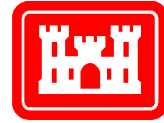


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Long-Term Management Strategy for Dredged Material Disposal for Naval Facilities at Pearl Harbor, Hawaii

Phase II – Evaluation of Alternatives

Paul R. Schroeder, Richard A. Price, Daniel E. Averett,
Roy Wade, Stephen A. Pranger, David C. Neumann,
and Javier Figueroa-González

March 2000

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by Paul R. Schroeder, Richard A. Price, Daniel E. Averett, Roy Wade,
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Preface

This report describes testing and analysis of dredged material from the Pearl Harbor Naval Complex (PHNC) for evaluating the suitability for disposal in an upland CDF on Waipio Peninsula. This work was conducted by the Environmental Laboratory (EL) of the U.S. Army Engineer Research and Development Center (ERDC). Funding was provided, respectively, by the U.S. Navy, Pacific Fleet, and the U.S. Navy, Naval Station (NAVSTA), Pearl Harbor, under Project Orders N0007098MPBA301 and N6281398MP21001. The project manager is Ms. Suzanne Baba of Pacific Division, Naval Facilities Engineering Command (PACNAVFACENGCOM).

This report was written by Dr. Paul R. Schroeder and Mr. Javier Figueroa-González of the Special Projects Group (SPG), Environmental Engineering Division (EED), EL; Mr. Richard A. Price of the Fate and Effects Branch, Environmental Processes and Effects Division, EL; and Messrs. Daniel E. Averett, Roy Wade, and Stephen A. Pranger of the Environmental Restoration Branch, EED, EL. Appendix A of this report was prepared by Dr. Schroeder and Messrs. Averett and Wade. Appendix B was prepared by Messrs. Averett, Wade, Figueroa-González, and Dr. Schroeder. Appendix C was prepared by Messrs. Price and Averett and Dr. Schroeder. Appendix D was prepared by Dr. Schroeder and Mr. Figueroa-González. Appendix E was prepared by Messrs. Price and David C. Neumann, ASCI Corporation, and Dr. Schroeder. Appendix F was prepared by Dr. Schroeder and Messrs. Figueroa-González and Pranger. Appendix G was prepared by Mr. Pranger and Dr. Schroeder. Technical editing was performed by Ms. Cheryl M. Lloyd. Technical review of this report was provided by Dr. Michael R. Palermo and Mr. Thomas R. Patin.

This study was conducted under the direct supervision of Mr. Norman R. Francingues, Chief, EED, and under the general supervision of Dr. John Keeley, Acting Director, EL. Dr. Lewis E. Link, Jr., was Acting Director, ERDC, and COL Robin R. Cababa, EN, was Commander.

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Conversion Factors, Non-SI Units to SI Units of Measurement

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

Multiply	By	To Obtain
acres	4046.873	square meters
acre-feet	1233.489	cubic meters
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
feet per second	0.3048	meters per second
gallons	0.003785412	cubic meters
inches	2.540	centimeters
pounds	0.4535924	kilograms
square feet	0.09290304	square meters
tons	907.1847	kilograms

Long-Term Management Strategy for Dredged Material Disposal for Naval Facilities at Pearl Harbor, Hawaii

Phase II - Evaluation of Alternatives

1 - Executive Summary

The purpose of this report is to document testing and analysis of upland disposal of dredged material unsuitable for ocean disposal from the Naval Station, Pearl Harbor. Phase I of this study identified an upland confined disposal facility (CDF) on the southern end of Waipio Peninsula as the preferred alternative; additionally, disposal in a CDF along the Reef Runway at the Honolulu Airport appeared to be a viable short-term option. The testing included physical and chemical characterization of the sediment to support design/management/operations decision making and contaminant pathway analysis. Additional analyses using characterization data were performed to predict the behavior of the contaminants in various pathways. The analyses were targeted for dredged material disposal in a CDF on Waipio Peninsula but would also be generally appropriate for disposal in the Reef Runway CDF.

Physical characterization included a number of geotechnical tests including grain-size analysis, Atterberg limits, soil classification, specific gravity, moisture content, self-weight and standard oedometer consolidation, and sedimentation testing. Chemical characterization included bulk sediment chemical analysis, toxicity characteristics leaching procedure (TCLP), and ambient water chemical analysis. Pathway testing included the modified elutriate test for effluent quality, the simplified laboratory runoff procedure for runoff quality, and diethylene triamine pentaacetic acid (DTPA) extraction for plant uptake. Using characterization data, leachate quality was predicted based on equilibrium partitioning of the contaminants between the soil and water. Air quality was estimated from computation of contaminant volatilization.

Analyses of effluent and runoff pathways were conducted to examine effects on surface water quality. Analysis of the leachate pathway predicted effects on groundwater and surface water quality. Analyses of volatilization and odor examined effects on air quality. Analysis of plant uptake pathway screened

viable future use of the disposal site or dredged material for habitat or agriculture. The results of TCLP examined the viability of material reuse for any of a number of potential beneficial uses. This evaluation is Phase II of a more comprehensive approach in developing a workable long-term management strategy (LTMS).

The evaluation of environmental effects was performed under the Phase II effort by executing detailed screening procedures using Tier 1 or Tier 2 approaches as outlined in "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments," Assessment and Remediation of Contaminated Sediments (ARCS) Program EPA 905-R96-001 (Myers et al. 1996a). A screening (Tier 1) evaluation of most of the CDF pathways of concern was conducted. An evaluation based on chemical water quality (Tier 2) was conducted for the effluent pathway because a Tier 2 evaluation of the effluent pathway would be required for the State 401 water quality certification. The effluent pathway involves movement of large masses of water for hydraulically filled sites and has the greatest potential for moving significant quantities of contaminants out of CDFs. The results of the Phase II evaluations and the needs for contaminant controls are summarized for each pathway in the following paragraphs.

Chemical evaluation of the effluent pathway was conducted for the Phase II study. Predictions of dissolved concentrations of contaminants in effluent were made using the modified elutriate test (Palermo 1985; Palermo and Thackston 1988; and EPA/USACE 1998). Predicted dissolved concentrations of only arsenic, copper, and selenium exceeded Hawaii marine water quality standards for chronic toxicity at the point of discharge. This set of marine water quality standards for chronic toxicity is a synthesis of the most stringent listed or proposed standards applicable to Pearl Harbor as issued by the Federal government or the State of Hawaii. The concentrations of arsenic, copper, and selenium were similar to the background water concentrations which also exceeded the chronic toxicity standards. The highest ratio of effluent concentration to chronic toxicity standard was 1.42 which was for copper. The Clean Water Act (CWA) regulations (40 CFR 230.11(f)(2) and 40 CFR 230.61 (b)(2)(ii)) provide for a mixing zone for effluent discharge from CDFs. A mixing zone analysis was conducted for the Waipio site using the CDFATE model (Chase 1994 and Havis Environmental 1994), an adaptation of the USEPA CORMIX model (Doneker and Jirka 1990). The maximum required dilution ratio for the effluent to be diluted within 10% of the background concentration is 3.2 which would require a mixing zone length of 140 ft* for the steady flow rate that might be anticipated from a 12-in. hydraulic dredge or pump. The effluent exceeds the Federal marine water quality criteria for chronic toxicity for ammonia, requiring a dilution ratio of 2.66 and a mixing zone length of 130 ft. The effluent also exceeds the State of Hawaii Pearl Harbor Estuary water

* A table of factors for converting non-SI units to SI units is presented on page v.

quality standard for ammonia nitrogen (10 ug/L); this standard was established to control eutrophication in the estuary. To meet the water quality standards for ammonia nitrogen, a dilution ratio of 150 is needed which requires a mixing zone length of 1230 ft for the steady flow rate from a 12-in. hydraulic dredge or pump. Based on these results no contaminant control (treatment) measures for dissolved contaminants in the effluent discharge are warranted if a mixing zone is allowed. Management of the ponded surface area and depth will optimize suspended solids retention and retention of contaminants associated with the suspended solids in the CDF. If a mixing zone is not allowed, mechanical placement of dredged material should be considered; otherwise, denitrification would be required.

An evaluation of the surface runoff chemical water quality using the simplified laboratory runoff procedure (SLRP) for predicting the long-term effects of drying and oxidation on surface runoff water quality was conducted (Price et al. 1998). The results of this test were similar to those for effluent discharge in that the dissolved concentrations of several parameters exceeded Hawaii marine water quality standards for chronic toxicity at the point of discharge. The critical condition for runoff water quality is during discharge from the CDF of excess precipitation off a dried, oxidized surface of dredged material. The runoff quality from the dried, oxidized dredged material surface exceeds Federal or Hawaii marine water quality standards for chronic toxicity by only copper and ammonia; runoff from the wet, reduced dredged material surface does not exceed any marine water quality standard for chronic toxicity. No other exceedances of any toxicity standard were obtained by the runoff pathway. The required mixing zone length for the dried, oxidized dredged material is about 135 ft. Runoff from both the unoxidized and oxidized dredged material surfaces exceeds the State of Hawaii Pearl Harbor Estuary water quality standard for ammonia nitrogen. Runoff from dried, oxidized dredged material would require a mixing zone length of 240 ft for a controlled runoff discharge rate while a mixing zone length of 180 ft would satisfy the dilution required for runoff from wet, unoxidized dredged material. Based on these results, the runoff pathway will be controlled by maintaining the weir board elevations such that surface runoff water will be ponded in the portion of the CDF near the weirs where it can gradually be released following a rainfall event. The maximum rate of discharge would be about 4 cfs, corresponding to 1 in. of discharge from 100 acres per day. Runoff discharges from CDFs having smaller areas would require smaller mixing zones or could be drained at a faster rate, greater than 1 in. per day.

Screening evaluation of the leachate quality and quantity was performed based on equilibrium partitioning and site hydrology. Subsurface drainage from upland CDFs may reach adjacent aquifers or may enter surface waters. There are no drinking water reserves below Waipio Peninsula, and the groundwater at the site is saltwater. The only potential groundwater impact relates to the discharge of leachate to receiving waters. The bulk sediment chemical

concentrations and site conditions at Waipio Peninsula were used to estimate the leachate quality and quantity using the Hydrologic Evaluation of Leachate Production and Quality model (HELPQ) (Aziz and Schroeder 1998). The attenuation by adsorption in the unsaturated zone beneath the CDF is sufficient for the leachate to achieve the Hawaii marine chronic toxicity standards for all of the contaminants except ammonia. For all contaminants except ammonia it will take hundreds of years for the contaminants to reach the groundwater or surface waters. The predicted leachate parameters for ammonia were then used as input to the USEPA MEPAS multimedia model to evaluate the attenuation (adsorption and dispersion) of leachate in saturated site foundation soils prior to discharge to receiving waters (Streile et al. 1996). Additional attenuation by volatilization and biological degradation would further reduce ammonia. The model results were compared to the State of Hawaii marine water quality standards for chronic toxicity and the Pearl Harbor Estuary water quality standard for ammonia nitrogen. All parameters were below the water quality standards. Based on these results, no contaminant controls for leachate to groundwater are warranted.

A diethylene triamine pentaacetic acid (DTPA) extraction procedure was used for the screening prediction of plant and animal uptake of metals (Folsom and Houck 1990). The DTPA extractions indicated that Pearl Harbor dredged material may contribute to elevated levels of cadmium and copper in leafy freshwater plants that may colonize the CDF. Elevated levels of lead may also be of concern for human food production of root vegetables and cereal grains. The predicted uptake of these heavy metals was compared with the predicted uptake from two reference soils taken from the proposed CDF site on Waipio Peninsula. The comparisons showed that the uptake from the dredged material would be about ten times higher than the reference samples. Animal uptake would also be expected to be similarly elevated because animal uptake is strongly correlated with DTPA extraction. These elevated levels of uptake pose some concern for using the dredged material for food production or animal feed production and merit a marginal level of environmental concern, indicating a need for further testing. Therefore, at the end of the service life of the CDF the surficial materials should be tested using plant bioassay tests using a variety of plants selected to represent anticipated use of the site. After the results of the plant bioassay tests are analyzed, appropriate control measures or restrictions will be implemented. These measures could include plant control, use restrictions, capping, phytoremediation, or soil amendments. The levels of uptake pose insignificant environmental concern during the service life of the facility because plant growth and animal inundation are unlikely until the salt has leached from the dredged material. Elution of the salt from the dredged material is a function of the net infiltration through the dredged material; depletion of salt from the top 6 in. of the dredged material should be sufficient for plant growth in 2 to 3 years. Plant growth may occur during the service life because the CDF may be unused for long periods, perhaps 5 years. This plant growth does not pose a significant environmental concern because plant growth

is very slow on Waipio Peninsula due to low rainfall and dry conditions. In addition, using the dredged material to raise the dikes poses insignificant environmental concern, especially considering that vegetation on the dikes will be controlled by mowing.

A screening evaluation of potential volatilization of contaminants to air was made using the method proposed by Thibodeaux in "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments," Assessment and Remediation of Contaminated Sediments (ARCS) Program EPA 905-R96-001 (Myers et al. 1996a). Ponded, wetted, dry, and re-wetted conditions were evaluated. The results of this evaluation were compared to Occupational Safety and Health Administration (OSHA) human health effects levels for workers at the site. The predicted contaminant levels in the air were well below OSHA health effects levels.

The potential for odor problems was also evaluated using testing procedures corresponding to those of the American Society for Testing and Materials (ASTM 1967). Odors are not normally a problem at CDFs and are not normally tested for in dredged materials, but were tested for in this project at the request of the Navy. A panel was used to sample the odors, and the response indicated that there was no strong odor or no objectionable odor for ponded, wet, dry, and re-wetted conditions. The odor was qualitatively described as earthy or musty, essentially the odor of a coastal soil. In addition, air dispersion modeling using a Gaussian dispersion model for a surface source was conducted to estimate dilution and dissipation of volatiles and odors from the site. Predictions were made at intervals of 820 ft (250 m) up to a distance of 4920 ft (1.5 km), equal to the distance from the CDF to most points of the Naval Station. Odors at the site would be decreased 40-fold at 1640 ft (0.5 km) and more than 200-fold at distances greater than 3280 ft (1 km) from the CDF and should not be noticeable.

In summary, disposal of Pearl Harbor dredged material unsuitable for ocean disposal in an upland CDF on Waipio Peninsula is technically feasible. Disposal in an upland CDF poses no significant impacts on human health. Potential contaminant releases by effluent, runoff, plant uptake, and animal uptake pathways pose small environmental impacts that should be acceptable with proper operation, management, and controls. Several contaminant concentrations in the effluent and runoff exceed Hawaii toxicity standards but are similar to the contaminant concentrations in the background site water. The effluent and runoff would only affect organisms in a small mixing zone. Plant and animal uptake of contaminants from the dredged material in a Waipio Peninsula CDF are expected to be elevated over that of the present uptake from Waipio Peninsula soils. The uptake poses limited concerns during operation because the saltwater dredged material will restrict plant and animal growth. Following operation of the site, controls can be implemented to limit contaminant uptake by plants and animals.

2 - Introduction

Background

The Naval Station (NAVSTA), Pearl Harbor, dredges a number of locations throughout the Pearl Harbor Naval Complex (PHNC) intermittently to maintain harbor operations. Dredging is required in both operational areas and in the main navigation channels. Dredging of the operational areas, averaging 75,000 cu yd per year, has typically been performed by mechanical clamshell dredges. Previous maintenance dredging of the main channels, averaging 200,000 cu yd per year, has been performed by the Corps of Engineers hopper dredge *Essayons*. A general layout of the Pearl Harbor channels and facilities is shown in Figure 1.

Recent testing of some sediments at the P-097 submarine berthing pier has indicated that some of the material is unsuitable for ocean disposal because of potential impacts from contaminants present in the sediments. Presently, more than 100,000 cu yd of sediment at NAVSTA Pearl Harbor docks have been identified as unsuitable for ocean disposal. Sediments unsuitable for ocean disposal are primarily in the operational areas. About 30% of the dredged material from the operational areas has been estimated to be unsuitable for ocean disposal based on a remedial investigation (RI) findings on toxicity of surficial sediments (Ogden Environmental 1996). In the main navigation channels only 5% of the dredged material is estimated to be unsuitable for ocean disposal. Dredged material from upper areas of Pearl Harbor is primarily fine-grained lagoonal silt with clay while dredged material from lower channels is primarily sand. Previous chemical analyses performed on Pearl Harbor surficial sediments indicated the presence of low concentrations of metals and some organic contaminants.

The recent finding that some of the dredged material is unsuitable for ocean disposal necessitates finding other disposal alternatives that are practicable, economical, and environmentally sound. These alternatives should provide disposal solutions for the next 30 years and maintain the future viability of naval operations at Pearl Harbor. Development of a long-term management strategy (LTMS) requires investigation of the various disposal alternatives and evaluation of their environmental effects. The Pacific Division, Naval Facilities Engineering Command (PACNAVFACENGCOM) has tasked the U.S. Army Corps of Engineers (USACE) Engineer Research and Development Center (ERDC) to

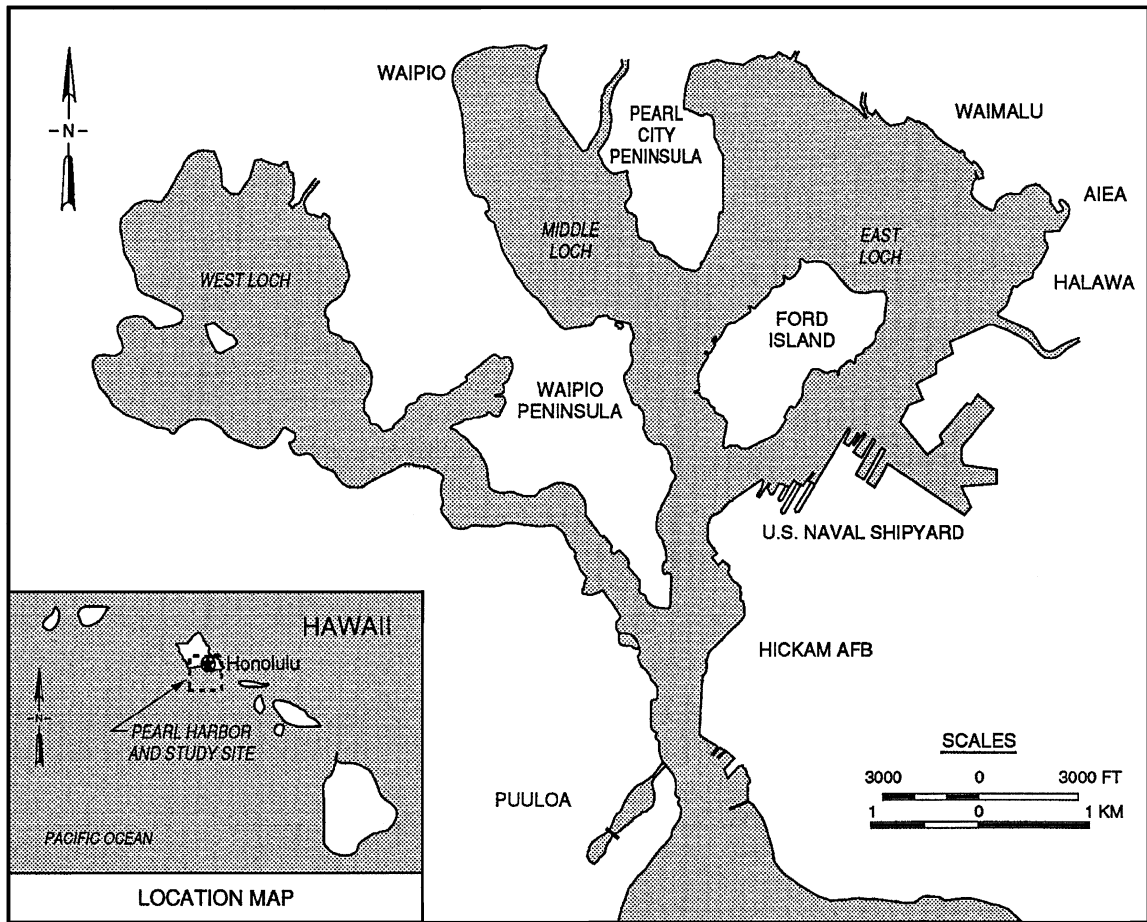


Figure 1. Layout of Pearl Harbor facilities and channels

develop the LTMS for PHNC. This report presents the findings of Phase II of the development of a LTMS for unsuitable dredged material from Pearl Harbor.

In Phase I of this study ten disposal alternatives, including contained aquatic disposal, upland or nearshore confined disposal, and beneficial uses alternatives, were identified for material that is unsuitable for ocean disposal. Several of the alternatives by themselves can provide adequate capacity for the next 30 years; the total required disposal volume for unsuitable dredged material could be as large as 1,600,000 cu yd. In addition, the alternative should be able to handle up to 300,000 cu yd in a single year to support periodic dredging of the main channels and other large areas. The costs of the alternatives are a function of the alternative; some are somewhat higher than open-water disposal, while others are much higher. Most of the alternatives would have high public acceptance and low environmental impacts. Upland disposal in a 124-acre confined disposal facility (CDF) on Waipio Peninsula would be the least costly and most technically feasible and implementable alternative that can accommodate the disposal requirements for the next 30

years or longer. Other alternatives which provide for beneficial use of the dredged material would typically require an upland disposal site as a storage and preparation area prior to implementation of the beneficial use; the Waipio Peninsula alternative could also serve these requirements. Due to the cost of developing the Waipio CDF, it may take a number of years to implement the alternative, and the facility may be constructed in stages as projects require additional storage capacity or retention time for clarification.

Based on the results of this Phase I effort, Phase II was conducted to evaluate the Waipio Peninsula and Reef Runway disposal alternatives. Phase II consisted of environmental and engineering studies including laboratory testing and modeling, determination of design parameters and operating conditions, and identification of data deficiencies.

Objective and Scope

The overall objective of this study is the development of a LTMS for disposal of dredged material unsuitable for ocean disposal from the PHNC. The LTMS will identify needs for additional disposal alternatives including quantities and frequencies of use; will formulate alternatives to accommodate the needs; and will apply the findings of detailed screening procedures. An integral part of this development is the environmental evaluation of dredged material disposal alternatives through the use of screening tools, laboratory testing, and modeling; and the determination of the need for imposing restrictions (operational controls, treatment, or structures) on the disposal alternatives. Evaluation of environmental effects will be performed by executing detailed screening procedures using Tier 1, Tier 2, or Tier 3 approaches as outlined in "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments," Assessment and Remediation of Contaminated Sediments (ARCS) Program EPA 905-R96-001 (Myers et al. 1996a). The approaches to be employed for the disposal alternatives are outlined below.

Tier 1 procedures apply sediment physical and chemical characteristics, management and operations data, and conservative literature contaminant release parameters to contaminant releases from the suite of contaminant pathways. Tier 2 employs sediment physical and chemical characteristics, management and operations data, and chemically based laboratory testing emulating the exposure mechanism. Tier 3 employs sediment physical and chemical characteristics, management and operations data, and biologically based laboratory testing emulating the exposure mechanism. Separate procedures are applied to each contaminant pathway, including water column impacts from initial release including toxicity and bioaccumulation, effluent, runoff, leachate, plant uptake, upland and aquatic animal uptake, and volatilization.

The scope of the study consists of three phases:

- 1) development of viable alternatives taking into consideration cost, existing technology, logistics, environmental concerns, and regulations;
- 2) evaluation of viable alternatives from Phase I by applying screening tools, performing laboratory tests, and numerically modeling the alternatives; and
- 3) analysis and report of evaluation findings as a LTMS report that includes preliminary design, size, need for restrictions and controls, and operations/handling requirements of the recommended and viable alternatives identified by Phase II evaluations.

The purpose of this report is to document Phase II testing. This report includes a review of contaminant loss pathways, laboratory results for contaminant loss testing, modeling and prediction of contaminant fluxes, and recommendations for contaminant loss controls. The LTMS report will support an Environmental Impact Statement or Environmental Assessment by describing the direct environmental impacts of the selected disposal alternatives.

Phase II - Evaluation of Alternatives

Activities associated with the evaluation of appropriate LTMS alternatives are listed next. Details for types and scopes of specific engineering and environmental studies are presented below in the section on testing requirements, based upon the preliminary findings of Phase I. The following tasks were conducted during Phase II.

- a. Perform appropriate environmental and engineering studies necessary to evaluate the preferred, viable dredging and disposal alternative(s) as outlined below in Table 1 for the upland CDF alternative.
- b. Obtain additional data on sediment and water samples and assess characteristics and disposal needs, more cultural/historic resources related to dredged material physical properties for evaluation of range of dredging induced environmental alternatives, beneficial uses, or other options. Conduct site studies for hydraulic analyses, upland, surface and groundwater evaluations, and environmental impact of dredged material disposal. Testing requirements for dredged material evaluation should be consistent with the CE's Regulatory Guidance Letter dated 19 August 1987. (U.S. Army Corps of Engineers Regulatory Guidance Letter, subject: Testing Requirements for Dredged Material Evaluations, dated 19 August 1987 and signed by BG Peter Offringa, Deputy Director of Civil Works.)

TABLE 1. TESTING REQUIREMENTS

Test	Method	Disposal Alternative
Effluent	Flocculent settling test and modified elutriate test.	Upland, Nearshore
Runoff	Simplified laboratory runoff elutriate test.	Upland, Nearshore
Leachate	HELPQ and multimedia screening model predictions.	Upland, Nearshore
Volatilization	Thibodeaux screening model predictions.	Upland, Nearshore
Plant Uptake	DTPA extract test.	Upland, Nearshore
Sedimentation	Zone and compression settling tests.	All
Sediment Characterization	Atterberg limits, specific gravity, grain-size distribution, organic content, in situ moisture content, and bulk chemistry.	All
Consolidation	Self-weight and standard oedometer consolidation tests.	Upland, Nearshore
TCLP	EPA method for toxicity characteristics leaching procedure.	Upland Reuse
Odor	Odor screening and control testing.	Upland

Sampling

The tests listed in Table 1 were conducted on sediment samples obtained in operational areas in and around the Southeast Loch and Magazine Loch shown in Figure 2. Sediment and water samples were collected from three areas. Fifteen gallons of sediment and 5 gallons of water were collected throughout the area between Wharves S-11 to S-12 and Wharf S-20 in Magazine Loch. Ten gallons of sediment and 5 gallons of water were collected throughout the area between Wharf S-9 and Wharves S-21 and Y-2 at the intersection of Southeast Loch and Magazine Loch. Ten gallons of sediment and 5 gallons of water were collected throughout the area enclosed by Wharves B-17 to B-21 in one of the Naval Shipyard repair basins. Areas are depicted in Figure 2 as Area 1, Area 2, and Area 3, respectively. The sediment samples were composited, blended, and divided in eight samples of varying sizes for the sediment characterization and contaminant pathway testing. Similarly, the water samples were composited, mixed, and divided into three samples of varying sizes for chemical analysis, sedimentation testing, and modified elutriate testing. In addition to sediment and water samples, two upland soil samples were taken from Waipio Peninsula to serve as reference soils for contaminant uptake by plants. The reference soil sampling locations are shown in Figure 2 as SC1 and UC1.

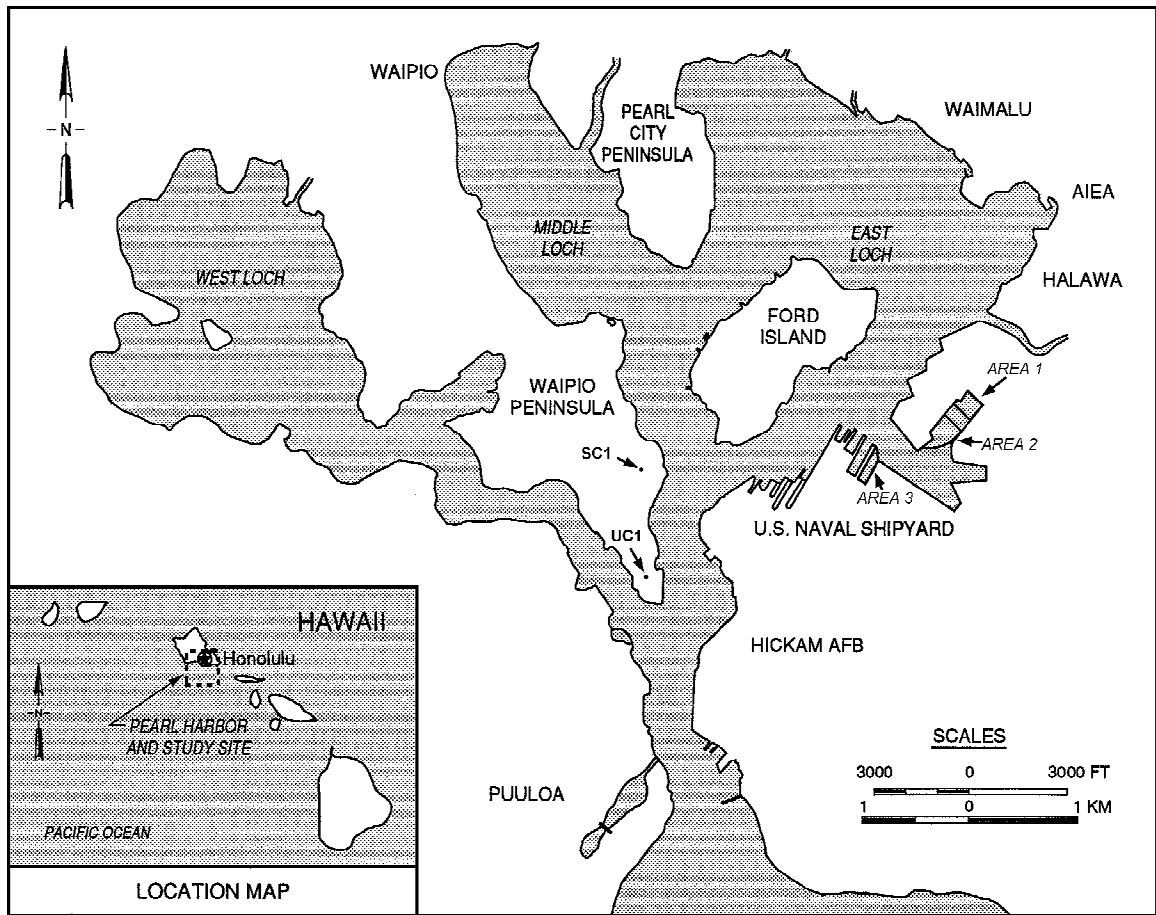


Figure 2. Locations of sediment and water sampling areas and soil samples

3 - Contaminant Loss Pathways for CDFs

Description

Upland confined disposal is placement of dredged material within upland (diked) confined disposal facilities. CDFs are engineered structures designed to retain dredged material solids, and in the case of hydraulic dredging, to provide acceptable suspended solids and/or contaminant concentrations for discharges to receiving waters. A true upland CDF allows for all dredged material fill to be placed above the water table. CDFs constructed in water may become upland sites once the fill reaches elevations above the mean high water elevation. Upland CDFs are not solid waste landfills. They are designed and constructed specifically for disposal of dredged material and normally have a return flow as effluent to waters of the United States. With such return flow, CDFs are regulated under Section 404 of the Clean Water Act.

Most sediment in Pearl Harbor operational areas where the sediment is more likely to be unsuitable for ocean disposal is dredged mechanically with bucket dredges. Barges or scows loaded with dredged material are expected to be offloaded using hydraulic filling. Hydraulic filling methods would include hydraulic slurry from barges filled with mechanical dredges or direct pumpout from hopper dredges.

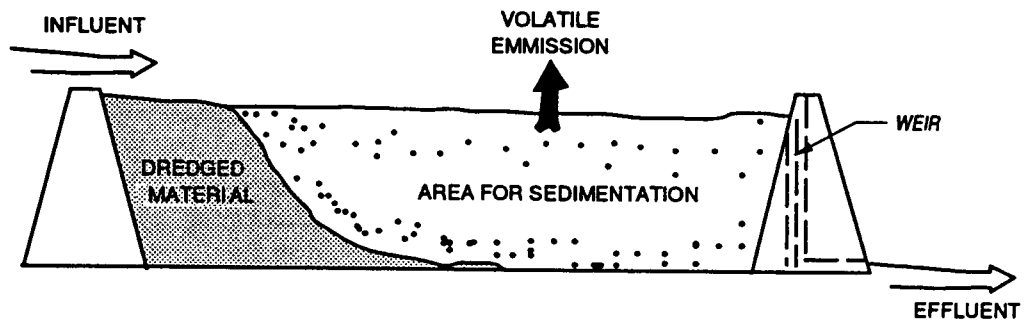
The three objectives inherent in design and operation of CDFs are to provide for adequate storage capacity for meeting dredging requirements, to maximize efficiency in retaining the solids, and to control contaminant releases to within acceptable limits. Basic guidance for design, operation, and management of CDFs is found in EM 1110-2-5027 (USACE 1987).

A principal design criterion of CDFs is to retain as high a percentage of the fine-grained sediment particles as practicable. This principle was based on the findings of the USACE Dredged Material Research Program (Saucier et al. 1978), which showed that most chemical contaminants associated with sediments could be effectively contained through efficient solids containment. Since most contaminants in sediment remain attached to solid particles during dredging and placement in the CDF, this process is reasonably efficient for containment of contaminants.

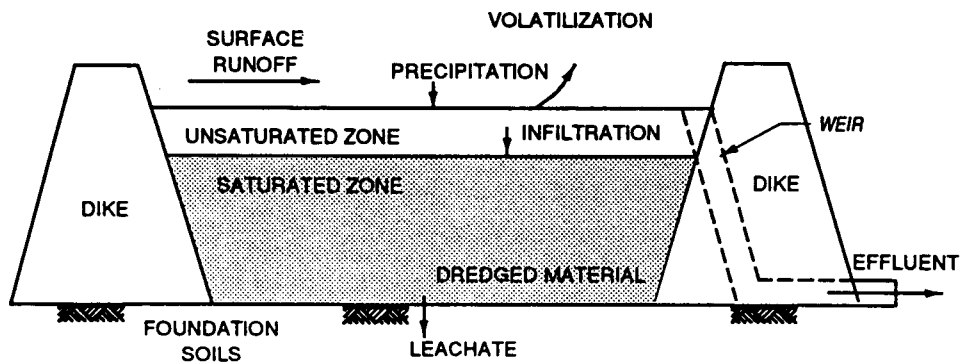
The hydraulic reslurry alternative generally adds several volumes of water for each volume of sediment removed, and this excess water is normally discharged as effluent from the CDF during the filling operation. The amount of water added depends on the design of the dredge or pumpout system, physical characteristics of the dredged material, and operational factors such as pumping distance. When the dredged material is initially deposited in the CDF, it may occupy several times its original volume. The settling process is a function of time, but the dredged material will eventually consolidate to its *in situ* volume or less if desiccation occurs. Adequate volume within the CDF must be provided during the dredging operation to contain the total volume of dredged material, accounting for any volume changes during placement. Design volumes for storage and for suspended solids removal (clarification) are based on column settling tests. These tests were performed during Phase II and will be used for design in Phase III. The descriptions and results of sedimentation and consolidation tests performed for clarification and storage design are presented in Appendix A.

The proposed CDF at Waipio Peninsula will be used over a period of many years, storing dredged material over the design life. Long-term storage capacity of this CDF is therefore a major factor in design and management. Once water is drained from the CDF following active disposal operations, natural drying forces begin to dewater the dredged material, adding additional storage capacity. The gains in storage capacity are therefore influenced by consolidation and drying processes and by the techniques used to manage the site both during and following active disposal operations.

The possible migration pathways of contaminants from confined disposal facilities in the upland environment are illustrated in Figure 3. These pathways include excess carrier water discharged as effluents during filling operations and subsequent settling and dewatering, surface runoff of rainfall, leachate into groundwater, volatilization to the atmosphere, and direct uptake. Direct uptake includes plant uptake and possible biomagnification through food webs and direct uptake by animal populations using the dredged material disposal site. Effects on surface water quality, groundwater quality, air quality, plants, and animals depend on the characteristics of the dredged material, management and operation of the site during and after filling, and the proximity of the CDF to potential receptors of the contaminants. A number of control measures are available to minimize impacts of losses by these pathways. The technical framework (USACE/EPA 1992; Francingues et al. 1985) that identifies standardized testing procedures for dredged materials was used to evaluate contaminant losses and environmental effects associated with a CDF on the Waipio Peninsula and to identify needs for restrictions. The descriptions and results of these contaminant pathway tests and screening procedures are presented in the appendices of this report.



a. during filling operations



b. during dewatering operations

Figure 3. Contaminant pathways from upland CDFs

Upland Geochemical Environment

When dredged material is placed in an upland environment, physical and/or chemical changes may occur (Francingues et al. 1985). The dredged material initially is dark in color and reduced, with little oxygen. Once disposal operations are completed, and any ponded water has been removed from the surface of the CDF, the exposed dredged material will become oxidized and lighter in color. The dredged material may begin to crack as it dries out. Accumulation of salts will develop on the surface of the dredged material and especially on the edge of the cracks. Rainfall events will tend to dissolve and remove these salt accumulations in surface runoff. Certain metal contaminants may become dissolved in surface runoff.

During the drying process, organic complexes become oxidized and decompose. Sulfide compounds also become oxidized to sulfate salts, and the

pH may drop drastically. These chemical transformations can release complex contaminants to surface runoff, soil pore water, and leachate. In addition, plants and animals that colonize the upland site may take up and bioaccumulate these released contaminants. Volatilization of contaminants depends on the types of contaminants present in the dredged material and the mass transfer rates of the contaminants from sediment to air, water to air, and sediment to water.

Pathway Testing and Evaluation

Effluent Discharge

The effluent from a hydraulically or mechanically filled CDF may contain both dissolved and particulate-associated contaminants. A large portion of the total contaminant concentration is tightly bound to the particulates. Effluent from a CDF (return flow to waters of the United States) is defined as a discharge of dredged material. As such, the discharge is regulated under Section 404 of the CWA, which is also subject to Section 401 of the CWA.

Prediction of effluent quality for hydraulically filled CDFs may be made using a modified elutriate test procedure (Palermo 1985; Palermo and Thackston 1988) that simulates the geochemical and physical processes occurring during confined disposal. This test provides information on the dissolved and particulate contaminant concentrations. The column settling test (USACE 1987) used for CDF design provides the effluent solids concentrations. Results of both tests are used to predict a total concentration of contaminants in the effluent. The predicted effluent quality, with allowance for any mixing zone, can be compared directly with water quality standards. Computer programs are also available for data reduction and analysis (Palermo and Schroeder 1991; Hayes and Schroeder 1992, Havis Environmental 1994, and Chase 1994). Results of data reduction and analysis using the EFQUAL and CDFATE models are given in Chapter 4.

Prediction of effluent quality for mechanically filled CDFs is not a well-defined procedure. Results of the modified elutriate test, runoff quality procedure, and leachate quality procedure would be used along with operational data to predict the effluent quality using equilibrium partitioning and solubility relationships. The predicted effluent quality, with allowance for any mixing zone, can be compared directly with water quality standards.

If effluent contaminant concentrations exceed the state's water quality standards for the waterway at the edge of the state allowed mixing zone, appropriate controls should be considered. Control measures available for effluent discharge include improved settling design or reduced flow to the

containment area, chemical clarification or filtration to remove particulate contaminants, and removal or destruction of dissolved contaminants by more sophisticated treatment processes.

Surface Runoff

Immediately after material placement in a CDF and after ponding water is decanted, the settled material may experience surface runoff. Rainfall during this initial period will likely be erosive, and runoff will contain elevated solids concentrations. Geochemically speaking, while the material is wet, the contaminant release is controlled by anaerobic conditions. Once the surface is allowed to dry, the runoff will contain a lesser concentration of solids, but the release is now controlled by aerobic conditions, and release of some dissolved contaminants may be elevated. Runoff quality under anaerobic and oxidized conditions can be predicted using the simplified laboratory runoff procedure (SLRP). Comparison of results with water quality standards and prediction of mixing zone requirements are given in Chapter 4.

If runoff concentrations exceed the state's water quality standards for the waterway at the edge of the state-allowed mixing zone, appropriate controls may include placement of a surface cover or cap on the site, maintenance of ponded water conditions (although this may conflict with other management goals), vegetation to stabilize the surface, treatments such as liming to raise pH, or treatment of the runoff as for effluent (Lee and Skogerboe 1987). Runoff water quality requirements will be a condition of the water quality certification or considered as part of the National Environmental Policy Act (NEPA) process.

Leachate

Subsurface drainage from upland CDFs may reach adjacent aquifers or may enter surface waters. Fine-grained dredged material tends to form its own disposal area liner as particles settle with percolation of water, but consolidation may require some time for this to occur. Since most contaminants potentially present in dredged material are closely adsorbed to particles, the dissolved fraction present in leachates is usually small relative to the total contaminant mass present in the dredged material.

Evaluation of the leachate quality from a CDF must include a prediction of which contaminants may be released in leachate and the relative degree of release or mass of contaminants. In a Tier 1 evaluation prediction of leachate quality is made using bulk sediment chemistry data and partitioning data based on results of modified elutriate tests or runoff quality tests and literature values. Tier 2 procedures are available for prediction of leachate quality which have been developed specifically for application to dredged material disposal sites

(Myers and Brannon 1991; Brannon, Myers, and Tardy 1994; and Myers et al. 1996b). These procedures are based on theoretical analysis and include laboratory batch and column testing.

The testing procedures only give data on leachate quality. Estimates of leachate quantity must be made by considering site-specific characteristics and groundwater hydrology. Computerized procedures such as the EPA Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al. 1994) or the USACE Hydrologic Evaluation of Leachate Production and Quality (HELPPQ) model (Aziz and Schroeder 1998) have also been used to estimate water balance (budget) for dredged material CDFs (Palermo et al. 1989; Francingues and Averett 1988; Aziz, Schroeder, and Myers 1994; USEPA 1996). Predictions of leachate production for a CDF on Waipio Peninsula are presented in Chapter 4.

If leachate concentrations exceed applicable criteria, multimedia or groundwater modeling may be performed to determine whether controls for leachate are needed. These may include proper site specification to minimize potential movement of water into aquifers, dewatering to reduce leachate generation, chemical modifications to retard or immobilize contaminants, physical barriers such as clay and synthetic liners, capping/vegetating the surface to reduce leachate production or collection and treatment of the leachate. Results of multimedia modeling are given in Chapter 4.

Plant and Animal Uptake

Some contaminants can be bioaccumulated in plant tissue and become further available to the food chain. If the contaminants are identified in the dredged material at levels which cause a concern, then prediction of uptake is based on a plant or animal bioassay (Folsom and Lee 1985; Simmers, Rhett, and Lee 1986; Stafford 1988). Appropriate plant or animal species are grown in either a flooded or dry soil condition using the appropriate experimental procedure and laboratory or field test apparatus. Contaminant uptake is then measured by chemical analysis of the biomass (tissue). Growth, phytotoxicity, and bioaccumulation of contaminants are monitored during the growth period in the case of the plant bioassay. Levels of contaminants in the biomass are compared with Federal criteria for food or forage and with ecological risk criteria and guidelines.

The technical framework procedures currently evaluate the plant uptake pathway using both the DTPA (data on contaminant extraction from sediment, dredged material, and soil) and the bioassay procedure (actual plant uptake data) in a tiered approach. The decision-making framework also requires that a reference material (the disposal site or background site determined by Regional Administrative Decision (RAD)) be included for comparison. Ideally, in Tier 1,

the DTPA procedure would be conducted on wet dredged material (the initial sediment sample), dried dredged material (a portion of the sediment sample that has been dried and oxidized), and a reference soil from the disposal environment. The DTPA procedure also provides valuable information about animal uptake. The contaminant concentrations in the DTPA extract are proportional to animal uptake; elevated concentrations indicate elevated animal uptakes. DTPA concentrations of any metal from the dried sample exceeding DTPA concentrations from the reference soil or the wet sample would invoke a RAD. Since site-specific standards for plant and animal uptake do not exist, it is necessary to evaluate the estimated increases in plant and animal uptake from a local or regional perspective to determine the acceptability based on Federal criteria for food or forage or ecological risk criteria or guidelines. Should the DTPA concentration of any metal from the dried test dredged material exceed both the reference and the wet test dredged material, then a Decision for Further Evaluation may require the plant bioassay evaluation in Tier 2. Other considerations under a RAD are also an option prior to Tier 2, such as 1) the number of DTPA extracted metals exceeding wet dredged material or reference sediment, 2) magnitude by which wet dredged material or reference sediment is exceeded, 3) toxicological importance of exceeding metals, and 4) proportion of sediment sampling sites with DTPA extracted metals from dried dredged material exceeding the wet dredged material or reference sediment, unless the test sediment is a composite. The application of the plant bioassay procedure is described in detail in Folsom and Price (1989). Results from the bioassay are evaluated on the basis of plant growth, bioaccumulation of contaminants, and total plant uptake. "Decisions of Further Evaluations and Decisions for Restrictions" are discussed in detail in Lee et al. (1991). Of particular importance is the evaluation of bioaccumulation. Contaminant concentrations are compared to available demonstrated effects levels, FDA-type action levels, or other human health levels. These comparisons provide some rationale for determining restrictions to prevent adverse uptake of contaminants or movement of contaminants to surface soils or into animals through plant uptake.

Evaluation of the plant uptake pathway with DTPA extract data is performed using a computer simulation protocol described in the Technical Note by Folsom and Houck (1990). The computerized program is called the Plant Uptake Program (PUP) and was written to analyze the predicted uptake of heavy metals from dredged material by freshwater plants. Efforts in addition to the procedures described in the above Technical Note were included to address the concerns associated with the possibly drastic physicochemical changes that occur when placing a saltwater dredged material in an upland, freshwater environment. These efforts include the use of oven-drying and oxidation with hydrogen peroxide to rapidly simulate the long-term drying and oxidation effects of exposure to air and drainage. The model requires total dredged material metals concentrations, DTPA extraction, organic matter percentage, and the dredged material pH in the condition of placement (wetland or upland). The

DTPA test description and results for the Pearl Harbor dredged material composite (PHS) and two reference soils from Waipio Peninsula (SC1 and UC1) are presented in Appendix E. The analysis of the results using the PUP model are presented in Chapter 4.

Volatilization to Air

Contaminant transport from in situ sediment to air is a relatively slow process because most contaminants must first be released to the water phase prior to reaching the air. Potential for volatilization should be evaluated in accordance with regulatory requirements of the State and Federal clean air acts. Thibodeaux (1989) discusses volatilization of organic chemicals during dredging and disposal and identifies four locales where volatilization may occur (volatilization is favored in the order of conditions listed):

- Dredged material exposed directly to air.
- Dredging site or other water area where suspended solids are elevated.
- Quiescent, ponded CDF with a low-suspended solids concentration.
- Dredged material covered with vegetation.

In cases where highly contaminated sediments are disposed, airborne emissions must be considered to protect workers and others who could inhale contaminants released through this pathway. Rate equations based on chemical vapor equilibrium concepts and transport phenomena fundamentals have been used to predict chemical flux (Thibodeaux 1989; Semmler 1990). First-generation laboratory tests for prediction of volatile losses have also been developed (Price et al. 1997). Emission rates are primarily dependent on the chemical concentration at the source, the surface area of the source, and the degree to which the dredged material is in direct contact with the air. Predictions of emission rates for Pearl Harbor dredged material are given in Appendix F. Modeling of the dispersion of the volatile emissions is given in Chapter 4.

Odors

Dredged material is composed of mainly fine-grained soils, such as silts and clays, which have a high affinity for many pollutants. Volatile organic chemicals (VOCs) comprise a general class of pollutants with finite vapor pressures and water solubilities that are known to be associated with waterborne soil particles. These VOCs are the dominant sources of odors associated with dredged

material. Dredging disposal operations result in the removal and relocation of in-place polluted dredged material and create conditions that enhance the release of VOCs into the air. The VOCs enter the air primarily as individual molecular species in a vapor state from water or dredged material surfaces.

The general criteria for chemical equilibrium as it applies to pollutants in the natural environment are presented by Thibodeaux (1989). In the case of VOCs associated with dredged material, three phases of matter are involved. The first phase consists of the solid particles that constitute the dredged material, including the subphases of organic matter and mineral matter. The organic matter can be both natural and anthropogenic in origin. The mineral matter is inorganic and includes the sand, silt, and clay fractions. The two other primary phases are the fluids--air and water. The emission of VOCs to air must commence with the proper theoretical chemical equilibrium laws between the three primary phases. A complete description in the case of the locales within a CDF will involve three binary-phase chemical equilibrium conditions and is presented by Thibodeaux (1989).

There are no units or systems by which to express the pollution of air with odoriferous matter; the experts have failed to suggest an acceptable unit and method of measurement or to construct an instrument for objectively measuring smells. Chemical trace-detection methods, such as chromatographic analysis, cannot replace "smelling" tests. The latter, however, are by no means objective, repeatable, or reliable; they depend on human behavior. In many areas no provisions are made by industrial waste manufacturers, or required by law, to prevent smells either from occurring or from spreading to other areas. The same holds true for dredged material disposal operations. However, it would be prudent to take steps to minimize offensive odors, if they occur, in order to placate the surrounding neighbors.

The principal dimensions of an odor are its detection threshold, intensity, and character. A multidescrptor scale from Harrison et al. (1976) contains over 100 descriptors to provide a better resolution of odor character. Panelists smell samples of various sizes or dilutions of the air column and give their estimates of the degree of applicability of each odor descriptor using a score scale of 0 to 5. The source strength ranged from 4 to 100%. The result is a multi-dimensional profile of the odor. The meaning of the scale points is as follows:

- 0 = described quality absent
- 1 = described quality slightly applicable
- 2 = described quality slightly more applicable
- 3 = described quality moderately applicable
- 4 = described quality moderately more applicable
- 5 = described quality extremely applicable

The sniffer test is designed to match anticipated field conditions and disposal operations. A steady wind would be the transport mechanism of any odors that emanated from the disposed material. Initially material would cover a small portion of the site and the rest of the site would be covered by water. Dredged material would settle and excess water would flow out of the site and evaporate due to the high transpiration rate, thus exposing the dredged material directly to the air. Since rain events also occur with some frequency, the material would dry and at times become re-hydrated. Thus, the odor detection test included different water content scenarios. The test sample conditions (scenarios) were as follows:

- a. Dredged material samples covered by water
- b. Samples with free water decanted; Wet
- c. Samples dried (reduced water content); Drying
- d. Dry samples (essentially no water content); Dry
- e. Re-hydrated samples; Re-wet

The procedures and results of odor testing are given in Appendix G. Modeling of odor dissipation by dispersion is presented in Chapter 4.

4 - Modeling and Analysis of Contaminant Pathways

Effluent Pathway

Comparisons with Toxicity Standards

A modified elutriate test was run on the Pearl Harbor sediment composite. The testing and results are given in Appendix B. The elutriate was analyzed for both organic and inorganic contaminants. The elutriate results were compared with the Federal and Hawaii marine water quality standards for acute and chronic toxicity using the EFQUAL (Effluent Quality) module (Palermo and Schroeder 1991) of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) (Schroeder and Palermo 1995). Comparisons were made for all contaminants found in the bulk sediment, the site water, or the elutriate samples. Results of the comparisons using the most stringent toxicity standards (Hawaii marine water quality standards for chronic toxicity) are shown in Tables 2 and 3.

The set of water quality standards termed "Hawaii marine water quality standards for chronic toxicity" is comprised of the synthesis of the most stringent value for each contaminant from applicable listed or proposed standards for acute or chronic toxicity in a marine environment issued in the Federal water quality criteria or the State of Hawaii water quality standards. All of the dissolved organic contaminants were below the analytical detection limit, well below the Federal and Hawaii marine acute and chronic toxicity standards. Most of the heavy metal dissolved contaminant concentrations in the elutriate were observed above the detection limit. However, only copper (17 ug/L) exceeded the acute marine toxicity standard, while arsenic (45 ug/L) and selenium (151 ug/L) exceeded just the chronic marine toxicity standard. The background site water concentration for all three metals also exceeded the chronic toxicity standard. The background site water sample was collected at the same location as the sediment sample. The water quality at the proposed dredged material off-loading facility and at the CDF discharge points would be expected to be similar but somewhat better. The concentrations of copper, arsenic, and selenium in the elutriate were similar to their concentrations in the site water (12 ug/L, 38 ug/L, and 141 ug/L, respectively). Ammonia (1,830 ug/L or 1510 ug/L as $\text{NH}_3\text{-N}$) was also measured above the marine chronic toxicity standard.

TABLE 2. EFFLUENT QUALITY COMPARISONS WITH STANDARDS FOR ORGANICS

Contaminant*	Detection Limit (L) ug/L	Background Conc. (B) ug/L	Predicted Conc. (P) ug/L	Standard (S) ug/L	Required Dilution Ratio (D) and Remarks	Result and Confidence Level
Aldrin	0.050	BD	BD	1.30	D= 0.0	S > P, >99.9%
Benzo(a) Anthracene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
Benzo(a) Pyrene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
Benzo(b) Fluoranthene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
Benzo(g,h,i) Perylene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
Chrysene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
DDT	0.096	BD	BD	0.001	D= 0.0	S > P, >99.9%
DDE	0.00010	BD	BD	1.20	D= 0.0	S > P, >99.9%
Di-2-Ethylhexyl Phthalate	10.	BD	BD	2944.	D= 0.0	S > P, >99.9%
Dieldrin	0.010	BD	BD	0.0019	D= 0.0	S > P, >99.9%
Fluoranthene	10.	BD	BD	13.00	D= 0.0	S > P, >99.9%
Indeno(1,2,3-c,d) Pyrene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%
Lindane	0.050	BD	BD	0.16	D= 0.0	S > P, >99.9%
PCB 1260	0.25	BD	BD	0.03	D= 0.0	S > P, >99.9%
Pyrene	10.	BD	BD	300**	D= 0.0	S > P, >99.9%

* List of contaminants contains only those contaminants detected.

** Individual values are not available; total value for PAHs used.

P - Average dissolved concentration of modified elutriate test replicates

S - Hawaii water quality standard for chronic toxicity

BD - Below Detection

TABLE 3. EFFLUENT QUALITY COMPARISONS WITH STANDARDS FOR METALS AND AMMONIA

Contaminant*	Detection Limit (L) ug/L	Background Conc. (B) ug/L	Predicted Conc. (P) ug/L	Standard (S) ug/L	Required Dilution Ratio (D) and Remarks	Result and Confidence Level
Ammonia Nitrogen	10.	BD	1510.	10.**	D= 150. meets S	P > S, >99.9%
Antimony	3.	BD	11.7	500.	D= 0.0	S > P, >99.9%
Arsenic	2.	38.	45.	36. for As(III)	D= 0.8 meets xB	P > S, 99.8%
Beryllium	1.	BD	BD	10.	D= 0.0	S > P, >99.9%
Cadmium	0.2	BD	BD	9.3	D= 0.0	S > P, >99.9%
Chromium	1.	6.	2.7	50. for Cr(VI)	D= 0.0	S > P, >99.9%
Copper	1.	12.	17.	2.9	D= 3.2 meets xB	P > S, 99.3%
Cyanide	5.	BD	BD	1.0	D= 0.0	S > P, 99.9%
Lead	1.	1.	BD	5.6	D= 0.0	S > P, >99.9%
Mercury	0.2	BD	BD	0.025	D= 0.0	S > P, >99.9%
Nickel	1.	7.	5.3	8.3	D= 0.0	S > P, >99.9%
Selenium	2.	141.	151.3	71.	D= 0.0 xB>P>S	P > S, >99.9%
Silver	1.	6.	0.7	0.92	D= 0.0	S > P, 86.1%
Thallium	0.002	BD	BD	710.	D= 0.0	S > P, >99.9%
Zinc	10.	14.	36.	86.	D= 0.0 S>P>B	S > P, 99.7%

* List of contaminants contains only those contaminants detected.

** Pearl Harbor Estuary water quality standard for eutrophication

P - Average dissolved concentration of modified elutriate test replicates

S - Hawaii water quality standard for chronic toxicity

BD - Below Detection

x = 1.10: Dilution is down to 10% above background since concentration in background site water exceeds water quality standard.

Mixing Zone Requirements

In accordance with the Clean Water Act, discharges from CDFs must meet appropriate water quality standards after allowing for initial mixing. For continuous discharges a small zone of initial dilution may typically exceed the water quality standard for acute toxicity while the water quality standard for chronic toxicity cannot be exceeded outside a larger mixing zone. Based on the required dilutions computed by the EFQUAL module, the mixing zone dimensions needed to obtain the desired dilutions were computed using the CDFATE module (Havis Environmental 1994 and Chase 1994) of ADDAMS. The CDFATE module is based on the USEPA CORMIX models (Doneker and Jirka 1990). The information was based on the fact that the extent of the mixing zone is determined by the contaminant that shows the highest dilution factor. The other data or assumptions used in the analysis are given below in the section entitled assumptions. The results are given in Table 4 which includes the distances at which the concentration of the contaminants fall below the criterion maximum concentration (CMC) or Hawaii marine water quality standard for acute toxicity, and the criterion continuous concentration (CCC) or Hawaii marine water quality standard for chronic toxicity. Ammonia, arsenic, and copper were selected to perform the analysis; selenium was not used because the predicted effluent concentration was within 10% of the background concentration, requiring very little dilution as shown in Table 3. In addition, the mixing zone length required to dilute the effluent concentration of ammonia down to the Pearl Harbor Estuary water quality standard is 1230 ft. The distance that is needed to achieve vertically well-mixed conditions is 1420 ft. The distance to achieve vertically well-mixed conditions is much longer than the required mixing zone indicating that the entire water column depth will not be impacted by the discharge.

TABLE 4. MIXING ZONE REQUIREMENT FOR EFFLUENT DISCHARGES

Parameter	Distance to Achieve Marine WQ Std. for Acute Toxicity ft	Distance to Achieve Marine WQ Std. for Chronic Toxicity ft	Distance to Achieve Pearl Harbor Estuary WQ Std. for Eutrophication ft
Ammonia-N	0	135	1230
Arsenic	0	130	--
Copper	140	140	--

Assumptions

The following input was used in the CDFATE model. The values represent typical values that are characteristic of effluent discharge and the receiving stream that should yield a conservative estimate of the mixing zone requirements.

- The mean depth of the receiving water is 12.00 m (39.4 ft).
- The receiving body of water is narrow.
- The channel geometry is straight and uniform.
- The width of the receiving water is 450.00 m (1476.4 ft).
- Bottom's roughness is represented by Manning's $n = 0.022$.
- The receiving water bottom is excavated, straight, clean, and smooth.
- The main velocity of the receiving water is 0.30 m/s (0.98 fps).
- The average value of the wind speed is between 1.0 and 6.0 m/s (3.3 and 19.7 fps).
- The receiving water density profile is uniform.
- The receiving water density is 1019.00 kg/m³ (63.63 lb/ft³).
- CDF effluent is discharged via a channel.
- Dredged material disposal effluent density is 1019 kg/m³ (63.63 lb/ft³).
- The channel discharge is from the right bank.
- The depth of receiving water at the point of discharge is 4.0 m (13.1 ft).
- The slope of receiving water bottom is 7.7%.
- The channel makes a 45° angle with the receiving water current.
- The discharge of the channel is 0.27 m³/s (9.53 ft³/s), 12-in dredge.
- The channel protrudes a distance of 5.0 m (16.4 ft) into the receiving water.
- The width of channel's bottom is 4.0 m (13.1 ft).
- The depth of the effluent in the channel is 0.60 m (2.0 ft).
- The width of mixing zone is 45 m (147.6 ft).
- The effluent presents a continuous, steady-state discharge.
- Steady-state conditions exist within the receiving water.
- Mixing within the receiving water is assumed to be due solely to hydrodynamic processes.
- The receiving water body can be modeled as a rectangular channel.

Runoff Pathway

Comparisons with Toxicity Standards

A SLRP was run on the Pearl Harbor dredged material composite in its original wet, unoxidized state and in a dried, oxidized state. The testing and results are given in Appendix C. The test samples were analyzed for both

organic and inorganic contaminants. The SLRP results were compared with the Federal and Hawaii marine water quality standards for acute and chronic toxicity using the RUNQUAL (Runoff Quality) module (Schroeder, Gibson, and Dardeau 1995) of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) (Schroeder and Palermo 1995). Comparisons were made for all contaminants found in the bulk sediment, the site water, or the elutriate samples. Results of the comparisons using the Hawaii water quality standards for chronic toxicity are shown in Tables 5 and 6. All of the dissolved organic contaminants were below the analytical detection limit and the Federal and Hawaii marine water quality standards for acute and chronic toxicity. The dissolved concentrations of three of the ten heavy metals in the runoff samples from the wet, unoxidized dredged material were observed above the detection limit. The dissolved concentrations of six of the ten heavy metals in the runoff samples from the dried, unoxidized dredged material were observed above the detection limit. However, only copper (23.3 ug/L) and ammonia (892 ug/L) in the dried, oxidized dredged material exceeded the marine water quality standards for chronic toxicity. Ammonia nitrogen exceeded the Pearl Harbor Estuary water quality standard for eutrophication in both the wet, unoxidized state (212 ug/L) and the dried, oxidized state (735 ug/L).

Mixing Zone Requirements

In accordance with the Clean Water Act, discharges from CDFs must meet appropriate water quality standards after allowing for initial mixing. For continuous discharges a small zone of initial dilution may typically exceed the water quality standard for acute toxicity while the water quality standard for chronic toxicity cannot be exceeded outside a larger mixing zone. Based on the required dilutions computed by the RUNQUAL module, the mixing zone dimensions needed to obtain the desired dilutions were computed using the CDFATE module (Havis Environmental 1994 and Chase 1994) of ADDAMS. The CDFATE module is based on the USEPA CORMIX models (Doneker and Jirka 1990). The information was based on the fact that the extent of the mixing zone is determined by the contaminant that shows the highest dilution factor. The other data or assumptions used in the analysis are given below in the section entitled Assumptions. The results are given in Table 7 which includes the distances at which the concentration of the contaminants fall below the criterion maximum concentration (CMC) or Hawaii marine water quality standard for acute toxicity, and the criterion continuous concentration (CCC) or Hawaii marine water quality standard for chronic toxicity. Ammonia and copper were selected to perform the analysis. The distance to achieve vertically well-mixed conditions is much longer than the required mixing zone indicating that the entire water column depth will not be impacted by the discharge.

TABLE 5. RUNOFF QUALITY COMPARISONS WITH STANDARDS FOR WET, UNOXIDIZED DREDGED MATERIAL

Contaminant	Detection Limit (L) ug/L	Background Conc. (B) ug/L	Predicted Conc. (P) ug/L	Standard (S) ug/L	Required Dilution Ratio (D) and Remarks	Result and Confidence Level
Ammonia-N	10.	BD	212.	10.**	D= 20.2 meets S	P > S, 77.5
Arsenic	2.0	38.	5.9	36.	D= 0.0	S > P, >99.9
Benzo(a) Anthracene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(a) Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(b,k) Fluoranthene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(G,H,I) Perylene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Beryllium	1.0	BD	BD	10.	D= 0.0	S > P, >99.9
Cadmium	0.20	BD	BD	9.3	D= 0.0	S > P, >99.9
Chromium	1.0	6.	2.2	50.	D= 0.0	S > P, >99.9
Chrysene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Copper	1.0	12.	1.1	2.9	D= 0.0	S > P, >99.9
Di-2-Ethylhexyl Phthalate	10.	BD	BD	2944.	D= 0.0	S > P, >99.9
Fluoranthene	10.	BD	BD	13.	D= 0.0	S > P, >99.9
Indeno(1,2,3-c,d) Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Lead	1.0	1.	BD	5.6	D= 0.0	S > P, >99.9
Mercury	0.20	BD	BD	0.025	D= 0.0	S > P, >99.9
Nickel	1.0	7.	BD	8.3	D= 0.0	S > P, >99.9
Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Silver	1.0	6.	BD	0.92	D= 0.0	S > P, >99.9
Zinc	10.	14.	BD	86.	D= 0.0	S > P, >99.9

* Individual values not available; total value for PAHs used.

** Pearl Harbor Estuary water quality standard for eutrophication

P - Average dissolved concentration of SLRP replicates at 500, 5000, and 50000 mg/L suspended solids

S - Hawaii water quality standard for chronic toxicity

BD - Below Detection

TABLE 6. RUNOFF QUALITY COMPARISONS WITH STANDARDS FOR DRIED, OXIDIZED DREDGED MATERIAL

Contaminant	Detection Limit (L) ug/L	Background Conc. (B) ug/L	Predicted Conc. (P) ug/L	Standard (S) ug/L	Required Dilution Ratio (D) and Remarks	Result and Confidence Level
Ammonia-N	10.	BD	735.	10.**	D= 72.5 meets S	P > S, >99.9
Arsenic	2.	38.	2.	36.	D= 0.0	S > P, >99.9
Benzo(a) Anthracene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(a) Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(b,k) Fluoranthene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Benzo(G,H,I) Perylene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Beryllium	1.	BD	BD	10.	D= 0.0	S > P, >99.9
Cadmium	0.2	BD	0.4	9.3	D= 0.0 S>P>B	S > P, >99.9
Chromium	1.	6.	48.3	50.	D= 0.0 S>P>B	P ≠ S, <50.0
Chrysene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Copper	1.	12.	23.3	2.9	D= 8.4 meets xB	P > S, 98.2
Di-2-Ethylhexylphthalate	10.	BD	BD	2944.	D= 0.0	S > P, >99.9
Fluoranthene	10.	BD	BD	13.	D= 0.0	S > P, >99.9
Indeno(1,2,3-c,d)Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Lead	1.	1.	BD	5.6	D= 0.0	S > P, >99.9
Mercury	0.2	BD	BD	0.025	D= 0.0	S > P, >99.9
Nickel	1.	7.	2.4	8.3	D= 0.0	S > P, >99.9
Pyrene	10.	BD	BD	300*	D= 0.0	S > P, >99.9
Silver	1.	6.	BD	0.92	D= 0.0	S > P, >99.9
Zinc	10.	14.	11.6	86.	D= 0.0	S > P, >99.9

* Individual values not available; value for total PAHs used.

** Pearl Harbor Estuary water quality standard for eutrophication

P - Average dissolved concentration of SLRP replicates at 50, 500, and 5000 mg/L suspended solids

S - Hawaii water quality standard for chronic toxicity

BD - Below Detection

x = 1.10: Dilution is down to 10% above background since background exceeds water quality standard.

TABLE 7. MIXING ZONE REQUIREMENT FOR RUNOFF DISCHARGES

Parameter	Distance to Achieve Marine WQ Std. for Acute Toxicity ft	Distance to Achieve Marine WQ Std. for Chronic Toxicity ft	Distance to Achieve Pearl Harbor Estuary WQ Std. for Eutrophication ft
Ammonia-N			
Unoxidized	0	0	180
Oxidized	0	125	240
Copper, Oxidized	135	135	--

Assumptions

The following input was used in the CDFATE model. The values represent typical values that are characteristic of runoff discharge and the receiving stream that should yield a conservative estimate of the mixing zone requirements.

- The mean depth of the receiving water is 12.00 m (39.4 ft).
- The receiving body of water is narrow.
- The channel geometry is straight and uniform.
- The width of the receiving water is 450.00 m (1476.4 ft).
- Bottom's roughness is represented by Manning's $n = 0.022$.
- The receiving water bottom is excavated, straight, clean, and smooth.
- The main velocity of the receiving water is 0.30 m/s (0.98 fps).
- The average value of the wind speed is between 1.0 and 6.0 m/s (3.3 and 19.7 fps).
- The receiving water density profile is uniform.
- The receiving water density is 1019.00 kg/m^3 (63.63 lb/ft^3).
- CDF surface runoff is discharged via a channel.
- Surface runoff density is 1001 kg/m^3 (62.51 lb/ft^3).
- The channel discharge is from the right bank.
- The depth of receiving water at the point of discharge is 4.0 m (13.1 ft).
- The slope of receiving water bottom is 7.7%.
- The channel makes a 45° angle with the receiving water current.
- The discharge of the channel is $0.11 \text{ m}^3/\text{s}$ ($3.88 \text{ ft}^3/\text{s}$), 1-in. storm per day.
- The channel protrudes a distance of 5.0 m (16.4 ft) into the receiving water.
- The width of channel's bottom is 4.0 m (13.1 ft).
- The depth of the discharge in the channel is 0.60 m (2.0 ft).
- The width of mixing zone is 45 m (147.6 ft).

The runoff presents a continuous, steady-state discharge. Steady-state conditions exist within the receiving water. Mixing within the receiving water is assumed to be due solely to hydrodynamic processes. The receiving water body can be modeled as a rectangular channel.

Leachate Pathway

A leachate quality screening was performed for the contaminants present in the dredged material using equilibrium partitioning theory as described in Appendix D. The results are shown in Table 8 where the attenuation factors required in the foundation soils and groundwater are given for the various contaminants. The attenuation factor is the ratio of the pore-water contaminant concentration to the Hawaii marine water quality standard for chronic toxicity. It represents the dilution, dispersion, degradation, or attenuation ratio required to meet the standard. An attenuation factor less than or equal to 1 indicates that the leachate satisfies water quality standard for that contaminant without the need for attenuation; a value greater than 1 indicates a need for attenuation by adsorption, degradation, dilution, or other means. Ammonia, copper, lead, mercury, nickel, silver, DDT, dieldrin, and PCB-1260 exceed the Hawaii marine water quality standard for chronic toxicity in the pore water as leachate initially leaves the dredged material.

The leaching of contaminants from the dredged material through the unsaturated foundation soils to the groundwater was modeled using the HELPQ model. The nine contaminants predicted to exceed the Hawaii water quality standard for chronic toxicity in the initial dredged material pore water were modeled. The model employs equilibrium partitioning coefficients to predict attenuation of the leachate by reversible adsorption in the unsaturated zone beneath the CDF. The partitioning coefficients, developed from the modified elutriate and runoff elutriate procedures and the literature, are given in Appendix D. Volatilization and biological degradation of the contaminants were not modeled; both could be important for ammonia, considering the long travel times. Therefore, the transport and exposure concentration of ammonia are likely to be much smaller than predicted and the modeling is conservative. Pearl Harbor dredged material characterization data and Pearl Harbor site hydrology based on weather data for Honolulu airport were also used as input to the model. The design profile consisted of 7 ft of saturated dredged material underlain by 6.6 ft of silty loam foundation soil. The contaminant transport was modeled for a 100-year simulation period. The HELPQ modeling results are given in Table 9.

TABLE 8. LEACHATE QUALITY SCREENING RESULTS

Contaminant	Hawaii WQ Std. for Chronic Toxicity ug/L	Sediment Composite Contaminant Conc mg/kg	Pore-Water Conc. ug/L	Attenuation Factor
Ammonia-N	10**	1.27	742.	74.2
Antimony	500	1.63	2.27	0.005
Arsenic	36 for As(III)	13.5	18.8	0.523
Beryllium	10	0.632	3.03	0.303
Cadmium	9.3	0.779	1.87	0.201
Chromium	50 for Cr(VI)	128	37.8	0.755
Copper	2.9	588	44.7	15.4
Lead	5.6	150	209.	37.4
Mercury	0.025	1.18	1.65	65.8
Nickel	8.3	74.3	21.9	2.64
Selenium	71	2.0	9.6	0.135
Silver	0.92	1.87	2.61	2.84
Thallium	710	0.2	0.96	0.001
Zinc	86	497	81.7	0.950
Aldrin	1.3	0.0074	0.0020	0.0016
Benzo(a)Anthracene	300*	0.72 J	0.117	0.00039
Benzo(b,k)Fluoranthene	300*	6.78	0.610	0.0020
Benzo(a)Pyrene	300*	3.09	0.278	0.00093
Benzo(G,H,I)Perlyene	300*	1.37 J	0.123	0.00041
Bis(2-Ethyl-Hexyl)Phthalate	2944	1.19 J	0.433	0.00015
Chrysene	300*	1.29 J	0.206	0.00069
DDE	1.2	0.0088	0.00049	0.00041
DDT	0.001	0.047	0.0038	3.76
Dieldrin	0.0019	0.0013 J	0.018	9.35
Fluoranthene	13	1.01 J	0.612	0.047
Indeno(1,2,3-C,D)Pyrene	300*	1.71 J	0.112	0.00037
Lindane	0.16	0.0059	0.0046	0.029
PCB-1260	0.03	0.949	0.0520	1.73
Pyrene	300*	1.06 J	0.278	0.00093

* Individual values not available; values for Total PAHs used.
 ** Pearl Harbor Estuary water quality standard for eutrophication
 J indicates estimated value.

TABLE 9. RESULTS OF HELPQ MODELING OF UNSATURATED ZONE

Parameter	Distance with Exceedances of Hawaii Marine WQ Std. for Acute Toxicity	Distance with Exceedances of Hawaii Marine WQ Std. for Chronic Toxicity	Peak Conc. in Groundwater Within 100 years
Ammonia	0 ft	6 ft; reaches groundwater in about 17 years	1080 ug/L at 24 years
Copper	0.8 ft in 16 years 2.1 ft in 79 years	0.8 ft in 16 years 2.1 ft in 79 years	0.0 ug/L
Lead	0.8 ft in 29 years <1.2 ft in 100 years	0.8 ft in 16 years 2.1 ft in 57 years <3.4 ft in 65 years	0.0 ug/L
Mercury	0 ft	0.8 ft in 1 year 2.1 ft in 27 years 3.4 ft in 57 years 4.7 ft in 95 years	0.0 ug/L
Nickel	0 ft	0.8 ft in 27 years 2.1 ft in 95 years	0.0 ug/L
Silver	0 ft	0.8 ft in 36 years 2.1 ft in 100 years	0.0 ug/L
DDT	0 ft	<0.1 ft in 100 years	0.0 ug/L
Dieldrin	0 ft	<0.8 ft in 100 years	0.0 ug/L
PCB-1260	0 ft	<0.1 ft in 100 years	0.0 ug/L

The results in Table 9 show that only ammonia leaves the unsaturated zone in the first 100 years and requires further attenuation to achieve the Hawaii marine water quality standard for chronic toxicity. The long-term transport and further attenuation of the ammonia in the saturated zone were modeled using the USDOE Multimedia Environmental Pollution Assessment System (MEPAS) developed by Battelle (Streile et al. 1996). Copper, lead, and DDT were also modeled to show the potential for transport and attenuation of other contaminants. The results are given in Table 10. Transport of the contaminants is quite slow due to retardation by adsorption to the soil. Ammonia will take decades to reach surface water, and the other contaminants will take centuries to migrate. Their peak concentrations will be well below any water quality standard.

TABLE 10. RESULTS OF MEPAS MODELING OF SATURATED ZONE

Parameter	Estimated Peak Conc. in Saturated Zone ug/L	Estimated Peak Conc. in Surface Water ug/L	Hawaii Marine WQ Std. for Chronic Toxicity ug/L
Ammonia-N	730 at 24 years	1 at 150 years	10*
Copper	35 at 400 years	0.05 at 10000 years	2.9
Lead	120 at 200 years	2.4 at 4000 years	5.6
DDT	<1 x 10 ⁻¹⁰ at 10000 years	<1 x 10 ⁻¹⁰ at 10000 years	0.001

* Pearl Harbor Estuary water quality standard for eutrophication

Assumptions

The following input was used in the MEPAS model. The values represent values that are characteristic of the Waipio Peninsula geohydrology that should yield a conservative estimate of contaminant transport by the leachate pathway.

Unsaturated Flow.

- The foundation soil is silty loam.
- The depth of the unsaturated zone is 2 m (6.6 ft).
- The saturated hydraulic conductivity is 0.45 cm/hr (0.18 in./hr).
- The effective porosity is 0.463.
- The organic matter content is 0.5%.
- The bulk density is 1.32 g/cm³ (1320 g/L).
- The longitudinal dispersivity is 0.0457.

Aquifer.

- The aquifer depth is 25 m (82.0 ft).
- The soil temperature is 14.4 °C.
- The soil pH is 6.8.
- The distances to receptors are 150, 500, and 1000 m (492, 1640, and 3281 ft).
- The groundwater seepage velocity is 32.3 m/yr (106 ft/yr).
- The hydraulic gradient is 0.0306.
- The retardation coefficient is 16.69.
- The longitudinal dispersivities are 15.00, 50.00, and 100.00 m (49, 164, and 328 ft).
- The transverse dispersivities are 4.95, 16.50, and 33.00 m (16.2, 54.1, and 108.3 ft).
- The vertical dispersivities are 0.0378, 0.125, and 0.250 m (0.124, 0.410, and 0.820 ft).

Source.

The infiltration rate is 17.1 cm/yr (6.74 in./yr).

The area is 404,687 m² (4,356,051 ft²).

The spread is 106.0 m (347.8 ft).

The recharge rate is 0.8560 m/yr (2.81 ft/yr).

The hydrolysis catalyzed rate is 0.0.

The biodegradation coefficient is 0.0 per/yr. (No decay occurs.)

The air diffusion coefficient is 0.0 cm²/s (0.0 in.²/s).

Plant Uptake Pathway

DTPA extracts were run on the Pearl Harbor composited sediment sample (PHS) in its wet, reduced state and in a dried, oxidized state. In addition, DTPA extracts were run on two soils (SC1 and UC1) from Waipio Peninsula to serve as reference materials. The testing and DTPA results are presented in Appendix E. Comparison of DTPA extracts for the reduced dredged material, the oxidized dredged material, and the two reference soils were made using the Plant Uptake Program (PUP) module (Folsom and Houck 1990) of the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) (Schroeder and Palermo 1995). PUP was developed to provide a tool for predicting uptake of heavy metals from freshwater dredged material by freshwater plants. The model requires total sediment metals concentrations, DTPA extraction, organic matter percentage, and the sediment pH in the condition of placement (wetland or upland). DTPA metals concentrations below the analytical method detection limit (MDL) were entered as the MDL value times 0.5.

Decision Criteria

The implications of these results are evaluated according to the DMF (Lee et al. 1991) and described in Folsom and Houck (1990). Comparisons of DTPA metals are based on the following decision criteria:

1. DTPA extractable concentrations of all metals from the oven-dried sediment are *less than or equal to* the reference sediment (Case 1a, Oven Dry PHS \leq Oven Dry Reference) and *less than or equal to* the saturated sediment (Case 1b, All Oven Dry PHS \leq Wet Reference). This leads to a **DECISION OF NO RESTRICTIONS** to protect against contaminant impacts on plants colonizing the dredged material.

2. DTPA extractable concentrations of any metal from the oven-dried sediment is *less than or equal to* the reference (Case 2a, Some Oven Dry PHS \leq Oven Dry Reference) and *greater than* the saturated sediment (Case 2b, Some Oven Dry PHS $>$ Wet PHS) or

3. DTPA extractable concentration of any metal from the oven-dried sediment is *greater than* the reference (Case 3a, Some Oven Dry PHS > Oven Dry Reference) and *less than or equal to* the saturated sediment (Case 3b, Some Oven Dry PHS ≤ Wet PHS). These criteria and criteria 2 lead to a **REGIONAL AUTHORITY DECISION** as to acceptability or need for controls or restrictions.

4. DTPA extractable concentration of any metal from the oven-dried sediment is *greater than* the reference (Case 3a, Some Oven Dry PHS > Oven Dry Reference) and *greater than* the saturated sediment (Case 2b, Some Oven Dry PHS > Wet PHS). This leads to a **DECISION FOR FURTHER EVALUATION** by conducting a plant bioassessment.

The results of the DTPA comparison cases as described above are shown in Tables 11 through 14. The DTPA results are noted as exceeded (EXCD) the comparison or did not exceed (DNEX) the comparison. As shown, As, Cd, Cr, Cu, Pb, Hg, and Zn exceeded all cases comparing the dried PHS to the SC1 reference, Table 11. When the dried PHS is compared to the original wet PHS, Cd, Cr, Cu, Pb, Hg, Ni, and Zn are exceeded. Table 12 shows comparisons with the dried and oxidized PHS. Results were the same except that the extract of As for the dried, oxidized sediment did not exceed that of the SC1 reference. Results of the UC1 reference are shown in Tables 13 and 14. Again the results were the same except that the PHS dried DTPA Ni exceeded the UC1 reference and the PHS dried/oxidized DTPA Ni and As exceeded the UC1 reference.

The results of the comparisons show that PHS DTPA Cd, Cr, Cu, Pb, Hg, and Zn will fail all cases in the decision criterion described above and result in a decision for further evaluation. This generally requires that a plant bioassessment be performed. This may lead to a determination that although the plant metal concentrations exceed the concentrations in the reference sediment or concentrations are elevated after drying and oxidation, the concentrations do not exceed FDA-type action levels or have no ecological importance.

Predicted Plant Metals

The plant metals concentrations and total plant uptake predicted by the PUP program are presented in Table 15. The results indicate that As uptake by plants will be decreased under dried, oxidized sediment conditions. In a previous study, (Folsom et al. 1981) difficulties with chemical interferences prevented analysis of As in DTPA extracts from dried saltwater and freshwater sediments. However, As in *C. esculentus* was lower when grown in dried freshwater sediment compared to the original wet sediment. In Environmental

TABLE 11. RESULTS OF DTPA COMPARISON FOR DRIED DREDGED MATERIAL (PHS) AND REFERENCE SOIL (SC1)

Case	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	No. Exceeded
1a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	7
1b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
2a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	7
2b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
3a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	7
3b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7

TABLE 12. RESULTS OF DTPA COMPARISON FOR DRIED, OXIDIZED DREDGED MATERIAL (PHS) AND REFERENCE SOIL (SC1)

Case	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	No. Exceeded
1a	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	6
1b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
2a	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	6
2b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
3a	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	DNEX	EXCD	6
3b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7

TABLE 13. RESULTS OF DTPA COMPARISON FOR DRIED DREDGED MATERIAL (PHS) AND REFERENCE SOIL (UC1)

Case	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	No. Exceeded
1a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
1b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
2a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
2b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
3a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
3b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7

TABLE 14. RESULTS OF DTPA COMPARISON FOR DRIED, OXIDIZED DREDGED MATERIAL (PHS) AND REFERENCE SOIL (UC1)

Case	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	No. Exceeded
1a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
1b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
2a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
2b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7
3a	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	8
3b	DNEX	EXCD	EXCD	EXCD	EXCD	EXCD	EXCD	DNEX	EXCD	7

TABLE 15. PREDICTED PLANT METAL CONTENT (UG/G) AND TOTAL PLANT UPTAKE (UG)

Metals	Wet Dredged Material		Oven Dry Dredged Material		Oven Dry, Oxidized Dredged Material	
	Content	Uptake	Content	Uptake	Content	Uptake
Arsenic	0.576	0.977	0.324	0.608	0.192	0.467
Cadmium	2.23	49.54	1.95	31.67	2.38	59.43
Chromium	12.33	15.93	9.33	22.10	19.79	143.3
Copper	21.02	178.48	26.04	162.5	25.09	171.35
Lead	2.07	6.86	1.63	9.81	1.65	8.94
Mercury	0.011	-0.382	0.048	-1.59	0.016	-0.608
Nickel	6.04	-20.62	5.32	5.45	6.04	10.26
Silver	na	na	na	na	na	na
Zinc	35.09	1321	44.1	2202	30.5	2212

Laboratory (1987) DTPA extracted As increased from 0.083 to 0.091 mg/kg when Indiana Harbor sediment was dried. Arsenic was not detectable in *C. esculentus* grown in either wet or dried sediment. No adverse effects are expected with As. Predicted Cd concentrations from both wet and dry sediments are above normal leaf concentrations (Table 16) and exceed the action levels listed in Table 17. Predicted Cr approached the phytotoxic leaf concentration; however, the information in Table 16 is based on Cr (III) oxides, not total Cr. Predicted Cu from wet, dried and dried, oxidized sediment exceeds the critical content leaf concentration and exceeds the action level for animal feeds. Drying and oxidation do increase availability of Cu to plants. Predicted plant lead concentrations were somewhat reduced as a result of

drying and oxidation. All of the predicted plant metals concentrations are expressed on a dry weight basis, and some of the action levels are reported on a fresh weight basis. A conservative conversion to dry weight is a factor of 10 (0.1 fresh weight = 1.0 dry weight). Based on this, predicted lead would exceed the action levels for root vegetables and cereal. Although drying and oxidation increased extractable Hg to detectable concentrations, predicted plant Hg is not of concern because it is smaller than the predicted uptake from the reference soils and it is much smaller than FDA action levels. Drying and oxidation did not increase predicted Ni concentrations. Although predicted Ni concentration was above the upper limit of normal leaf concentrations, it was below the critical leaf content. No action level concentrations were available for Ni. Predicted plant Zn concentrations were well within the range of normal leaf concentrations. Prediction equations have not been developed for Ag and all DTPA extracted Ag in this study was below method detection limit (MDL).

Analysis Results

The purpose of the Tier I PUP procedure is to screen sediments for potential problems relating to plant uptake of heavy metals. Failure of the decision criterion invokes the Tier II testing protocol, the Plant Bioassay Procedure. Tier I testing indicated failure for Cd, Cr, Cu, Pb, Hg, and Zn. The PUP results predict that Pearl Harbor sediment may contribute to elevated levels of Cd and Cu in leafy freshwater plants that may colonize or be established in an upland CDF. Elevated levels of Pb may be of concern under limited situations. Uptake of some metals may be minimized by management of selected vegetation and/or use of soil amendments to render metals less

TABLE 16. DEMONSTRATED EFFECTS OF METAL UPTAKE BY PLANTS (MG/KG LEAF CONTENT)

Metals	Normal ^a Leaf Conc.	Critical Content ^b Leaf Conc.	25% Yield Reduction ^c Leaf Conc.	Phytotoxic ^a Leaf Conc.
Arsenic	0.1-1.0	-	-	3-10
Cadmium	0.1-1.0	8	varies	5-700
Chromium (III) oxides	0.1-1.0	-	-	20
Copper	3-20	20	20-40	25-40
Lead	2-5	-	-	-
Nickel	0.1-5	11	50-100	500-1,000
Zinc	15-150	200	500	500-1500

^a Chaney (1983).

^b Davis, Beckett, and Wollan (1978); Davis and Beckett (1978); and Beckett and Davis (1977).

^c Chaney et al. (1978).

**TABLE 17. ACTION LEVELS FOR METALS IN FOODSTUFFS
USED BY VARIOUS COUNTRIES**

Heavy Metals	Source	Commodity	Concentration	References
Copper	Dutch	Animal Feed	20.0 (DW)*	DMAFCMN (1973)
Cadmium	World Health Organization	Root vegetable	0.05 (FW)**	WHO (1972)
		Leafy vegetables	0.10 (FW)	
		Potatoes, cereal	0.10 (FW)	
	Dutch (unofficial)	Single animal feed	0.50 (DW)	European Community (1974)
Mixed animal feed	1.00 (DW)			
Roughage	1.00 -2.00 (FW)			
Mercury	FDA	Wheat seed	1.00 (DW)	FDA (1987)
Lead	World Health Organization	Root vegetable	0.10 (FW)	WHO (1972)
		Cereal	0.10 (FW)	
		Leafy vegetables	1.20 (FW)	
	Britain	All foods	1.00 (FW)	MAFF (1972)
	European Economic Community	Single animal feed	10.0 (DW)	Van Driel, Smilde and Van Luit (1985)
		Mixed animal feed	5.0 (DW)	
Roughage	1.0 - 2.0 (FW)			

* DW is Dry Weight.

** FW Fresh Weight.

available. Use of Pearl Harbor dredged material may be restricted to non-agricultural uses or require placement in nonsensitive habitats to minimize exposure to colonizing plants. Prohibiting plant growth would of course eliminate the plant pathway concerns. Selection of a management option is best determined by the quantitative results that can only be achieved through Tier II testing (plant bioassay for growth and bioaccumulation).

Volatilization and Odor Pathway

A major contaminant loss pathway from a confined disposal facility (CDF) is volatilization. Appendix F presents results of contaminant volatilization, and Appendix G presents the results of odor testing. Odors are predominantly caused by release of volatile organic compounds (VOCs) to the atmosphere.

Volatilization was found to occur at a low level, too small to pose a health or safety hazard. However, the dredged material was found to have a slight to moderate odor, though not particularly objectionable, under dewatering or drying conditions. The odor and volatile compounds will disperse or dissipate as they migrate from the site. An analysis of volatiles dispersion from a CDF on Waipio Peninsula was performed and is reported in this section. Contaminant concentrations and dilution factors were calculated for a 4920-ft (1.5-km) range downwind of the center of the exposed area.

After volatilization has occurred, the emissions or contaminants of concern are dispersed into the air above the CDF. At this point, air dispersion modeling was performed to predict the displacement of contaminants into the areas surrounding the CDF. Air dispersion of the contaminants of concern was modeled using the Gaussian dispersion equation given below with the respective simplifications to describe a ground level source with no thermal or momentum flux. The concentration and the dilution factor were calculated for all contaminants for a 4900-ft (1.5-km) range with increments of 165 ft (50 m) downwind of the center of the CDF. The results at increments of 820 ft (250 m) for ponded conditions are given in Table 18 and for drying conditions in Table 19. The concentration of all volatile contaminants except cyanide was below detection in the ponded water of the CDF as predicted by the modified elutriate test. Several volatiles including pesticides and PAHs are present in freshly drying dredged material. Those contaminants having established volatilization properties are included in Table 19 and are representative of the range of contaminants in the dredged material. Contaminant concentrations decrease around three orders of magnitude during that range, and the dilution factor at the higher limit of the range was about 767.0, vol./vol.

$$C_{x,0,0} = \frac{Q}{\pi \sigma_y \sigma_z u} \quad (1)$$

where

$C_{x,0,0}$ = concentration of pollutants at coordinate x, mg/m³.

Q = emission rate of pollutants, mg/s

σ_y = horizontal standard deviation of pollutant concentration along the centerline of plume, m

σ_z = vertical standard deviation of pollutant concentration along the centerline of plume, m

u = mean wind velocity, m/s

The dilution factor is computed as follows:

$$D = \frac{C_o - C_x}{C_x - C_B} \quad (2)$$

where

C_o = pollutant concentration at center of exposed area, mg/m³

C_x = pollutant concentration at X distance from the center of the exposed area, mg/m³

C_B = pollutant concentration in the background air, mg/m³

TABLE 18. VOLATILES DISPERSION FROM PONDED DREDGED MATERIAL

Parameter	Contaminant Concentration in ug/L at Various Distances from CDF					
	250 m 820 ft	500 m 1640 ft	750 m 2460 ft	1000 m 3280 ft	1250 m 4100 ft	1500 m 4920 ft
Cyanide	7.12e-04	1.27e-04	4.44e-05	2.09e-05	1.16e-05	7.20e-06
Dilution Factor	1 : 6.78	1 : 42.59	1 : 123.6	1 : 263.31	1 : 474.03	1 : 767.12

TABLE 19. VOLATILES DISPERSION FROM DRYING DREDGED MATERIAL

Parameter	Contaminant Concentration in ug/L at Various Distances from CDF					
	250 m 820 ft	500 m 1640 ft	750 m 2460 ft	1000 m 3280 ft	1250 m 4100 ft	1500 m 4920 ft
Aldrin	1.32e-05	2.35e-06	8.23e-07	3.88e-07	2.16e-07	1.33e-07
Chrysene	3.57e-05	6.38e-06	2.23e-06	1.05e-06	5.85e-07	3.62e-07
DDT	8.79e-06	1.57e-06	5.49e-07	2.59e-07	1.44e-07	8.90e-08
Dieldrin	2.10e-07	3.74e-08	1.31e-08	6.17e-09	3.43e-09	2.12e-09
Fluoranthene	2.03e-04	3.62e-05	1.27e-05	5.97e-06	3.32e-06	2.05e-06
Dilution Factor	1 : 6.78	1 : 42.59	1 : 123.6	1 : 263.31	1 : 474.03	1 : 767.12

Assumptions

Total area of CDF is 100 acres.
Available area to each deposit event is 10 acres.
Event occurs every 2 to 3 years.
Exposure period to exposed material is 6 hr.
Exposure period to ponded material is 12 hr.
Air control volume is 50 acre-ft.
Bulk density of dredged material is 0.86 g/cm^3 (860 g/L).
Volatilization is so small that it does not affect dissolved chemical concentration.
Deeper material replenishes the dissolved chemical mass as it volatilizes.
Dredged material begins evaporative drying and volatile chemical emission as soon as it is exposed to air.
The sediment (exposed material) is exposed directly to air and void of vegetative or other cover.
Wind-driven currents are of the order of 3.0% of the wind speed, assuming continuity of shear stresses at the air-water interface.
Average weight of adult is 72.57 kg (160 lb).
Lung ventilation is 28.6 L/min.
Molecular weight of air is 28.97 g/gmol.
Molar volume of air is 24.46 L/gmol.
Gas constant = 0.0821 L-atm/gmol-°K.
All gases present ideal behavior ($Z = 1$).
Atmospheric pressure is 1 atm.
Temperature is 298 °K (77 °F).
Total porosity of settled dredged material is 0.75.
Air-filled porosity is 0.2.
Wind velocity is 2.5 m/s (8.2 fps).
Wind-driven water velocity is 0.075 m/s (0.246 fps).
Contaminant diffusivity in water is $5.00 \text{ cm}^2/\text{s}$ ($1.64 \text{ ft}^2/\text{s}$).

5 - Conclusions

The findings of this Phase II evaluation and their basis can be summarized as follows:

- a. Dredged material from upper areas of Pearl Harbor is primarily fine-grained lagoonal silt with some clay and fine sand, while dredged material from lower channels is primarily sand. The dredged material has high plasticity and is highly compressible. Metals and some organic contaminants are present in the dredged material, but concentrations are low. The organic content of the dredged material is 14.9 percent and in the midrange of typical values for maintenance dredged material.
- b. The results of the TCLP performed on the sediment passed the RCRA criteria. As such, material reuse is viable for any number of potential beneficial uses.
- c. Based on the flocculent settling test, clear effluent with low suspended solids and turbidity can be achieved. The modified elutriate test showed that effluent exceeded the Federal marine water quality standard for chronic toxicity for ammonia by a factor of 2.7 but did not exceed the Federal marine water quality standard for acute toxicity. The Hawaii marine water quality standard for acute toxicity by copper was exceeded by a factor of 4.9, but the predicted effluent concentration was similar to the background site water concentration. The Hawaii marine water quality standards for chronic toxicity by copper, arsenic, and selenium were exceeded by a factor of 4.9, 0.25, and 0.07, respectively. The Pearl Harbor Estuary water quality standard for eutrophication by ammonia nitrogen was exceeded by a factor of 150. The Pearl Harbor Estuary water quality standard for ammonia nitrogen is unusually and inappropriately low for dredged material disposal operations which are infrequent, intermittent, and short-term. In addition, the disposal operation is not adding ammonia to Pearl Harbor; it is increasing its release rate from the sediment.
- d. For a disposal project using a 12-in. pump, Hawaii marine water quality standards for chronic toxicity or near background conditions can be achieved within a mixing zone length of 140 ft. The Pearl Harbor Estuary water quality standard for ammonia nitrogen can be met within a mixing zone length of 1230 ft.

e. A SLRP was run on a sediment composite in its original, wet, unoxidized state and a dried, oxidized state. The SLRP showed that runoff from the wet, unoxidized sediment did not exceed any of the Hawaii marine water quality standards for chronic toxicity. The SLRP showed that runoff from the dried, oxidized sediment exceeded the Federal and Hawaii marine water quality standards for chronic toxicity only for ammonia and copper, ammonia by a factor of 0.8 and copper by a factor of 7. The concentration of copper was about twice the copper concentration in the background site water. The Pearl Harbor Estuary water quality standard for eutrophication by ammonia nitrogen was predicted to be exceeded by a factor of 20 in the runoff from wet, unoxidized dredged material and by a factor of 73 in the runoff from dried, oxidized dredged material.

f. For runoff at a rate of 1 in./day, Hawaii marine water quality standards for chronic toxicity or near background conditions can be achieved within a mixing zone length of 135 ft. The Pearl Harbor Estuary water quality standard for ammonia nitrogen can be met within a mixing zone length of 240 ft.

g. A Tier 1 leachate screening evaluation was performed using equilibrium partitioning theory and modeling of site hydrology. Subsurface drainage from upland CDFs may reach adjacent aquifers or may enter surface waters. There are no drinking water reserves below at Waipio Peninsula, and the groundwater at the site is brackish. The only potential groundwater impact relates to the discharge of leachate to receiving waters. The contaminant concentrations in the pore water under oxidized conditions were estimated to exceed the Hawaii marine water quality standards for acute toxicity by lead and copper and the Hawaii marine water quality standards for chronic toxicity by copper, lead, mercury, nickel, silver, ammonia, DDT, dieldrin, and PCB-1260. The attenuation in the unsaturated zone is predicted to be sufficient for the leachate to achieve the water quality standards for chronic toxicity except for ammonia. Diffusion/dispersion of ammonia nitrogen in the saturated zone decreased the concentration to well below the Pearl Harbor Estuary water quality standard.

h. A diethylene triamine pentaacetic acid (DTPA) extraction procedure was used for a Tier 1 screening prediction of plant and animal uptake of metals (Folsom and Houck 1990). The DTPA extractions indicated that Pearl Harbor dredged material may contribute to elevated levels of cadmium and copper in leafy freshwater plants that may colonize the CDF. Elevated levels of lead may also be of concern for human food production of root vegetables and cereal grains. The predicted uptake of these heavy metals was compared with the predicted uptake from two reference soils taken from the proposed CDF site on Waipio Peninsula. The comparisons showed that the uptake from the dredged material would be about ten times higher than the reference samples. Animal uptake is strongly correlated with DTPA extraction, and therefore animal uptake would be elevated similarly. These elevated levels of uptake pose some concern for using the dredged material for food production or animal feed and

merit a marginal level of environmental concern, indicating a need for further testing. A number of control measures are available to limit the potential environmental impacts.

i. A Tier 1 evaluation of potential volatilization of contaminants to air was made using the method proposed by Thibodeaux in "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments," Assessment and Remediation of Contaminated Sediments (ARCS) Program EPA 905-R96-001 (Myers et al. 1996a). Ponded, wetted, dry, and re-wetted conditions were evaluated. The results of this evaluation were compared to Occupational Safety and Health Administration (OSHA) human health effects levels for workers at the site. The predicted contaminant levels in the air were well below OSHA health effects levels.

j. The potential for odor problems was also evaluated using testing procedures corresponding to those of the American Society for Testing and Materials (ASTM 1967). A panel sampled the odors, and their responses indicated that there was no strong odor or no objectionable odor for ponded, wet, dry, and re-wetted conditions. The odor was qualitatively described as earthy or musty, essentially the odor of a coastal soil. In addition, air dispersion modeling using a Gaussian dispersion model for a surface source was conducted to estimate dilution and dissipation of volatiles and odors from the site. As predicted by the dispersion analysis of the concentration of volatiles in the plume from the CDF, odors at the site would be decreased 40-fold at 1650 ft and more than 200-fold at distances greater than 3300 ft from the CDF. Based on the decreases in odors generated from smaller surface areas, the odors should not be noticeable at distances greater than 1600 ft from the CDF.

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Appendix A - Sediment Characterization -- Chemical and Geotechnical

Introduction

The purpose of this appendix is to document and present the results of sediment characterization including bulk sediment chemistry, toxicity characteristic leaching procedure (TCLP) test results, and geotechnical properties including sedimentation and consolidation test results for a representative composite of sediment samples. In addition to these characterizations, water column chemistry was performed on the site water from the area where the sediment samples were collected. The water quality data are presented in Appendix B with the rest of the testing for effluent quality.

Characterization Objectives

The objectives of sediment characterization were to define the chemical and geotechnical properties of the sediment for assessing contaminant releases and design parameters. The objective of the TCLP test was to demonstrate that potential beneficial use of the dredged material removed from the CDF would not be subject to Resource Conservation Recovery Act (RCRA) standards.

Scope Of Work

The scope of work included performing chemical analyses on the homogenized sediment. An initial screening for contamination was performed to determine if the sediment contained any contaminant at a significant concentration and to identify the contaminants that should be analyzed in the contaminant pathway evaluations. The TCLP test was run to determine the leachability of any contaminant from the sediment under TCLP conditions. Geotechnical characteristics, including grain-size distribution, specific gravity, Atterberg limits, self-weight and standard consolidation properties, and zone and compression settling properties, were also measured.

Laboratory Testing

All chemical analyses for this study were conducted according to SW-846 (USEPA 1986) standard procedures given in Table A1 (American Public Health Association (APHA) 1989). Metals were analyzed using one of the following instruments: Inductively Coupled Argon Plasma (ICP), Perkin-Elmer 5000 (Cold Vapor), and Zeeman 5100. Organic analyses were performed using gas chromatograph/mass spectrometers (GC/MS). The Environmental Chemistry Branch (ECB) at ERDC performed these analyses.

TABLE A1. LABORATORY ANALYTICAL PROCEDURES

Parameter	Analytical Method	Reference
Base/Neutrals/Acid Extractables (BNA)	USEPA Method 8270	SW-846 (USEPA 1986)
Metals	USEPA Method 7470 USEPA 7000 Series/6010	SW-846 SW-846
Pesticides/PCBs	USEPA Method 8080	SW-846
Total Organic Carbon (TOC)	USEPA Method 9060	SW-846
Total Recoverable Petroleum Hydrocarbons (TRPH)	USEPA Method 418.1	EPA-600 (USEPA 1979)
Volatile Organic Compounds (VOC)	USEPA Method 8240	SW-846

Bulk Chemistry

Homogenized samples of the sediment and site water were sent to the ECB in triplicate to determine their chemical characteristics. The sediment and site water were analyzed for total metals; organic priority pollutants including volatiles, total recoverable petroleum hydrocarbons (TRPH), and total organic carbon (TOC); and other constituents of interest to water quality evaluations. Results of these analyses are shown in Tables A2, A3, and A4.

TCLP Test

The TCLP test was used to determine regulatory implications for reuse of the dredged material (40 CFR Part 261). The TCLP was performed according to the USEPA Method 1311 (USEPA 1986). The TCLP test method consists of air-drying and crushing the sediment to pass a 9.5-mm standard sieve. The sample was placed in a 0.5 N acetic acid extract or an acetate buffer extract, depending on the buffering capacity of the soil, at a 20:1 liquid-to-solids ratio.

TABLE A2. BULK CHEMISTRY (SEMIVOLATILES) ANALYSIS OF PEARL HARBOR SEDIMENT COMPOSITE

Parameter	Sediment Concentration, mg/kg		
	Replicate 1	Replicate 2	Replicate 3
Phenol	<1.8	<1.8	<1.8
2-Chlorophenol	<1.8	<1.8	<1.8
2-Nitrophenol	<1.8	<1.8	<1.8
2,4-Dimethylphenol	<1.8	<1.8	<1.8
2,4-Dichlorophenol	<1.8	<1.8	<1.8
4-Chloro-3-Methylphenol	<1.8	<1.8	<1.8
2,4,6-Trichlorophenol	<1.8	<1.8	<1.8
2,4-Dinitrophenol	<4.5	<4.5	<4.5
4-Nitrophenol	<4.5	<4.5	<4.5
2-Methyl-4,6-Dinitrophenol	<4.5	<4.5	<4.5
Pentachlorophenol	<4.5	<4.5	<4.5
Benzoic Acid	<4.5	<4.5	<4.5
2-Methylphenol	<1.8	<1.8	<1.8
4-Methylphenol	<1.8	<1.8	<1.8
2,4,5-Trichlorophenol	<1.8	<1.8	<1.8
Benzyl Alcohol	<1.8	<1.8	<1.8
Bis(2-Chloroisopropyl)Ether	<1.8	<1.8	<1.8
N-Nitroso-Di-N-Propylamine	<1.8	<1.8	<1.8
Nitrobenzene	<1.8	<1.8	<1.8
Isophorone	<1.8	<1.8	<1.8
Bis(2-Chloroethoxy)Methane	<1.8	<1.8	<1.8
2,6-Dinitrotoluene	<1.8	<1.8	<1.8
2,4 Dinitrotoluene	<1.8	<1.8	<1.8
Benzidine	<9.0	<9.0	<9.0
3,3'Dichlorobenzidine	<3.6	<3.6	<3.6
Bis(2-Chloroethyl)Ether	<1.8	<1.8	<1.8
1,3-Dichlorobenzene	<1.8	<1.8	<1.8
1,4-Dichlorobenzene	<1.8	<1.8	<1.8
1,2-Dichlorobenzene	<1.8	<1.8	<1.8
Hexachloroethane	<1.8	<1.8	<1.8
1,2,4-Trichlorobenzene	<1.8	<1.8	<1.8
Naphthalene	<1.8	<1.8	<1.8
Hexachlorobutadiene	<1.8	<1.8	<1.8
Hexachlorocyclopentadiene	<1.8	<1.8	<1.8
2-Chloronaphthalene	<1.8	<1.8	<1.8

(continued)

TABLE A2. continued

Parameter	Sediment Concentration, mg/kg		
	Replicate 1	Replicate 2	Replicate 3
Acenaphthylene	<1.8	<1.8	<1.8
Dimethyl Phthalate	<1.8	<1.8	<1.8
Acenaphthene	<1.8	<1.8	<1.8
Fluorene	<1.8	<1.8	<1.8
Diethyl Phthalate	<1.8	<1.8	<1.8
4-Chlorophenyl Phenyl Ether	<1.8	<1.8	<1.8
N-Nitrosodiphenyl Amine	<1.8	<1.8	<1.8
4-Bromophenyl Ether	<1.8	<1.8	<1.8
Hexachlorobenzene	<1.8	<1.8	<1.8
Phenanthrene	<1.8	<1.8	<1.8
Anthracene	<1.8	<1.8	<1.8
Dibutylphthalate	<1.8	<1.8	<1.8
Fluoranthene	0.77 J	0.64 J	1.61 J
Pyrene	0.98 J	0.87 J	1.33 J
Butylbenzylphthalate	<1.8	<1.8	<1.8
Chrysene	1.16 J	1.19 J	1.53 J
Benzo(a)Anthracene	0.65 J	0.58 J	0.92 J
Bis(2-Ethylhexyl)Phthalate	0.98	1.15	1.43 J
Di-N-Octylphthalate	<1.8	<1.8	<1.8
Benzo(b)Fluoranthene	4.05	4.27	4.04
Benzo(k)Fluoranthene	2.46	2.8	2.72
Benzo(a)Pyrene	3.19	3.13	2.94
Indeno(1,2,3-C,D)Pyrene	1.84	1.71 J	1.57
Dibenzo(A,H)Anthracene	<1.8	<1.8	<1.8
Benzo(G,H,I)Perylene	1.39 J	1.43 J	1.28 J
Aniline	<1.8	<1.8	<1.8
4-Chloroaniline	<1.8	<1.8	<1.8
Dibenzofuran	<1.8	<1.8	<1.8
2-Methylnaphthalene	<1.8	<1.8	<1.8
2-Nitroaniline	<4.5	<4.5	<4.5
3-Nitroaniline	<4.5	<4.5	<4.5
4-Nitroaniline	<4.5	<4.5	<4.5

J indicates estimated value.

(concluded)

**TABLE A3. BULK CHEMISTRY (PESTICIDES/PCBS) ANALYSIS
OF PEARL HARBOR SEDIMENT COMPOSITE**

Parameter	Sediment Concentration, mg/kg		
	Repl. 1	Repl. 2	Repl. 3
Aldrin	0.0082	0.0070	0.0071
A-BHC	<0.0045	<0.0043	<0.0043
B-BHC	0.0051	0.0057	0.0070
G-BHC	0.0011 J	<0.0043	<0.0043
D-BHC	<0.0045	<0.0043	<0.0043
PPDDD	<0.0087	<0.0084	<0.0084
PPDDE	0.0093	0.0083	0.0088
PPDDT	0.067	0.031	0.042
Heptachlor	<0.0045	<0.0043	<0.0043
Dieldrin	0.0013 J	0.0012 J	0.0013 J
A-Endosulfan	<0.0045	<0.0043	<0.0043
B-Endosulfan	<0.0087	<0.0084	<0.0084
Endosulfan Sulfate	<0.0087	<0.0084	<0.0084
Endrin	<0.0087	<0.0084	<0.0084
Endrin Aldehyde	<0.0087	<0.0084	<0.0084
Heptachlor Epoxide	<0.045	<0.0043	<0.0043
Methoxychlor	<0.045	<0.043	<0.043
Toxaphene	<0.11	<0.11	<0.11
PCB-1016	<0.11	<0.11	<0.11
PCB-1221	<0.11	<0.11	<0.11
PCB-1232	<0.11	<0.11	<0.11
PCB-1242	<0.11	<0.11	<0.11
PCB-1248	<0.11	<0.11	<0.11
PCB-1254	<0.11	<0.11	<0.11
PCB-1260	1.018	0.877	0.951
A-Chlordane	<0.0045	<0.0043	<0.0043
G-Chlordane	<0.0045	0.0028 J	0.0027 J

J indicates estimated value.

TABLE A4. BULK CHEMISTRY (AMMONIA NITROGEN, CYANIDE, TOC, SULFIDE, AND METALS) FOR PEARL HARBOR SEDIMENT COMPOSITE

Parameter	Sediment Concentration, mg/kg		
	Repl. 1	Repl. 2	Repl. 3
Ammonia Nitrogen	1.27	<1.62	<1.64
Cyanide	<0.005	<0.005	<0.005
Total Organic Carbon (TOC)	36,800	34,900	36,400
Sulfide	104	212	137
Tributyltin	0.110	0.130	0.100
Tetrabutyltin	<0.0082	<0.0085	<0.008
Dibutyltin	0.035	0.047	0.032
Monobutyltin	0.0083	0.0092	0.0084
Antimony	1.63	1.58	1.67
Arsenic	14.3	12.9	13.3
Beryllium	0.599	0.599	0.699
Cadmium	0.729	0.829	0.779
Chromium	130	125	129
Copper	591	547	626
Lead	142	140	167
Mercury	1.37	1.07	1.10
Nickel	74.4	76.4	72.1
Selenium	1.8	2.3	1.9
Silver	0.799	2.20	2.60
Thallium	0.2	0.2	0.2
Zinc	511	478	502
Aluminum	34,800	35,100	34,800
Barium	33	29.5	30.8
Calcium	148,000	131,000	160,000
Cobalt	25.5	23.8	24.3
Iron	50,100	48,900	50,100
Magnesium	16,100	16,600	15,800
Manganese	586	546	570
Potassium	3,270	3,320	3,230
Sodium	28,900	33,100	24,600
Vanadium	86.9	81.5	83.2

The sediment and extract were placed in 1-gal glass jars and tumbled end-over-end. After 18 hr of tumbling, the samples were filtered using a Whatman GF/F 0.75- μ m filter. The filtered extracts were placed in precleaned sample bottles and stored at 4°C prior to analysis. The TCLP extracts were analyzed for the contaminants of concern.

TCLP Test Results

The TCLP extracts were prepared using Method 1311 and were analyzed by ECB. The TCLP extract result shows that all of the analyte concentrations were below detection limits except barium, chromium, and lead. The TCLP concentrations and the regulatory limit from the Federal Register (Vol 55, No. 61, 29 March 1990) are presented in Table A5. The Pearl Harbor TCLP concentrations were below the regulatory limits for all parameters.

Geotechnical Characteristics

Geotechnical characteristics of the dredged material are important in the design of a confined disposal facility (CDF). Descriptions of geotechnical and engineering testing are given below. Average geotechnical characteristics for Pearl Harbor sediment are presented in Table A6. Using the Unified Soil Classification System, the sediment was classified to be a gray sandy clay (CH) of high plasticity and compressibility.

Specific Gravity. Specific gravity (SG) of the particulates in the sediment was measured using the procedures given in the Laboratory Soils Testing Engineer Manual (USACE 1970). The average specific gravity was 2.89.

Water Content. The in situ water content (W) of fine-grained sediment samples is also an important parameter in evaluating settling behavior and the volumetric changes occurring following dredging and disposal. It should be noted that the water content as used here is the term normally used in geotechnical engineering, defined as the ratio of weight of water to weight of solids expressed as a percent. Water contents so defined can exceed 100 percent. The procedures are given in the Laboratory Soils Testing Engineer Manual (USACE 1970). Using the specific gravity and water content, the void ratio (e) and solids concentration (S) can be computed as follows:

$$e = \frac{W * SG}{100}$$

$$S = \frac{1000 SG}{1 + e}$$

TABLE A5. TCLP RESULTS FOR PEARL HARBOR SEDIMENT COMPOSITE

Analyte	*TCLP Conc., mg/L	Regulatory Limit, mg/L
Arsenic	<0.020	5
Barium	0.365	100
Cadmium	<0.005	1
Chromium	0.002	5
Lead	0.036	5
Mercury	<0.0002	0.2
Selenium	<0.050	1
Silver	<0.0010	5
Lindane (G-BHC)	<0.000054	0.4
Heptachlor	<0.000054	0.008
Endrin	<0.00011	0.02
Heptachlor Epoxide	<0.000054	-----
Methoxychlor	<0.00054	10
Chlordane	<0.00054	0.03
Toxaphene	<0.00027	0.5
2,4,6-Trichlorophenol	<0.050	2
Pentachlorophenol	<0.12	100
2-Methylphenol	<0.050	5
4-Methylphenol	<0.050	200
2,4,5-Trichlorophenol	<0.050	400
Nitrobenzene	<0.050	2
2,4-Dinitrotoluene	<0.050	0.13
1,4-Dichlorobenzene	<0.050	7.5
Hexachloroethane	<0.050	3
Hexachlorobutadiene	<0.050	0.5
Hexachlorobenzene	<0.050	0.13
Pyridine	<0.050	5

* Denotes average concentration for metals

TABLE A6. SEDIMENT PHYSICAL CHARACTERISTICS

Characteristic	Value
Specific Gravity	2.89
Solids Concentration (in situ)	
Water content	170.8 percent
Void ratio	4.94
Solids (particulate) concentration	442 g/L
Organic Matter	14.9 percent
Atterberg Limits	
Liquid limit	100
Plastic limit	37
Plasticity index	63
Grain-Size Distribution	
Percent sand	15
Percent silt	73
Percent clay	12
Classification	Gray Sandy Clay (CH)

Organic Matter. Organic matter (OM) was determined by weight loss on ignition at 550°C on upland sediment using USEPA Method 8240 of SW-846 (USEPA 1986).

Plasticity. Liquid limit (LL) and plastic limit (PL) were determined for composite sediment sample using standard soils testing procedures as outlined in the Laboratory Soils Testing Engineer Manual (USACE 1970). The plasticity index (PI) was then computed; $PI = LL - PL$.

Grain-size Distribution. Grain-size distributions were determined on the samples using standard sieve and hydrometer analyses as outlined in the Laboratory Soils Testing Engineer Manual (USACE 1970). A grain-size curve is shown in Figure A1.

USCS Classification. Visual classifications and classifications using results of the grain-size distribution and plasticity tests as described below were determined using the Unified Soil Classification System (USCS) as outlined in the Laboratory Soils Testing Engineer Manual (USACE 1970).

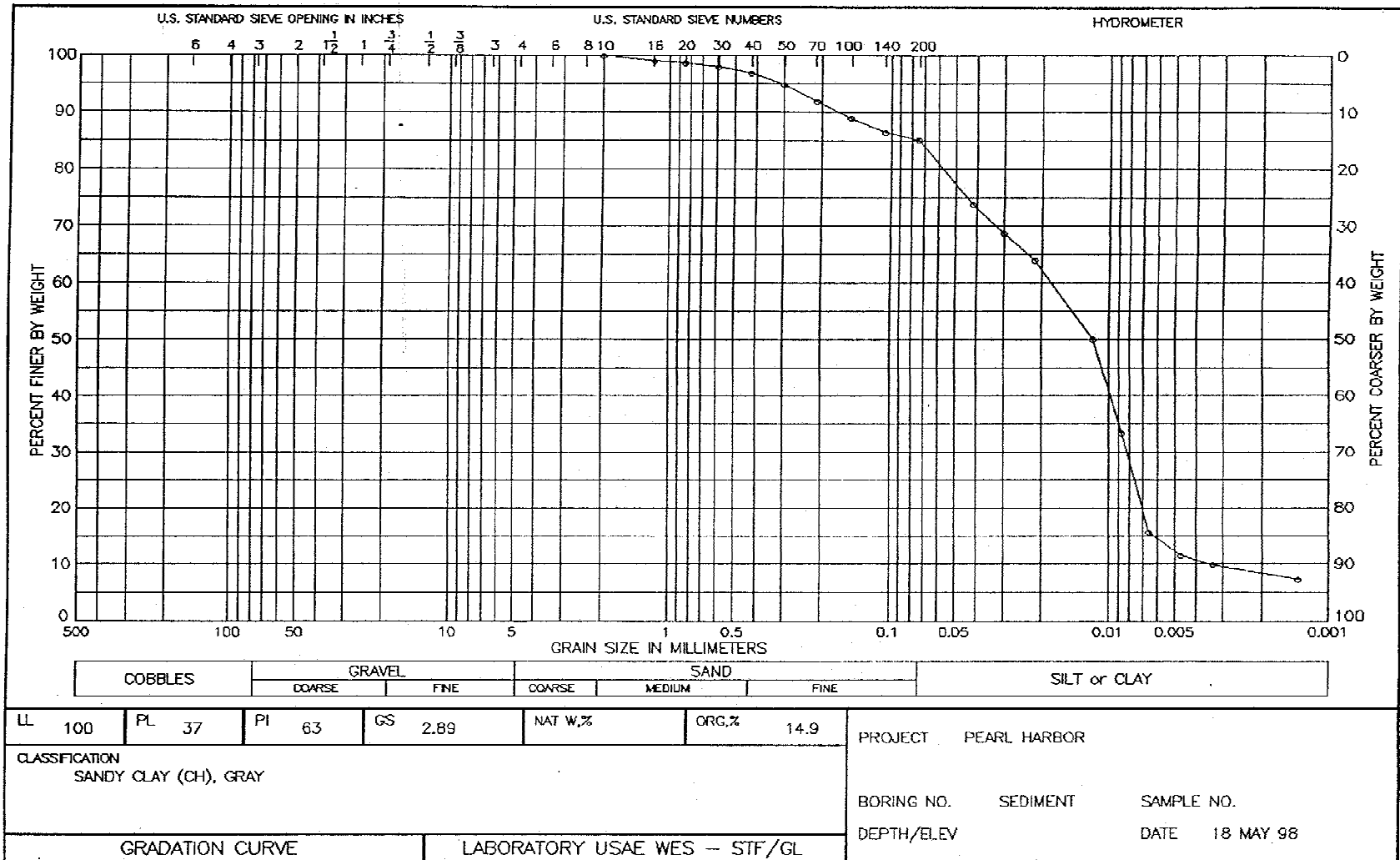


Figure A1. Grain-size distribution of Pearl Harbor sediment composite

Settling Test Experimental Procedures

Sediment removal is required to maintain navigable waterways in Pearl Harbor. One disposal alternative being considered for the Pearl Harbor dredged material is hydraulic placement in an upland CDF. The design of the facility requires an evaluation of the settling behavior and properties of the dredged material in order to estimate the storage requirements and to promote good settling within the CDF. Using the column settling test results, the storage capacity of a CDF can be determined based on compression settling data.

Samples of sediment and site water were collected from potential dredging areas and used to conduct the column settling tests. The settling tests followed procedures found in Palermo et al. (1978), EM 1110-2-5027 (USACE 1987), Palermo and Thackston (1988), and Montgomery et al. (1983). The tests involved mixing sediment and site water to simulate a dredged material slurry, placing the material in a settling column, and observing the settling behavior (i.e., discrete, zone, compression, and flocculent). The general procedures are described below.

Zone, compression, and flocculent settling data were collected by conducting a settling test for the composite samples. The three types of settling data were collected from a single settling test. The zone and compression settling tests are presented in this appendix while the flocculent settling test is presented in Appendix B.

Slurry preparation. The target slurry concentration selected for the settling test was 100 g/L considered representative of the inflow concentration for hydraulic filling. The slurry was prepared by mixing the Pearl Harbor composite sediment with water prepared to have a salinity of 33.8 parts per thousand. The average solids concentrations for the sediment samples prior to mixing were 442 g/L (Table A7). To achieve the target slurry concentration for the composite materials, approximately 16 liters of sediment were mixed with 54 liters of site water using a Lightning mixer in a large container. The average slurry concentration after mixing was 107 g/L (Table A7). The slurry was transferred into an 8-in.-diameter, 7-ft column, with ports at 0.5-ft intervals starting at the 7.0-ft height (see Figure A2).

Zone Settling. The zone settling test consisted of placing the slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as height of the interface versus time. The slope of the curve in the constant velocity settling zone is the zone settling velocity, which is a function of the initial slurry concentration. The zone settling velocity is used in the design process to determine the minimum ponded area required for a given flow rate.

TABLE A7. TOTAL SOLIDS CONCENTRATIONS FOR SETTLING TESTS

Sediment Concentration, g/L			
Replicate 1	Replicate 2	Replicate 3	Average
440.9	444.8	439.8	441.8
Slurry Concentration, g/L			
Replicate 1	Replicate 2	Replicate 3	Average
106.1	117.7	97.0	106.9

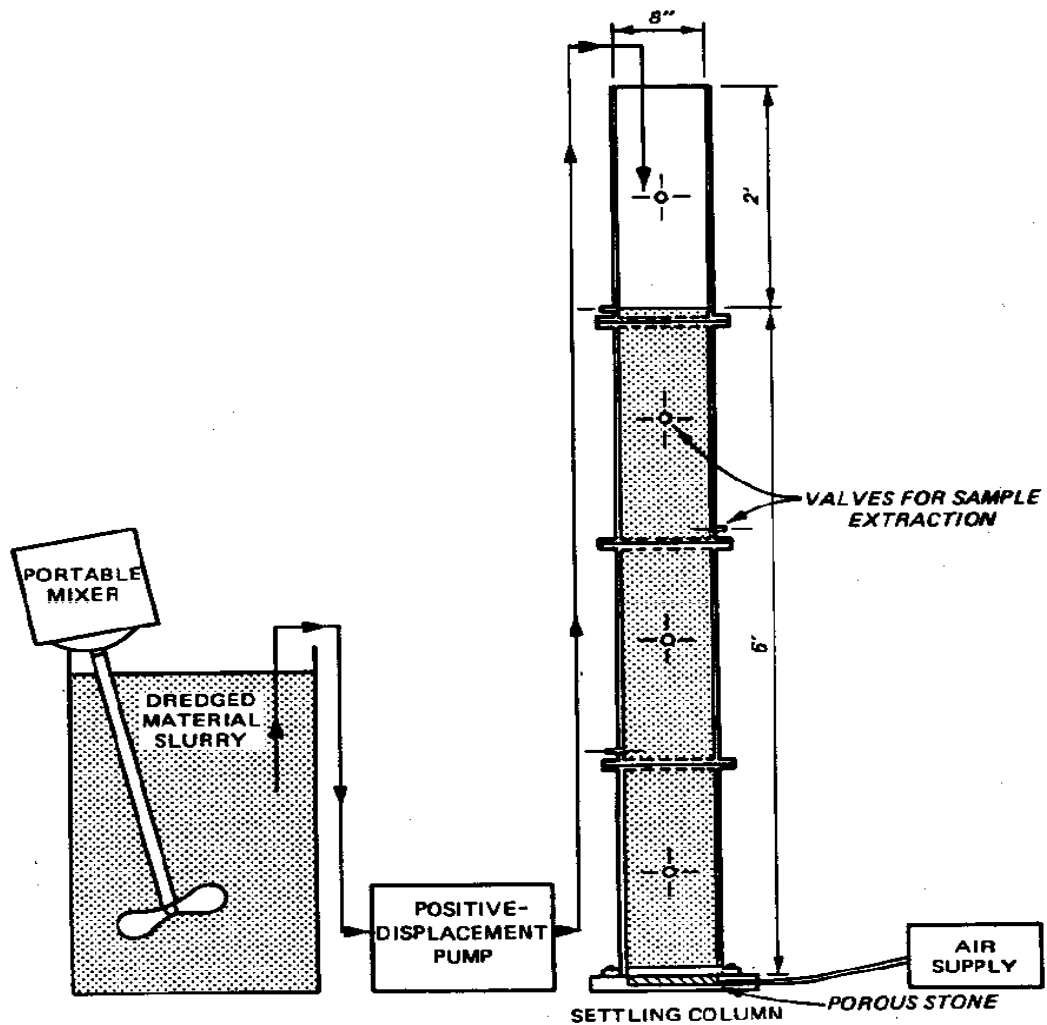


Figure A2. Schematic of settling column

The zone settling test was performed concurrently with the compression settling test on the same slurry. Zone settling typically occurs during the first 12 hours of a dredged material settling test and compression settling occurs after the first 24 hours of the dredged material settling test. The height of the interface was read periodically during the first 9 hours with sufficient frequency to define the zone settling velocity. From the plot of the height of interface (ft) versus time (hr), zone settling velocity was determined.

Compression Settling. The compression settling test must be run to obtain data for estimating the volume required for initial storage of the dredged material. For slurries exhibiting zone settling, the compression settling data can be obtained by continuing the zone settling test for a period of 15 days during which a relationship of log of concentration versus log of time in the compression settling range is observed (USACE 1987). The height of the interface was measured for 15 days at 1- to 2-day intervals, and these data were used for the compression settling analysis.

Sedimentation Data Analysis and Results

The behavior of Pearl Harbor sediment at slurry concentrations equal to that expected for inflow to a CDF is governed by zone settling processes. The sediments exhibited a clear interface between settled material and clarified supernatant.

The settling test data were analyzed using the Automated Dredging and Disposal Alternatives Management System (ADDAMS) (Schroeder and Palermo 1995) which is a family of computer programs developed at ERDC to assist in planning, designing, and operating dredging and dredged material disposal projects. The SETTLE module of ADDAMS was used for the settling test data (Hayes and Schroeder 1992).

Column Settling Tests

Zone settling test. Zone settling velocity for the Pearl Harbor composite sample was determined to be 0.275 ft/hr for the zone settling test. Heights of the interface and their corresponding time intervals (Table A8) were entered into a plotting routine (SETTLE) used to determine the zone settling velocity. When the zone settling curve departs from a linear relationship, compression settling begins (Figure A3). The transition from zone to compression settling occurred between 10 and 12 hours (Figure A3).

TABLE A8. ZONE SETTLING TEST DATA

Time	Time Interval, hr	Interface Height, ft
0825 28 April 1998	0.00	6.37
0845	0.33	6.33
0855	0.50	6.28
0910	0.75	6.19
0925	1.00	6.12
0940	1.25	6.02
0955	1.50	5.95
1010	1.75	5.88
1025	2.00	5.81
1040	2.25	5.73
1055	2.50	5.66
1110	2.75	5.59
1125	3.00	5.52
1155	3.50	5.36
1210	3.75	5.33
1225	4.00	5.27
1325	5.00	5.02
1355	5.50	4.89
1425	6.00	4.74
1510	6.75	4.54
1525	7.00	4.47
1540	7.25	4.42
1555	7.50	4.35
1605	7.67	4.29
1710	8.75	3.97
1725	9.00	3.89
1750	9.42	3.77
2225	14.00	3.16

Note:

The initial slurry height was 6.37 ft.

The slurry concentration was 106.9 g/L.

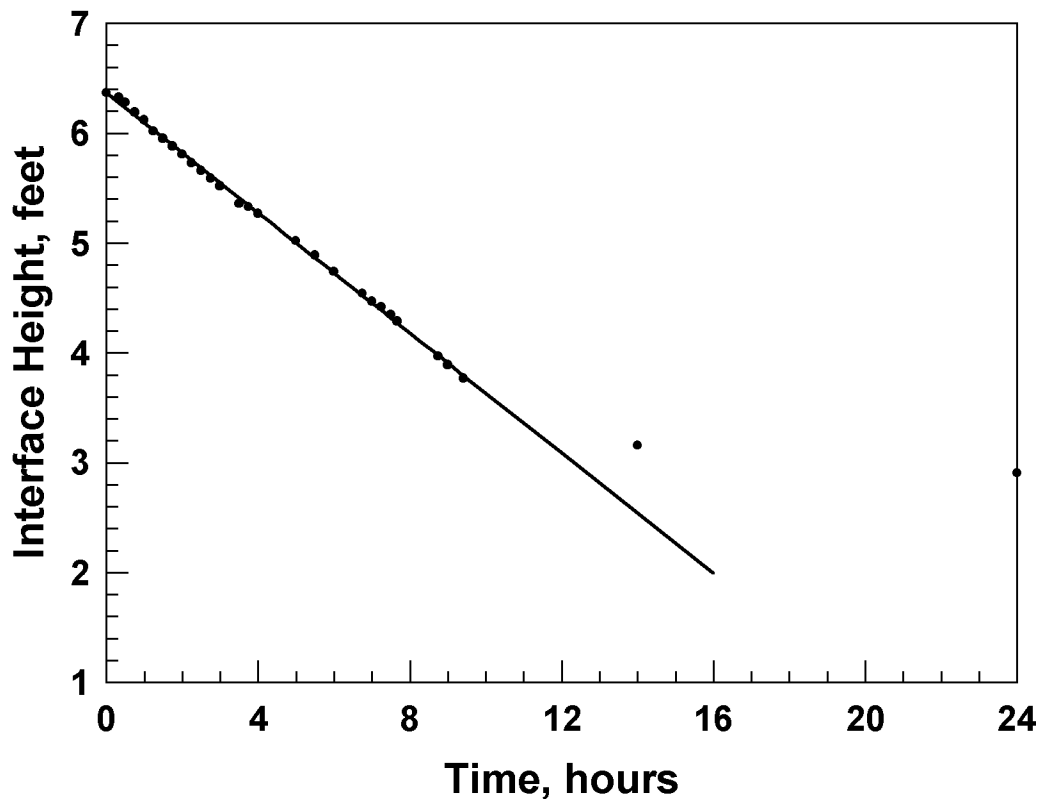


Figure A3. Pearl Harbor zone settling velocity curve

Compression settling test. For the compression settling test, the initial slurry concentration and height, and height of the interface versus time were entered into SETTLE (Table A9). The SETTLE program used the initial slurry concentration of 107 g/L and height of 6.37 ft to determine the solids concentration at a given time. A plot was generated showing the relationship between solids concentration (g/L) and retention time (days) (Figure A4). ADDAMS also developed a regression equation for the resulting power curve relating solids concentration to time. The composite sample regression equation may be used to determine the solids concentration at any given time. The regression equation used was:

$$C = 234 \times T^{0.163}$$

where

C = solids concentration, g/L
 T = time, days

TABLE A9. COMPRESSION SETTLING TEST DATA

Date	Time	Time Interval, hr	Time Interval, days	Interface Height, ft
28 April 1998	0825	0.00	0.00	6.37
29 April 1998	0825	24.00	1.00	2.91
30 April 1998	0825	48.00	2.00	2.61
02 May 1998	0825	96.00	4.00	2.32
04 May 1998	0825	144.00	6.00	2.16
05 May 1998	0825	168.00	7.00	2.10
06 May 1998	0825	192.00	8.00	2.06
08 May 1998	0825	240.00	10.00	1.99
09 May 1998	2225	278.00	11.58	1.95
11 May 1998	0825	312.00	13.00	1.92
13 May 1998	0825	360.00	15.00	1.89

Note: The initial slurry height and slurry concentration were 6.37 ft and 106.9 g/L, respectively.

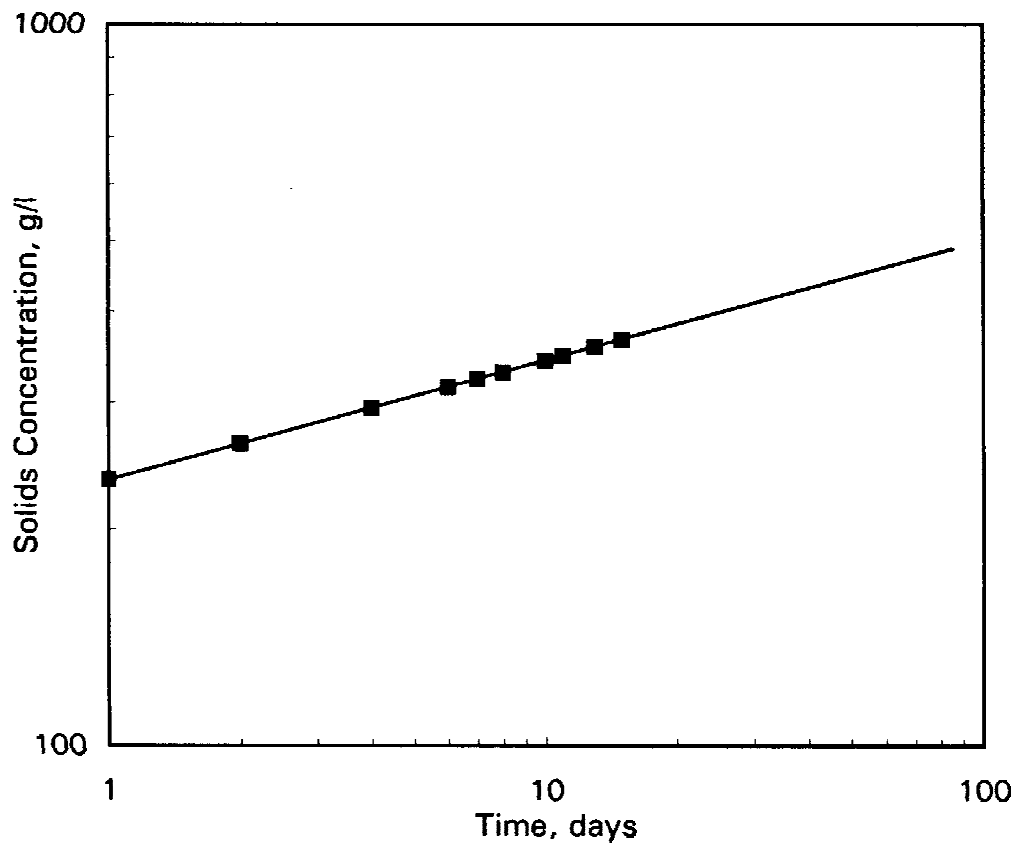


Figure A4. Compression settling curve

Consolidation Tests

This section presents the results of consolidation testing conducted using the composite sample of Pearl Harbor sediment. The test provides data for evaluation of filling and settlement rates for confined disposal facilities. The test results are applicable for evaluation of both intertidal and upland sites. The tests were conducted using standard oedometers and self-weight consolidation test procedures developed specially for soft sediments (Cargill 1983).

The results of the self-weight consolidation test are shown in Figure A5 where the consolidation of a 6-in. sample is plotted as a function of time. The self-weight consolidation test provides data for the initial period of consolidation including the period of compression settling. The time curves from the standard oedometer consolidation tests for six loadings (0.01, 0.02, 0.04, 0.08, 0.16, and 0.32 tons per square feet) are plotted in Figure A6. The void ratio versus the effective stress relationship from the standard oedometer test is plotted in Figure A7. The standard oedometer test provides data for consolidation of thick layers or layers of dredged material with a desiccated crust. The combined relationship of void ratio versus the effective stress from the standard oedometer test and the self-weight test is plotted in Figure A8.

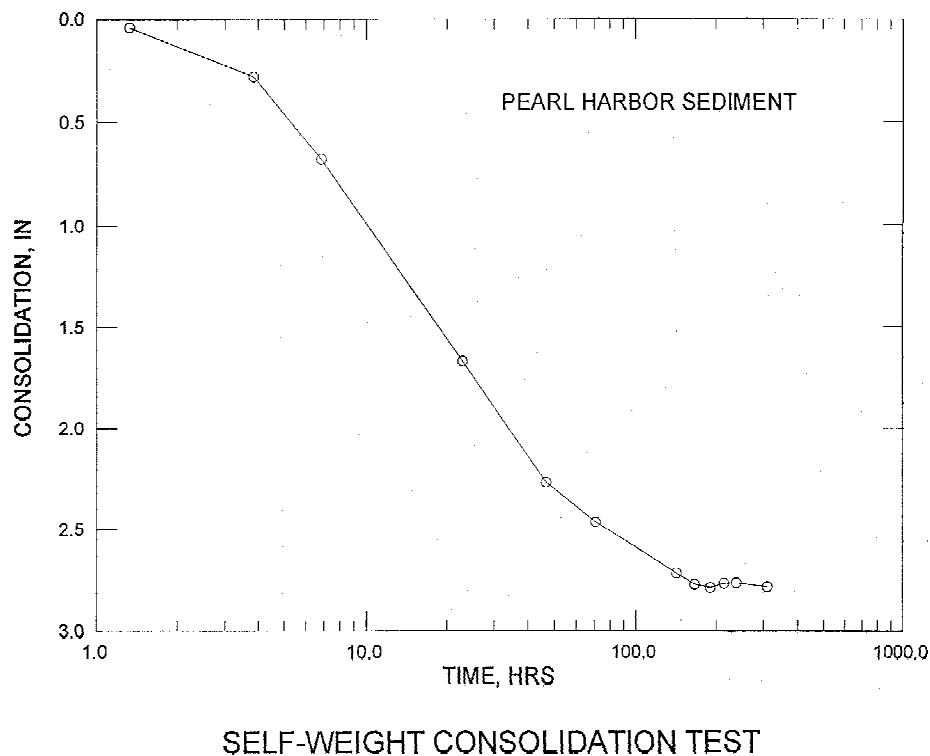


Figure A5. Self-weight consolidation test results for Pearl Harbor sediment

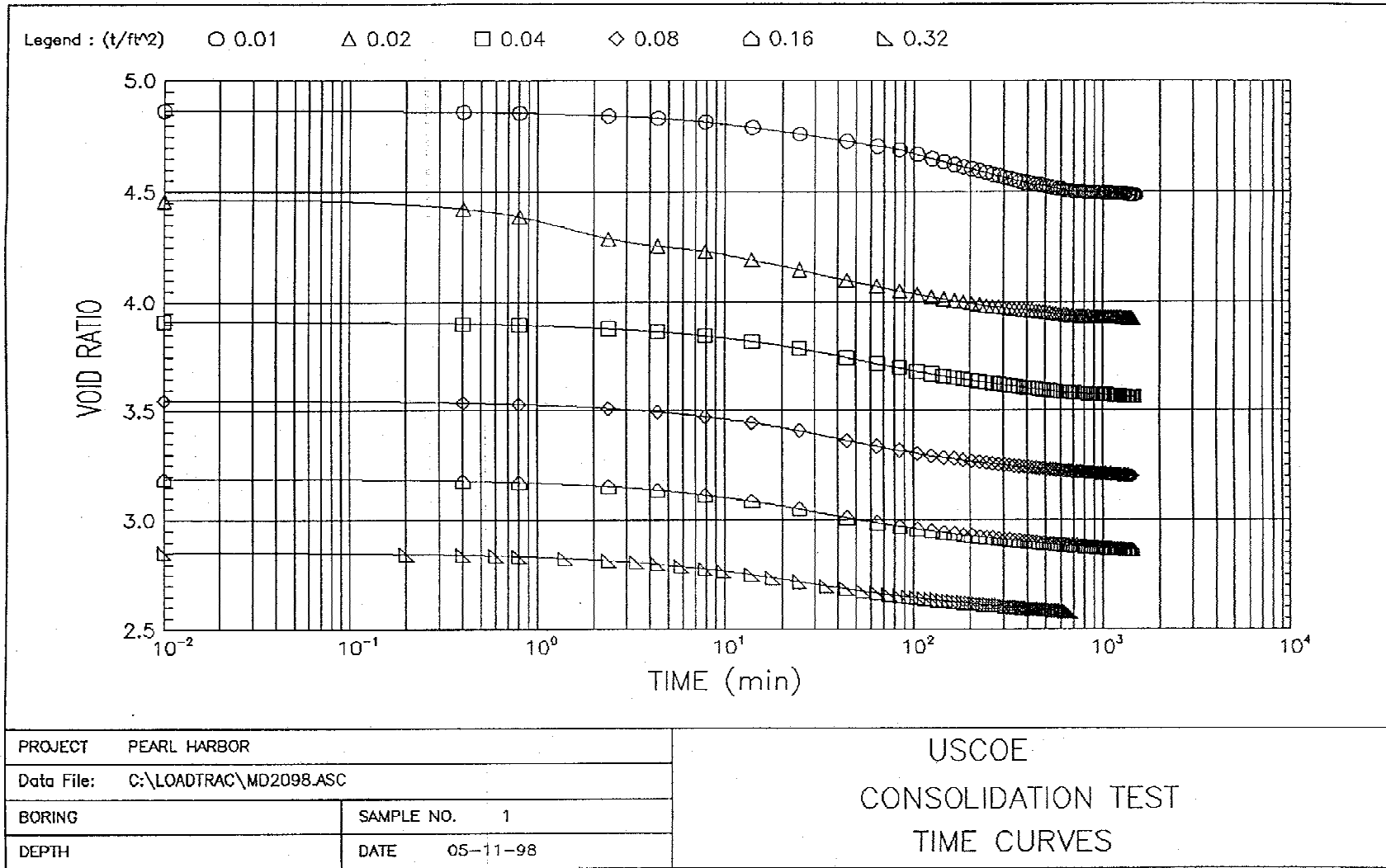


Figure A6. Time curves from standard oedometer consolidation test on Pearl Harbor sediment composite

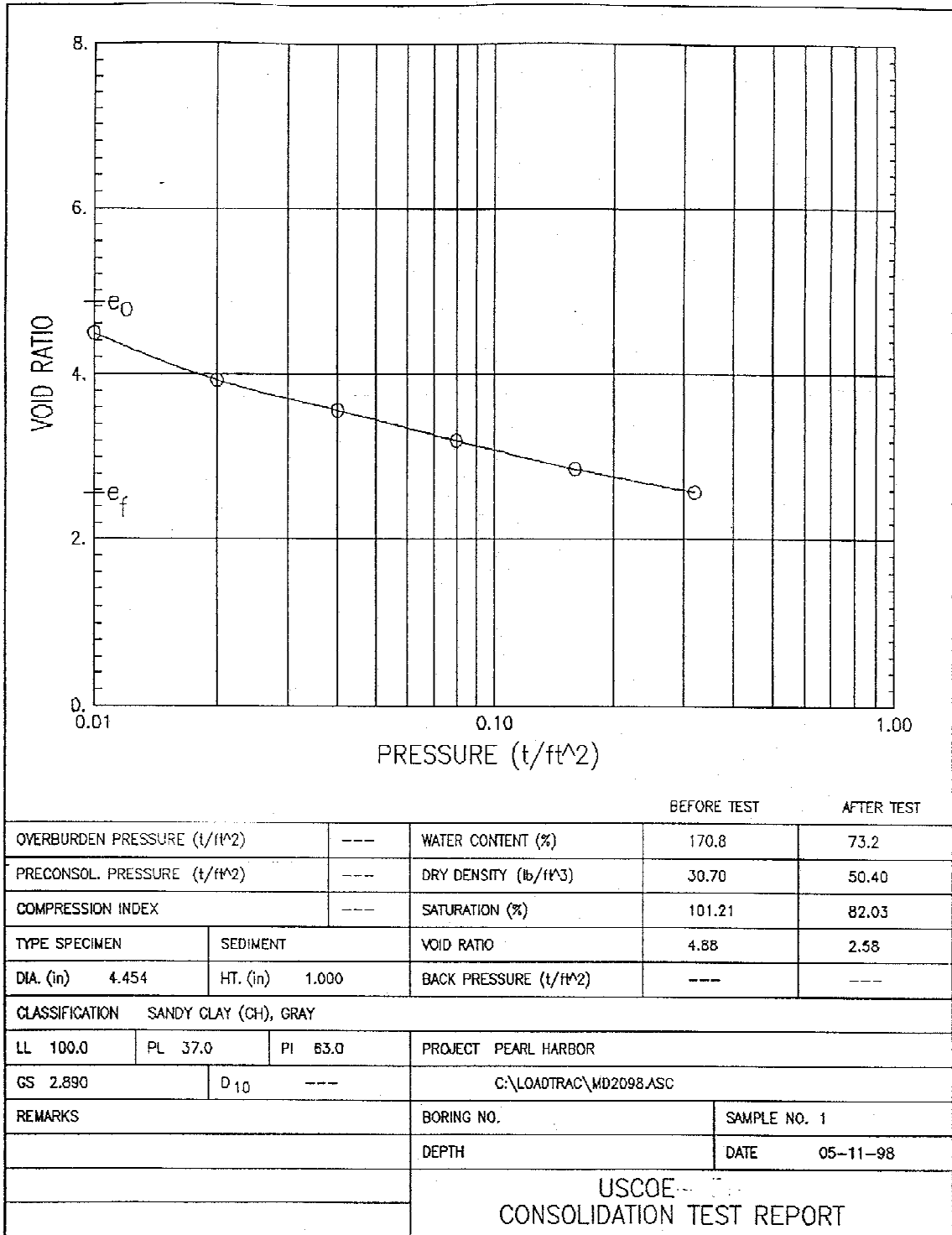


Figure A7. Void ratio-effective stress relationship from standard oedometer consolidation test on Pearl Harbor sediment composite

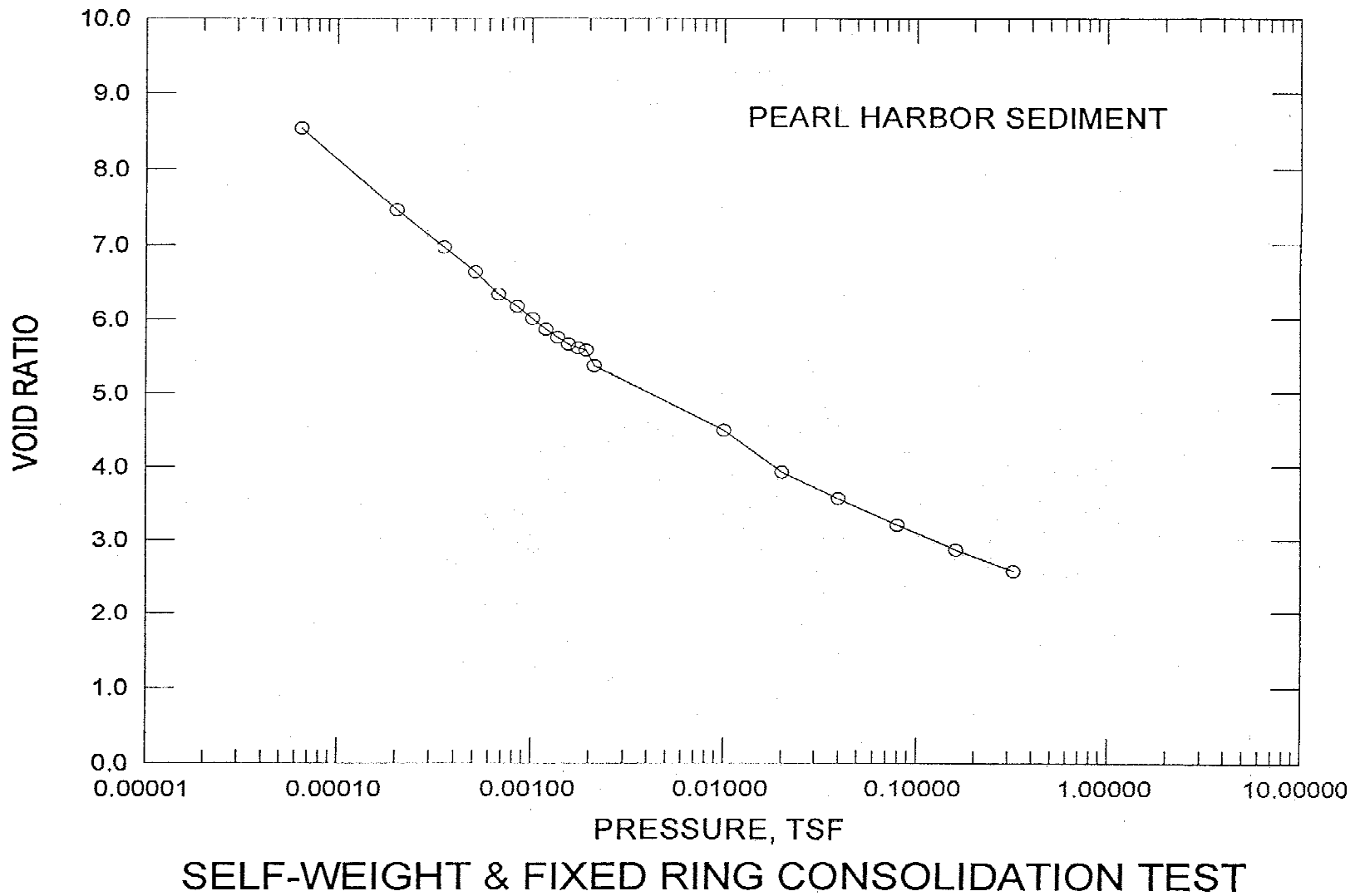


Figure A8. Combined void ratio-effective stress relationship for Pearl Harbor sediment composite

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Appendix B - Effluent Pathway Testing

Introduction

The purpose of this appendix is to document and present the results of the column flocculent settling and modified elutriate tests performed to predict effluent quality from a confined disposal facility (CDF) as part of the development of a long-term management strategy for Pearl Harbor dredged material.

Testing Objectives

The objective of the laboratory settling test was to predict the settling behavior of Pearl Harbor sediment when placed in a confined disposal facility (CDF) at Waipio Peninsula. The objective of the modified elutriate test was to predict the quality of effluent discharge from the proposed CDF at Waipio Peninsula for the dissolved concentrations of contaminants and the solid contaminant fraction associated with the total suspended solids (TSS) released. Prior to running the settling and modified elutriate tests, homogenized sediment and water samples were collected and analyzed for organic and inorganic constituents.

Scope Of Work

The scope of work included performing a laboratory column settling test on the homogenized sediment. This information will be used in Phase III to design the CDF(s) to provide adequate retention time for sedimentation. An initial screening for contamination was performed to determine if the sediment contained any contaminant at a significant concentration and to identify the contaminants that should be analyzed in the modified elutriate test. The modified elutriate test procedure was run to define the dissolved concentration and the fraction of the particle-associated contaminant in the TSS under quiescent settling conditions for each contaminant of concern. This procedure also accounts for geochemical changes occurring in the CDF during active disposal operations.

Laboratory Testing

Background

Dredging is required to maintain navigable waterways in the Pearl Harbor Naval Complex. One disposal alternative being considered for the Pearl Harbor dredged material is hydraulic placement in an upland CDF. The conceptual design of the facility requires an evaluation of the settling properties of the dredged material to estimate storage requirements and promote good settling within the CDF. Efficient solids removal may benefit CDF effluent quality by reducing possible particulate-associated contaminants along with lower suspended solids concentrations. Settling test procedures (Palermo and Thackston 1988) are used to predict the concentration of suspended solids in the effluent for given operational conditions at the Pearl Harbor site. Modified elutriate tests (Thackston and Palermo 1990 and Palermo 1985) are used to predict both the dissolved concentrations of contaminants and particulate-associated contaminant fractions of the suspended solids under quiescent settling conditions. Using results from both the column settling test and the modified elutriate test, the total concentration of contaminants in the effluent can be predicted.

Description of a Typical CDF

A CDF is a diked enclosure used to retain dredged material placed in the site. The CDF must be designed to provide adequate storage capacity for the settled sediments and efficient sedimentation to minimize the discharge of suspended solids (Montgomery, Thackston, and Parker 1983). Figure B1 shows an active CDF where the dredged material undergoes sedimentation, resulting in a "thickened" deposit of settled material overlain by the clarified supernatant. The supernatant waters are normally discharged as effluent from the site, containing dissolved and/or particulate-associated contaminants.

Figure B1 also shows several factors influencing the concentration of suspended particles and contaminants present in supernatant waters. As dredged material slurry enters the ponded water, finer particles remain suspended in the water column at the point of entry due to turbulence and mixing. The suspended particles are partially removed from the water column by gravity settling. Some of the settled particles may reenter the water column because of the upward flow of water through the slurry mass during thickening or may reenter the water column by wind and/or surface wave action. If supernatant water is released during active phases of disposal, all solids cannot be retained. Therefore, dissolved and particulate-associated contaminants may be transported with the particles in the effluent to the receiving water outside the containment area.

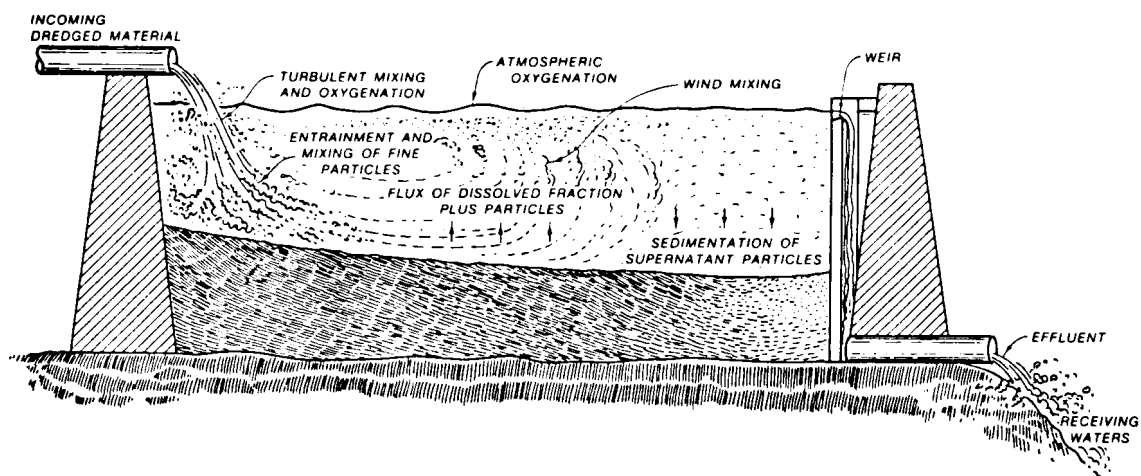


Figure B1. Schematic of an active confined disposal facility (CDF)

Settling Test Experimental Procedures

Samples of sediment and site water were collected from areas containing potential unsuitable dredged material for ocean disposal and used to conduct the column settling and modified elutriate tests. Settling and modified elutriate tests results were used to predict the effluent suspended solids and the concentration of contaminants that may be present in the effluent. A flow chart illustrating the effluent quality prediction technique is shown in Figure B2.

The settling tests followed procedures found in Palermo et al. (1978), EM 1110-2-5027 (USACE 1987), Palermo and Thackston (1988), and Montgomery et al. (1983). The tests involved mixing sediment and site water to simulate a dredged material slurry, placing the material in a settling column, and observing several types (i.e., discrete, zone, compression, and flocculent) of settling behavior. The general procedures are described below.

Zone, compression, and flocculent settling data were collected by conducting a settling test for the composite samples. The three types of settling data were collected from a single settling test. The zone and compression tests are presented in Appendix A; only the flocculent settling test is presented in this appendix.

Slurry preparation. The target slurry concentration selected for the settling test was 100 g/L. The slurry was prepared by mixing the Pearl Harbor composite sediment with water having a salinity of 33.8 parts per thousand. The average solids concentrations for the sediment samples prior to mixing were 442 g/L

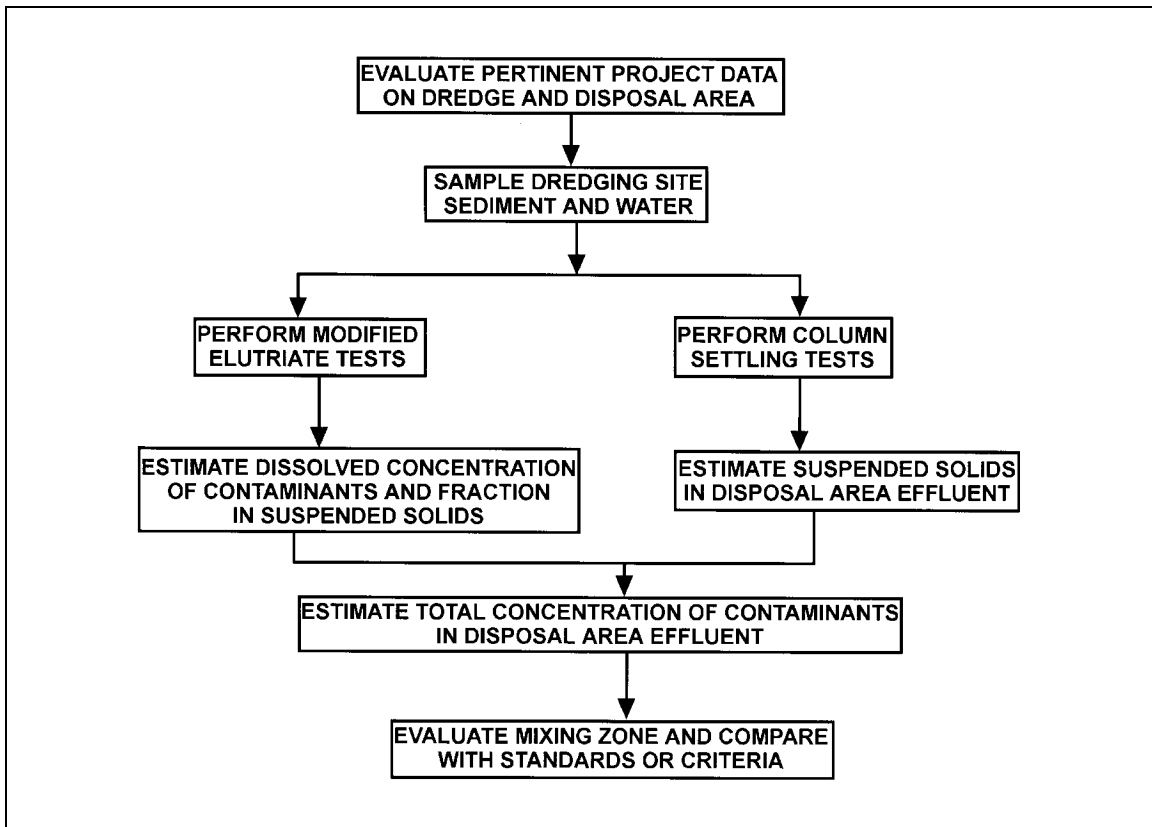


Figure B2. Steps for predicting effluent water quality

(Table B1). To achieve the target slurry concentration for the composite materials, approximately 16 liters of sediment were mixed with 54 liters of water using a Lightning mixer in a large container. The average slurry concentration after mixing was 107 g/L (Table B1). The slurry was transferred into an 8-in.-diameter, 7-ft column, with ports at 0.5-ft intervals starting at the 7.0-ft height (see Figure B3).

Flocculent Settling. The flocculent settling test consisted of measuring the concentration of suspended solids at various depths and time intervals in a settling column. An interface formed near the top of the settling column during the first day of the test; therefore, sedimentation of the material below the interface is described by zone settling. The flocculent test procedure was continued only for that portion of the water column above the interface. Samples of the supernatant were extracted from each sampling port above the liquid-solid interface at different time intervals. The suspended solids concentrations of the extracted samples were determined. Substantial reductions of suspended solids are expected to occur during the early part of the test, but reductions should lessen at longer retention times (USACE 1987).

TABLE B1. TOTAL SOLIDS CONCENTRATIONS FOR SETTLING TESTS

Sediment Concentration, g/L			
Replicate 1	Replicate 2	Replicate 3	Average
440.9	444.8	439.8	441.8
Slurry Concentration, g/L			
Replicate 1	Replicate 2	Replicate 3	Average
106.1	117.7	97.0	106.9

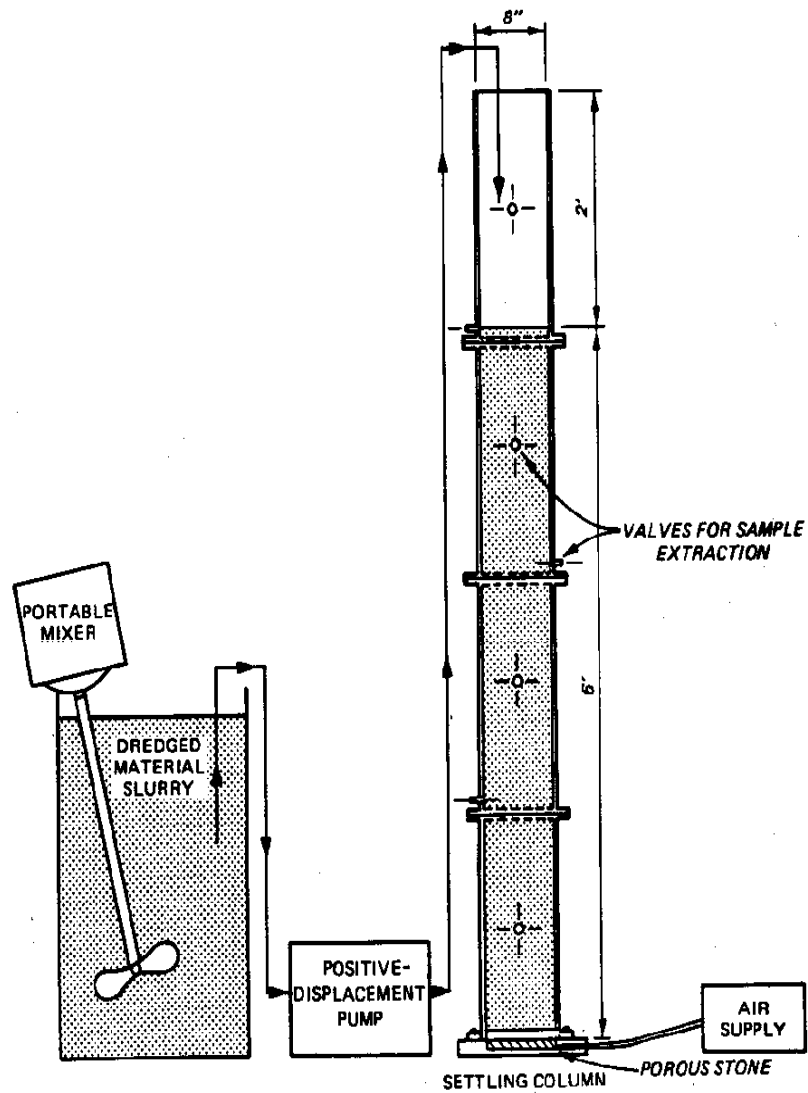


Figure B3. Schematic of settling column

Flocculent settling tests were performed concurrently with the zone and compression settling tests on the same slurry. Therefore, the flocculent, zone, and compression settling tests initial slurry concentrations were the same. Samples of the supernatant were extracted with a syringe (Figure B4) at 6.0-, 5.5-, 5.0-, 4.5-, 4.0-, 3.5-, 3.0-, 2.5-, and 2.0-ft ports above the liquid-solid interface at different time intervals (2, 4, 6, 14, 24, 48, 96, 168, 278, and 360 hr). Suspended solids concentrations were then determined on the supernatants by Standard Method 2540D (APHA-AWWA-WPCF 1989). Turbidities of the supernatants were measured using a Digital model 2008 turbidimeter and determined by Standard Method 2130B (APHA-AWWA-WPCF 1989).



Figure B4. Flocculent test extraction procedure

Modified Elutriate Test Procedure

The procedure for conducting a modified elutriate test is illustrated in Figure B5. The modified elutriate testing apparatus consists of a laboratory mixer and several 4-L graduated cylinders. The volume required for each analysis, the number of parameters measured, and the desired analytical replication will influence the total elutriate sample volume required. The test procedure involves mixing site water and sediment to a concentration expected in the influent to a CDF. The mixture is then aerated for one hour to simulate the oxidizing conditions present at the disposal site. Next, the mixture is allowed to settle for a time equal to the expected or measured mean retention time of the disposal area up to a maximum of 24 hours. The sample of the supernatant water is extracted for single analysis of dissolved and total contaminant concentrations. Detailed procedures for the modified elutriate test as conducted for this study are presented below.

Sample Preparation. The sediment and dredging site water were mixed to a target slurry concentration of 150 g/L. The average sediment concentration was 442 g/L. Each 4-L cylinder to be filled required a mixed slurry volume of 3.75-L. The slurries were prepared by adding 1.27-L of sediment to 2.48-L of site water.

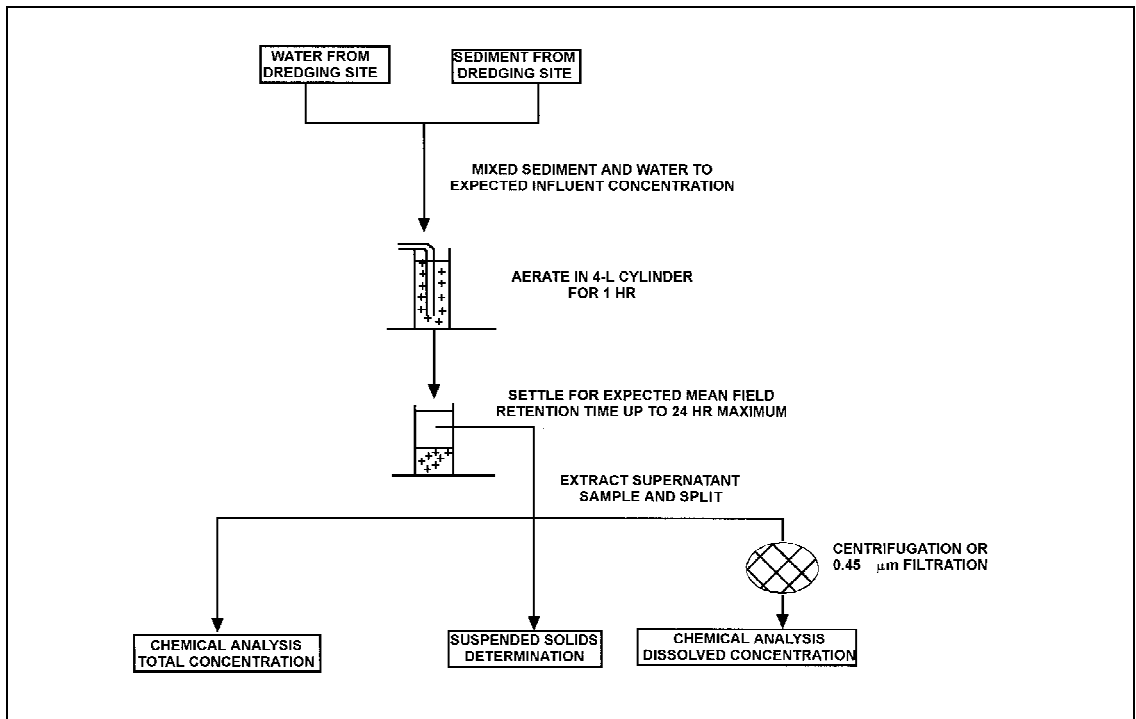


Figure B5. Modified elutriate test procedure

Mixing of the Slurry. The slurries were mixed to a uniform consistency in large containers for 15 minutes with a laboratory mixer.

Aeration of the Slurry. Aeration was used to ensure oxidizing conditions in the supernatant water to simulate dredging operation during the mixing phase. The mixed slurry was poured into 4-L graduated cylinders. The slurry was aerated by using compressed air, which passed through a deionized water trap, through glass tubing, and bubbled through the slurry. The agitation was vigorous and continued for one hour.

Settling of the Slurry. The tubing was then removed from the cylinder allowing the aerated slurry to undergo quiescent settling for 24 hr, a suggested default value when the field mean retention time is not known.

Sample Extraction. After the 24-hr settling period, the supernatant water was extracted from the cylinder at a point midway between the water surface and the interface using a syringe and tubing. Care was taken not to resuspend settled material. The extracted samples from the cylinders were homogenized, split, and analyzed for total suspended solids concentration, dissolved contaminants, and total contaminants of selected constituents. Samples for the analysis of dissolved contaminants were filtered through a 0.45- μm Millipore glass fiber filter.

Data Analysis and Results

The behavior of Pearl Harbor sediment at slurry concentrations equal to that expected for inflow to a CDF is governed by zone settling processes. The sediments exhibited a clear interface between settled material and clarified supernatant.

The settling test data and the modified elutriate test data were analyzed using the Automated Dredging and Disposal Alternatives Management System (ADDAMS) (Schroeder and Palermo 1995) which is a family of computer programs developed at ERDC to assist in planning, designing, and operating dredging and dredged material disposal projects. The SETTLE module of ADDAMS was used for the settling test data (Hayes and Schroeder 1992), and the EFQUAL module of ADDAMS was used for the modified elutriate test data (Palermo and Schroeder 1991).

All chemical analyses for this study were conducted according to SW-846 (USEPA 1986) standard procedures (Table B2). Metals were analyzed using one of the following instruments: Inductively Coupled Argon Plasma (ICP), Perkin-Elmer 5000 (Cold Vapor), and Zeeman 5100. Organic analyses were performed using gas chromatograph/mass spectrometers (GC/MS). The Environmental Chemistry Branch (ECB) at ERDC performed these analyses.

TABLE B2. LABORATORY ANALYTICAL PROCEDURES

Parameter	Analytical Method	Reference
Base/Neutrals/Acid Extractables (BNA)	USEPA Method 8270	SW-846 (USEPA 1986)
Metals	USEPA Method 7470 USEPA 7000 Series/6010	SW-846 SW-846
Pesticides/PCBs	USEPA Method 8080	SW-846
Total Organic Carbon (TOC)	USEPA Method 9060	SW-846
Total Recoverable Petroleum Hydrocarbons (TRPH)	USEPA Method 418.1	EPA-600 (USEPA 1979)
Volatile Organic Compounds (VOC)	USEPA Method 8240	SW-846

Bulk Chemistry

Homogenized samples (in triplicate) of the sediment and site water were sent to the ECB to determine their chemical characteristics. The sediment and site water were analyzed for total metals; organic priority pollutants including volatiles; TRPH; and TOC. The bulk sediment chemistry is reported in Appendix A; the site water chemistry is given in Tables B3, B4, and B5.

Modified Elutriate Test

Results for the modified elutriate test are shown in Tables B3, B4, and B5. The chemical analysis of the modified elutriate samples provided the data used to predict dissolved and total concentrations of contaminants in milligrams per liter. The total suspended solids (TSS) concentration was also determined. The average (in triplicate) TSS concentration was 68 and 39 mg/L for unfiltered and filtered samples, respectively.

To predict the total concentration of each contaminant in the effluent, one must first calculate the fraction of each contaminant associated with the TSS in the elutriate samples using the following equation:

$$F_{ss} = (1 \times 10^6) \times \frac{C_{total} - C_{diss}}{SS} \quad (B1)$$

TABLE B3. MODIFIED ELUTRIATE SEMIVOLATILE ORGANIC ANALYSES

Parameter	Site Water mg/L	Total Concentration mg/L			Dissolved Concentration mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Phenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2-Chlorophenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2-Nitrophenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4-Dimethylphenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4-Dichlorophenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Chloro-3-Methylphenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4,6-Trichlorophenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4-Dinitrophenol	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
4-Nitrophenol	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
2-Methyl-4,6-Dinitrophenol	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Pentachlorophenol	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
Benzoic Acid	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
2-Methylphenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Methylphenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4,5-Trichlorophenol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzyl Alcohol	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Bis(2-Chloroisopropyl)Ether	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
N-Nitroso-Di-N-Propylamine	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Nitrobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Isophorone	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Bis(2-Chloroethoxy)Methane	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,6-Dinitrotoluene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2,4 Dinitrotoluene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzidine	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
3,3'Dichlorobenzidine	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Bis(2-Chloroethyl)Ether	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
1,3-Dichlorobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
1,4-Dichlorobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
1,2-Dichlorobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Hexachloroethane	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
1,2,4-Trichlorobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Naphthalene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Hexachlorobutadiene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Hexachlorocyclopentadiene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010

(continued)

TABLE B3. continued

Parameter	Site Water mg/L	Total Concentration mg/L			Dissolved Concentration mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
2-Chloronaphthalene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dimethyl Phthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Acenaphthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluorene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Diethyl Phthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Chlorophenyl Phenyl Ether	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
N-Nitrosodiphenyl Amine	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Bromophenyl Ether	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Hexachlorobenzene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Phenanthrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibutylphthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Butylbenzylphthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Chrysene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(a)Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Bis(2-Ethylhexyl)Phthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Di-N-Octylphthalate	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(b)Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(k)Fluoranthene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(a)Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Indeno(1,2,3-C,D)Pyrene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzo(A,H)Anthracene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Benzo(G,H,I)Perylene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Aniline	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
4-Chloroaniline	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Dibenzofuran	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2-Methylnaphthalene	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
2-Nitroaniline	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
3-Nitroaniline	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025
4-Nitroaniline	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025	<0.025

(concluded)

TABLE B4. MODIFIED ELUTRIATE TEST PESTICIDES/PCBS ANALYSES

Parameter	Site Water mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Aldrin	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
A-BHC	<0.00019	<0.00019	<0.00020	<0.00019	<0.00020	<0.00021	<0.00021
B-BHC	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
G-BHC	<0.000019	<0.00019	<0.00020	<0.00019	<0.00020	<0.00021	<0.00021
D-BHC	<0.000049	<0.00019	<0.000051	<0.000048	<0.000051	<0.000051	<0.000053
PPDDD	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
PPDDE	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
PPDDT	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
Heptachlor	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
Dieldrin	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
A-Endosulfan	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
B- Endosulfan	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
Endosulfan Sulfate	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
Endrin	<0.00097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
Endrin Aldehyde	<0.000097	<0.000097	<0.00010	<0.000096	<0.00010	<0.00011	<0.00011
Heptachlor Epoxide	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
Methoxychlor	<0.0049	<0.0049	<0.00050	<0.00048	<0.00051	<0.00052	<0.00053
Chlordane	<0.000049	<0.000049	<0.000051	<0.000048	<0.000051	<0.000052	<0.000053
Toxaphene	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1016	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1221	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1232	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1242	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1248	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1254	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
PCB-1260	<0.00025	0.00014 J	0.00023 J	0.00029	<0.00025	<0.00025	<0.00025

J indicates estimated value.

TABLE B5. MODIFIED ELUTRIATE TEST RESULTS FOR AMMONIA-N, CYANIDE, SULFIDE, TOC, TSS, TOTAL SOLIDS, AND METALS

Parameter	Site Water mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Ammonia Nitrogen	<0.010	1.5	1.49	1.35	1.47	1.47	1.58
Cyanide	<0.005	0.10	0.14	<0.005	<0.005	<0.005	0.01
Sulfide	0.03	0.028	0.030	0.032	0.032	0.025	0.034
TOC	<1.0	1.9	1.9	1.9	1.9	1.8	1.9
TSS	23	61	82	62	49	28	39
Total Solids	44,852	46,588	43,068	50,624	51,384	47,116	52,132
Antimony	<0.003	0.010	0.011	0.011	0.012	0.012	0.011
Arsenic	0.038	0.047	0.047	0.047	0.045	0.044	0.046
Beryllium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cadmium	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Chromium	0.006	0.026	0.020	0.021	0.003	0.003	0.002
Copper	0.012	0.079	0.102	0.053	0.02	0.016	0.015
Lead	0.001	0.02	0.014	0.014	<0.001	<0.001	<0.001
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	0.007	0.024	0.025	0.031	0.007	0.005	0.004
Selenium	0.141	0.145	0.157	0.153	0.15	0.15	0.154
Silver	0.006	0.004	0.003	0.002	0.001	<0.001	<0.001
Thallium	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Zinc	0.014	0.075	0.071	0.067	0.031	0.033	0.044
Aluminum	0.112	7.38	5.14	5.07	<0.025	<0.025	<0.025
Barium	0.006	0.016	0.014	0.014	0.062	0.040	0.038
Calcium	359	363	355	363	392	400	403
Cobalt	0.001	0.004	0.003	0.006	0.001	0.001	0.001
Iron	0.416	8.28	4.95	4.85	<0.020	<0.020	<0.020
Magnesium	1310	1298	1279	1298	1333	1416	1368
Manganese	0.005	0.36	0.244	0.244	0.095	0.114	0.118
Potassium	349	376	380	398	432	443	439
Sodium	9487	9497	9138	9476	10710	11050	10930
Vanadium	<0.001	0.019	0.012	0.014	0.003	0.004	0.003
Total Recoverable Petroleum Hydrocarbons	<0.7	0.18			<0.7		

TABLE B6. SUMMARY RESULTS FOR MODIFIED ELUTRIATE TEST

Parameter	Avg. Total Concentration, mg/L	Avg. Dissolved Concentration, mg/L	Fraction of TSS, mg/kg of TSS
Ammonia-Nitrogen	1.45	1.51	* 0
Cyanide	0.12	0.01	1618
Sulfide	0.03	0.03	0
Antimony	0.011	0.011	0
Arsenic	0.047	0.045	29.4
Chromium	0.022	0.003	289.2
Copper	0.078	0.017	897.1
Lead	0.016	<0.001 ^a	235.3
Nickel	0.027	0.005	313.7
Selenium	0.152	0.151	4.9
Silver	0.003	<0.001	44.1
Zinc	0.071	0.036	514.7
Aluminum	5.86	<0.025	86225
Barium	0.015	0.047	* 0
Cobalt	0.004	0.001	49
Iron	6.03	<0.020	88627
Manganese	0.283	0.109	2554
Vanadium	0.015	0.003	171.6

“<” values were assigned zero.
 * Avg. Dissolved Concentration was used for the Avg. Total Concentration since the dissolved concentration measured was greater than the total concentration measured.

where

F_{ss} = fraction of contaminant in the total suspended solids, mg contaminant/kg of suspended solids

(1×10^6) = conversion factor, mg/mg to mg/kg

C_{total} = total concentration, mg contaminant/L of sample

C_{diss} = dissolved concentration, mg contaminant/L of sample

SS = total suspended solids concentration, mg solids/L of sample

The results for these calculations using Equation B1 are summarized in Table B6 that shows only the detected parameters. This procedure is used to predict the total concentration in the effluent because the TSS in the field varies with the design.

Flocculent Column Settling Test

For the flocculent settling test, an extension to this procedure is presented in USACE (1987). Palermo (1985) analyzed the effects of several possible assumptions regarding the magnitude of the value to be used as the initial concentration in the laboratory test and showed that all gave essentially the same final result. Therefore, it was recommended that, for simplicity, the concentration in the first sample taken at the highest sampling port be used as the initial concentration. SETTLE generates two curves based on the settling data in Table B7: the concentration profile curve (Figure B6) and the supernatant suspended solids curves (Figure B7). The concentration profile curve, which plots the depth below the surface (ft) versus percent of initial concentration, shows that the suspended solids concentrations decrease with time and increase at deeper ponding depths (1, 2, and 3 ft) at the weir. The supernatant suspended solids curves derived from the concentration profile curves compare the effect of retention time on supernatant suspended solids at 1-, 2-, and 3-ft ponding depths. This curve shows that increasing the retention time beyond 48 hr for 1, 2, or 3 ft of ponding depth provides little additional improvement in supernatant suspended solids concentration. Actual field suspended solids will be greater because of resuspension by wind and wave action. Based on field experience, a resuspension factor ranging from 1.5 to 2.5 depending on ponding depth and surface area (Table B8) is applied.

TABLE B7. FLOCCULENT SETTLING TEST DATA

Time hr	Suspended Solids Concentration ¹ , mg/L								
	Port Height, ft								
	6.00	5.50	5.00	4.50	4.00	3.50	3.00	2.50	2.00
2.0	123.21 ²	BI ³	BI	BI	BI	BI	BI	BI	BI
4.0	35.00	34.00	BI	BI	BI	BI	BI	BI	BI
14.0	23.33	30.98	20.00	38.33	35.93	31.15	BI	BI	BI
24.0	17.57	19.54	16.66	23.04	21.67	21.48	21.67	BI	BI
48.0	8.25	15.38	7.14	8.33	5.41	7.41	9.09	BI	BI
96.0	4.08	5.48	5.63	3.28	1.23	2.74	4.71	5.88	BI
168.0	---	5.68	3.49	1.18	3.37	---	---	---	BI
360.0	---	4.10	2.44	2.00	3.00	2.54	2.54	2.34	3.03

¹ The slurry concentration was 106.9 g/L.

² Concentration at highest port used as initial supernatant concentration.

³ Port is below interface (BI), and no sample was collected at this time interval.

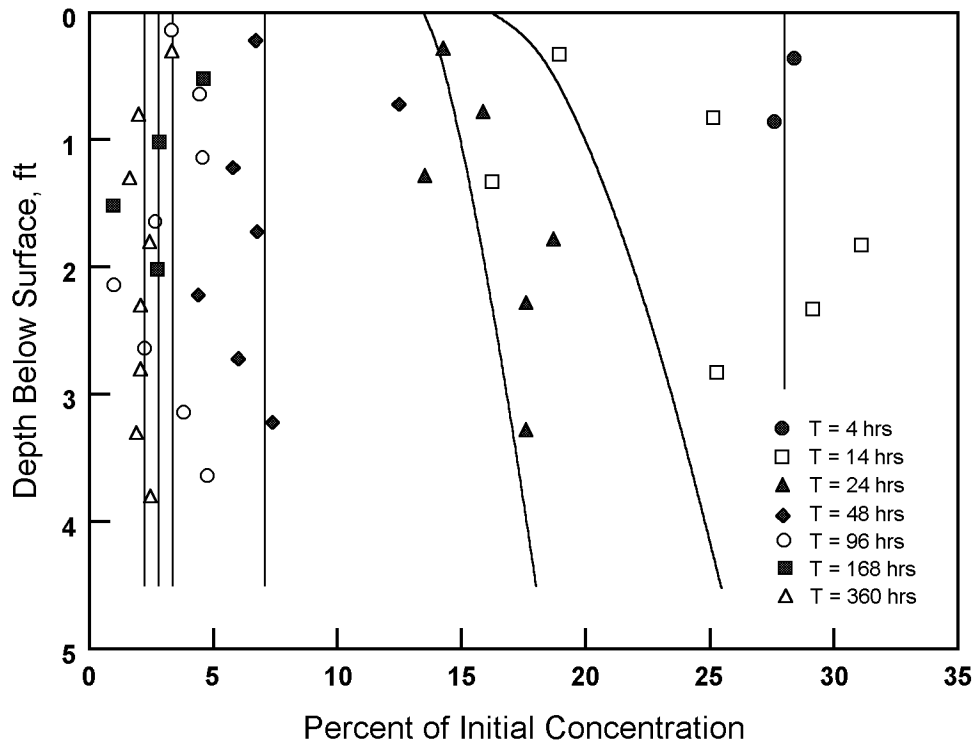


Figure B6. Flocculent settling test suspended solids relationship to time and depth-below-surface

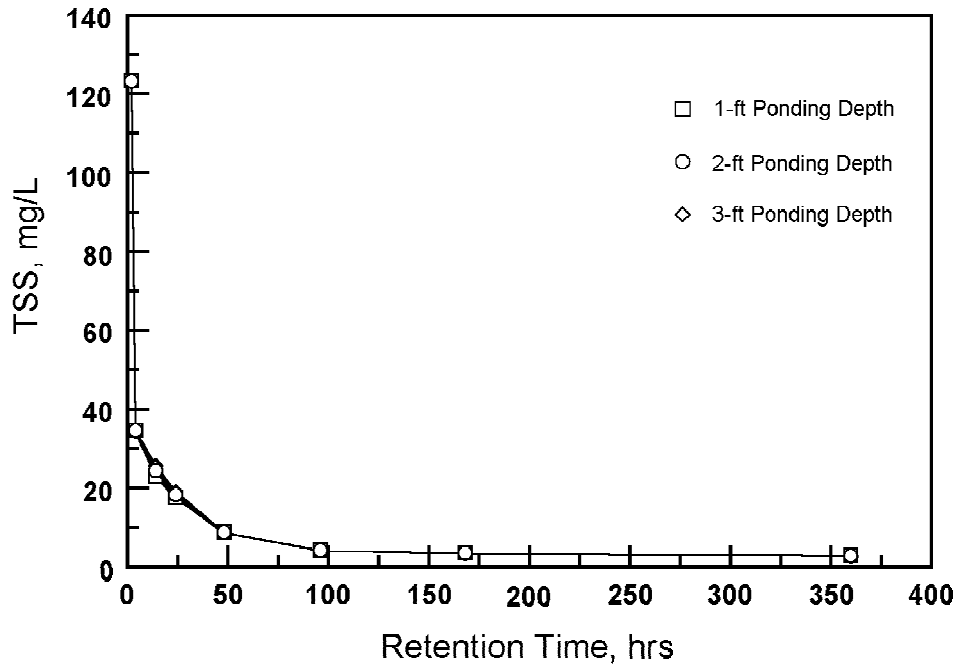


Figure B7. Supernatant suspended solids curves

TABLE B8. RECOMMENDED RESUSPENSION FACTORS FOR VARIOUS PONDED AREAS AND DEPTHS

Anticipated Poned Area	Anticipated Average Poned Depth	
	Less than 2 ft	2 ft or Greater
Less than 100 acres	2.0	1.5
Greater than 100 acres	2.5	2

Turbidity

Samples of the supernatant from the flocculent settling test were split to measure turbidity of corresponding TSS concentration (Table B9). TSS will be used as an indicator of overall performance of CDF both for solids retention and for most other contaminants which are strongly associated by adsorption or ion exchange. Turbidity, being much more easily measured than TSS, may be used instead of TSS during routine operational monitoring if approved by the regulatory agency.

Figure B8 shows the correlation between turbidity and TSS for the Pearl Harbor sediment. The field inspector and others can measure the turbidity of the effluent with a turbidity meter and estimate a TSS concentration from the curve. Samples for TSS measurement can be collected less frequently for compliance monitoring and to field verify the correlation for laboratory samples.

TABLE B9. TOTAL SUSPENDED SOLIDS CONCENTRATIONS AND TURBIDITY MEASUREMENTS FROM SETTLING TEST DATA

Time Hr	Port No.	Turbidity NTU	TSS mg/L	Time Hr	Port No.	Turbidity NTU	TSS mg/L
2	6.0	110	123.21	96	4.5	28	3.28
4	6.0	50	35.00		4.0	28	1.23
	5.5	45	34.00		3.5	29	2.74
6	6.0	36	15.00		3.0	28	4.71
	5.5	48	32.79		2.5	30	5.88
	5.0	36	11.67	168	5.5	24	5.68
14	6.0	39	23.33		5.0	22	3.49
	5.5	32	40.98		4.5	22	1.18
	5.0	30	10.00		4.0	22	3.37
	4.5	40	18.33		3.5	22	0 *
	4.0	54	55.93		3.0	22	0 *
	3.5	38	31.15		2.5	23	0 *
24	6.0	36	17.57	278	5.5	6.0	1.00
	5.5	36	19.54		5.0	5.4	0 *
	5.0	34	15.66		4.5	4.4	0 *
	4.5	32	13.04		4.0	3.7	0 *
	4.0	30	21.67		3.5	3.6	0 *
	3.5	32	11.48		3.0	3.8	0 *
	3.0	41	31.67		2.5	3.8	0 *
48	6.0	30	8.25		2.0	5.0	1.00
	5.5	31	15.38	360	5.5	6.0	4.10
	5.0	28	7.14		5.0	4.6	2.44
	4.5	27	8.33		4.5	4.8	2.00
	4.0	26	5.41		4.0	4.4	3.00
	3.5	26	7.41		3.5	3.9	2.54
	3.0	25	9.09		3.0	4.0	2.54
96	6.0	28	4.08		2.5	5.0	2.34
	5.5	29	5.48		2.0	4.6	3.03
	5.0	28	5.63				

* Final weight less than initial weight

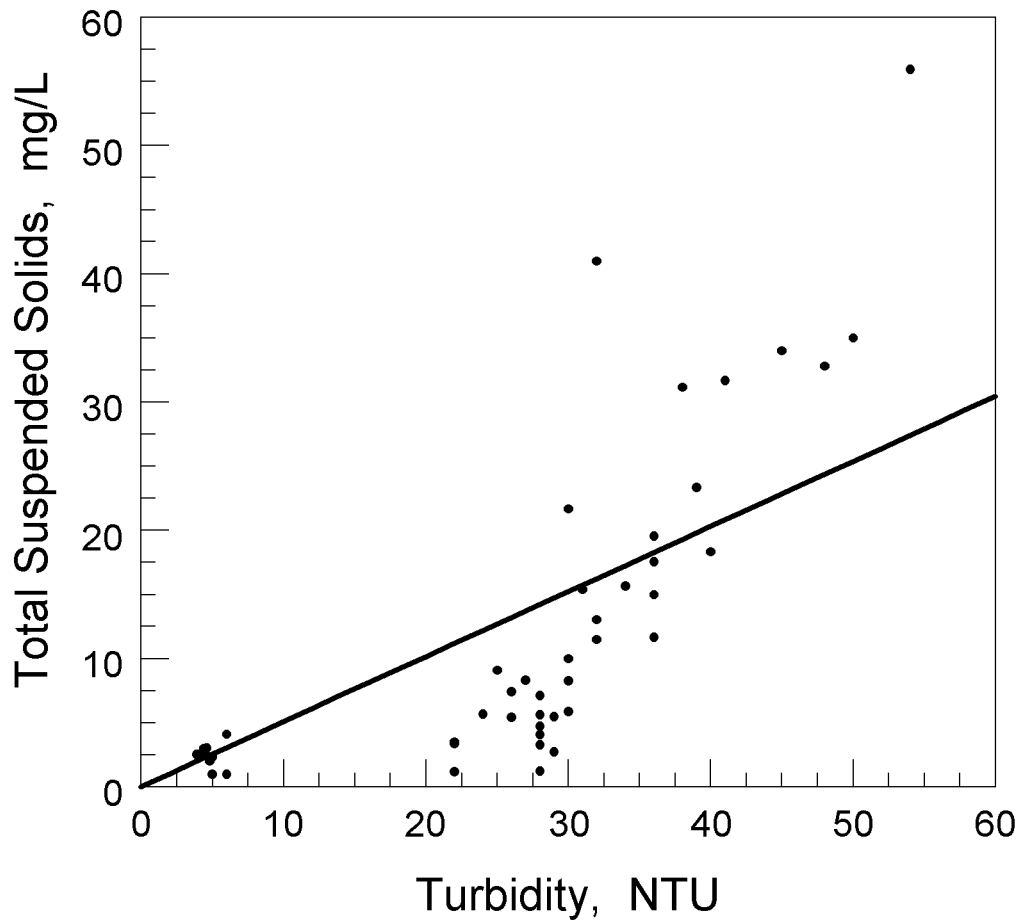


Figure B8. TSS versus turbidity curve

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Appendix C - Surface Runoff Testing

Background

The surface runoff water quality component of the Decision-Making Framework (DMF) for the management of dredged materials (Lee et al. 1991) evaluates the potential water quality problems that may result from discharges of storm water from contaminated dredged material placed in upland environments. Water leaving an upland confined disposal facility (CDF) must meet applicable State water quality standards for discharge into receiving waters. When dredged material is placed in a CDF, contaminant movement from the wet, unoxidized dredged material will be mainly associated with suspended solids. As the dredged material dries and oxidizes, suspended solids concentration may decrease while contaminants such as heavy metals may become more soluble. The rainfall simulator/lysimeter system (RSLS) predicts these effects so that restrictions and/or treatments, such as controlling movement of suspended solids or providing adequate mixing zones, can be incorporated into the CDF design.

The testing protocol for surface runoff water quality, described by Skogerboe et al. (1988), has been applied to dredged material from a number of locations including Indiana Harbor (Environmental Laboratory 1987), Black Rock Harbor (Skogerboe et al. 1987), New Bedford Harbor (Skogerboe et al. 1988), Oakland Harbor (Lee et al. 1992a, 1992b, 1993a, 1993b), and others. Contaminants have included heavy metals, PAHs, PCBs, pesticides, organotins, and dioxins. The procedure uses a rainfall simulator/lysimeter system (RSLS) in the laboratory as shown in Figure C1. The RSLS requires a minimum of eleven 208-liter drums of dredged material, representative of the proposed dredging site. After placing the dredged material in a soil lysimeter, surface runoff tests are conducted on the wet, unoxidized dredged material. The lysimeter is then moved outside, covered with a ventilated top, and allowed to dry naturally for six months. The runoff tests are then repeated on the dry, oxidized dredged material.

Although the RSLS is a very effective tool for predicting surface runoff water quality from an upland CDF, the procedure is expensive, time consuming, and can only be conducted at ERDC. A need for a faster, less expensive response to surface water quality concerns prompted the development of a simple laboratory procedure that could be performed by any qualified laboratory with widely available equipment. The simplified laboratory runoff procedure (SLRP)



Figure C1. The RSLS in the laboratory

is designed to provide a less expensive, rapid response screening evaluation of surface runoff water quality from upland CDFs.

A number of sediment drying and oxidation procedures were evaluated on Indiana Harbor sediment and compared to RSLS tests of the same material (Environmental Laboratory 1987). A procedure using oven drying and hydrogen peroxide was selected as the best sediment treatment to simulate the long-term effects of drying and oxidation. Since then, the SLRP has been applied to San Francisco Bay and Black Rock Harbor sediments and compared to the RSLS results (Skogerboe 1995 and Price et al. 1998). The results from these two sediments demonstrated the value of the SLRP as a screening procedure to determine the need for the more expensive RSLS procedure. After testing on other sediments and the further development of regression equations, the SLRP may eventually replace the RSLS completely.

Methods and Materials

Simplified Laboratory Runoff Procedure

Two 5-gal polyethylene buckets of the Pearl Harbor sediment composite were thoroughly mixed together with a Lightning mixer to ensure homogeneity for the runoff tests. Samples were collected for the determination of sediment physical and chemical characteristics. The mixed sediment was placed back in the original buckets and stored in a walk-in cold room at 4 °C until needed. The SLRP requires the preparation of simulated runoff water using wet, unoxidized and dry, oxidized sediment in sediment:water ratios corresponding to the ranges of suspended solids concentrations measured in surface water runoff from previous studies. Ratios used for the Pearl Harbor sediment are shown in Table C1. Each ratio for the wet and dry procedure was replicated three times. For purposes of describing runoff water quality from CDFs, total contaminants refer to unfiltered samples and dissolved refers to filtered samples.

TABLE C1. SEDIMENT-TO-WATER RATIOS AND CORRESPONDING SUSPENDED SOLIDS CONCENTRATIONS

Sediment Condition	Sediment-to-Water Ratio			
	1:20	1:200	1:2,000	1:20,000
	Suspended Solids, mg/L			
Wet	50,000	5,000	500	-
Dry	-	5,000	500	50

Wet, Unoxidized Dredged Material. The purpose of the wet portion of the SLRP is to predict the quality of surface water leaving an upland CDF soon after filling with dredged material, particularly after dewatering when maximum surface exposure exists and movement of soil particles due to the impact of rainfall is high. This represents the worst case scenario for loss of contaminants bound to soil particles in runoff water at concentrations from 500 to 50,000 mg/L. After thorough mixing, sediment was removed from the bucket, placed in polycarbonate centrifuge bottles, and mixed with reverse osmosis (RO) water to the appropriate sediment:water ratios on a dry weight equivalent basis. The prepared samples were then placed on a mechanical shaker and agitated for one hour to ensure adequate suspension and dissolution of the sediment, as indicated in Figure C2. Half of the samples were divided into separate 1-L glass bottles for PAHs and 500-mL Nalgene bottles for metals and ammonia, acidified to less than pH 2.0 with nitric and sulfuric acid, respectively.

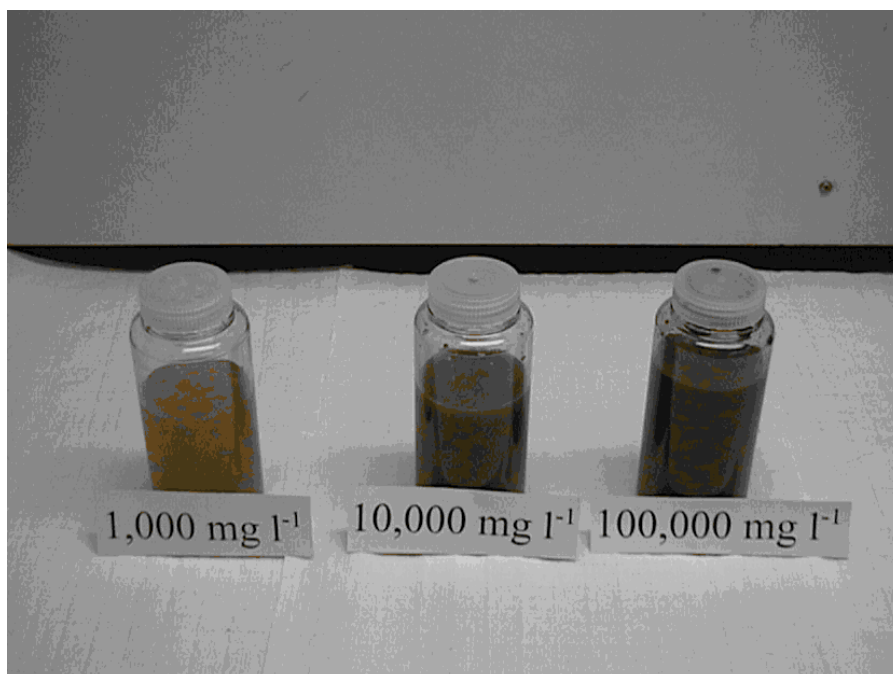


Figure C2. Wet sediment simulated runoff samples

These analyses represent the total contaminants in unfiltered water. The other half were centrifuged at 7,000 RPM and 15°C for 10 min. The supernatant was decanted and filtered through a 0.45- μm filter prior to placement in the proper containers and preservation with acid. Analyses of these samples represent the dissolved contaminants in filtered water.

Dry, Oxidized Sediment. The purpose of the dry portion of the SLRP is to predict the long-term effects of drying and oxidation of dredged material on movement of contaminants from an upland CDF. Wet, unoxidized sediment was collected from the bucket and placed in a drying oven at 90°C for 48 hours. After drying was complete, hydrogen peroxide H_2O_2 was added to rapidly oxidize the sediment, simulating long-term exposure to drying and exposure to oxygen. A pretest was necessary to determine the amount of H_2O_2 necessary to fully oxidize the Pearl Harbor sediment. Ten grams of dried sediment were placed in a 3.8-L glass jar and 30% H_2O_2 was slowly and incrementally added, each time observing for an effervescent reaction, Figure C3. When the oxidation process was complete as indicated by lack of reaction, the amount of H_2O_2 used was recorded and the resulting H_2O_2 per gram of sediment was used in the SLRP procedure. The oven dry sediment was oxidized with H_2O_2 and then mixed with RO water to the sediment:water ratios indicated previously in Table C1. The samples were shaken overnight as described above, and half of the samples were immediately placed in the appropriate sample containers. The remaining half was then centrifuged and filtered as described for the wet sediment. Samples for both the wet and dry



Figure C3. Oxidation of oven-dry sediment with hydrogen peroxide

sediment were submitted for chemical analysis of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni), silver (Ag), zinc (Zn), polynuclear aromatic hydrocarbons (PAHs) and ammonia nitrogen ($\text{NH}_3\text{-N}$) using the methods described by EPA (1986a).

Prediction of Surface Runoff Water Quality

The SLRP procedure is currently in development for nationwide application using a single procedure. Results of the SLRP are compared to results from an actual rainfall simulation using the RSLs in the laboratory. Multiple linear regression is used to develop prediction equations by relating the SLRP results to sediment sand content, sediment total organic carbon (TOC), and the results from the RSLs. Once this procedure has been applied to a sufficient number of sediments from various locations of the U.S., analytical results of the extraction procedure can simply be fed into prediction equations for each contaminant. At this time, these prediction equations apply to only a few metals (As, Cd, Cr, Cu, Pb, and Zn) and only for Oakland Harbor, CA, sediments (Skogerboe 1995 and Price et al. 1998). Other sediments (New York Harbor and Black Rock Harbor) have since had the SLRP procedure applied with the RSLs. Data are currently being compiled for inclusion in the regression analysis and improvement to the prediction equations.

Since the evaluation of surface runoff water quality from Pearl Harbor sediment did not include the RSLs procedure, actual suspended solids concentrations during simulated rainfall events were not determined. The SLRP evaluates water quality using a range of expected suspended solids concentrations in the simulated runoff water. These ranges reflect the range of concentrations measured in previous studies as indicated in Table C2. It would be expected that the suspended solids concentrations would be in the range of 5000 mg/L in surface runoff during the initial wet stage after filling the CDF with Pearl Harbor dredged material. Once the material dries and forms a surface crust, suspended solids should fall to within the range of 500 mg/L. The SLRP addresses concentrations on an order of magnitude above and below these concentrations. The concentrations of dissolved constituents were compared with Hawaii marine water quality standards for chronic toxicity. In the absence of State standards, it was assumed the Federal marine water quality criteria for chronic toxicity (EPA 1986b) would apply. Soluble contaminant concentrations that exceed the standards or criteria are reason for concern and may require pretreatment prior to discharge of runoff or adequate mixing zones to reduce concentration.

TABLE C2. SUSPENDED SOLIDS (SS) CONCENTRATIONS FROM OTHER SEDIMENTS EVALUATED USING THE RSLs

Sediment	SS Wet, mg/L	SS Dry, mg/L
Indiana Harbor	6,600	56
Black Rock Harbor	10,326	167
Everett Harbor	6,900	1,000
New Bedford	7,730	268
Oakland Inner	4,447	1,686
Oakland Upper	9,140	970
Pinole Shoal	1,500	618
West Richmond	3,290	2,340
Santa Fe Channel	6,240	2,130

Results and Discussion

The sum total PAHs are presented in Table C3. Mean contaminant concentrations across the three suspended solids concentrations are also provided for metals and ammonia nitrogen in Table C4. Analytical results for

metals, ammonia nitrogen and PAHs are provided in Tables C7 through C11 at the *end of this appendix*. Except for in the unfiltered runoff water from wet sediment, PAHs were not detectable in runoff samples.

TABLE C3. SUMMARY OF TOTAL PAHS IN SIMULATED RUNOFF WATER

Suspended Solids, mg/L	PAHs, ug/L			
	Wet Total	Wet Dissolved	Dry Total	Dry Dissolved
50,000	363.6	BDL ¹	NA ²	NA
5,000	89.7	BDL	BDL	BDL
500	BDL	BDL	BDL	BDL
50	NA	NA	BDL	BDL

¹ All PAH analytes were below method detection limits (BDL).

² Not applicable.

TABLE C4. COMPARISON OF MEAN PREDICTED METALS AND AMMONIA NITROGEN CONCENTRATIONS IN SURFACE RUNOFF TO HAWAII WATER QUALITY STANDARDS

Parameter	Hawaii Marine Chronic Toxicity Standard ug/L	Wet Total ug/L	Wet Dissolved ug/L	Dry Total ug/L	Dry Dissolved ug/L
As	36	25	5.9	9**	1.3**
Cd	9.3	9.4	<0.2	1.1**	0.4**
Cr	50	648	2.2	123.7	48.3
Cu	2.9	6309	0.8**	742.7	23.2**
Pb	5.6	2196	<1	242.4	0.6**
Hg	0.025	23.8	<0.2	2.3**	<0.2
Ni	8.3	393	0.6**	55.7**	2.1**
Ag	0.92 /p/	16.5**	0.6**	2**	<1
Zn	86	6572	<10	884**	7.1**
Ammonia Nitrogen	10*	278**	209**	1212**	733**

* Pearl Harbor Estuary water quality standard for eutrophication.

** Some replicates were below detection limits.

< All of the replicates were below detection limits.

/p/ Proposed Federal criteria.

Surface Runoff from Wet Dredged Material

Analytical results of the SLRP simulated runoff samples for metals indicate that while the dredged material is in a wet, unoxidized state, movement of metals will be associated with the suspended solids as most of the metals were not very soluble (Table C5). As long as the transported suspended solids remain in a reduced state, an increase in solubility would not be expected. Only As and Ag exhibited significant solubility at 24% and 17%, respectively. However, predicted soluble As and Ag from the wet sediment were well below the water quality standards of 36 and 0.92 ug/L, respectively. None of the dissolved heavy metal concentrations were predicted to exceed the Hawaii marine water quality standards for chronic toxicity even at the worst case suspended solids load of 50,000 mg/L. Under storm events of 5.08 cm/hr suspended solids concentrations in runoff are expected to be closer to 5,000 mg/L, based on previous evaluations of surface runoff from freshly placed dredged material in a CDF as previously shown in Table C2. Although the SLRP does not currently predict the suspended solids concentrations, this function will be incorporated into the final SLRP procedure.

TABLE C5. SOLUBILITY OF METALS AND AMMONIA NITROGEN IN SIMULATED RUNOFF

Status	Percent Soluble									
	As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	NH ₃
Wet	24	1.1	0.4	0.0001	0.3	0.6	0.2	17	0.0008	75
Dry	14	36	39	3.1	0.2	4.3	3.6	25	4.5	62

The analytical detection limit for ammonia nitrogen in this evaluation was 10 ug/L, equal to the Pearl Harbor estuary criteria. Dissolved ammonia nitrogen was not detected in simulated runoff from wet sediment at suspended solids concentrations of 500 and 5,000 mg/L. However, results for ammonia nitrogen at suspended solids concentrations of 50,000 mg/L indicate that during the wet stage movement of ammonia nitrogen may be of concern. Ammonia nitrogen was very soluble (75%) in the wet stage; movement into receiving waters will exceed the 10 ug/L Pearl Harbor estuary criteria.

Analytical results indicated PAHs in runoff water to be very limited. The PAH results are presented in full in Tables C10 and C11 for wet sediment and dry sediment, respectively. All of the detectable PAH analytes were associated with the suspended solids in the 5,000 to 50,000 mg/L simulated runoff samples, and no soluble PAHs were determined in the samples. Mean summations of the PAHs for each sediment condition and suspended solids

concentration were determined. Where at least one analyte was above detection limits, the remaining analytes were entered as half the detection limit value for summation purposes; the results are presented in Table C3. These results indicate PAHs will not be a concern in runoff water.

Surface Runoff from Dry Sediment

Drying and oxidation typically result in physicochemical changes to sediment. The effects of simulated drying and oxidation are shown in Table C6. As shown drying and oxidation had little effect on pH, electrical conductivity (EC), and salinity. Total metals are expected to be reduced in runoff from dry sediment as the suspended solids will be reduced. However, solubility of some metals will increase as the dredged material is dried and oxidized. This was previously shown in Table C5. Solubility increased significantly for Cd, Cr, Cu, Hg, Ni, and Zn compared to solubility in runoff from wet sediment. However, as shown in Table C4, soluble Cd, Cr, Hg, Ni, and Zn are predicted to be below the Hawaii marine water quality standards for chronic toxicity as well as for As, Ag, and Pb. After drying and oxidation, soluble Cu is predicted to exceed the State standard of 2.9 ug/L when suspended solids concentrations are in the 500-mg/L range and higher (Table C8). At suspended solids concentrations of 50 mg/L the standard for copper was not exceeded in the runoff sample. Mean soluble Cu was 23.2 ug/L across the suspended solids range for the dry sediment nearly an order of magnitude above the standard (Table C4).

Drying and oxidation of Pearl Harbor sediment increased both total and soluble ammonia nitrogen in simulated runoff water samples compared to wet sediment. The dissolved ammonia nitrogen in surface runoff water from the dried, oxidized dredged material was predicted to significantly exceed the Pearl Harbor estuary water quality standard for eutrophication of 10 ug/L. Mean concentrations of soluble ammonia nitrogen across the range of suspended solids concentrations were 733 ug/L or 73 times the State standard (Table C4).

TABLE C6. EFFECT OF OVEN-DRYING AND H₂O₂ TREATMENT ON PEARL HARBOR SEDIMENT CHARACTERISTICS

Parameter	Wet	Oven Dried	H ₂ O ₂ Treated
pH	8.0	7.7	7.8
Moisture, %	192.1	NA	NA
EC, mmhos/cm	52.8	44.4	66.1
Salinity, ppt	38	33	36
Organic Matter, %	16.8	16.8	20.3

All PAHs in runoff from the dry, oxidized sediment were below the method detection limits and will not be a concern in surface water runoff from the dried, oxidized dredged material.

Summary and Conclusions

Surface water runoff is one of the pathways by which contaminants in dredged material may leave an upland disposal facility and impact receiving waters. If Pearl Harbor dredged material is placed in an upland environment, heavy metals in rainfall-induced runoff from the wet, unoxidized dredged material will be mostly insoluble and bound to suspended particulates in the surface water runoff as will PAHs. Soluble metals are not predicted to exceed State of Hawaii saltwater standards during this period. Retention of suspended solids will significantly restrict all movement of metals and PAHs from the upland disposal site. Assuming the higher level of suspended solids in runoff water, dissolved ammonia nitrogen will exceed the Pearl Harbor estuary water quality standard for eutrophication, but this condition should not persist. PAHs in surface runoff water were not soluble and were closely associated with suspended solids. Total PAHs did not exceed a mean total of 300 ug/L in runoff water. Drying and oxidation of Pearl Harbor sediment significantly increased the solubility of most metals. However, only copper will exceed the Hawaii Water Quality Standards for saltwater during the dried conditions. Both total and soluble ammonia increased as the sediment dried and oxidized. Soluble ammonia concentrations are predicted to be 73 times the Pearl Harbor estuary water quality standard for eutrophication. Polynuclear aromatic hydrocarbons were not detectable in runoff samples from dry sediment and should not be a concern.

Based on the results of the SLRP, a mixing zone or other treatment alternative will be required to reduce soluble ammonia while Pearl Harbor dredged material is in a wet, unoxidized condition. As the material dries, the same requirement will be necessary for soluble copper. Soluble ammonia will increase requiring further considerations for treatment and/or controls.

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TABLE C7. METALS IN SURFACE RUNOFF WATER FROM WET SEDIMENTS

Conc. Type	SS Level mg/L	Repl. No.	Contaminant, ug/L												
			As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	TBT	TeBT	DBT	MBT
Total	A: 50,000	1A	43	22.4	1,690	17,100	NA	65.6	1,040	49.1	17,200	0.04 J	<0.1	<0.1	0.04 BJ
		2A	44.7	25.3	1,510	16,200	NA	64.8	942	44.1	16,400	NA	NA	NA	NA
		3A	39.7	25.6	1,380	16,500	NA	61.0	875	38.2	16,600	NA	NA	NA	NA
	B: 5,000	1B	23.4	3.34	329	1,920	709	6.52	187	4.6	2,780	NA	NA	NA	NA
		2B	27.3	3.39	366	2,080	653	6.38	206	5.9	2,620	NA	NA	NA	NA
		3B	24	3.06	356	2,170	630	6.84	197	5.5	2,390	NA	NA	NA	NA
	C: 500	1C	8.7	0.42	93	324	602	1.20	37	<1	578	NA	NA	NA	NA
		2C	6.7	0.34	50	241	72	0.70	27	<1	297	NA	NA	NA	NA
		3C	7.4	0.34	54	242	85	0.78	28	<1	288	NA	NA	NA	NA
Dissolved	A: 50,000	1A	10	<0.2	3	2	<1	<0.2	1	1	<10	<0.1	<0.1	<0.1	<0.1
		2A	10	<0.2	2	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		3A	10	<0.2	3	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
	B: 5,000	1B	6	<0.2	3	<1	<1	<0.2	<1	<1	<10	<0.1	<0.1	<0.1	0.06 BJ
		2B	6	<0.2	2	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		3B	5	<0.2	2	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
	C: 500	1C	2	<0.2	1	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		2C	2	<0.2	2	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		3C	2	<0.2	2	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA

J indicates estimated value. BJ indicates best estimated value.

TABLE C8. METALS IN SURFACE RUNOFF WATER FROM DRY SEDIMENTS

Conc. Type	SS Level mg/L	Repl. No.	Contaminant, ug/L												
			As	Cd	Cr	Cu	Pb	Hg	Ni	Ag	Zn	TBT	TeBT	DBT	MBT
Total	A: 5,000	1A	21.8	3.38	377	2,200	756	8.04	163	5.2	2,550	<0.1	<0.1	<0.1	0.04 BJ
		2A	18.8	2.77	284	1,900	616	5.18	125	4.6	2,250	NA	NA	NA	NA
		3A	22.1	2.77	328	1,960	600	4.88	142	5.1	2,180	NA	NA	NA	NA
	B: 500	1B	5.9	0.36	42	193	62	1.04	19	<1	218	NA	NA	NA	NA
		2B	4.9	0.23	36	184	64	0.76	28	<1	465	NA	NA	NA	NA
		3B	4.7	0.25	37	191	68	0.72	17	<1	244	NA	NA	NA	NA
	C: 50	1C	<2	<0.2	4	24	7.1	<0.2	<5	<1	20	NA	NA	NA	NA
		2C	<2	<0.2	2	17	4.6	<0.2	<5	<1	<10	NA	NA	NA	NA
		3C	<2	<0.2	4	15	3.7	<0.2	<5	<1	24	NA	NA	NA	NA
Dissolved	A: 5,000	1A	2	1.9	121	65	<1	<0.2	11	<1	24	<0.1	<0.1	<0.1	0.07 BJ
		2A	2	0.4	126	46	<1	<0.2	2	<1	<10	NA	NA	NA	NA
		3A	2	<0.2	133	42	<1	<0.2	3	<1	<10	NA	NA	NA	NA
	B: 500	1B	<2	0.4	13	19	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		2B	<2	<0.2	14	17	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		3B	<2	<0.2	16	18	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
	C: 50	1C	<2	<0.2	4	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA
		2C	<2	<0.2	3	<1	1	<0.2	<1	<1	<10	NA	NA	NA	NA
		3C	<2	<0.2	5	<1	<1	<0.2	<1	<1	<10	NA	NA	NA	NA

BJ indicates best estimated value.

TABLE C9. AMMONIA NITROGEN IN SURFACE RUNOFF ELUTRIATES

Sediment	Concentration Type	SS Level mg/L	Replicate Number	NH ₃ -N ug/L
Wet	Total	A: 50,000	1A	761
			2A	659
			3A	953
		B: 5,000	1B	39
			2B	19
			3B	52
		C: 500	1C	<10
			2C	<10
			3C	<10
	Dissolved	A: 50,000	1A	584
			2A	638
			3A	625
		B: 5,000	1B	<10
			2B	<10
			3B	<10
		C: 500	1C	<10
			2C	<10
			3C	<10
Dry	Total	D: 5,000	1D	3430
			2D	2900
			3D	3,280
		E: 500	1E	375
			2E	460
			3E	448
		F: 50	1F	<10
			2F	<10
			3F	<10
	Dissolved	D: 5,000	1D	1,520
			2D	1920
			3D	2,060
		E: 500	1E	394
			2E	342
			3E	348
		F: 50	1F	<10
			2F	<10
			3F	<10

TABLE C10. PAHS IN SURFACE RUNOFF WATER FROM WET SEDIMENT

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					
			Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
Total	A: 50,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	<10	0.8 J	0.8 J	0.8 J	4.7 J	5.2 J
		3A	<11	<11	<11	<11	4.0 J	<11
	B: 5,000	1B	NA*	NA*	NA*	NA*	NA*	NA*
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 500	1C	NA*	NA*	NA*	NA*	NA*	NA*
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 50,000	1A	<10	<10	<10	<10	<10	<10
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 5,000	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 500	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

* Samples lost in clean up.
 J indicates estimated values.

(continued)

TABLE C10. PAHS IN SURFACE RUNOFF WATER FROM WET SEDIMENTS (continued)

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					
			Fluoranthene	Pyrene	Chrysene	Benzo(a) Anthracene	Benzo(b) Fluoranthene	Benzo(k) Fluoranthene
Total	A: 50,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	17.1	22.9	43.8	19.9	146	72.4
		3A	11.7	15.1	20.8	10.2	53.6	35.0
	B: 5,000	1B	NA*	NA*	NA*	NA*	NA*	NA*
		2B	<10	<10	<10	<10	5.7 J	5.8 J
		3B	<10	<10	<10	<10	9.4 J	7.4 J
	C: 500	1C	NA*	NA*	NA*	NA*	NA*	NA*
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 50,000	1A	<10	<10	<10	<10	<10	<10
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 5,000	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 500	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

* Samples lost in clean up.
J indicates estimated values.

(continued)

TABLE C10. PAHS IN SURFACE RUNOFF WATER FROM WET SEDIMENTS (continued)

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					Total PAHs
			Benzo(a) Pyrene	Indeno(1,2,3-C,D)Pyrene	Dibenzo(A,H) Anthracene	Benzo(G,H,I) Perylene	2-Methyl-naphthalene	
Total	A: 50,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	87.8	18.9	5.1 J	20.6	<10	476.8
		3A	42.4	3.8 J	<11	14.8	<11	249.9
	B: 5,000	1B	NA	NA	NA	NA	NA	NA
		2B	5.4 J	<10	<10	<10	<10	86.9
		3B	7.3 J	4.6 J	<10	3.7 J	<10	92.4
	C: 500	1C	NA*	NA*	NA*	NA*	NA*	NA*
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 50,000	1A	<10	<10	<10	<10	<10	<10
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 5,000	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 500	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

* Samples lost in clean up
 J indicates estimated values.

(concluded)

TABLE C11. PAHS IN SURFACE RUNOFF WATER FROM DRY SEDIMENT

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					
			Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
Total	A: 5,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 5,000	1A	<12	<12	<12	<12	<12	<12
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

* Samples lost in clean up.

(continued)

TABLE C11. PAHS IN SURFACE RUNOFF WATER FROM DRY SEDIMENT (continued)

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					
			Fluoranthene	Pyrene	Chrysene	Benzo(a) Anthracene	Benzo(b) Fluoranthene	Benzo(k) Fluoranthene
Total	A: 5,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 5,000	1A	<12	<12	<12	<12	<12	<12
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

* Samples lost in clean up.

(continued)

TABLE C11. PAHS IN SURFACE RUNOFF WATER FROM DRY SEDIMENT (continued)

Concentration Type	SS Level mg/L	Repl. No.	Contaminant, ug/L					Total PAHs
			Benzo(a) Pyrene	Indeno(1,2,3-C,D)Pyrene	Dibenzo(A,H) Anthracene	Benzo(G,H,I) Perylene	2-Methyl-naphthalene	
Total	A: 5,000	1A	NA*	NA*	NA*	NA*	NA*	NA*
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10
Dissolved	A: 5,000	1A	<12	<12	<12	<12	<12	<10
		2A	<10	<10	<10	<10	<10	<10
		3A	<10	<10	<10	<10	<10	<10
	B: 500	1B	<10	<10	<10	<10	<10	<10
		2B	<10	<10	<10	<10	<10	<10
		3B	<10	<10	<10	<10	<10	<10
	C: 50	1C	<10	<10	<10	<10	<10	<10
		2C	<10	<10	<10	<10	<10	<10
		3C	<10	<10	<10	<10	<10	<10

*Samples lost in clean up.

(concluded)

Appendix D - Leachate Evaluation

Leachate Quality Screening

A leachate quality screening was performed for the contaminants present in the sediment using equilibrium partitioning theory. Based on the bulk sediment chemistry 29 chemical constituents which could pose toxicity concerns for aquatic organisms were present at detectable levels. Water quality criteria were available for 22 of the constituents. The other 7 constituents were members of the PAH class of constituents which has a criteria for total PAHs.

According to equilibrium partitioning theory, transfer between solid and liquid phases of dredged material occurs when a difference in chemical potentials exists in the two phases. When chemical potentials are equal, then the net transfer of contaminant across the solid-water interface is zero, and the concentration of contaminant in each phase is constant but not necessarily equal. This stage is considered to be the equilibrium condition, and the ratio of leachable contaminant concentration in the solid phase (q') to contaminant concentration in the aqueous phase (C) is the equilibrium partitioning or distribution coefficient, K_d . The equilibrium partitioning coefficient, K_d (L/kg), is written as

$$K_d = \frac{q'}{C} \quad (D1)$$

where

$$q' = q - q_r \quad (D2)$$

- and
- K_d = contaminant distribution coefficient at equilibrium, L/kg
 - q = contaminant concentration in the solid phase at equilibrium, mg/kg
 - q_r = residual (nonleachable) contaminant concentration in the solid phase, mg/kg
 - q' = leachable contaminant concentration in the solid phase at equilibrium, mg/kg
 - C = contaminant concentration in the aqueous phase at equilibrium, mg/L

Equation D1 describes the equilibrium distribution of a single contaminant in a dredged material. Equilibrium partitioning coefficients are contaminant and dredged material specific.

Estimation of contaminant concentration in leachate or pore water requires the leachable contaminant concentration in the bulk sediment, the dry bulk density and porosity of the material, and the partitioning distribution coefficient (K_d). The partitioning for metals in particular is strongly a function of the geochemical condition of the material (oxidized state versus reduced state). An oxidized condition represents the worst case for contaminant mobilization, particularly for metals. Under ideal operation it is anticipated that the dredged material will be fully desiccated and oxidized between disposals. During the actual disposal and dewatering periods the sediment is likely to be in a reduced state and mobility would be one to two orders of magnitude lower. For metals and ammonia the partitioning distribution coefficient and leachable fraction were estimated from the measured dissolved and total contaminant concentrations from the results of the modified elutriate test presented in Appendix B and the simplified runoff laboratory procedure for oxidized sediment presented in Appendix C. The leachable fraction was used to compute q' as given in Table D1.

The equilibrium partitioning coefficients for the organic constituents (K_{ow}) were obtained from the literature (Battelle 1994) since most of the dissolved concentrations in the pathway testing were below detection. K_d is computed as a function of the dissolved organic carbon (DOC) and the total organic carbon (TOC) expressed as a fraction of the dry weight. From the bulk sediment chemistry data the DOC and TOC were 1.9 mg/L and 0.0368, respectively. The K_{ow} values and the computed K_d values are given in Table D2. The leachable fraction for the organic constituents was assumed to be 1 (fully leachable).

$$K_d = \frac{0.617 \text{ TOC} \cdot K_{ow}}{1 + (0.617 \times 10^{-6} \text{ DOC} \cdot K_{ow})} \quad (D3)$$

where

TOC = total organic carbon, dimensionless

K_{ow} = octanol-water partitioning coefficient, dimensionless

DOC = dissolved organic carbon, mg/L

The results of the screening procedure are the contaminant concentrations in the leachate or pore water as computed by Equation D4 and the relative contaminant concentration in the pore water or attenuation factor as computed by Equation D5.

$$C_{pw} = \frac{1000 q' (1-n) SG \rho_w}{n + [K_d (1-n) SG \rho_w]} \quad (D4)$$

where

C_{pw} = contaminant concentration in pore water, ug/L
 q' = bulk contaminant concentration in sediment, mg/kg
 n = porosity, dimensionless
 SG = specific gravity of sediment solids, dimensionless
 ρ_w = water density, kg/L

$$RPC = \frac{C_{pw}}{C_c} \quad (D5)$$

where

RPC = relative concentration in pore water (attenuation factor)
 C_c = water quality criteria, ug/L

The relative concentration is the ratio of the concentration to the water quality criteria. It represents the dilution, dispersion, degradation or attenuation ratio required to meet the criteria. A relative concentration less than or equal to 1 indicates that the leachate satisfies water quality criteria for that contaminant without the need for attenuation; a value greater than 1 indicates a need for attenuation by adsorption, degradation, dilution, or other means. The results are given in Tables D1 and D2. As shown in Table D1, only ammonia nitrogen, copper, lead, mercury, nickel, and silver exceeded the water quality criteria in the pore water. Of these six contaminants mercury and lead pose the greatest concern due to their lower distribution coefficients, conservative nature, and higher attenuation requirement. As shown in Table D2, three of the organics require attenuation: DDT, dieldrin, and PCB-1260. Of these three only dieldrin poses a potential leachate problem due to its relatively low distribution coefficient; however, its potential for concern is less than that for lead and mercury because it requires lower attenuation and is subject to degradation. The sum of the PAHs was less than 2 percent of the criteria for total PAHs. Analysis (modeling) of attenuation is required for these nine constituents and is presented in the main body of this report.

Reference

Battelle Memorial Institute. (1994). "Multimedia-Modeling Environmental Database Editor, Version 1.0," Richland, WA.

TABLE D1. LEACHATE QUALITY SCREENING RESULTS FOR METALS AND AMMONIA

Contaminant	Hawaii Marine WQ Std. for Chronic Toxicity C_c ug/L	Sediment Conc. C_s or q mg/kg	Leachable Fraction	Leachable Conc. q' mg/kg	Site Water Conc. C_b ug/L	Distribution Coefficient K_d L/kg	Pore-Water Conc. C_{pw} ug/L	Attenuation Factor RPC
Ammonia Nitrogen	10*	1.27	1	1.27	0	0.0227	742.	74.2
Antimony	500	1.63	0.1	0.163	0	70	2.27	0.005
Arsenic	36 for As(III)	13.5	0.1	1.35	38	70	18.8	0.523
Beryllium	10	0.632	0.2	0.1264	0	40	3.03	0.303
Cadmium	9.3	0.779	0.1	0.0779	0	40	1.87	0.201
Chromium	50 for Cr(VI)	128	0.03	3.84	6	100	37.8	0.755
Copper	2.9	588	0.01	5.88	12	130	44.7	15.4
Lead	5.6	150	0.1	15	1	70	209.	37.4
Mercury	0.025	1.18	0.1	0.118	0	70	1.65	65.8
Nickel	8.3	74.3	0.03	2.229	7	100	21.9	2.64
Selenium	71	2.0	0.2	0.4	141	40	9.59	0.135
Silver	0.92	1.87	0.1	0.187	6	70	2.61	2.84
Thallium	710	0.2	0.2	0.04	0	40	0.960	0.00135
Zinc	86	497	0.02	9.94	14	120	81.7	0.950

* Pearl Harbor estuary water quality standard for eutrophication.

TABLE D2. LEACHATE QUALITY SCREENING RESULTS FOR ORGANICS

Contaminant	Hawaii Marine WQ Std. for Chronic Toxicity C _c ug/L	Sediment Conc. C _s or q' mg/kg	Site Water Conc. C _b ug/L	Octanol Water Partitioning Coef. K _{ow} L/kg	Distribution Coefficient K _d L/kg	Pore-Water Conc. C _{pw} ug/L	Attenuation Factor RPC
Aldrin	1.3	0.0074	0	200000	3680.	0.0020	0.0016
Benzo(a)Anthracene	300*	0.72	0	398000	6160.	0.117	0.00039
Benzo(b,k)Fluoranthene	300*	6.78	0	1150000	11120.	0.610	0.0020
Benzo(a)Pyrene	300*	3.09	0	1150000	11120.	0.278	0.00093
Benzo(G,H,I)Perlyene	300*	1.37 J	0	1150000	11120.	0.123	0.00041
Bis(2-Ethyl-Hexyl)Phthalate	2944	1.19 J	0	141000	2750.	0.433	0.00015
Chrysene	300*	1.29 J	0	407000	6260.	0.206	0.00069
DDE	1.2	0.0088	0	10000000	17850.	0.00049	0.00041
DDT	0.001	0.047	0	1550000	12490.	0.0038	3.76
Dieldrin	0.0019	0.0013 J	0	3160	71.5	0.0178	9.35
Fluoranthene	13	1.01 J	0	79400	1650.	0.612	0.047
Indeno(1,2,3-C,D)Pyrene	300*	1.71 J	0	3160000	15250.	0.112	0.00037
Lindane	0.16	0.0059	0	60300	1280.	0.0046	0.029
PCB-1260	0.03	0.949	0	14100000	18260.	0.0520	1.73
Pyrene	300*	1.06 J	0	209000	3810.	0.278	0.00093

* Individual values not available; values for Total PAHs used.

J indicates estimated values.

Appendix E - Tier I Screening for Plant Uptake of Heavy Metals from Dredged Material in an Upland Environment

Purpose and Scope

The placement of dredged material in an upland or nearshore environment requires that a number of pathways be evaluated to determine the potential for adverse impacts. These pathways and the Decision Making Framework (DMF) for Management of Dredged Material are described by Lee et al. (1991). One of the pathways for evaluation is the plant uptake pathway. Unless adverse conditions exist (excessively low pH, high phytotoxic contaminant concentrations, etc.), plant communities will colonize dredged material that has been placed in a confined disposal facility (CDF) and dewatered. The potential for plants to mobilize contaminants from the dredged material, bioaccumulate contaminants, and transfer contaminants to the food chain is of concern. Dredged material placed in an upland environment is subject to physicochemical changes over time that will affect availability of contaminants to plants. The plant bioassay procedure, developed under the Long-Term Effects of Dredging Operations (LEDO) program, addresses these changes and the effects on plant uptake of contaminants. The procedures are described by Folsom and Price (1989) for freshwater plants and by Lee et al. (1992) and by Lee et al. (1995) for saltwater upland and saltwater wetland, respectively. The plant bioassay procedure consists of the exposure of an index plant to sediment from a proposed dredging project. The sediment is prepared to simulate wetland/flooded conditions or processed to simulate the long-term effects of drying and oxidation before being planted with seedlings of the appropriate specie. *Spartina alterniflora* and *Sporobolus virginicus* are used for saltwater wetland and saltwater upland, respectively. *Cyperus esculentus* is used for both freshwater upland and freshwater wetland conditions. The procedure calls for sediment exposure through maturity of the plant or 45 days in an environmentally controlled greenhouse. Above ground plant tissues are harvested and analyzed for contaminant concentrations. The data obtained are compared to FDA-type action levels and recommended limitations prescribed by various European countries. Currently, U.S. standards for plant contaminant concentrations do not exist, and action levels are limited. However, concentrations in plant tissues must be addressed to provide for an appropriate risk analysis and environmental assessment of dredged material placement.

Screening Tools

A simplified tool for the prediction of plant uptake of metals is the extraction of metals from sediment using diethylenetriamine-pentaacetic acid (DTPA). The DTPA extraction procedure is described by Lee et al. (1978) and Folsom et al. (1981) and is based on the procedure of Lindsay and Norvell (1978). The DTPA procedure has been used in several studies to successfully predict plant uptake from dredged material placed in upland environments (Lee et al. 1982, 1983 and 1991 and Environmental Laboratory 1987) and compared well with actual concentrations of metals in leaves of bioassay plants. A computerized program, the Plant Uptake Program (PUP), was developed to provide a tool for predicting uptake of heavy metals from freshwater dredged material by freshwater plants (Folsom and Houck 1990). The model requires total sediment metals concentrations, DTPA extraction, organic matter percentage and the sediment pH in the condition of placement (wetland or upland).

Tiered Approach Evaluations and Decision Making

The Decision Making Framework (DMF) currently evaluates the plant uptake pathway using both the DTPA (soil extraction data) and the bioassay procedure (actual plant uptake data) in a tiered approach. The DMF also requires that a reference sediment (the disposal site or background site determined by Regional Administrative Decision (RAD)) be included for comparison. Ideally, the DTPA procedure would be conducted on the original wet sediment, dried sediment, and a reference sediment or soil in Tier I. DTPA concentrations of any metal from the dry test sediment exceeding DTPA concentrations from the reference sediment or the wet test sediment would invoke a RAD. Should the DTPA concentration of any metal from the dried test sediment exceed both the reference and the wet test sediment, then a Decision for Further Evaluation may require a plant bioassay evaluation in Tier II. Other considerations under a RAD are also an option prior to Tier II, such as 1) the number of DTPA extracted metals exceeding wet sediment or reference sediment, 2) magnitude by which wet sediment or reference sediment is exceeded, 3) toxicological importance of exceeding metals, and 4) proportion of sediment sampling sites with DTPA extracted metals from dried sediment exceeding the wet sediment or reference sediment, unless the test sediment is a composite. The application of the plant bioassay procedure is described in detail in Folsom and Price (1989). Results from the bioassay are evaluated on the basis of plant growth, bioaccumulation of contaminants, and total plant uptake. Decisions of Further Evaluations and Decisions for Restrictions are discussed in detail in Lee et al. (1991). Bioaccumulated contaminant concentrations are compared to available demonstrated effects levels, FDA-type action levels, or other human health levels. These provide for some rationale in determining restrictions to prevent adverse uptake of contaminants or movement of contaminants to surface soils or into animals through plant uptake.

Objective

The objective of this study was to determine the DTPA extractable metals from the saltwater Pearl Harbor sediment placed in an upland environment. The assumptions are that the saltwater dredged material will eventually dry and oxidize, salts will be leached, and establishment or colonization of freshwater plants will occur. DTPA extracts are indicative of freshwater plants; DTPA extracts are significantly higher than saltwater plant uptake.

Approach

The plant uptake pathway was evaluated using the DTPA and computer simulation protocol described in the Technical Note EEDP-04-12 by Folsom and Houck (1990). Initially, only one Pearl Harbor test sediment (PHS) was provided. Later, two Waipio Peninsula soil samples (SC1 and UC1) were provided as the references. The metal contents of the reference soils are presented in Tables E1 and E2. Copper, mercury, and silver are present in the dredged material at higher concentrations than in the reference soils. Efforts in addition to the procedures described in the above-cited technical note were included to address the concerns associated with the possibly drastic physicochemical changes that occur when placing a saltwater sediment in an upland, freshwater environment. These efforts include the use of oven-drying and oxidation with hydrogen peroxide to rapidly simulate the long-term drying and oxidation effects of exposure to air and drainage. This application is currently used in the Simplified Laboratory Runoff Procedure (SLRP) for predicting the long-term effects of drying and oxidation on surface runoff water quality as described by Price et al. (1998). The SLRP was used for the surface water runoff pathway portion of the study presented in Appendix C.

Methods and Materials

Sediment Preparation and Analysis

Sediment preparation. Two 5-gal polyethylene buckets of Pearl Harbor sediment (PHS) composite were consolidated and thoroughly mixed with a Lightning mixer to ensure homogeneity, and samples were collected for the determination of sediment physical and chemical characteristics. The mixed sediment was placed back in the original buckets and stored in a walk-in cold room at 4° C until needed. The two reference soils were not mixed together. Each of two reference soils were handled individually following the above procedures.

TABLE E1. METALS ANALYSIS FOR REFERENCE SOILS

Parameter	Concentration, mg/kg					
	Reference Soil UC1			Reference Soil SC1		
	Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Arsenic	7.71	7.91	8.06	33.8	32.2	33.1
Cadmium	1.9	1.9	1.9	4.2	3.8	4.0
Chromium	98.9	94.7	102	202	194	195
Copper	64.6	71.8	74.4	100	100	103
Lead	309	263	333	19.5	22.6	19.9
Mercury	0.138	0.154	0.156	0.268	0.256	0.244
Nickel	70.6	72.7	73.4	232	205	219
Silver	0.15	0.27	0.20	0.10	0.11	0.11
Zinc	766	658	714	151	141	144

TABLE E2. METALS ANALYSIS FOR PEARL HARBOR SEDIMENT AND REFERENCE SOILS

Parameter	Concentration, mg/kg Average of 3 Replicates		
	Pearl Harbor Sediment	Reference Soil UC1	Reference Soil SC1
Arsenic	13.5	7.89	33.0
Cadmium	0.779	1.9	4.0
Chromium	128	98.5	197
Copper	588	70.3	101
Lead	150	302	20.7
Mercury	1.18	0.149	0.256
Nickel	74.3	72.2	219
Silver	1.87	0.21	0.11
Zinc	497	713	145

Electrical Conductivity and Salinity. Electrical conductivity (EC) was determined on saturated extracts of each wet, dried, and dried + peroxide sediment using the method of Rhoades (1982). The extracts were measured on a YSI model 32 conductance meter to determine EC in mmhos cm^{-1} . Salinity was also measured on the extracts using a model 10419 hand refractometer (American Optical, Buffalo, NY).

Sediment pH. Ten grams (oven dry weight (ODW) to nearest 0.001 g) of original wet, dried, and dried + peroxide sediments were weighed into a tall 50-mL Pyrex glass beaker. Twenty milliliters of distilled water were added, and the mixture was stirred with a polyethylene rod until all particles were saturated. The mixture was stirred with a magnetic stirrer for 1 min every 15 min for 45 min. After 45 min, the pH electrode was placed into the solution above the surface of the sediment, and the pH was read on a pH meter (Folsom et al. 1981).

Organic Matter. Organic matter (OM) was determined by weight loss on ignition at 550° C on AD (air-dried) and ADW (air-dried, washed) sediment. Procedure No. 209E (American Public Health Association 1976) was used for this test. A 5-g subsample (ODW) was weighed to the nearest 0.001 g and dried at 105 ± 2° C until constant weight (48 hr). Five grams of the oven-dried sediment were weighed to the nearest 0.001 g and combusted at 550 ± 5° C for 24 hr in a muffle furnace. The sample was allowed to cool to room temperature in a moisture desiccator and weighed to the nearest 0.001 g. Weight loss on ignition was calculated and reported as % OM using the following formula:

$$\% \text{ organic matter} = \frac{\text{oven dry weight} - \text{combusted weight}}{\text{oven dry weight}} \times 100$$

DTPA Extraction. The DTPA extractions were conducted on the wet and dry sediments following the methods in Folsom and Houck (1990) except that the sediment was oven dried at 90 °C for 48 hr compared to air drying for three weeks. In addition, oven dry sediment was oxidized using 30% hydrogen peroxide to completely oxidize the sediment and simulate the long-term exposure to oxygen. The peroxide oxidation procedure is also used to predict the long-term effects of drying and oxidation on surface runoff water quality and has been shown to accurately predict concentrations of most metals in surface runoff water from sediment placed in upland environments (Price et al. 1998). In previous studies, hydrogen peroxide was not included in the DTPA procedure and was included in this study to provide some continuity of materials evaluated for the surface runoff and the plant uptake evaluations. A pretest was necessary to determine the amount of H_2O_2 necessary to fully oxidize the Pearl Harbor sediment. Ten grams of dried sediment was placed in a 3.8-L glass jar,

and 30% H₂O₂ was slowly and incrementally added, each time observing for an effervescent reaction. When the oxidation process was complete as indicated by lack of reaction, the amount of H₂O₂ used was recorded; the resulting H₂O₂ per gram of sediment was used to fully oxidize sufficient sediment to conduct the DTPA extraction. After oxidation with H₂O₂, the sediment was again oven dried and then used in the extraction procedure.

Prediction of Plant Uptake

The mean DTPA and total sediment metal concentrations were input along with pH and organic matter content into the PUP as described in Folsom and Houck (1990). DTPA metals concentrations below the analytical method detection limit (MDL) were entered as the MDL value times 0.5. Results are presented as plant metals concentration in ug/g and as total plant uptake in ug on an oven dry weight basis.

Results and Discussion

Effects of Drying and Oxidation

The effects of drying and oxidation of PHS, SC1, and UC1 are shown in Table E3. Based on the results, it is assumed that the reference soils provided, SC1 and UC1, are upland, freshwater soils. The drying and oxidation procedures were not expected to result in significant physicochemical changes in these two soils. For some dredged materials, the results may be similar. Drying did not significantly affect the pH of the PHS nor did oxidation with peroxide. Soluble salts in the PHS were reduced slightly by drying and then resolubilized by oxidation with peroxide. Organic matter was not changed by drying, but was increased by oxidation. This appears inconsistent with the purpose of the oxidation procedure which is to reduce organic matter content. However, the procedure that has been used throughout the development of the PUP procedure overestimates organic matter. Nelson and Sommers (1982) state that procedures based on combustion overestimate organic matter as both organic and inorganic carbon (C) lose weight on ignition at high temperatures. Assuming a reduction of organic matter by peroxide oxidation prior to combustion, the resulting oxidized sediment would yield a higher inorganic carbon percentage by weight. Based on the bulk sediment analysis, mean total organic carbon (TOC) is 36,800 mg/kg or 3.68%. Organic matter can be directly estimated by the universally accepted conversion factor of 2 (Nelson and Sommers 1982). This would result in an estimated organic matter content of wet Pearl Harbor dredged material of 7.36%. If the PHS is placed in an upland condition, little change in the parameters shown in Table E3 is expected. However, soluble salts would be expected to decrease over time provided adequate removal by leaching and surface runoff water.

TABLE E3. EFFECTS OF DRYING AND OXIDATION ON PHYSICOCHEMICAL CHARACTERISTICS

Parameter	Wet			Oven Dry			Oven Dry H ₂ O ₂ Oxidized		
	PHS	SC1	UC1	PHS	SC1	UC1	PHS	SC1	UC1
pH	8.0	7.4	7.5	7.7	7.3	7.5	7.8	7.4	7.6
Moisture, %	192.1	6.37	2.19	NA			NA		
EC, ms	52.8	0.91	2.77	44.4	1.24	2.57	66.1	1.79	3.35
Salinity, ppt	38	0	0	33	0	0	36	0	0
OM, %	16.8	14.1	15.7	16.8	14.1	15.7	20.3	15.8	15.5

DTPA Extractable Metals

Mean DTPA extracted metals from the wet, unoxidized and dry oxidized PHS, SC1, and UC1 are presented in Table E4. Numbers shown in () represent the increases (percent) in DTPA extractable metals over the wet sediment or soil, with decreases indicated by (-). Drying the PHS sediment increased DTPA extractable Cd, Cr, Cu, Pb, Hg, Ni, and Zn. Arsenic concentrations decreased, and Ag was undetectable in all samples analyzed. DTPA extractable Hg was at or near the detection limits in all samples. Additional treatment of dry sediment with H₂O₂ had little effect on the availability of most metals. Arsenic was reduced even further, likely by volatilization or transformation to less extractable organic or inorganic arsenical compounds. Oxidation with H₂O₂ significantly increased extractable chromium. Most attempts to relate soil Cr to plant characteristics have been unsuccessful (Pratt 1966, Mortvedt and Giordano 1975, and Shewery and Peterson 1976). Reisenauer (1982) attributes this in part to the slow rate of ligand exchange of Cr(III) complexes, which reduces the usefulness of common chelating extractants such as DTPA. Earley and Cannon (1965) determined elevated temperatures or long reaction times in the preparation of Cr(II) complexes are required for quantitative extractions or separations. One result of the oxidation reaction of sediment with H₂O₂ is the generation of heat which may explain the increased DTPA extracted Cr. In Folsom et al. (1981) the results of air drying of 8 saltwater sediments had variable results on DTPA extractable Cr ranging from no effect to a 300% increase.

Changes in DTPA extractable metals from the two reference soils were not expected to be as significant as the PHS since the soils were already in a dried, upland condition. The results of the oven-drying and oxidation with H₂O₂ for the SC1 and UC1 are provided to demonstrate the different effects these processes have on DTPA extractable metals in soil materials that are in

TABLE E4. DTPA EXTRACTED METALS IN PEARL HARBOR AND REFERENCE SOILS

Metals	Concentration, mg/kg								
	PHS	Wet SC1	UC1	Oven Dry			Oven Dry, H ₂ O ₂ Oxidized		
				PHS	SC1	UC1	PHS	SC1	UC1
Arsenic	0.282	0.0556	0.0185	0.097 (-68) ¹	0.071 (28)	0.025 (35)	0.024 (-91)	0.079 (42)	0.425 (2197)
Cadmium	0.178	0.325	0.400	0.563 (216)	0.454 (40)	0.570 (43)	0.502 (182)	0.418 (29)	0.425 (6)
Chromium	0.025	<0.01	0.046	0.163 (552)	<0.01 (NA)	0.33 (617)	4.77 (18980)	<0.01 (NA)	0.405 (780)
Copper	26.9	15.85	12.5	242 (800)	18.75 (18)	13.5 (8)	215.5 (701)	20.8 (31)	15.95 (28)
Lead	52	1.105	56.5	97.2 (87)	1.44 (30)	55.5 (-2)	78.5 (51)	1.42 (29)	65.5 (16)
Mercury	<0.001	<0.001	<0.001	0.0021 (320)	<0.001 (NA)	<0.001 (NA)	0.0008 (60)	<0.001 (NA)	<0.001 (NA)
Nickel	1.54	7.35	2.15	4.75 (208)	7.95 (8)	2.59 (20)	3.65 (137)	10.17 (38)	2.95 (37)
Silver	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc	85.2	5.84	159.0	354.2 (315)	10.34 (77)	140.5 (-12)	280.3 (229)	8.28 (42)	154.9 (-3)

¹ Percent increase () or decrease (-) in DTPA extractable metal as a result of drying and oxidation.

anaerobic vs. aerobic conditions. Comparisons of DTPA extractable metals from the wet, dried and oxidized PHS would only need to be compared to the wet (field condition) SC1 and UC1 DTPA metals. As shown previously in Table E3, these soils were in a very dry condition. Except for As and Cu, DTPA extractable metals from one or both of the wet (field condition) SC1 and UC1 were equal to or higher than the wet PHS. All of the metals in the PHS, except Ag and Ni, exceeded metals in the wet reference soils after drying and oxidation.

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Appendix F - Contaminant Volatilization from Dredged Material CDF

Background

One of the major contaminant loss pathways from a confined disposal facility (CDF) is volatilization. The approach used for data analysis was taken from "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments" (USEPA 1996). This appendix presents results of contaminant volatilization for dredged material disposal at Pearl Harbor, Hawaii.

Volatilization

Volatilization is the movement of a chemical into the air from a liquid surface. Volatilization from dredged material solids involves desorption through a water film covering the solids and then from the water to the air. Because chemicals must enter the water phase before they can volatilize from dredged material, the tendency of a chemical to volatilize from dredged material can be generally related to the Henry's constant. Henry's constant is the equilibrium distribution of a volatile chemical between air and water if true solutions exist in both phases (Thibodeaux 1979).

Henry's constant and, therefore, volatilization tendency depend on aqueous solubility, vapor pressure, and molecular weight. Chemicals with high Henry's constant will tend to volatilize while chemicals with low Henry's constant will tend to dissolve in water. Henry's constant is directly proportional to vapor pressure and inversely proportional to aqueous solubility. The actual direction of chemical movement across the air-water interface depends on chemical concentrations in aqueous and air phases and Henry's constant. The transfer rate (desorption for transfer to water and volatilization for transfer to air) depends on wind-induced turbulence at the air-water interface.

Theoretical chemodynamic models for volatile emission rates from dredged material were described by Thibodeaux (1989). Thibodeaux identified four emission locales, each with its own sources and external factors affecting emission rates. These four locales were as follows:

- a. Dredged material transportation devices.
- b. Ponded dredged material.
- c. Exposed sediment.
- d. Vegetation-covered dredged material.

Of these four locales b and c are dominant and therefore the volatile loss analysis presented in this appendix is limited to the ponded dredged material and exposed dredged material solids.

The assumptions used in modeling were established as specific to the proposed CDF and disposal operation for Pearl Harbor and Waipio Peninsula. The assumptions are conservative in nature so as to predict the greatest exposure. The sensitivity of these assumptions considering their likely range of values is small in comparison to contaminant-specific coefficients. The assumptions are as follows:

1. Total area of CDF = 100 acres.
2. Available area to each deposit event = 10 acres.
3. Events every 3 years.
4. Exposition period to exposed material = 6 hr.
5. Exposition period to ponded material = 12 hr.
6. Control volume = 50 acre-ft.
7. Bulk density of dredged material = 0.86 g/cm^3 (860 g/L).
8. Volatilization is so small that it does not affect dissolved chemical concentration.
9. There is a source of chemical that replenishes the dissolved chemical mass as it volatilizes.
10. Dredged material begins evaporative drying and volatile chemical emission as soon as it is exposed to air.
11. The sediment (exposed material) is exposed directly to air and void of vegetative or other cover.
12. Wind-driven currents are of the order of 3.0% of the wind speed, assuming continuity of shear stresses at the air-water interface.
13. Average weight of adult = 72.57 kg (160 lbs).
14. Minute ventilation = 28.6 L/min.
15. Molecular wt. of air = 28.97 g/gmol.
16. Molar volume of air = 24.46 L/gmol.
17. Gas constant = 0.0821 L-atm/gmol-°k.
18. All gases present ideal behavior ($Z=1$).
19. Pressure = 1 atm.
20. Temperature = 298°K.
21. Total porosity = 0.75

22. Air-filled porosity = 0.2.
23. Wind velocity = 2.5 m/s (8.2 fps).
24. Wind-driven water velocity = 0.075 m/s (0.246 fps).
25. Contaminant diffusivity in water = 5.00 cm²/s (1.64 ft²/s).

Locale b - Poned Dredged Material

Dredged material slurries pumped to primary settling facilities or CDFs undergo sedimentation, resulting in a thickened deposit of settled material overlain by clarified supernatant. Thus, the ponded dredged material locale is characterized by water containing contaminated suspended solids and a thickened bottom deposit of dredged material. The volatilization pathway in this case involves desorption from the contaminated suspended solids followed by transport through the air-water interface.

The bottom deposit is not part of the pathway because suspended solids control dissolved contaminant concentrations, and it is dissolved chemicals that volatilize. While bottom deposits can contribute to dissolved contaminant concentrations, the contribution from bottom deposits is not important until the suspended solids concentration becomes negligible. In a primary settling facility, there is a continuous flux of suspended solids through the water column while dredged material is being pumped in. Diffusion from bottom deposits is, therefore, unimportant relative to desorption from suspended solids in controlling dissolved contaminant concentrations in primary settling facilities.

The equation for volatilization from the ponded dredged material locale is given below (Thibodeaux 1989):

$$N_W = K_{OL}(C_W - C_W^*) \quad (F1)$$

where

N_W = flux through air-water interface, g/cm²-s

K_{OL} = overall liquid phase mass transfer coefficient, cm/s

C_W = dissolved contaminant concentration, g/cm³

C_W^* = hypothetical dissolved chemical concentration in equilibrium with background air, g/cm³

The dissolved contaminant concentration can be estimated using the specific contaminant distribution coefficient, or data on dissolved contaminant concentrations from the modified elutriate test can be used. For primary settling facilities, the ponded water area is known, and the suspended solids can be predicted using the column settling tests. Equation F1 is applicable

when the dissolved contaminant concentration is constant. Since volatilization continuously removes chemical mass from the dissolved phase, there is an implicit assumption for application of Equation F1 that either volatilization is so small that it does not affect dissolved chemical concentrations or there is a source(s) of chemical that replenishes the dissolved chemical mass as fast as it volatilizes. The effect that volatilization has on dissolved chemical concentrations depends on physical and chemical properties of the chemical of interest and site conditions. For these reasons, the relative significance of volatilization as a process affecting dissolved concentrations cannot be evaluated without applying a fate and transport model that simulates all the important processes. In primary settling facilities, however, there are two sources that can replenish chemical mass lost through volatilization. First, the chemical is being continuously added in dissolved form by disposal operations. Second, there is a continuous solids flux through the water column that through partitioning processes tends to maintain constant dissolved chemical concentrations. For these reasons, the assumption of a constant dissolved chemical concentration is probably a good approximation of the field condition. It is also a conservative assumption since the gradient driving the volatilization process is not allowed to decrease.

Equation F1 has not been field verified for dredged material in pretreatment facilities or CDFs. The equation is, however, widely accepted and has been verified for volatile chemical emissions from various water bodies and waste impoundments (Liss and Slater 1974, Dilling 1977, Thibodeaux 1979, and Thibodeaux et al. 1984). Probably the largest source of error in Equation F1 is estimation of the overall liquid phase mass transfer coefficient.

The overall liquid phase mass transfer coefficient depends on a variety of variable environmental and hydrodynamic factors that are difficult to quantify. Lunney et al. (1985) correlated overall liquid phase mass transfer coefficients to wind speed and molecular diffusivity in water. Thomas (1990a) describes some alternative techniques for estimating the overall liquid phase mass transfer coefficient that are based on two-resistance theory as follows (Liss and Slater 1974 and Thibodeaux 1979):

$$\frac{1}{K_{OL}} = \frac{1}{K_L} + \left[\frac{1}{HK_G} \right] \quad (F2)$$

where

K_L = liquid-side mass transfer coefficient, cm/s

K_G = gas-side mass transfer coefficient, cm/s

H = Henry's constant, dimensionless

Although Equation F1 is a theoretical equation, estimation of the mass transfer coefficients is highly empirical. Thomas (1990a) suggests using Southworth's correlations for volatilization of polynuclear aromatic hydrocarbons to estimate gas-side and liquid-side mass transfer coefficients as follows:

$$K_G = 0.32(V_x + V_{Curr}) \sqrt{\frac{18}{M_A}} \quad (F3)$$

where

V_x = wind speed, m/s

V_{Curr} = water velocity, m/s

M_A = molecular weight of chemical A, g/gmol

For wind speeds greater than 1.9 m/s and less than 5 m/s:

$$K_L = 0.0065 \left[\frac{V_{Curr}^{0.969}}{Z^{0.673}} \right] \sqrt{\frac{32}{M_A}} e^{0.526(V_x^{-1.9})} \quad (F4)$$

where

Z = water depth, m

When there exists no mean advective current in a CDF, wind-driven currents are of the order of 3 percent of wind speed, assuming continuity of shear stresses at the air-water interface. Thus, V_{curr} in Equations F3 and F4 can be replaced with 3 percent of the wind speed.

In view of the lack of field data on volatilization from dredged material pre-treatment and disposal facilities, it is not possible to determine which technique is the most accurate for estimating mass transfer coefficients. The correlations in Equations F3 and F4 were developed, however, for very similar situations of evaporation from surface impoundments. The information from the literature suggests that the techniques discussed in this report should be accurate to within an order of magnitude (Thomas 1990a).

Locale c - Exposed Sediment

This volatilization locale is characterized by sediment that is exposed directly to air and void of vegetative or other cover. Exposed sediment is

probably the most significant of the four volatilization locales as a source of volatile emissions (Thibodeaux 1989). Exposed sediment will be a source of volatile emissions during various stages of pretreatment and flow equalization as follows:

- a. Delta formed during primary settling of dredged material slurries.
- b. Dredged material in filled primary settling facilities after ponded water is drawn off.
- c. Delta formed during mechanical placement of dredged material in in-water or nearshore flow equalization facilities.
- d. Dredged material in upland flow equalization facilities for mechanically dredged material.

The rate at which chemicals volatilize from exposed sediment is affected by many factors. Geotechnical properties such as porosity and water content, chemical factors such as water and air diffusivities, and environmental factors such as wind speed and relative humidity all affect volatilization rates. In addition, processes such as air-water-solids chemical partitioning, diffusion of thermal energy, evaporation of water, and desiccation cracking of the sediment can have pronounced impacts on volatile emission rates for exposed sediment. Complete mathematical coupling of all these processes and the factors affecting these processes into a model equation(s) would lead to a very complex model requiring site-specific data that are usually unavailable. For this reason, the vignette models proposed by Thibodeaux (1989) are recommended for *a priori* prediction and are used in this appendix.

Dredged material begins evaporative drying and volatile chemical emission as soon as it is exposed to air. Initially, the chemical emission rate is affected by gas-side resistance. The top microlayer quickly becomes depleted of volatile chemicals (and water); so that, continuing losses of volatile chemicals come from the pore spaces within the dredged material. At this point, the emission process is transient and changes from being gas-side resistance controlled to dredged material-side vapor diffusion controlled. The overall process is modeled by Equation F5 (Thibodeaux 1989).

$$n_{\theta} = \frac{\left[\frac{C_s H}{1000 K_d} - C_{ai} \right]}{\sqrt{\frac{\pi t}{D_{A3} \left(\epsilon_1 + \frac{K_d}{\rho_b} \right)} + \frac{1}{K_G}}} \quad (F5)$$

where

n_e = instantaneous flux of chemical A through the dredged material-air interface at time t , mg/cm²-s

C_s = solid phase contaminant concentration, mg/kg

K_d = contaminant specific equilibrium distribution coefficient, cm³/g

C_{ai} = background concentration of chemical A in air at dredged material-air interface, mg/cm³

π = 3.1416

t = time since initial exposure, sec

D_{A3} = effective diffusivity of chemical A in the dredged material pores, cm²/s

ϵ_1 = air-filled porosity, dimensionless

ρ_b = bulk density, g/cm³

Equation F5 is an idealized diffusion model that describes chemical movement in the unsaturated zone near the air-dredged material interface. The emission pathways modeled include surface depletion, desorption from particle surfaces into a water film surrounding the particle surfaces (K_d), desorption from the water film into the pore gas (H) and vapor phase diffusion in the dredged material pore spaces (D_{a3}, e, p). When top microlayer depletion is neglected, the average volatile flux over some time t is twice the instantaneous flux at time t . Average flux multiplied by the area of exposed sediment and the exposure time yields the total volatile loss.

The diffusion equation on which Equation F5 is based is well established for pesticide volatilization from soil surfaces (Hamaker 1972, Mayer et al. 1974, and Thomas 1990b) and has been successfully applied to modeling emissions from landfarming operations (Thibodeaux and Hwang 1982) and hazardous waste impoundments (Dupont 1986). Solutions to the diffusion equation involving different boundary conditions than those used in deriving Equation F5 are available (Carslaw and Jaeger 1959) and have been applied to modeling volatilization of pesticides from soil (Thomas 1990b).

However, extrapolation of models for soils to dredged material has not been verified, and there are aspects of the simple model previously discussed that need further development. For example, the effects of water content and water evaporation on volatilization rates are not included in Equation F5. The effective diffusion coefficient can be estimated by:

$$D_{A3} = D_{A1} \frac{\epsilon_1^{\frac{10}{3}}}{\epsilon^2} \quad (\text{F6})$$

where

D_{A1} = air diffusivity of compound, cm^2/s

ε = total dredged material porosity

Diffusivities in air can be estimated by:

$$D_{A1} = \frac{\sqrt{M_r} \cdot 1 \times 10^{-3} \cdot T^{1.75}}{\left[V_a^{\frac{1}{3}} + V_b^{\frac{1}{3}} \right]^2 P} \quad (\text{F7})$$

where

T = temperature, K

V_a = molar volume of air, cm^3/gmol

V_b = molar volume of contaminant, cm^3/gmol

P = pressure, atm

$M_r = (M_a + M_b) / M_a M_b$

M_b = molecular weight of chemical B, g/mole

This relationship shows that the effective diffusion coefficient is very sensitive to changes in the water content and porosity of the dredged material. Fully saturated dredged material exhibits a very low diffusion coefficient. The effects of desiccation and the subsequent reduction of porosity on volatile emissions from dredged material have not been systematically investigated. Since porosity is an important parameter, the assumption of constant porosity could lead to substantial errors in volatile emission estimated from exposed dredged material.

Thibodeaux (1989) and Taylor and Glotfelty (1988) discuss the importance of water content and evaporation of water as factors and processes affecting volatilization. Major differences in diurnal volatilization rates have been observed that are related to water content. Volatilization rates decrease during the day as the soil surface dries and increase at night as soil moisture losses during the day are replaced by subsurface soil moisture. Volatilization rates have also been observed to increase significantly following rainfall. The effect is probably due to competitive adsorption between water molecules and contaminant molecules for sorption sites on soil particles.

Evaporation induces an upward movement of water that results in convective flow of the bulk pore gas. Thibodeaux (1989) presented an enhancement factor approach to account for evaporation that simplifies coupling convective movement of water and diffusive movement of volatile chemicals. Convective movement of water, however, distorts diffusive gradients, and evaporation is not

a continuously steady process. Evaporation varies greatly under field condition and may cease at high relative humidity.

Thibodeaux (1989) also recognized desiccation cracking of the dredged material surface as a process likely to affect volatilization and suggested some approaches to developing volatile emission models that include the effects of desiccation cracking. Such cracks can encompass up to 20 percent of the volume of the surface crust that develops by evaporative drying (Haliburton 1978).

Volatile Emission Summary

Predictive techniques for the ponded dredged material and the exposed sediment volatilization locales have been described. The predictive techniques, however, are based on simple models that in some cases do not account for important factors and/or processes. Development of predictive models that take into account water content, water evaporation, and desiccation cracking is a critical need for estimating volatilization losses from exposed dredged material. Laboratory testing and field testing are needed to build a higher degree of confidence in the predictive capability of the available volatilization models.

Two emission locales were identified as applicable to the Waipio Peninsula confined disposal facilities: ponded dredged material and exposed dredged material. Tables F1 and F2 present the breathing potential that was determined for the contaminants of concern. Table F1 was generated for the ponded condition for all volatile contaminants present above detection levels in the ponded water as indicated by the modified elutriate results presented in Appendix B. The values presented in Table F1 were generated using the dissolved concentrations from the modified elutriate test results for the concentration in the water employed in Equation F1. Table F2 was generated for the drying exposed dredged material for the principal volatile contaminants found in the bulk sediment having established volatilization coefficients and inhalation reference doses. The values presented in Table F2 were generated using the sediment concentrations from the characterization data presented in Appendix A for the concentration in the sediment employed in Equation F5. The inhalation reference dose (I.R.D.) for each of the contaminants is also presented. As the tables show, none of the contaminants exceed the I.R.D. The differences between the I.R.D. and the determined breathing potential are in a range of 53% to five (5) orders of magnitude. The conservative assumptions used in the modeling and exposure assessment are likely to predict worst case breathing potential that are 1 to 2 orders of magnitude greater than average conditions. In the case of the ponded dredged material, it was assumed that all the water would evaporate during a period of six (6) months; a linear time distribution is presented.

TABLE F1. VOLATILIZATION FOR PONDED DREDGED MATERIAL

Contaminant	Worst Case Breathing Potential, mg/kg/day						
	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	I.R.D.
Aldrin	7.21E-06	6.01E-06	4.81E-06	3.61E-06	2.40E-06	1.20E-06	3.00E-05
Cyanide	1.57E-03	1.31E-03	1.05E-03	7.85E-04	5.23E-04	2.62E-04	2.00E-02
Dieldrin	2.67E-06	2.22E-06	1.78E-06	1.33E-06	8.89E-07	4.44E-07	5.00E-05

TABLE F2. VOLATILIZATION FOR EXPOSED SEDIMENT

Contaminant	Worst Case Breathing Potential mg/kg/day	Inhalation Reference Dose mg/kg/day
Aldrin	1.59E-05	3.00E-05
Chrysene	4.27E-05	No data
DDT	1.07E-05	5.00E-04
Dieldrin	2.54E-07	5.00E-05
Fluoranthene	2.38E-04	4.00E-02

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Appendix G - Characterization of Odors from Dredged Material

Background

This appendix describes an investigation and characterization study of potential odor problems associated with upland disposal of dredged material from Pearl Harbor. It includes a literature search, site description, modified odor detection test and results obtained along with recommendations for the treatment of possible odors of Pearl Harbor sediment. The scope of the study was limited to examination of a homogenized sediment sample from three Pearl Harbor locations.

Characterization of odors is not usually done for a dredging project because odors are very seldom a problem at CDFs. There are hundreds of CDFs in the United States and odors have been a problem at only several. In these few problem cases the cause of the odor was generally caused by poor CDF design and operation for disposal of dredged material with significant organic matter content. The operation allowed stagnation to occur which caused reduced conditions in the surficial dredged material and ponded water, allowing the release of hydrogen sulfide and mercaptans. Characterization of odors was done in this project at the request of the Navy to ensure that odor was not likely to pose a problem.

A confined disposal facility (CDF) is a diked area for gravity separation and storage of dredged material solids. When contaminated dredged material is placed in a CDF, the potential exists for volatile organic chemicals (VOCs) as well as other chemical vapors which if present in sufficient quantities may be deemed "odorous." Emission rates can only be estimated quantitatively for certain chemicals, but a measurement of odor or unpleasant smell is very subjective and not easily quantifiable.

Air dispersion models based on point source generation can predict the amount of chemical vapors that are present at some distance from a site. However, some of these vapors may not be detectable or unpleasant to the human receptor. A literature search shows that numerous studies have been conducted on the detection and treatment of certain vapors that emanate from various industrial and waste treatment sources. However, very little research has been done on the detection and/or treatment of odors from dredged material.

Odor Sources

Dredged material is composed of mainly fine-grained soils, such as silts and clays, which have a high affinity for many pollutants. Volatile organic chemicals comprise a general class of pollutants with finite vapor pressures and water solubilities that are known to be associated with waterborne soil particles. Dredging disposal operations result in the removal and relocation of in-place polluted sediments and create conditions that enhance the release of VOCs into the air. The VOCs enter the air primarily as individual molecular species in a vapor state from water or sediment surfaces.

The general criteria for chemical equilibrium as it applies to pollutants in the natural environment are presented by Thibodeaux (1989). In the case of VOCs associated with sediment, three phases of matter are involved. The first phase consists of the solid particles that constitute the sediment, including the subphases of organic matter and mineral matter. The organic matter can be both natural and anthropogenic in origin. The mineral matter is inorganic and includes the sand, silt, and clay fractions. The two other primary phases are the fluids--air and water. The emission of VOCs to air must commence with the proper theoretical chemical equilibrium laws between the three primary phases. A complete description in the case of the locales within a CDF will involve three binary-phase chemical equilibrium conditions and is presented by Thibodeaux (1989).

Smell Detection and Quantification

Air pollution is not a feature of the industrial age, although it is often linked with the beginning of the "industrial revolution." Besides dust and noise, one atmospheric offender is smell. Pollution by smell may not be as harmful as the other components but can affect the mental attitudes of those affected. In most cases it is a question of an obnoxious smell, one that causes discomfort and distress, but sometimes it is an odor which, under different conditions, might be considered pleasing. Trimethylamine has a fishy smell at low concentration, but changes to a pungent ammonia smell at higher concentrations. Hydrogen sulfide loses its characteristic smell of rotten eggs at lethal concentrations, when it causes a pleasant odor sensation. A person with a pleasant memory of a particular smell, or of an occasion connected with that smell, will classify this odor as pleasing, while another person with a different background, will take a different view (Summer 1971).

There are no units or systems by which to express the pollution of air with odoriferous matter; the experts have failed to suggest an acceptable unit and method of measurement or to construct an instrument for objectively measuring smells. Chemical trace-detection methods, such as chromatographic analysis, cannot replace "smelling" tests. The latter, however, are by no means

objective, repeatable, or reliable; they depend on human behavior. In many areas no provisions are made by industrial waste manufacturers, or required by law, to prevent smells either from occurring or from spreading to other areas. The same holds true for dredged material disposal operations. However, it would be prudent to take steps to minimize offensive odors, if they occur, in order to placate the surrounding neighbors.

An odor problem usually resolves into two steps: (1) to decide upon the method of odor control most appropriate to the case in point and (2) to overcome the financial argument that capital spent on "waste" is wasted. There are two fundamental approaches to odor control: (1) to avoid the production of smell, which may be possible or partly possible, by altering that stage of the process which causes the smell and, should that not be feasible, (2) to reduce the chances of the general air becoming polluted with air from the production areas by treating the latter by appropriate means before discharging it to open atmosphere.

One of the more important drawbacks in present work is the lack of an exact terminology concerning odor. Degrees of intensity of smell, names of smells, and other classifying details vary from investigator to investigator, and a comparison of values obtained from different laboratories is often a difficult and complex matter. Sensations of sound or of sight can be exactly defined, because they can be exactly measured. This is not the case in olfaction studies. Chemical and physical characteristics of an odor can be measured by standard or specially developed techniques, but these measurements don't allow for an exact interpretation.

Determination of Odor Properties

Due to the scant amount of material on the subject of odors and testing of them, an extensive literature search was conducted. A search on the subject of odors and dredged material yielded only one report entitled "Abatement of Malodors at Confined Dredged Material Sites" (Harrison et al. 1976). Most of the remaining literature describes detection methodology and treatment of known odorous chemicals found in industrial waste streams or typical organic fumes found at sewage treatment plants. Some of the methods involve detection or treatment equipment in small confined areas (flue gas, stack scrubbers) and/or treatment of a relatively small area (wastewater treatment plant). By comparison, CDFs encompass "open" disposal into a large (100-acre) area. The approach for characterizing odors presented in "Abatement of Malodors at Confined Dredged Material Sites" (Harrison et al. 1976) was used in this project to provide a basis for comparison with other dredged materials.

The principal dimensions of an odor are its detection threshold, intensity, and character. In odorous air pollution measurements, the detection threshold is

traditionally defined in terms of the American Society for Testing and Materials (ASTM) odor units (ASTM 1967). The numerical value in odor units indicates the extent of dilution with nonodorous air needed to reach an odor detection threshold. Thus, one volume of odorous air that is 12 odor units strong needs an additional 11 volumes of odorless air (to produce a total of 12 volumes) to obtain a diluted sample with an odor that 50% of the panelists on an odor panel would, and the other 50% would not, find odorous.

Odor intensity is only loosely related to the odor-unit content of an odorous air sample. Odor intensity S is the intensity of the odorous sensation (ASTM 1975) and increases with the concentration of odorants in accordance with a function:

$$S = kC^n$$

where C is the concentration of the odorants in the sample, for instance in odor units, and k and n are coefficients that are different for different odorants. Therefore, odor-unit content is not a direct measure of the odor intensity of the undiluted sample; rather, it indicates simply the extent of dilution needed to make a sample reasonably odorless.

The other important dimension of odor is its character. A multidescrptor scale (Table G1) from Harrison et al. (1976) contains over 100 descriptors to provide a better resolution of odor character. Panelists smell the sample and give their estimates of the degree of applicability of each odor descriptor using a score scale of 0 to 5. The result is a multidimensional profile of the odor. The meaning of the scale points is as follows:

- 0 = described quality absent
- 1 = described quality slightly applicable
- 2 = described quality slightly more applicable
- 3 = described quality moderately applicable
- 4 = described quality moderately more applicable
- 5 = described quality extremely applicable

There has been some work on the establishment of “standards” by the ASTM, Sensory Evaluation of Materials and Products committee (ASTM 1975). These standards outline the procedure for referencing smells against a known quantity of previously identified odorants. The standards describe an olfactometer (vapor sniffer) apparatus, precise test procedures, and use of “sniffer” panelists. In the interest of time and money, a modified olfactometer (Figure G1) was designed and built using readily available materials at the ERDC. The panelists were selected for their social diversity as well as their previous knowledge of working with dredged material.

TABLE G1. ODOR DESCRIPTOR FORM

	Quality Scale														
	Absent 0	Slightly 1					Moderately 3					Extremely 5			
		0	1	2	3	4	5		0	1	2	3	4	5	
Fragrant		0	1	2	3	4	5	Oily, Fatty	0	1	2	3	4	5	
Sweaty		0	1	2	3	4	5	Like Mothballs	0	1	2	3	4	5	
Almond-like		0	1	2	3	4	5	Like Gasoline, Solvent	0	1	2	3	4	5	
Burnt, Smoky		0	1	2	3	4	5	Cooked Vegetables	0	1	2	3	4	5	
Herbal, Green, Cut Grass, etc.		0	1	2	3	4	5	Sweet	0	1	2	3	4	5	
Etherish, Anaesthetic		0	1	2	3	4	5	Fishy	0	1	2	3	4	5	
Sour, Acid, Vinegar, etc.		0	1	2	3	4	5	Spicy	0	1	2	3	4	5	
Like Blood, Raw Meat		0	1	2	3	4	5	Paint-like	0	1	2	3	4	5	
Dry, Powdery		0	1	2	3	4	5	Rancid	0	1	2	3	4	5	
Like Ammonia		0	1	2	3	4	5	Minty, Peppermint	0	1	2	3	4	5	
Disinfectant, Carbolic		0	1	2	3	4	5	Sulphidic	0	1	2	3	4	5	
Aromatic		0	1	2	3	4	5	Fruit (citrus)	0	1	2	3	4	5	
Meaty (cooked)		0	1	2	3	4	5	Fruity (other)	0	1	2	3	4	5	
Sickening		0	1	2	3	4	5	Putrid, Foul, Decayed	0	1	2	3	4	5	
Musty, Earthy, Moldy		0	1	2	3	4	5	Woody, Resinous	0	1	2	3	4	5	
Sharp, Pungent, Acid		0	1	2	3	4	5	Musk-like	0	1	2	3	4	5	
Caraway		0	1	2	3	4	5	Cat-Urine-like	0	1	2	3	4	5	
Orange (fruit)		0	1	2	3	4	5	Bark-like, Birch Bark	0	1	2	3	4	5	
Household Gas		0	1	2	3	4	5	Rose-like	0	1	2	3	4	5	
Peanut Butter		0	1	2	3	4	5	Celery	0	1	2	3	4	5	
Violets		0	1	2	3	4	5	Burnt Candle	0	1	2	3	4	5	
Tea-Leaves-like		0	1	2	3	4	5	Mushroom-like	0	1	2	3	4	5	
Wet Wool, Wet Dog		0	1	2	3	4	5	Pineapple (fruit)	0	1	2	3	4	5	
Chalky		0	1	2	3	4	5	Fresh Cigarette Smoke	0	1	2	3	4	5	
Leather-like		0	1	2	3	4	5	Nutty (walnut, etc.)	0	1	2	3	4	5	
Pear (fruit)		0	1	2	3	4	5	Fried Fat	0	1	2	3	4	5	
Stale Tobacco Smoke		0	1	2	3	4	5	Wet Paper-like	0	1	2	3	4	5	
Raw Cucumber-like		0	1	2	3	4	5	Coffee-like	0	1	2	3	4	5	
Raw Potato-like		0	1	2	3	4	5	Peach (fruit)	0	1	2	3	4	5	
Mouse-like		0	1	2	3	4	5	Laurel Leaves	0	1	2	3	4	5	
Pepper-like		0	1	2	3	4	5	Scorched Milk	0	1	2	3	4	5	
Bean-like		0	1	2	3	4	5	Sewer Odor	0	1	2	3	4	5	
Banana-like		0	1	2	3	4	5	Sooty	0	1	2	3	4	5	
Burnt Rubber-like		0	1	2	3	4	5	Crushed Weeds	0	1	2	3	4	5	

TABLE G1. ODOR DESCRIPTOR FORM (continued)

		Quality Scale													
Absent	Slightly						Moderately	4	Extremely						
0	1	2	3	4	5	3		5							
Camphor-like		0	1	2	3	4	5	Soapy		0	1	2	3	4	5
Light		0	1	2	3	4	5	Garlic, Onion		0	1	2	3	4	5
Heavy		0	1	2	3	4	5	Animal		0	1	2	3	4	5
Cool, Cooling		0	1	2	3	4	5	Vanilla-like		0	1	2	3	4	5
Warm		0	1	2	3	4	5	Fecal (like manure)		0	1	2	3	4	5
Metallic		0	1	2	3	4	5	Floral		0	1	2	3	4	5
Perfumery		0	1	2	3	4	5	Yeasty		0	1	2	3	4	5
Malty		0	1	2	3	4	5	Cheesy		0	1	2	3	4	5
Cinnamon		0	1	2	3	4	5	Honey-like		0	1	2	3	4	5
Popcorn		0	1	2	3	4	5	Anise (licorice)		0	1	2	3	4	5
Incense		0	1	2	3	4	5	Turpentine (pine oil)		0	1	2	3	4	5
Melony (cantaloupe, honey dew)		0	1	2	3	4	5	Fresh Green Vegetables		0	1	2	3	4	5
Tar-like		0	1	2	3	4	5	Medicinal		0	1	2	3	4	5
Eucalyptus		0	1	2	3	4	5	Strawberry-like		0	1	2	3	4	5
Buttery		0	1	2	3	4	5	Stale		0	1	2	3	4	5
Like Burnt Paper		0	1	2	3	4	5	Cork-like		0	1	2	3	4	5
Cologne		0	1	2	3	4	5	Lavender		0	1	2	3	4	5
Geranium Leaves		0	1	2	3	4	5	Rubbery (new rubber)		0	1	2	3	4	5
Urine-like		0	1	2	3	4	5	Bakery (fresh bread)		0	1	2	3	4	5
Beery (beer-like)		0	1	2	3	4	5	Oak Wood, Cognac-like		0	1	2	3	4	5
Cedarwood-like		0	1	2	3	4	5	Grapefruit		0	1	2	3	4	5
Coconut-like		0	1	2	3	4	5	Grape-juice-like		0	1	2	3	4	5
Rope-like		0	1	2	3	4	5	Eggy (fresh eggs)		0	1	2	3	4	5
Seminal, Sperm-like		0	1	2	3	4	5	Bitter		0	1	2	3	4	5
Like Cleaning Fluid (Carbona)		0	1	2	3	4	5	Cadaverous, like Dead Animal		0	1	2	3	4	5
Cardboard-like		0	1	2	3	4	5	Maple (as in Syrup)		0	1	2	3	4	5
Lemon (fruit)		0	1	2	3	4	5	Seasoning (for meat)		0	1	2	3	4	5
Dirty Linen-like		0	1	2	3	4	5	Apple (fruit)		0	1	2	3	4	5
Kippery (smoked fish)		0	1	2	3	4	5	Soup		0	1	2	3	4	5
Caramel		0	1	2	3	4	5	Grainy (as grain)		0	1	2	3	4	5
Sauerkraut-like		0	1	2	3	4	5	Clove-like		0	1	2	3	4	5
Crushed Grass		0	1	2	3	4	5	Raisins		0	1	2	3	4	5
Chocolate		0	1	2	3	4	5	Hay		0	1	2	3	4	5
Molasses		0	1	2	3	4	5	Kerosene		0	1	2	3	4	5

(concluded)



Figure G1. Modified olfactometer

Approach

In order to design the sniffer test, certain assumptions were made in regards to the Pearl Harbor CDF. Anticipated dredged material disposal operations will consist of hydraulic pumping of material into a 100-acre site, which is roughly square in shape. A steady wind from the ocean would be the transport mechanism of any fumes that emanated from the disposed material. Initially dredged material would cover a small portion of the site and would be covered by water. Dredged material would settle and excess water would flow out of the site and evaporate due to the high transpiration rate, thus exposing the dredged material directly to the air. Since rain events also occur with some frequency, the material would dry and at times become re-hydrated. Thus, the odor detection test included different water content scenarios.

The test sample conditions (scenarios) were as follows:

- a. Dredged material samples covered by water
- b. Samples with free water decanted; Wet
- c. Samples dried (reduced water content); Drying
- d. Dry samples (essentially no water content); Dry
- e. Re-hydrated samples; Re-wet

Since a 100-acre CDF covers 4,356,000 square feet, it would be impractical to build a reasonable scale model of the site. Even at a hundred to one scale, the model would need to be over 200 ft square. A 55-gal drum has a bottom surface area of 2.6 sq ft, and a 5-gal bucket has a surface area of approximately 0.6 sq ft. The 5-gal plastic bucket was selected for a variety of reasons (cost, ease of use), and test results indicate that it provided a reasonable surrogate for the site.

An air dispersion model was used to estimate the anticipated amounts of vapors expected from various chemicals at a location 1.5 km from the disposal site. With an assumed wind speed of 2.5 meters/second (5.6 mph) and a 100-acre area, the residence time (time for wind to pass over the site and collect vapors) was calculated to be 4.2 min. Thus, air was circulated over the sample for 5 min before being sampled by the panel.

In order to circulate air over the sample, a small fan commonly used in computers was connected to a 6-volt battery (Figure G2). The fan's movement of air was determined to be approximately 30 gal per min or 4 cu ft/min. Since the sampling bucket contained 0.75 cu ft of air, the fan size and speed were determined to be sufficient to ensure proper circulation. This air circulation rate and time (5 min) ensured that vapors were released from the samples and were well distributed in the bucket.

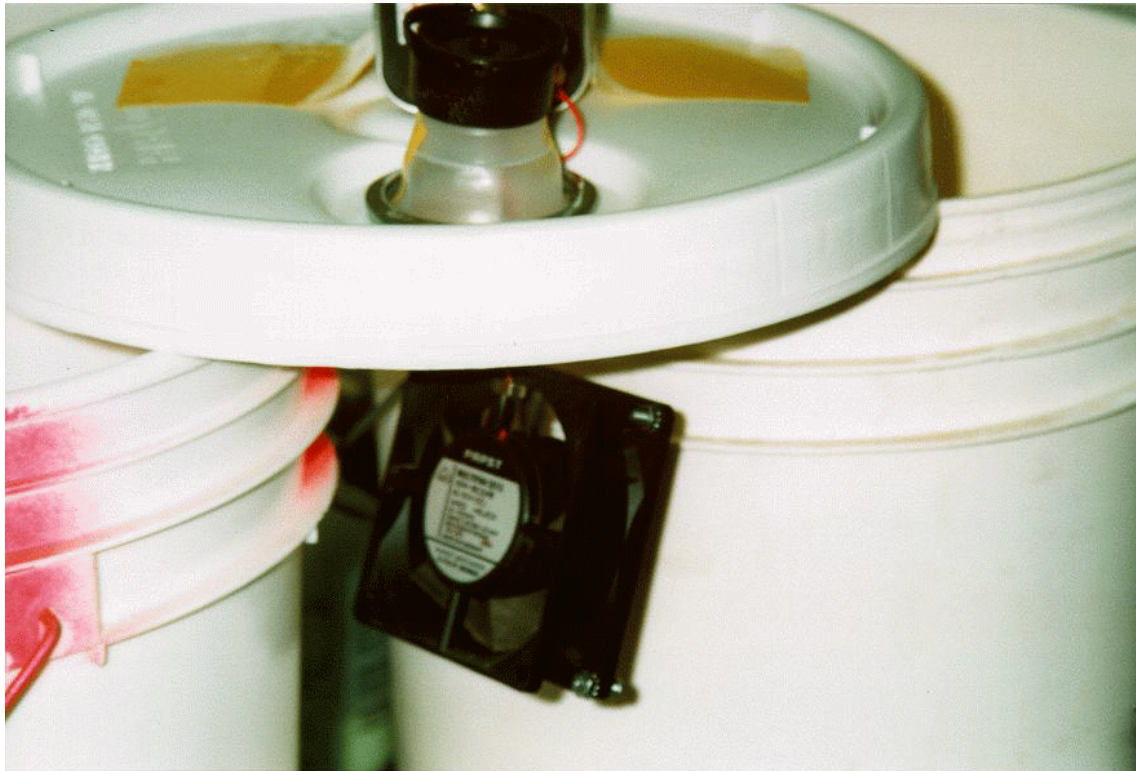


Figure G2. Air circulation fan used in modified olfactometer

Test Procedures

The Pearl Harbor odor detection panelists were told about the nature of the tests and given the multidescrptor scale sheets (Table G1) to review. Dredged material containers were prepared in a separate room in order not to bias the judging process. Samples were placed in the buckets, and air was allowed to circulate for the five minutes before being sniffed through the pour spout. The panelists were then asked to provide a score (0 - 5) as well as to determine the distinguishing characteristics (descriptors).

Initial samples were clean buckets and samples under 1 to 2 in. of water. As expected there were no odors associated with either of these conditions. Dredged material was placed in various sized sample dishes which corresponded to different percentages of the exposed surface (pail bottom = 100%). Containers used were aluminum and plastic dishes (Figure G3) which corresponded to the following surface area percentages: 80, 50, 30, 10, and 4. Each sample was then weighed in order to determine water content (after drying).



Figure G3. Containers of dredged material used in odor detection test

To determine a worst case and a baseline, a small full bucket of material was presented to the panelists. With this sample the panelists were able to determine the odor characteristics as well as establish the maximum or “full strength” odor. The sample was described as “Musty, earthy” and “Oily (diesel)” with a scale of factors ranging from 2.0 to 3.0.

The next set of samples contained the five different levels of surface area and was presented to the panelists in random order. Responses (characteristics and strength) were recorded on the odor descriptor sheets. Figure G4 shows a panelist sniffing a sample. After evaluation, samples were placed in a drying oven with temperature of 105°C. Samples were allowed to dry for approximately 30 minutes, re-weighed, allowed to cool, and then put into the buckets. This drying reduced the sample weight approximately 10% and represented the early drying phase of disposal operations.

After the panelists rated the samples, they were put back in the oven for 4 hours. Samples appeared to be thoroughly dried with typical cracking patterns. They were weighed, allowed to cool, and put into the buckets for odor detection.

The last scenario was re-hydration of the dried samples. Water was added to the samples simulating a rain event, raising the water content to approximately 10 - 20 %. Samples were allowed to absorb the water and then placed in the buckets for panelist testing.



Figure G4. Panelist performing odor detection evaluation

Test Results

Table G2 contains the sample types, water contents, panelists odor ratings, and odor descriptors. The completely dried (Dry) samples were used as the baseline dry weight for water content calculations. Figures G5 through G8 show the relationship between the Surface area and Odor strength for each of the scenarios. Figure G9 combines the results in a bar graph for direct comparison between the scenarios.

Discussion

Although the odor detection test was conducted using a modified olfactometer (5-gal bucket), the data collected indicate some trends which can be extrapolated to anticipated field conditions. It should be noted that the vapors were contained and concentrated in the bucket prior to “sniffing.” In the field, the odors would be less concentrated by dispersing both vertically and horizontally into the air stream before reaching the nearest human receptor.

Table G2 indicates that the Pearl Harbor dredged material produces detectable odors under certain conditions. The primary odor descriptors were “Musty, Earthy” and “Oily (diesel)” which is to be expected from harbor sediment. However, none of the panelists indicated that the odor was “obnoxious” or overpowering, even in the worst case scenario. Other descriptors used were “Cardboard-like” or “Wet Paper,” but they were infrequent and at low odor levels. During the test, the odor appeared to change based on the dry/wet condition of the samples. This may be due to the release of different VOCs from the material during the drying and re-hydration processes.

Odor strength levels ranged from zero up to 3.0 on a scale of 0 to 5 as shown in Table G2. Figures G5 through G8 demonstrated the general trend of increasing odor strength as the percent surface area or sample size increased. This is expected since the vapor volatilization rate is directly proportional to the exposed surface area. During the drying scenario, it was noted that vapors were much stronger when initially removed from the drying ovens. Thus samples were allowed to cool off before being placed in the buckets and evaluated. On Figure G7, the 50% data point should be considered an anomaly, since the sample was not completely dry at the time of evaluation. The results also indicate that the panelists' evaluations were accurate and not biased since the samples were presented in varying order.

Figure G9 contains the test results plotted in a bar graph for the four scenarios. Again it can be noted that odor strength increases with larger surface area.

TABLE G2. ODOR STRENGTH

Sample Condition	% Surface Area	% Water Content	Panelists Odor Ratings					Avg	Odor Descriptor
			1	2	3	4			
Blank		0.	0.	0.	0.	0.	0.	0.	Clean bucket
Wet	100 Poned	60	0.	0.	0.	0.	0.	0.	None, covered by 2" water
	100	60	3.	2.	2.	1.	2.		Musty, earthy and oily (diesel)
	80	58.6	1.5	1.5	1.5	1.5	1.50		" "
	50	61.3	1.	1.	1.	0.	0.75		" "
	30	60.6	1.	1.	1.	0.	0.75		" "
	10	58.8	0.5	0.5	0.	0.	0.25		" "
	4	60.1	0.5	0.5	0.	0.	0.25		" "
Drying	80	55.2	3.	2.	1.5	1.5	2.00		" " Plus cardboard-like
	50	58.0	3.	2.5	2.5	2.	2.50		" "
	30	57.1	2.	2.	1.	1.	1.50		" "
	10	54.2	1.5	1.5	2.	2.	1.75		" " Plus wet paper
	4	52.1	1.	0.5	0.5	0.5	0.63		" "
Dry	80	0.0	2.	1.5	1.	1.	1.38		" "
	50	12.8	2.	2.	1.5	1.5	1.75		" " Plus sweaty
	30	0.0	0.5	0.5	0.5	0.5	0.50		" " (not totally dry)
	10	0.0	0.	0.	0.	0.	0.00		
	4	0.0	0.	0.	0.	0.	0.00		
Re-Wet	80	17.9	3.	3.	3.	3.	3.00		" "
	50	7.5	1.5	1.5	1.5	1.5	1.50		" " Plus wet paper and sulphidic
	30	16.3	2.5	2.5	2.	2.	2.25		" "
	10	19.3	1.5	1.5	1.	0.5	1.13		" "
	4	11.2	1.	1.	1.	1.	1.00		" " Plus acidic

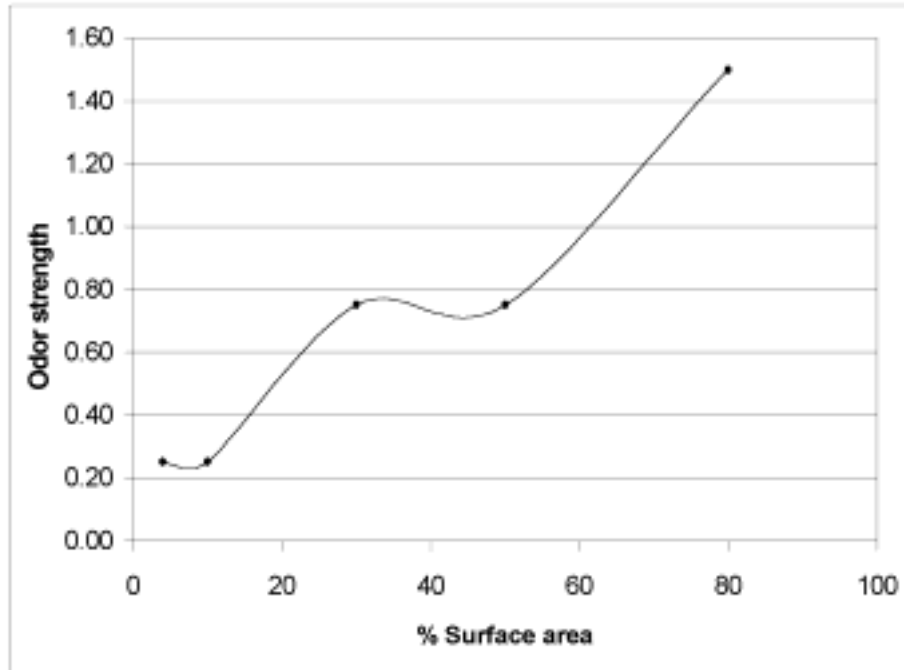


Figure G5. Odor strength vs. surface area for wet scenario

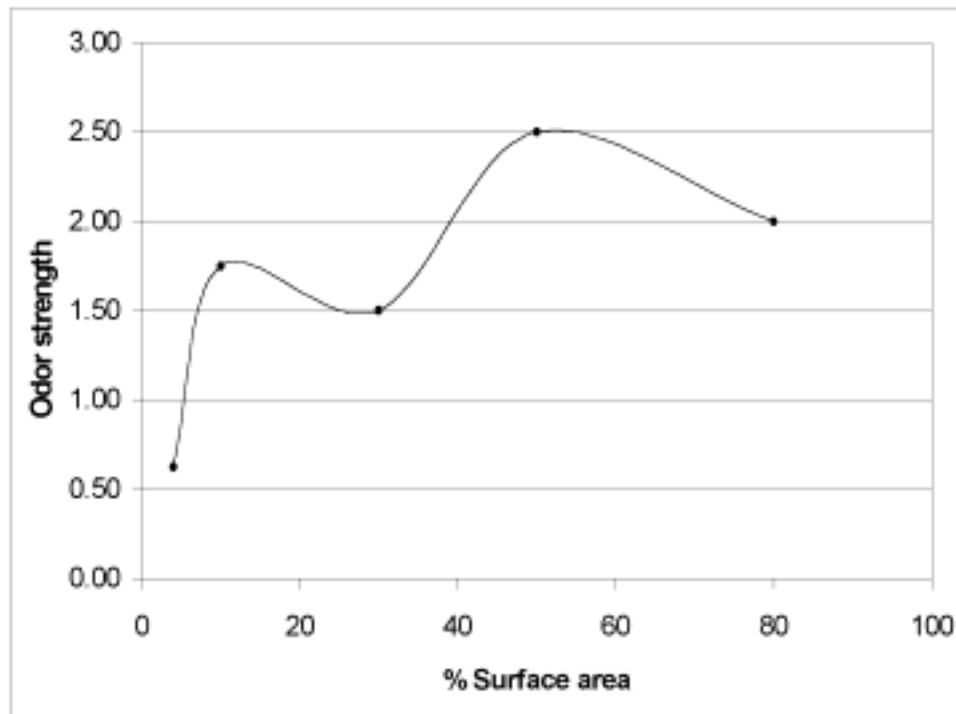


Figure G6. Odor strength vs. surface area for drying scenario

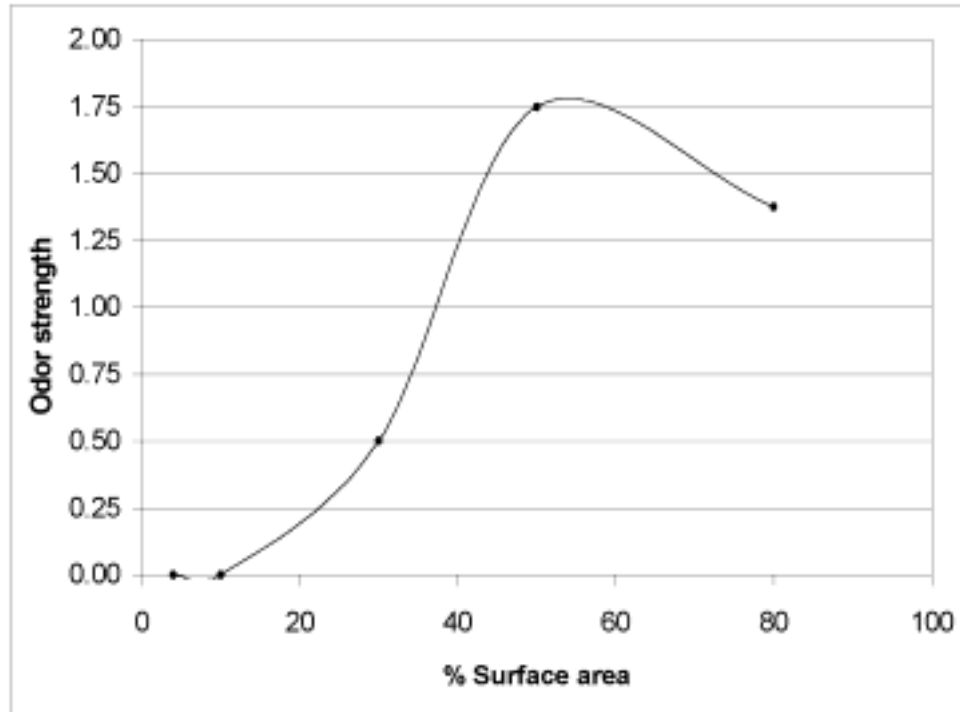


Figure G7. Odor strength vs. surface area for dry scenario

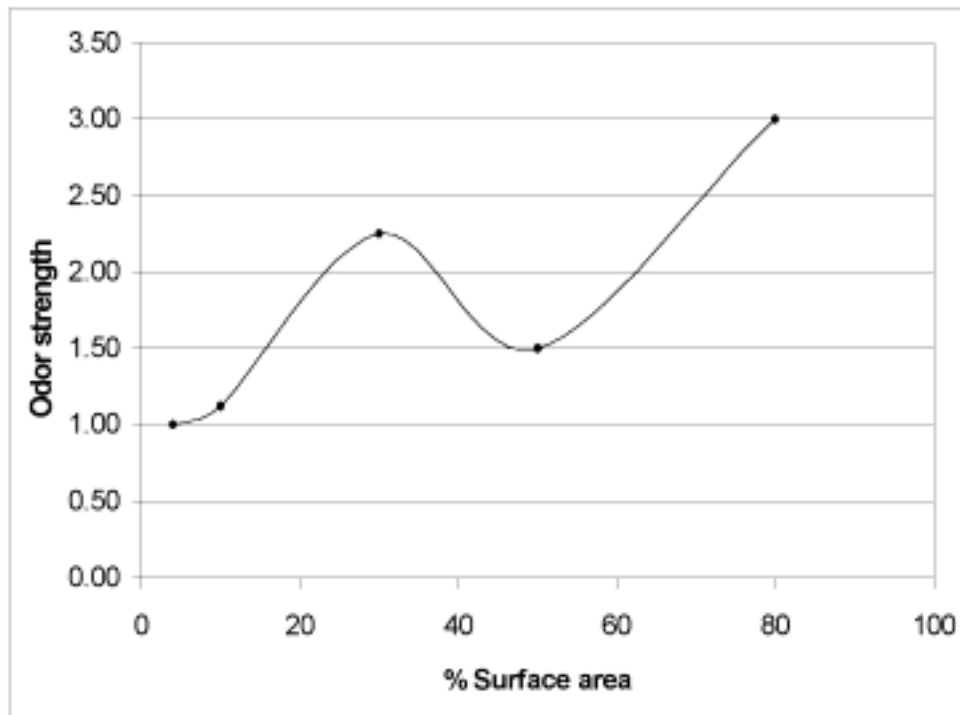


Figure G8. Odor strength vs. surface area for re-wetting scenario

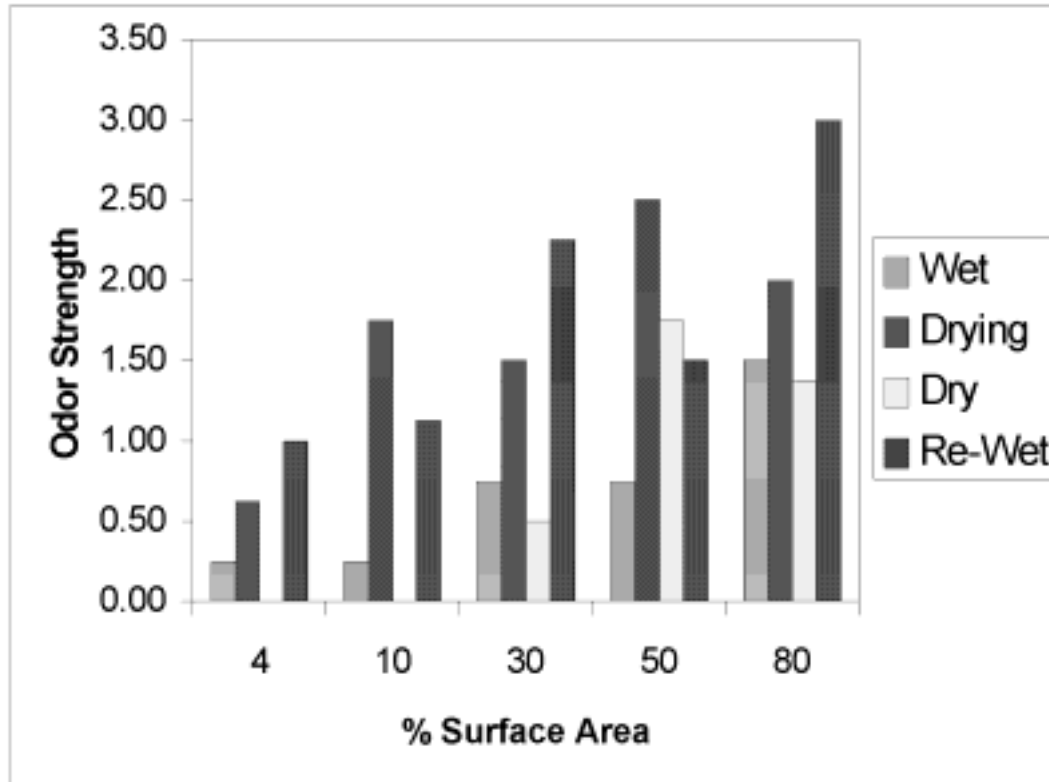


Figure G9. Odor strengths vs. surface area for all four scenarios

The bar graph indicates that the Wet and Dry scenarios produce the lowest odor levels for each of the surface area samples. The lower value for 50% area, Re-wet case may be due to the significantly lower amount of water which was added to the sample (7.5% instead of 15 - 20%).

Based on the limited data, it is difficult to determine if the Drying or Re-wetting phase produced the strongest odors. These two represent the most likely scenarios for the field operations since filling operations or totally dry conditions will occur a relatively small percentage of the year. We can use these as the worst case scenario and note that the maximum odor strength values were 2.5 - 3.0.

Summary

Many processes exist for the treatments of odiferous material, ranging from scent masking, adding adsorbents, chemical and biological treatments up to incineration and encapsulation (Cullinane et al. 1990). Based on the low levels of smell, nature of the odor and the associated costs of these processes, it is recommended that no special treatments of the disposed dredged material be undertaken. Keeping the material wet and/or covered in water will greatly

reduce any odors. In addition, vegetation can be introduced to the area which will reduce the volatiles released from the material. Trees and shrubs planted around the site will increase odor dispersion.

In summary, it has been determined that the Pearl Harbor dredged material will produce detectable odors at the site during the various disposal phases. However, it is anticipated that these odors at distances more than 0.5 mile from the site will be at a low strength level and contain no unpleasant smells; they can be considered nonobnoxious to potential human receptors. It is anticipated that these odors will not smell worse than the natural occurring odors around the harbor.

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14. ABSTRACT <p>This report documents Phase II of a three-phase study to develop a Long-Term Management Strategy (LTMS) for Pearl Harbor. Physical and chemical characterization and contaminant pathway testing and analysis of Pearl Harbor sediment were performed for the proposed Waipio Peninsula confined disposal facility (CDF). Modeling was performed to support design/management/operations decision making and contaminant pathway analysis.</p> <p>Physical characterization included a number of geotechnical tests including grain-size analysis, Atterberg limits, soil classification, specific gravity, moisture content, self-weight and standard oedometer consolidation, and sedimentation. Chemical characterization included bulk sediment chemical analysis, toxicity characteristics leaching procedure (TCLP), and ambient water chemical analysis. Pathway testing included the modified elutriate test for effluent quality, the simplified laboratory runoff procedure (SLRP) for runoff quality, and diethylene triamine pentaacetic acid (DTPA) extraction for plant uptake. Using characterization data, leachate quality was predicted based on equilibrium partitioning of the contaminants between the soil and water. Air quality was estimated from computation of contaminant volatilization.</p> <p>The results of the Phase II study show that disposal of Pearl Harbor dredged material unsuitable for ocean disposal in an upland CDF on Waipio Peninsula is technically feasible. Disposal in an upland CDF poses no significant impacts on human health. Potential contaminant</p> <p style="text-align: right;">(Continued)</p>															
15. SUBJECT TERMS <table style="width: 100%; border: none;"> <tr> <td style="width: 15%;">Contaminant</td> <td style="width: 15%;">LTMS</td> <td style="width: 15%;">Pathway testing</td> <td style="width: 15%;">Screening</td> <td style="width: 15%;">Waipio</td> </tr> <tr> <td>Dredged material</td> <td>Odor</td> <td>Pearl Harbor</td> <td>Sediment</td> <td></td> </tr> </table>						Contaminant	LTMS	Pathway testing	Screening	Waipio	Dredged material	Odor	Pearl Harbor	Sediment	
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16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 175	19a. NAME OF RESPONSIBLE PERSON										
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14. (Concluded).

releases by effluent, runoff, plant uptake, and animal uptake pathways pose small environmental impacts that should be acceptable with proper operation, management, and controls. Copper, arsenic, and ammonia concentrations in the effluent and runoff exceed water quality standards for toxicity but except for ammonia are similar to the contaminant concentrations in the background site water. Plant and animal uptake of cadmium, copper, and lead from the dredged material in a Waipio Peninsula CDF are expected to be elevated over that of the present uptake from Waipio Peninsula soils. The uptake poses limited concerns during operation because the saltwater dredged material will restrict plant and animal growth. Following operation of the site, controls can be implemented to limit contaminant uptake by plants and animals.

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