover upon completion of individual dredging projects (nearshore, upland)

  Serial closure (capping) for each cell as it reaches capacity

- Site Closure

  Activities conducted after 20 year life of site that are required for future use of the site or for final closure (e.g. revegetation, deed restrictions, pavement)

- Post Closure

  Implementation of monitoring program
  Contingency plan for possible failures

The environmental and public health issues associated with each phase are identified in the next section of the report. This categorization of potential impact by type of site and phase of development facilitates the identification of mitigation measures to reduce impacts. For the following discussions it has been assumed that: 1) dredging for disposal at aquatic and upland sites is by clamshell dredge and that either clamshell or hydraulic dredging will be used for nearshore sites, 2) transport to the disposal site is by barge for aquatic sites, by barge or pipeline for nearshore sites, and barge and truck for upland sites.

MULTIUSER SITE ENVIRONMENTAL AND PUBLIC HEALTH EFFECTS AND MITIGATION

The generic potential environmental and public health effects of disposing contaminated sediments in multiuser confined sites are presented in Table 1. This table identifies the potential impacts associated with each of the six phases of development, as described in the previous section, and by type of site (confined aquatic, nearshore, upland). For example, the loss and resettling of contaminated particles (action) in the dredging process (project phase) potentially causes benthic biota (affected receptor) to be exposed over the long term to contaminated sediments (potential impact). The water column (pathway) carries the particles away from the dredging site where they will resettle and may impact benthic biota.

DREDGING AND TRANSPORT

Dredging of contaminated sediments and the transport of the dredged material to the disposal site are two phases that apply to all three types of multiuser sites. In the case of the upland site, an additional transportation route would be required to off-load and transfer the material for transport to the disposal site by truck.

Pathways for Release of Contaminants

Dredging disturbs bottom sediments, which results in the release of fine particles and soluble contaminants in waters contained in the pores between sediment particles (interstitial water) and organic matter to the water column. Loss of sediments during bucket raising (i.e. clamshell dredge) could occur if the bucket is not completely watertight. Although most of the dredged material solids

TABLE 1

SUMMARY OF POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

PROJECT PHASE	TYPE OF SITE	ACTIVITIES AND PATHWAYS	ACTION THAT DRIVES POTENTIAL IMPACTS	AFFECTED RECEPTORS	POTENTIAL IMPACTS
Dredging	All	Water column	Resuspension and resettling. Loss of soluble contaminants. Release from bucket.	Benthic biota	Long-term exposure of benthic biota to resettled contaminated sediments.
				Water column biota	Short-term exposure of water column biota to soluble contaminants. Turbidity from suspended solids. Low dissolved oxygen. Increase in toxic contamination in sea surface microlayer.
			Removal of dredged material.	Benthic biota	Loss of habitat, destruction of benthos.
Transport to Disposal Site	All	Water column	Leakage of soluble and particulate contaminants.	Benthic biota Water column biota	Exposure of benthic biota to contaminated sediments. Short-term exposure of water column biota to contaminated sediments and soluble contaminants. Increase in toxic contamination in sea surface microlayer.
		Airborne emissions	Volatilization of organics.	Humans and other biota in immediate vicinity	Inhalation of toxic contaminants during transport.
	Upland	Transportation corridors	Leakage of soluble and particulate contaminants.	Upland biota	Exposure to toxic contaminants.

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PROJECT PHASE	TYPE OF SITE	ACTIVITIES AND PATHWAYS	ACTION THAT DRIVES POTENTIAL IMPACTS	AFFECTED RECEPTORS	POTENTIAL IMPACTS
Disposal Site Construction - excavation, cell development, dike construction	Aquatic	Water column	Removal of clean material for depression or diking.	Water column biota	Turbidity from suspended solids. Low dissolved oxygen.
			Dike construction.	Benthic biota	Loss of habitat and biota through burial and smothering.
	Nearshore	Direct impact	Site preparation and construction, conversion of existing land and water uses.	Marine and intertidal species and habitat	Destruction of intertidal and subtidal habitat at site.
	Nearshore	Surface water	Soil erosion, runoff.	Water column biota	Turbidity from suspended solids.
	Upland	Direct impact	Conversion of existing land use.	Upland biota	Removal of habitat.
		Surface water	Soil erosion, runoff.	Water column biota Aquatic resources	Turbidity from suspended solids. Sedimentation of stream beds and spawning grounds.
Disposal Site Operations	Aquatic	Direct impact	Covering bottom with dredged material.	Benthic biota	Loss of habitat and biota through burial and smothering.
		Water column	Resuspension and resettling. Loss of soluble and particulate contaminants.	Water column biota	Short-term exposure of water column biota to contaminants. Turbidity. Increase in toxic contamination in sea surface microlayer. Low dissolved oxygen. Aesthetics. Food chain effects from toxic contaminants.

TABLE

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PROJECT PHASE	TYPE OF SITE	ACTIVITIES AND PATHWAYS	ACTION THAT DRIVES POTENTIAL IMPACTS	AFFECTED RECEPTORS	POTENTIAL IMPACTS
				Benthic biota.	Exposure of benthic biota to settled contaminated sediments.
				Humans	Human health effects from ingestion of contaminated fish and shellfish.
	Nearshore	Surface water	Runoff from fill in unsaturated zone. Seepage, diffusion or convection through dike.	Marine and intertidal species	Short-term exposure to toxic contaminants. Low dissolved oxygen.
				Humans	Consumption of contaminated fish and shellfish.
		Return water (hydraulic)	Discharge of slurry water	Marine and intertidal species	Exposure to toxic contaminants.
	Nearshore, upland	Ground water	Leachate migration.	Ground water resources Humans	Degradation of water quality and drinking water sources. Ingestion of contaminated ground water.
				Marine species	Exposure of marine species to toxic contaminants
	Nearshore, upland	Airborne emissions	Volatilization of organics, dust.	Humans and other biota in immediate vicinity	Inhalation of toxic contaminants. Transportation of contaminants off site.
	Nearshore, upland	Plants	Biological uptake.	Nearshore and upland biota	Food chain effects. Toxicity to biota

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PROJECT PHASE	TYPE OF SITE	ACTIVITIES AND PATHWAYS	ACTION THAT DRIVES POTENTIAL IMPACTS	AFFECTED RECEPTORS	POTENTIAL IMPACTS
Closure - placement of cap[1]	Aquatic	Water column	Resuspension and resettling of contaminated material during cap placement.	Water column biota Benthic biota	Turbidity from suspended solids. Exposure to contaminated sediments.
			Isolation of contaminated sediments from surrounding environment.	Benthic biota	Recolonization of new communities in the cap.
	Nearshore	Direct impact	Isolation of contaminated sediments from surrounding environment.	Humans	Beneficial use of site for commercial/industrial development.
	Upland	Direct impact	Isolation of contaminated sediments from surrounding environment.	Upland biota Humans	Recolonization of plant communities. Creation of habitat for birds and animals. Beneficial use of site.
Post Closure	Aquatic	Water column	Loss of cap integrity by burrowing species or erosion	Water column	Exposure of water column biota to toxic contamination.
	Nearshore, upland	Surface water	Soil erosion, runoff Dike failure	Water column biota Water column biota Benthic biota	Turbidity from suspended solids. Exposure to contaminated sediments.

TABLE .

SUMMARY OF POTENTIAL ENVIRONMENTAL AND PUBLIC HEALTH IMPACTS

PROJECT PHASE	TYPE OF SITE	ACTIVITIES AND PATHWAYS	ACTION THAT DRIVES POTENTIAL IMPACTS	AFFECTED RECEPTORS	POTENTIAL IMPACTS
	Upland	Ground water	Liner failure	Water quality Humans	Leaching to potable ground water supplies.
			Erosion of cap	Upland biota	Bioaccumulation of toxic contaminants.

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[1] Note: The impacts of capping the dredged contaminated sediments with clean material are primarily positive. Refer to text for discussion.

Benthic organisms - Organisms that live in or on the bottom of a water body.
Sea surface microlayer - The thin top layer of water that can contain high concentrations of natural and other organic substances.

that are lost will settle to the bottom, dredged material will contain some material that could rise to the surface and cause aesthetic concerns or contamination of sea surface microlayer.

Barge transport of dredged material could result in two additional migration pathways. Leakage of contaminated sediments could occur from the barge. The organics could volatilize if the sediments dry and are exposed to the air. Truck transport of dredged material to an upland site represents another activity in which contaminated sediments could leak to roadways and, subsequently, be carried into soil and water.

Affected Receptors

Dredging and transport of contaminated sediments could result in potential impacts to the following receptors: 1) benthic biota; 2) water column biota; 3) sea surface microlayer, and; 4) humans.

Benthic Biota - Benthic biota are organisms that live in or on the bottom of a water body. Table 2 presents examples of benthic biota that could potentially be affected by the dredging or transport of contaminated sediments to multiuser sites. Benthic biota include sedentary and mobile organisms that live in or consume food in the bottom sediments.

Water Column Biota - Water column biota include plankton communities, and anadromous and marine fish. Plankton are the microscopic animal (zooplankton) and plant (phytoplankton) life found floating or drifting in marine or fresh waters, and are sources of food for fish. Anadromous fish include adult and juvenile salmon and some species of trout.

TABLE 2

EXAMPLES OF BENTHIC AND WATER COLUMN BIOTA IN PUGET SOUND

BENTHIC BIOTA	WATER COLUMN BIOTA
Small invertebrates	Plankton communities
Shellfish	phytoplankton
Dungeness crab	
rock crab	(algae)
shrimp	
mussels	zooplankton
geoduck	
	Anadromous fish
Bottom Fish	
English sole	salmon
slender sole	
	steelhead trout
	Marine fish
	Pacific herring

Sea Surface Microlayer - The sea surface microlayer consists of the top 100 micrometers (a micrometer is one one millionth of a meter) of the sea surface. This microlayer contains phytoplankton, and eggs and larvae of marine biota. In addition, the sea surface microlayer often concentrates materials that are not very soluble, are lighter than water, and/or adhere to floatable matter and debris. It has also been shown that contaminants will concentrate in the microlayer. Contaminant contributions to the sea surface microlayer originate from a variety of natural and man-made sources, including air (e.g. particulate fallout and rainfall), land (e.g. shoreline erosion, discharge of sewage and industrial effluents, stormwater runoff, and spills from land based facilities), and nearshore sediments.

Observations of shoreline contamination in Puget Sound reveal that sewage discharges and urban runoff may be the principal sources of contamination of the sea surface microlayer (Word and Ebbesmeyer, 1984). Once in the sea surface microlayer, these contaminants can adversely affect marine eggs and larvae and can be carried to nearby beaches. While solar and bacterial degradation of some of the contaminants occurs over time, wind and surface currents often concentrate rather than disperse the surface materials (U.S. COE, 1986).

Humans - Humans that could be affected by dredging and transport activities include workers on the tug/barge and people who consume contaminated fish or shellfish. Workers could be exposed to organic contaminants that vaporize from the sediments in the barge. Possible adverse health effects could occur from eating fish and shellfish that accumulate released contaminants.

Potential Impacts

The significance of any impacts due to dredging and transport will depend in part on the type of dredging methods used, transport mode (barge or truck) and transportation distance.

Dredging Methods - Two basic types of dredges, hydraulic or mechanical, can be used for the removal of contaminated sediments. Regardless of type of method selected, the dredging process involves four basic tasks: 1) the loosening or dislodging of sediment by mechanically penetrating, grabbing, raking, cutting, drilling, blasting, or hydraulically scouring; 2) a lifting action accomplished by mechanical devices such as buckets or by hydraulic suction; 3) transporting the dredged material by pipelines, scows, hopper dredges, or trucks; and 4) disposing the material by either discharging from a pipeline, by dumping from trucks, bottom dumping from barges, pumping out of scows or hoppers, or transfer from barges to trucks.

The type of equipment and methods used depend on the quantity of sediment to be dredged, physical characteristics of the dredged material, water depths and hydrologic characteristics, and the type and location of sites. The dredging of contaminated sediments requires the additional consideration of contaminant loss during the extraction process and meeting applicable criteria for removal efficiencies and/or environmental protection. The controlling factors in the equipment selection are the degree of contaminant confinement and the cost associated with that confinement.

Mechanical dredges remove bottom sediment through the use of a bucket to dislodge and excavate the material. Bucket dredges load dredged material into scows or barges that are towed to the disposal site. Hydraulic dredges remove and transport sediment in liquid slurry form. A pump supplies the force to transport the slurry (dredged materials and water) through a pipeline to the barge or disposal site. Types of mechanical and hydraulic dredges are listed below.

Mechanical	Hydraulic
clamshell	cutterhead
dipper	suction
dragline	dustpan
ladder	hopper
	special-purpose

The clamshell and cutterhead are the most common type of dredges used in the Pacific Northwest and are assumed to be the candidate dredges for the removal of contaminated sediments.

Dredging Impacts - The principal impact of dredging is the loss of or severe disruption of benthos and habitat in the dredging area. Dredging of contaminated sediments could also result in the loss of contaminants from release of water that contains soluble contaminants from spaces (pores) in between the dredged solids, from escape of solids, and from the release of contaminants in the form of a gas when the dredged material is exposed to air. In addition, the dredging method can also influence the contaminant losses at both the dredging and disposal sites. The environmental impacts associated with dredging are illustrated in Figure 1. A summary of the advantages and disadvantages of the hydraulic and mechanical dredges is presented in Table 3.

Transportation Impacts - Leakage of contaminated sediments could occur during both barge and truck transport. Potential impacts could occur on benthic biota, water column biota, sea surface microlayer, and humans as a result of contaminant loss during barge transport. Contaminated sediments could result in the exposure to water column biota. Contaminants that adhere to floating matter could concentrate in the sea surface microlayer. Leaked sediments that sink to the bottom could result in the long-term exposure of benthic biota to contaminated sediments.

Organics contained in the sediments in the barge could be released to the air. Workers near the barge could potentially inhale these toxic contaminants.

Contaminants could leak onto roads during the truck transport of dredged material to an upland site. Plants and animals present along transportation corridors could accumulate toxic contaminants that are washed off the roads by rainfall into the soils and surface waters.

FIGURE 1
DREDGING IMPACTS

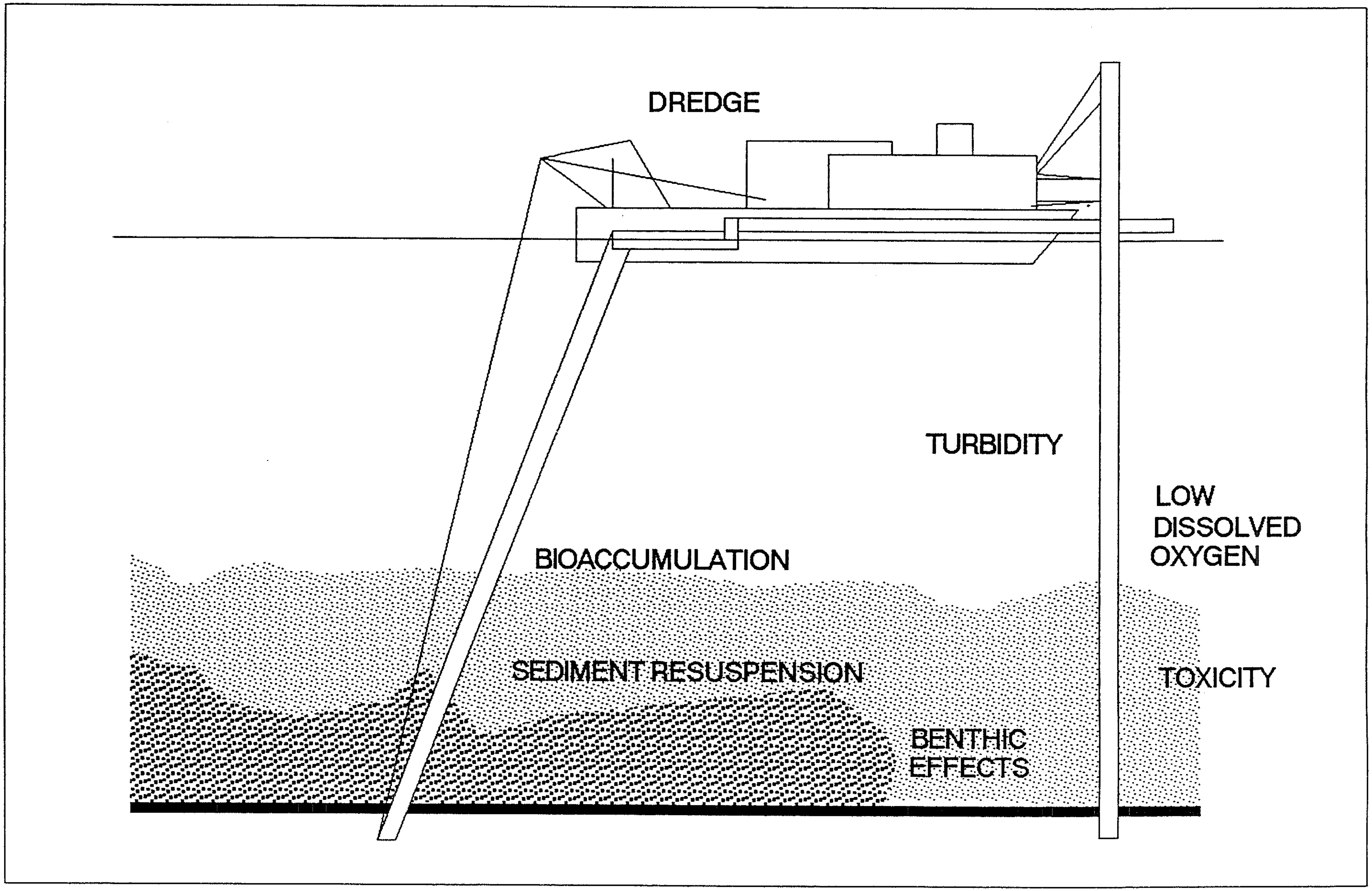


TABLE 3

COMPARISON OF MECHANICAL AND HYDRAULIC DREDGING METHODS DURING DREDGING AND TRANSPORT

Mechanical	Hydraulic
Advantages	
o Less disturbance to the sediments due to the absence of slurry water results in less loss of volatile contaminants during transport o Less opportunity for sediment-bound contaminants to go into solution o Greater maneuverability o Less water to deal with at disposal site	o Less exposure time of dredged sediments to air o Less loss of soluble contaminants at dredging site(s) o Removal of a greater percentage of the sediments at the dredging site(s) results in less resuspension
Disadvantages	
o Longer exposure time of sediments to the air o Efficiency of removing liquids from the sediments is low	o Loss of volatile contaminants due to mixing of sediments with slurry water o Dredged sediment difficult to consolidate and control at the disposal site o Use of water to move sediments can provide for release of soluble contaminants o Return water must be disposed of and may require pretreatment

Source: U.S. Army Corps of Engineers. Evaluation of Alternative Dredging Methods and Equipment, Disposal Methods and Sites and Site Control and Treatment Practices for Contaminated Sediments. June 1985.

Mitigation

Mitigation measures that can be implemented to reduce the potential impacts associated with dredging and transport are presented in Table 4. Although some release of contaminants can occur, the impacts are not expected to be significant if necessary mitigation measures are implemented. These measures could include silt curtains, selection of dredge type, sealed transport vehicles, and scheduling dredging operations. The loss or disruption of benthos in the dredging area, however, cannot be mitigated. Repopulation of the area would be expected upon completion of dredging.

Organic vapors are not expected to be a significant issue with respect to human health due to the dilution of the volatilized contaminants by the surrounding air, as well as the low level of contamination involved. Soluble contaminants released to the water column will be quickly diluted and should not result in significant accumulation in fish and shellfish. Contaminated particles that resuspend and move from the dredging site should also be diluted by cleaner particles upon resettling.

CONFINED AQUATIC SITES

Activities and Pathways for Impacts and Loss of Contaminants

Impacts and loss contaminants can be associated with the following activities and project phases: 1) the removal of clean material from the bottom to excavate a depression or construct a dike; 2) dike construction; 3) discharge of dredged material from the barge to the site; 4) migration of contaminants from the dredged material while the site is actively in operation; 5) placement of the cap on the

TABLE 4

MITIGATION FOR DREDGING AND TRANSPORTATION IMPACTS

PROJECT PHASE	POTENTIAL IMPACT	MITIGATION		
		SITING	TECHNOLOGY	OPERATIONS
Dredging	Loss of or severe disruption of benthos.			
	Loss of volatiles during hydraulic dredging.		Collection and treatment of gas from degassing systems.	
	Exposure of benthic biota to contaminated sediments. Health impacts from consumption of contaminated fish and shellfish.		Silt curtain. Watertight buckets. Selection of dredge type to minimize losses.	Dredging operator controls, e.g. control speed of bucket through water column; careful placement of material in hopper (mechanical). Minimize dredging period. Select dredge type to minimize losses.
	Exposure of water column biota to soluble contaminants.		Selection of dredge type to minimize losses. Watertight buckets.	
	Disturbance to fisheries resources from turbidity and low dissolved oxygen.			Schedule dredging operations at times to protect juvenile salmon and steelhead outmigration. Monitor and cease operations if exceed standards.
Transportation	Loss of soluble and particulate contaminants during barge and truck transport.	Minimize distance between dredging site(s) and disposal site.	Sealed transport vehicles.	Designate navigation and truck routes to maximize safety.
	Volatilization of organics.		Selection of dredge type to reduce mixing of sediments.	Keep sediments saturated.

disposed material during closure, and; 6) loss of cap integrity and escape of contaminants through the cap during post-closure.

The construction phase of an aquatic site would involve preparing the selected site for accepting dredged material. Excavation of a depression for disposal may be desirable or necessary. Construction of a dike(s) to contain the material may be required depending on site-specific factors. The water column would provide a transport pathway for the clean sediments that would be disturbed as part of the construction process. The water column is also the transport pathway for the process of disposing the material into the site.

Figure 2 illustrates the environmental issues associated with discharge of dredged material to an aquatic site. Figure 3 presents graphically the contaminant pathways of concern during site operations, closure, and post-closure. Post-closure refers to the time period after a cap has been placed on the dredged material. During that time there could be active disposal areas adjacent to or in the vicinity of the capped mounds, since capping will occur serially over the life of the disposal area.

The mechanisms for transporting contaminants once the dredged material has been disposed at the aquatic site are soluble diffusion, convection, and bioturbation. These mechanisms can transport contaminants both before and after the cap has been placed on the mound to differing degrees. The water column is the pathway for transporting contaminants.

A potential problem with underwater capping is the potential for displacement of the contaminated mass by capping. The cap material could displace and redistribute

FIGURE 2
AQUATIC DISCHARGE

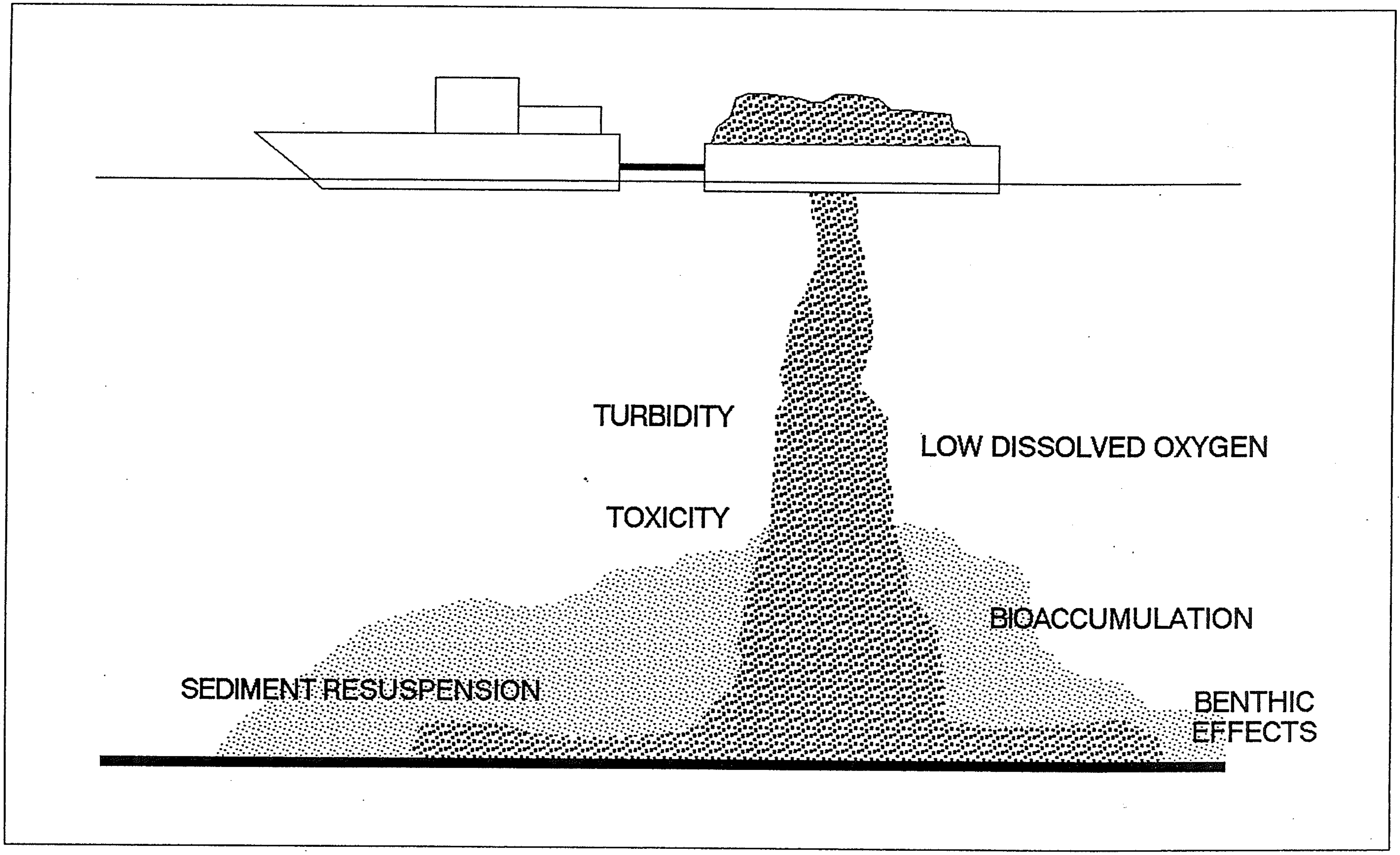
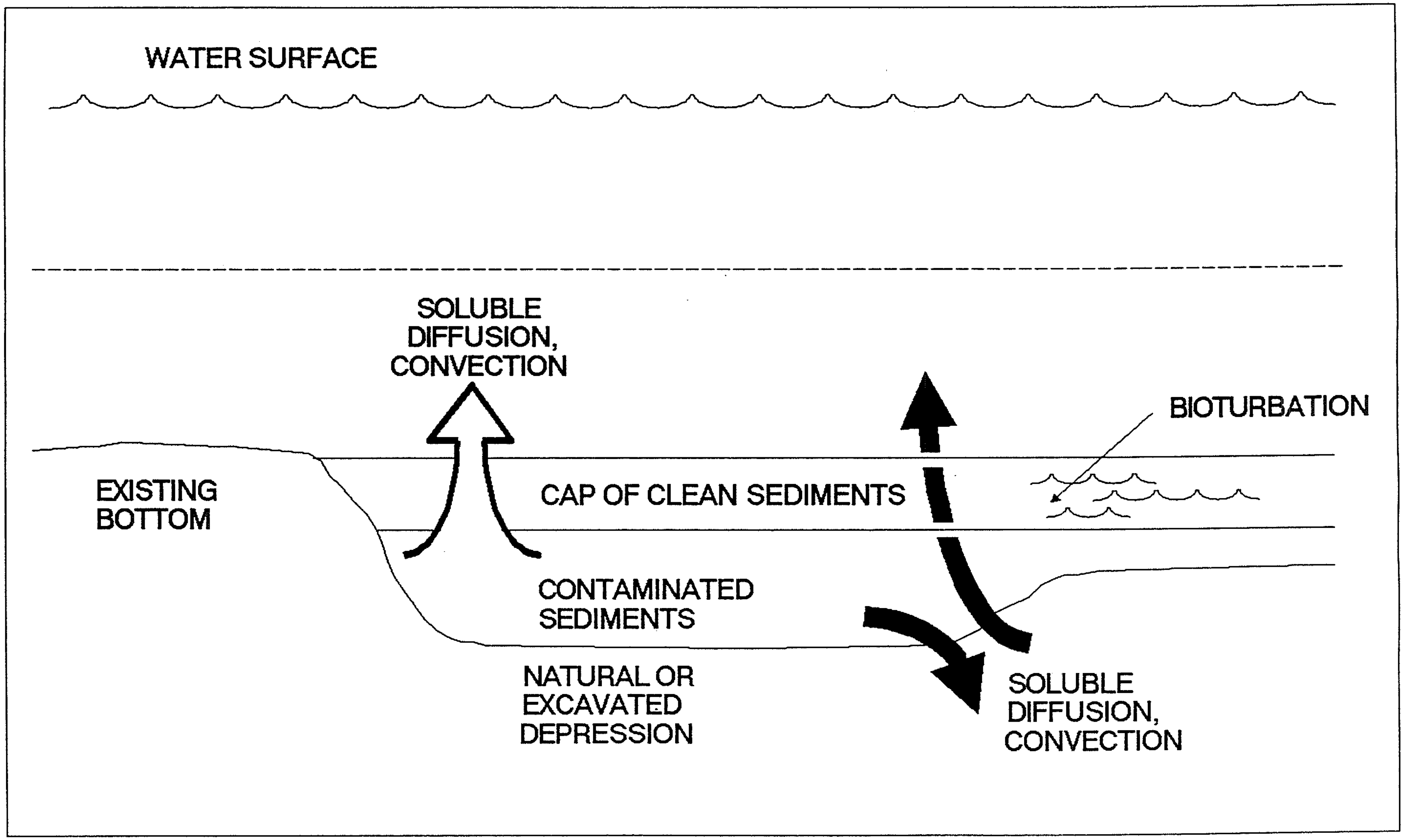


FIGURE 3

CONFINED AQUATIC DISPOSAL



the contaminated material, particularly if the capping material were of a higher density or coarser size than the contaminated material. This situation would depend on substrate firmness and density of the contaminated mass, and the characteristics of the capping material and method of placement.

Once a contaminated sediment mound is capped, the pathways of concern are limited, providing the cap is thicker than the depth of expected biological activity. The current understanding is that if cap thickness is sufficient to minimize the effects of bioturbation, or the mechanical disturbances of the underlying contaminated sediments due to currents and wave action, contaminant loss should be limited to diffusion through the cap at a low rate over a long time period. The U.S. Army Corps of Engineers has identified a cap thickness of approximately 3-6 feet as appropriate for most contaminated dredged material.

Affected Receptors

The construction and operations of a confined aquatic site could result in potential impacts to: 1) benthic biota; 2) water column biota; 3) sea surface microlayer, and; 4) humans. These receptors are described in the previous section on Dredging and Transport.

Potential Impacts

The principal impact associated with the construction and operations of an aquatic site is the burial and smothering of benthic biota, which occurs during site excavation and actual disposal of the dredged material. The other potential impacts are: 1) effects on water column biota from turbidity; 2) exposure of benthic and water column biota to toxic contaminants and bioaccumulation of toxics in the food chain; 3) aesthetics, and; 4) potential public health impacts from the consumption of contaminated fish and shellfish. These potential impacts are listed in Table 1, Summary of Potential Environmental and Public Health Impacts, and described below.

Smothering or Burial of Benthic Biota - Benthic resources in the disposal area would be affected directly by the sediment mass discharged from the barge during disposal. The physical impact would be the loss of benthic species due to burial and smothering by clumps of cohesive material. During periods of disposal inactivity and after capping, partial recovery of benthos at the disposal site could occur due to migration from surrounding areas.

Effects on Water Column Biota from Turbidity- Construction, disposal, and placement of the cap could result in the resuspension of either bottom sediments or contaminated dredged material. The intermittent pulses of suspended materials could reduce the potential for plankton production by reducing light. In addition, nutrients could be released, thereby stimulating growth of nuisance species. Impacts to fish from suspended sediments could include respiratory distress from low dissolved oxygen levels and gill clogging.

Exposure of Benthic and Water Column Biota to Toxic Contaminants - As dredged material is disposed and descends through the water column, the sediment mass entrains water, and both particles and pore water can be stripped away. The water column losses could consist of both dissolved and particulate-associated contaminants. Disposed material could become resuspended by the action of currents or through biological activity and resettle on the site or be transported off-site. Suspended contaminants could become available to water column biota. Larval and adult forms of benthic species that settle on the newly deposited material prior to capping come into contact with particle-bound contaminants and with dissolved chemicals of concern within the sediment pore water. Accumulation of these chemicals of concern depends largely on the concentration of the chemicals and their relative biological availability. Transport of chemicals of concern from the disposal site, other than through material release of suspended particles and soluble diffusion, can occur when benthic organisms that have accumulated contaminants emigrate from the site or, via the food chain, when predators feed on benthic species inhabiting the site.

Aesthetics - Viewers from the shoreline areas would see the occasional presence of a tug and barge. Viewers on boats and close to the disposal site could observe a localized turbidity plume in the immediate vicinity of the barge following disposal. This plume would exist only for a short term during and following disposal.

Human Health Effects - Human health impacts could result from the ingestion of contaminanted fish and shellfish. Impacts from the consumption of contaminated fish and shellfish could occur if fish and shellfish caught and consumed by people have accumulated contaminants to levels of concern.

Mitigation

Mitigation measures that could be used to reduce impacts at aquatic sites are presented in Table 5. The measures are presented in three categories: siting, technology, and operations.

Two major mitigation measures are the placement of a cap of clean material over the contaminated material to isolate the contaminants from the active biological and physical environment and to slow the migration of contaminants, and the selection of a disposal site. Disposal site selection is critical since, although other impacts can be mitigated through technology or operations, the impact of burying benthic biota can only be mitigated by locating sites in non-critical habitat areas. However, it is expected that benthic biota would repopulate the site after placement of the cap. Siting is also important in minimizing the loss of contaminants during disposal and prior to and after capping and in maintaining cap integrity after cap placement. Some loss of contaminants during disposal and prior to and during capping will occur. The impacts of contaminants that are released and move off site even after mitigation measures are taken can be monitored and changes to disposal requirements can be made if monitoring results indicate a problem.

It is not expected that loss of contaminants would be a problem due to the significant dilution that would occur and the short term nature of the releases. Therefore, accumulation by fish and shellfish that may be caught and consumed by people should be minimal.

NEARSHORE SITES

Activities and Pathways for Impacts and Loss of Contaminants

The transport of contaminated sediments at a nearshore site can be associated with the following activities and phases: 1) construction of the disposal cell(s) and dikes; 2) loss of contaminants during operations; 3) placement of the

TABLE 5

CONFINED AQUATIC DISPOSAL SITE MITIGATION MEASURES

PROJECT PHASE	POTENTIAL IMPACT	MITIGATION		
		SITING	TECHNOLOGY	OPERATIONS
Construction	Disturbance or loss of habitat from depression excavation and/or dike construction.	Locate site in non-critical habitat area. Locate site in area of natural depression. Locate site in flat area where dikes are not required.	Using mound disposal in absence of natural depression.	NA
	Turbidity from suspended solids and low dissolved oxygen.			Monitor and suspend operations if exceed water quality standards.
Disposal/Operations	Loss of habitat and biota through burial and smothering.	Locate site in non-critical, low use habitat area.	NA	Strict operational controls and accuracy of dump placement.
	Short-term exposure of water column biota to soluble and particulate contaminants.		Submerged discharge using conduit or downpipe (hydraulic dredge).	Schedule dumping to occur during slack tide to minimize diffusion of plume.
	Exposure of benthic biota to contaminated sediments that are released from the site prior to capping.	Locate site in low or weak current environment and at depths below influence of surface wave action.		Schedule disposal to avoid heavy use periods by migratory biota.
	Increase in toxic contamination in sea surface microlayer. Aesthetics - sheens and slicks.	Locate site in non-critical, low use habitat area. Locate site away from public use beaches and shorelines.	No proven mitigation.	Control quality of material to be disposed.

TABL[

CONFINED AQUATIC DISPOSAL SITE MITIGATION MEASURES

PROJECT PHASE	POTENTIAL IMPACT	SITING	TECHNOLOGY	OPERATIONS
	Turbidity and low dissolved oxygen.	Locate site in non-critical, low use habitat area.	Silt curtains. Submerged discharge using conduit or downpipe (hydraulic dredge).	Schedule disposal to avoid heavy use periods by mitgratory biota. Monitor and suspend operations if exceed water quality standards.
	Exposure of water column and benthic biota to disposed contaminated sediments.	Locate site in non-critical, low use habitat area.	Cap site. Accurate placement and depth of cap.	Minimize time mound is exposed to surrounding biota (e.g. 1-2 months) Schedule dumping at times to protect mitgratory biota. Monitor during placement.
	Human health effects from ingestion of contaminated fish and shellfish.	Refer to exposure of biota.		Monitor bioaccumulation in fish and shellfish.
Closure	Resuspension and resettling of contaminated material during cap placement. Turbidity during cap placement.	Locate site in low current, non-dispersive area.	Mechanical dredge cap material and bottom dump from barge. Submerged placement of cap using conduit or downpipe (hydraulic).	Monitor for effectiveness and institute changes as necessary.
Post-Closure	Increase in toxic contamination due to loss of cap integrity.	Low current, non-dispersive area. Site in area not influenced by wave action.	Replacement of cap. Removal of disposed material.	Long-term monitoring to ensure integrity. Develop and implement contingency plan.

NA - not applicable

cap on the filled cell during closure, and; 4) potential loss of cap integrity and failure of dikes during post-closure.

The construction phase would involve building a dike, or a series of dikes, to contain the dredged materials. A direct physical impact would occur in covering habitat with the dike material. The water column would provide a transport pathway for the clean sediments that would be disturbed during site preparation and construction.

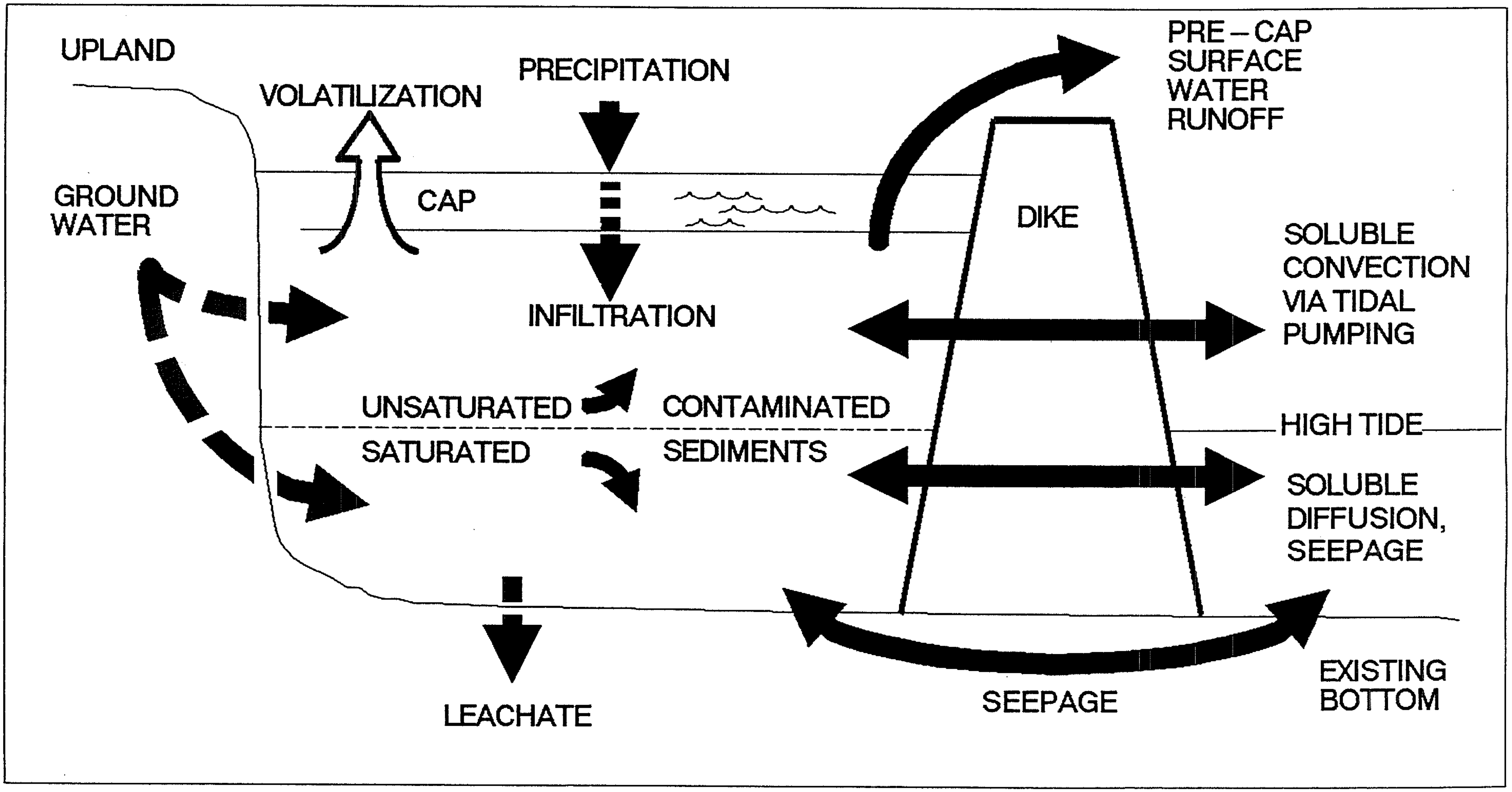
The activities and pathways that result in potential impacts during site operations, closure and post closure are presented graphically in Figure 4. During operations loss of contaminants can occur in transferring the dredged material from the barge to the site. Soluble contaminants could be released in the discharge of slurry water from the site (hydraulic) or from discharge from dewatering (mechanical) the sediments. In addition, contaminants can migrate due to erosion and surface runoff from the site prior to capping the disposal cell.

The activities and pathways of concern for a nearshore disposal site are:

- Loss of contaminants as a gas (volatilization)
- Runoff to surface water
- Leachate to groundwater
- Loss of contaminants through the dike (soluble diffusion, seepage, soluble convection via tidal pumping)
- Plant and animal toxicity and bioaccumulation
- Human inhalation, ingestion, and direct contact with the contaminanted sediments.

FIGURE 4

NEARSHORE DISPOSAL SITE



Volatilization occurs as chemicals of concern (e.g. organics) are released directly to the atmosphere. Prior to placement of the cap, surface runoff can occur from loss of water in the dredged sediments and/or precipitation. Leaching occurs from water carrying the contaminants to the ground water or through dikes. Although groundwater is not typically a potable water source at nearshore sites, it could be a pathway to marine waters. Contaminants can also be lost through the dike by soluble diffusion. Within the tidal zone, tidal pumping would facilitate contaminant migration. Plants adjacent to the site and animals feeding on those plants can accumulate chemicals in the tissue; animals higher up in the food chain that feed on those animals can concentrate chemicals in their tissue (bioaccumulation).

Affected Receptors

Development of a nearshore site could result in potential impacts to: 1) water column biota; 2) marine and intertidal species and habitat; 3) marine waters, and; 4) humans. The water column biota are described in the Dredging and Transport section.

Marine and Intertidal Species and Habitat - Species and habitat are site-specific but could include benthic habitat, wetlands, fish feeding and rearing habitat, shoreline vegetation, and habitat for waterfowl and birds.

Marine Waters - The quality of marine water is a concern due to the potential adverse effects on the biota. The impacts from effluent during dewatering or seepage through the dike will depend on the water quality and hardness of the receiving waters. The release of chemicals via leachate could enter the groundwater, which can act as a pathway to marine surface waters. Potential imapcts include changes in dissolved constituents, suspended solids levels, and increased levels of sediment bound chemicals.

Humans - Humans potentially impacted include workers at the disposal facility, people who consume fish or shellfish that may become contaminated, and nearby residents who inhale wind-blown contaminated dust.

Potential Impacts

Potential adverse impacts from the development of a nearshore site are presented in Table 1. The most significant impact would be the destruction of marine and intertidal habitat. Other impacts can be generally categorized as follows: 1) effects on water column biota from suspended solids due to soil erosion; 2) exposure of marine and intertidal species to contaminants, and; 3) exposure of humans to chemicals of concern through direct contact, inhalation of organic vapors or wind-blown dust, and consumption of contaminated fish and shellfish.

Destruction of Marine and Intertidal Habitat- Development of a nearshore site would involve converting subtidal and intertidal areas and shoreline to a disposal facility. Infill of intertidal areas with dredged material between dikes or piers is typically involved.

Site preparation and use results in destruction of the existing habitat. Loss of wetlands and other critical habitat would displace waterfowl, birds, and small mammals.

Exposure of Marine and Intertidal Species to Contamination - Marine and intertidal species could become exposed through loss of contaminants through surface runoff, slurry water discharge, or seepage through the dike. Following disposal, adverse impacts to plants recolonizing the area could occur. The presence of chemicals of concern could hinder successful germination and growth of plant species. For those plants that become established on the disposal site, contaminants could accumulate in plant tissue. Animals utilizing the site could access contaminants by foraging. In turn, these animals could act as vectors in the transport of chemicals off-site.

Human Health Effects - Human health impacts could result from the following pathways: 1) ingestion of contaminated fish and shellfish; 2) inhalation of contaminated dust, and; 3) direct exposure prior to closure.

Dredged material that dries out provides a potential source of dust that may carry contaminants and could have an impact on workers and residents living near the site. Dust production can especially be of concern where the dredged material is being reworked. Direct exposure of workers to the contaminated dredged material could occur through handling the material (e.g. unloading, disposing, covering). Impacts from the consumption of contaminated fish and shellfish could occur if fish and shellfish caught and consumed by people have accumulated contaminants to levels of concern.

Mitigation

Measures to mitigate impacts of developing a nearshore site are presented in Table 6. The removal of habitat can only be mitigated through the siting process (i.e. selecting a site that has no critical habitat) or by creating replacement habitat in another shoreline area. All other potential impacts can be minimized through siting, technology, and operations procedures. Some release of contaminants to marine waters during disposal may occur through handling of dredged material and diffusion through the dike, even after mitigation measures are applied. It is expected that these contaminants will be quickly diluted by the surrounding waters and would not pose a problem to either biota or humans consuming fish and shellfish. The slow release of contaminants through the dike over the long term cannot be readily mitigated. Monitoring can be required to determine potential impacts and a contingency plan can be implemented in the event a problem is detected.

UPLAND SITES

Activities and Pathways for Impacts and Loss of Contaminants

Impacts and loss of contaminated sediments at an upland disposal site can be associated with the following activities and phases: 1) removal of existing habitat during construction of the site and access road; 2) truck transport of dredged material from the transfer/off-loading facility to the site; 3) migration of contaminants during site operations; 4) placement of the cap during closure of the site, and; 5) loss of cap integrity or failure of structures and systems during the post-closure phase.

The construction phase would involve excavating the site to develop the disposal cell(s), dike construction, installing the liners and leachate detection and collection systems, and building a site access road. Pathways occurring during transport were addressed in the Dredging and Transport section.

TABLE 6

NEARSHORE DISPOSAL SITE MITIGATION MEASURES

		MITIGATION		
PROJECT PHASE	POTENTIAL IMPACT	SITING	TECHNOLOGY	OPERATIONS
Construction	Burial of intertidal and subtidal species by dike construction.	Locate site away from wetlands, habitat for birds and waterfowl Avoid areas that contain threatened and endangered species, and avoid critical habitat.	Create replacement habitat.	
	Soil erosion and turbidity from suspended solids.		Detention ponds. Infiltration basins. Run on/run off controls.	Avoid heavy construction during heavy rain periods.
Disposal/Operations	Exposure of marine and intertidal species to toxic contaminants from return water and from seepage through dike.	Ensure adequate dilution. Keep material saturated.	Increase ponding and/or treatment prior to discharge of slurry water (hydraulic dredge). Cap site to prevent infiltration through unsaturated zone.	Monitor and correct as necessary.
	Turbidity and low dissolved oxygen.	Avoid discharging return water to confined or small waterways.	Same as above.	Monitor and correct as necessary.
	Human consumption of contaminated fish and shellfish.	Ensure adequate dilution. Keep material saturated.	Same as above.	Monitor.

TABLE

NEARSHORE DISPOSAL SITE MITIGATION MEASURES

PROJECT PHASE	POTENTIAL IMPACT	MITIGATION		
		SITING	TECHNOLOGY	OPERATIONS
	Burial of intertidal and subtidal species by fill.	Avoid critical habitat.	Implement program to replace habitat in another location.	
	Inhalation of toxic contaminants that volatilize from the sediments or are wind blown.		Erect wind fences. Interim cover.	Spray dust suppressant chemicals or water.
	Land-based food chain effects.		Final cap.	
	Toxicity to land-based biota through biological uptake.		Final cap.	Restrict use of site.
Closure	Beneficial use of site for commercial/industrial development.	Site near compatible land uses.	Final cap.	Deed restrictions.
Post-Closure	Soil erosion resulting in turbidity and impacts on fisheries resources. Loss of contaminants due to dike failure. Erosion of cap.		Design cap to be stable and not subject to erosion. Detention basins. Run on/run off controls.	Revegetate with saline-tolerant plants to stabilize soils if site is not developed for commercial or industrial uses. Monitor to ensure effectiveness of cap. Monitor to ensure no problems with leachate through dikes. Monitor to ensure dike integrity. Develop and implement contingency plan.

Figure 5 presents the contaminant pathways of concern during site construction, operations, closure and post-closure phases of the project.

The activities and pathways of concern for an upland disposal site are:

- Loss of contaminants to the air (volatilization)
- Wind blown dust that contains contaminants
- Runoff to surface water
- Leachate to groundwater
- Plant and animal toxicity and bioaccumulation
- Human inhalation, ingestion, and direct contact with the contaminated sediments
- Loss of contaminants from small mammals burrowing in the intermediate cover and sediments (bioturbation)

Affected Receptors

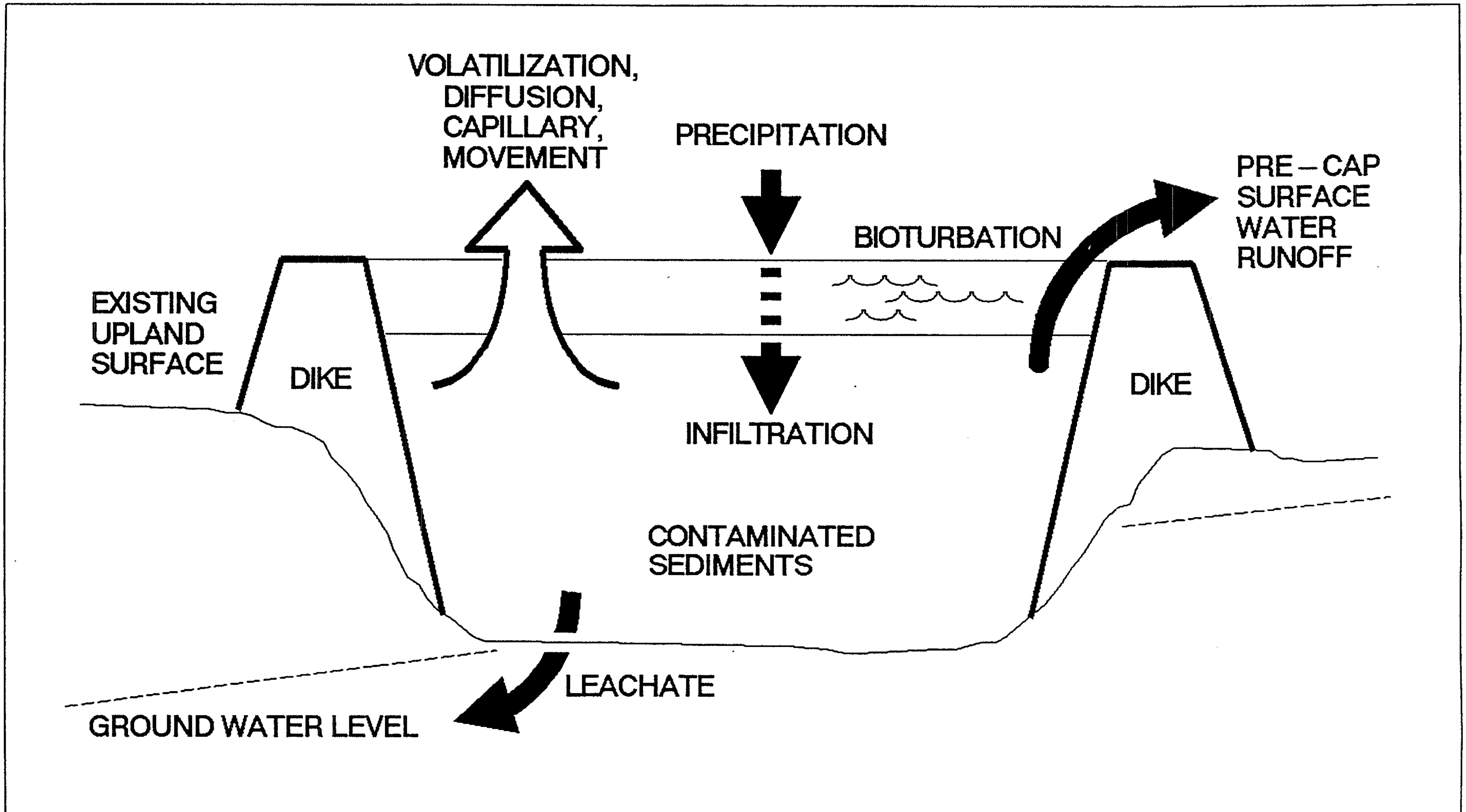
Receptors that could be affected by the development of an upland site are: 1) upland biota; 2) water column biota in nearby surface waters; 3) surface and ground water quality, and; 4) humans. With the exception of upland biota and groundwater quality, the other receptors have been described in previous sections.

Upland Biota - Upland biota refers generically to any plants, animals, and birds that inhabit the vicinity of a proposed upland site. A site-specific inventory of species would need to be taken to identify any sensitive or critical species.

Surface and Ground Water - Ground water and/or surface water can be a source of drinking water. Depending on flow velocities and direction, hydraulic gradients, and the

FIGURE 5

UPLAND DISPOSAL SITE



permeability and porosity of subsurface strata, soluble contaminants can be transported by ground water. Recharge areas, such as wetlands, provide an interface between surface and ground waters and a possible pathway for transporting contaminants. Contaminants contained in surface runoff can be carried into streams and reservoirs, thereby entering drinking water supplies.

Potential Impacts

The principal impact of developing an upland disposal site would be the removal of vegetation and habitat for site preparation and construction of the disposal cell(s), dikes and access roads. Other impacts include: 1) effects of soil erosion and runoff on water quality, water column biota and fisheries resources in any nearby surface waters; 2) exposure of plants to contaminated sediments and bioaccumulation in the food chain; 3) contamination of ground water, and; 4) human exposure to chemicals of concern through direct contact, inhalation of organic vapors or wind-blown dust, and drinking contaminated ground water.

Contamination of Surface and Ground Water - The impacts on ground water from upland disposal could occur from: 1) release of contaminants in the effluent during dewatering; or uncontrolled rainfall runoff, and; 2) leaching to ground or surface water.

Effects on Freshwater Resources - Adverse impacts to freshwater resources are possible. Disposal of dredge material in upland environments could result in exposure of freshwater fish and other biota if untreated leachate, dewatering discharge, uncontrolled runoff or contaminated ground water reaches surface waters. Uncontrolled erosion during site construction, operations, closure and post-closure could result in adverse impacts to freshwater habitats.

Mitigation

Measures that could be implemented to reduce potential impacts at an upland facility are presented in Table 7. The key mitigation measures are siting; facility design, and treatment and control systems; and monitoring.

Disposal site selection is critical since the impact of removing habitat can only be mitigated by locating sites in areas that do not contain critical or sensitive habitats. The siting process is also important in protecting ground and surface water resources. In addition to considering the important of water and biological resources, the siting process should incorporate additional criteria to prevent or minimize the impacts on the environment and public health.

The disposal facility can be designed to minimize the release of contaminants off site. Design requirements can incorporate a double liner system, a leachate collection and treatment system, and stormwater runon and runoff controls. Interim cover consisting of clean material can be placed upon completion of each dredging project to minimize the time the contaminated sediments are exposed to the actions of wind and precipitation. A final cover could be placed once a cell reaches capacity.

Some loss of contaminants will occur during disposal and prior to final capping. A monitoring program could be designed to track the effects of any contaminant losses both during operations and the approximately 30 year post-closure period. Changes to the disposal operations can be made if the monitoring indicates any negative results. In the event of design or structural failure during the post-closure period, a contingency plan could be developed and implemented to correct any adverse effects that are detected through monitoring.

TABLE

UPLAND DISPOSAL SITE MITIGATION MEASURES

PROJECT PHASE	POTENTIAL IMPACT	MITIGATION		
		SITING	TECHNOLOGY	OPERATIONS
Construction	Removal of upland habitat.	Avoid areas that contain threatened and endangered species, designated critical habitat.		
	Soil erosion and turbidity from suspended solids, sedimentation of stream beds and spawning grounds affecting fisheries resources.	Locate site outside 100 year floodplain and away from water bodies. Locate site away from streams with anadromous fish.	Sedimentation ponds. Run on/run off controls.	Monitor effectiveness of controls.
Disposal/Operations	Degradation of groundwater quality and drinking water sources from leachate migration.	Locate site in area where the bottom of the lowest liner is sufficiently above the seasonal high level of ground water. Avoid locating site over a sole source aquifer. Maximize distance of site from downgradient private or public water sources.	Install double liners and leachate collection and removal system. Interim cover. Run on controls.	Monitor effectiveness of liners and leachate collection systems through use of monitoring wells.
	Inhalation of toxic contaminants.		Erect wind fences. Interim and final cover.	Minimize exposure time through scheduling. Specify interim cover. Spray dust suppressant chemicals or water.
	Food chain effects.		Interim and final cover.	
	Toxicity to biota through biological uptake.	Establish buffer zone.	Interim and final cover.	Fence site at boundary of buffer zone.

TABLE 7

UPLAND DISPOSAL SITE MITIGATION MEASURES

PROJECT PHASE	POTENTIAL IMPACT	MITIGATION		
		SITING	TECHNOLOGY	OPERATIONS
Closure	Recolonization of plant communities.		Final cover.	Revegetate with plants that have shallow root systems to prevent uptake of toxic contaminants.
	Creation of habitat for birds and animals.		Final cover.	Monitor.
	Beneficial use of the site.		Final cover.	
Post-Closure	Soil erosion resulting in turbidity and impact on fisheries resources. Liner failure. Erosion of cap.		Design cap for stability. Detention basins. Run on/run off controls.	Monitor to ensure effectiveness of cap, liner, leachate collection system. Develop and implement contingency plan.

CONCLUSIONS

- The environmental and public health issues associated with the disposal of contaminated sediments are, in general, the same for multiuser sites as for sites established on a project by project basis.

- The key difference of a multiuser site program is that the number of sites is minimized by operating larger sites over a long period (e.g. 20 years). The use of fewer sites would result in fewer areas disrupted by site construction and operation. The efficiency and effectiveness of site selection, monitoring, and regulatory oversight, would be greater with multiple sites. On the other hand, the potential impacts on areas where multiuser sites are located could be much larger than at single project sites.

- Although some release of contaminants is technically unavoidable, mitigation measures, including siting requirements, engineered design of the facility, other technology controls, operations procedures, and regulatory controls, could be implemented to prevent or minimize impacts.

- Siting a multiuser site is a key mitigation measure. Sites should be located in areas where the impact of contaminant release on environmental resources and human health, should it occur, is minimized.

- The use of cells or mounds that are filled and closed sequentially over the life of the facility is a concept similar to single project sites. The use of cells is common practice at sanitary landfills and could be applied similarly to an upland multiuser site. Serially closed mounds should be required at aquatic sites to limit the time that the disposal material is exposed. The environmental benefit of serial cells in nearshore areas needs further examination.

- Aquatic sites have the fewest number of pathways for release of contaminants and receptors to impact, the lowest potential for release, but are more difficult to monitor and have limited mitigation options and remedial alternatives in the event of failure.

- Upland sites have the highest number of pathways for release and types of receptors to impact, and the highest potential for release, but have the most mitigation options and remedial alternatives in the event of failure. The siting process can be very effective in avoiding habitats of concern, and surface and ground water.

- Nearshore sites are in between aquatic and upland sites with respect to pathways, receptors, and mitigation. It is more difficult to avoid sensitive habitat areas in selecting a site and, therefore, the impact of habitat loss is more significant than for either aquatic or upland sites.

- Monitoring programs and contingency plans should be required that specify actions to be taken if monitoring yields negative results or if structural failure occurs.

RECOMMENDATIONS

- The standards being developed for confined disposal of contaminated sediments should take into account the cellular design of a facility with sequential filling and closure of cells over a 20 year operating life.

- If cellular design proves to be technically and economically feasible for nearshore sites, an evaluation should be conducted of the environmental advantages and disadvantages associated with both the one cell and multiple cell nearshore facility.

- Siting guidelines should be developed and are a key factor in identifying potential multiuser sites that could avoid receptors of concern. Using the siting methodology of Zones of Siting Feasibility would provide continuity with the PSDDA efforts of siting in-water unconfined sites, particularly for siting multiuser facilities in the aquatic and nearshore environments.

- The effectiveness of mitigation measures at each type of multiuser site should be investigated and documented. During preparation of this report, documentation of the effectiveness of mitigation measures was limited.

- Mitigation measures should be selected for each phase on the basis of activities and potential impacts that could occur throughout all phases of a multiuser project (dredging, transport, and disposal).

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GLOSSARY

Aquifer	A permeable body of rock or soil capable of yielding groundwater to wells and springs; a water-bearing rock, rock formation, or group of formations.
Bathymetry	Shape of the bottom of a water body expressed as the spatial pattern of water depths.
Benthic	Of, or pertaining to, or living on, the bottom of a body of water.
Bioaccumulation	The accumulation of chemical compounds in the tissues of animals and plants.
Biota	The animals and plants that live in a particular area or habitat.
Bioturbation	The movement and relocation of sediments by the activities of burrowing organisms.
Bottomfish	Fish that live on or near the bottom of a body of water.
Cap	A layer of clean sediment placed over contaminated sediment to isolate the contaminated sediment from the surrounding environment.
Clamshell Dredging	Scooping of the bottom sediments using a mechanical clamshell bucket of varying size. Commonly used in over a wide variety of grain sizes and calm water, the sediment is dumped onto a separate barge and towed to a disposal site when disposing in open water.
Confined Aquatic Disposal (CAD)	Confined disposal in a water environment. Usually accomplished by placing a layer of soil or dredged material (i.e., cap) over material that has been placed on the bottom of a water body.

Contaminant	A chemical substance in dredged material that might cause adverse effects on environmental and/or human health as a result of exposure to the substance.
Diffusion	The movement of dissolved contaminants through water due to concentration gradients.
Dredged Material	Sediments excavated from the bottom of a waterway or water body.
Dredging	Any physical digging into the bottom of a water body. Dredging can be done with mechanical or hydraulic machines and is performed in many parts of Puget Sound for the maintenance of navigation channels that would otherwise fill with sediment and block ship passage.
Effluent	Liquid that flows out of a contained disposal facility. Effluent usually refers to water discharged during the disposal operation.
Entrainment	The addition of water to dredged material during disposal, as it descends through the water column.
Environmental Pathways	Transport processes which move contaminants from a source to a final destination (e.g., from a dredged sediment into the overlying water to the gills of a fish and finally into the muscle tissue of the fish).
Erosion	The process of wearing away of rock or soil via gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical and chemical forces.
Ground Water	Underground water body, also called an aquifer. Aquifers are created by rain which soaks into the ground and flows down until it collects above a point where the ground is not permeable.

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

Hydraulic Dredging — Dredging accomplished by the erosive force of a water suction and slurry process, requiring a pump to move the water-suspended sediments.

Intertidal Area — The area between high and low tide levels. The alternate wetting and drying of this area makes it a transition between land and water organisms and creates special environmental conditions.

Leachate — Water or other liquid that may contain dissolved (leached) materials, such as organic salts and mineral salts, derived from a solid material. Rainwater that percolates through a sanitary landfill and picks up contaminants is called the leachate from the landfill.

Mobility — The movement of contaminants within dredged material, between dredged material and the environment, or in the environment. Mobility is a function of the kind of contaminant, the type of environment in which it is found, the concentration of the contaminant, the transport pathway at the site, and the conditions (e.g., aquatic, upland, nearshore).

Nearshore Disposal — A disposal site where dredged material is placed in water along the shoreline, but the final elevation of the fill is above water. Thus part of the fill is saturated and part is unsaturated.

pH — The degree of alkalinity or acidity of a solution. A pH of 7 represents a neutral condition. A pH of less than 7.0 indicates an acidic solution, and a pH greater than 7.0 indicates a basic solution. The pH of water influences many of the types of chemical reactions that occur in it. Puget Sound waters, like most marine waters, are typically pH neutral.

Runoff — The flow of surface water off of a site that results from rainfall on the site.

Salmonid — A fish of the family Salmoniidae. Fish in this family include salmon and trout. Many Puget Sound salmonids are anadromous, spending part of their life cycles in fresh water and part in marine waters.

Saturated — The condition that occurs when the sediment can absorb no more water and all interstitial spaces are filled with water.

Sea Surface Microlayer — The extremely thin top layer of water that can contain high concentrations of natural and other organic substances. Contaminants such as oil and grease, many lipophylic (fat or oil associated) toxicants, and pathogens may be present at much higher concentrations in the microlayer than they are in the water column. The microlayer is biologically important as a rearing area for marine organisms.

Sediment — Material suspended in or settling to the bottom of a liquid, such as the sand and mud that make up much of the shorelines and bottom of Puget Sound. Sediment input to Puget Sound comes from natural sources, such as erosion of soils and weathering of rock, or man-made sources, such as forest or agricultural practices or construction activities. Certain contaminants tend to collect on and adhere to sediment particles.

Sediment Resuspension — The stirring-up of sediments into the overlying water by some physical action, such as dredging, currents, or bioturbation.

Sedimentation — The process of accumulating sediment at the bottom of a water body over time from the settling of particles in the water.

Seepage — The slow movement of water out of soil or sediments.

Subtidal — The marine environment below low tide.

Suspended Solids — Organic or inorganic particles that are suspended in water. The term includes sand, mud, and clay particles as well as other solids suspended in the water column.

Toxicity — The harmful effects of a chemical substance on a plant, animal, or human. Toxicity may be acute (resulting in severe short term effects, including death) or chronic (long-term effects from prolonged exposure to sublethal concentrations of contaminants). Chronic toxicity can include responses such as cancer, mutations, birth defects, or growth impairment.

Turbidity — A measure of the amount of material suspended in the water, as measured by light penetration. 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 Disposal — A disposal site located on land (away from tidal waters) in which the dredged material is confined. Upland conditions also occur in the portion of nearshore sites which dry out.

Volatilization	The loss of a chemical substance from dredged material into the air.
Water Column	A vertical profile of a body of water from the sediment/water interface to the water/atmosphere interface.
Wetlands	Habitats where the influence of surface or ground water has resulted in development of plant or animal communities adapted to such aquatic or intermittently wet conditions. Wetlands include tidal flats, shallow subtidal areas, swamps, marshes, wet meadows, bogs, and similar areas.