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Evaluation of Dredged Material Disposal and Management for Appomattox River Federal Navigation Channel, Petersburg, Virginia

Phases I and II – Environmental and Engineering Studies

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Final report

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Preface

This report describes testing and analysis of dredged material from the Appomattox River for evaluating the suitability for upland disposal. This work was performed by the Environmental Laboratory (EL), with laboratory work executed in the Geotechnical and Structures Laboratory (GSL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. The project manager is Mr. Stephen J. Powell, U.S. Army Engineer District, Norfolk, the funding agency.

This report was written by Messrs. Roy Wade and Richard A. Price, Dr. John W. Simmers, Mses. Cynthia Price and Alfreda B. Gibson, Environmental Processes and Effects Division (EPED), EL, and Dr. Michael R. Palermo, Special Projects Group, EL.

This study was conducted under the direct supervision of Mr. Michael Channell, Acting Chief, Environmental Restoration Branch, and under the general supervision of Dr. Richard E. Price, Chief, EPED, and Dr. Edwin A. Theriot, Director, EL.

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Conversion Factors, Non-SI 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	4,046.873	square meters
acre-feet	1,233.489	cubic meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
Fahrenheit degrees	5/9	degrees Celsius or kelvins[1]
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
inches	2.54	centimeters
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
pounds (mass) per ton	0.0005	kilograms
square feet	0.09290304	square meters
tons (2,000 pounds, mass)	907.1847	kilograms
yards	0.9144	meters

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F -32). To obtain kelvin (K) readings, use: K = (5/9)(F -32) + 273.15.

1 Executive Summary

The purpose of this report is to document testing and analysis of upland disposal of dredged material from the Appomattox River, Petersburg, VA. Phase I of this study evaluated the environmental and engineering effect of dredging and placing the Appomattox River sediment in the proposed Puddledock site or in an upland disposal facility. The Puddledock site is expected to be flooded by owner and then allowed to maintain natural ponded elevation. Phase II of this study evaluated screening of potential contaminate release to atmosphere and evaluated environmental dredging case studies conducted by the U.S. Army Corps of Engineers (USACE). Phase I 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. Phase II testing included tests that predict the potential emission release of volatiles during and after dredging.

Physical characterization included a number of geotechnical tests including grain-size analyses, 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 (SLRP) for runoff quality, diethylene triamine pentaacetic acid (DTPA) extraction for plant uptake, earthworm bioassay for animal uptake, and 96-hr elutriate bioassay for water column toxicity. Using characterization data, leachate quality was predicted based on equilibrium partitioning of the contaminants between the soil and water.

Analyses of effluent and runoff pathways were conducted to examine effect on surface water quality. Analysis of the leachate pathway predicted effects on groundwater and surface water quality. Analysis of plant and animal uptake pathway screened viable future use of the disposal site or dredged material for habitat or agriculture. The water column toxicity test evaluated the potential transport of toxicity of the contaminated sediment to the water column during and after dredging. The results of TCLP examined the viability of material reuse for any of a number of potential beneficial uses.

The evaluation of environmental effects was performed under the Phase I effort by executing detailed screening procedures using the Tier II approach as outlined in “Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments,” Assessment and Remediation of Contaminated Sediments (ARCS) Program, Environmental Protection Agency (EPA), 905-R96-001 (Myers et al. 1996).[1] A screening evaluation of most of the confined disposal facility (CDF) pathways of concern was conducted. An evaluation based on chemical water quality (Tier II) was conducted for the effluent pathway, because a Tier II 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 I 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 I study. Predictions of dissolved concentrations of contaminants in effluent were made using the modified elutriate test (Palermo 1985; Palermo and Thackston 1988; and USEPA/USACE 1998).

An evaluation of the surface runoff chemical water quality using the SLRP for predicting the long-term effects of drying and oxidation on surface runoff water quality was conducted (Price, Skogerboe, and Lee 1998). The results of this test were similar to those for effluent discharge in that the dissolved concentrations of several parameters exceeded State of Virginia 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. If Appomattox dredged material is placed in an upland environment, heavy metals in rainfall induced runoff from the wet unoxidized wet dredged material will be mostly insoluble and bound to suspended particulate in the surface water runoff, as will total recoverable petroleum hydrocarbon (TRPH). Soluble metals are not predicted to exceed water quality standards during this period. Retention of suspended solids will significantly restrict all movement of metals and TRPH from the upland disposal site. Drying and oxidation of Appomattox sediment significantly increased the solubility of some metals. However, only copper and zinc were predicted to exceed the water quality standard during the dried conditions. Based on the results of the RUNQUAL evaluation of Cu and Zn, a dilution factor of 2.6 is required in a mixing zone to bring runoff water discharge into compliance with water quality standards.

A DTPA extraction procedure was used for the screening prediction of plant and animal uptake of metals (Folsom and Houck 1990). The DTPA extracts indicated that Appomattox River dredged material may contribute to elevated levels of heavy metals in leafy freshwater plants that may colonize the CDF. The predicted uptake of these heavy metals was compared with the predicted uptake from Puddledock site. Except for chromium, total metals were higher in Appomattox River sediment than in the Puddledock sediment as well as the DTPA metals. However, predicted levels were below levels of concern and should pose no significant adverse ecological effect. Animal uptake levels would

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[1] Reference information is presented following main text.

be similar because animal uptake is strongly correlated with DTPA extraction. These elevated levels of uptake may 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. However, the earthworm bioassay conducted on Appomattox River and Puddledock sediments did not indicate excessive bioavailability of metals or TRPH. If plants and animals are permitted to colonize the disposal site, retesting may be required. Therefore, at the end of the service life of the CDF, the surficial materials may be analyzed by 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 sorted and classified, appropriate control measures or restrictions will be implemented. These measures could include plant control, use restrictions, capping, phytoremediation, or soil amendments.

The water column toxicity test was used to evaluate dredged material impact on the water column during and after dredging. The 96-hr elutriate bioassay test was employed. The fathead minnow called *Pimephales promelas* was exposed to sediment dilutions ranging from 100 to 6 percent. The results show that survival met or exceeded the test acceptability criterion of 90 percent in the control treatment. Only the 100-percent elutriate treatment was significantly different from the control. Based on the Trimmed Spearman-Karber method, the calculated LC_{50} value was 67.20 percent. The initial and final ammonia levels in the 100-percent elutriate exposure ranged from 0.806 to 1.01 mg/L, respectively. These ammonia (NH_3) levels closely approximate the LC_{50} of 1.24 mg/L for 5-day old *Pimephales promelas* (USEPA 1989).

In summary, disposal of Appomattox River dredged material is technically feasible. Based on collected sediments, disposal in an upland CDF poses no significant impacts on human health. Potential contaminant releases by effluent, runoff, dredging, 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 Virginia toxicity standards but are similar to the contaminant concentrations in the background sediment and 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 an upland CDF may colonize. The predicted levels of contaminants were below levels of concern and should pose no significant adverse ecological effect. The water column downstream should be of little concern during dredging operation, because elutriate exposures of less than 50 percent (i.e., elutriates mixed with site water during dredging) did not adversely affect survival of the fathead minnows.

If the Appomattox dredged material is to be disposed of in the Puddledock site, each above summary is valid except plant and animal uptake and surface runoff results. No plant or animal uptake and surface runoff will occur as the result of purposely flooding the site and maintaining a natural ponding elevation.

2 Introduction

Background

Dredged material disposal alternatives

Four major types of alternatives are available for dredged material disposal: open-water disposal, confined disposal, contained aquatic disposal, and beneficial use. Open-water disposal is the placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline, mechanical placement, barges, etc. Open-water disposal may also involve capping. Confined disposal is placement of dredged material within diked nearshore or upland confined disposal facilities (CDF) via pipeline or mechanical dredge. Contained aquatic disposal is a combination of both open water and CDF. It is the open-water disposal of dredged material into an underwater CDF followed by capping. Beneficial use includes a variety of options which utilize the material for some productive purpose, such as habitat restoration (wetland, upland, or island), parks and recreation, agriculture, landfill cover, shoreline stabilization, etc. Of the four disposal alternatives, CDF is usually the most viable alternative.

The disposal of dredged material must be performed in accordance with the requirements of the National Environmental Policy Act (NEPA), the Clean Water Act, and the Marine Protection, Research, and Sanctuaries Act (MPRSA). Therefore, the technical framework outlined in the USACE/EPA technical guidance document, “Evaluating Environmental Effects of Dredged Material Management Alternatives – A Technical Framework” (USACE/EPA 1992), will be followed. Additional guidance on the evaluation, design, operation, and management of CDF is found in Engineer Manual (EM) 1110-2-5027 (Headquarters, Department of the Army (HQDOA) 1987). Guidance for beneficial use applications is given in EM 1110-2-5026 (HQDOA 1986).

Assessment of a confined disposal facility

There are four major components of the CDF assessment process: selection and characterization, evaluation of direct physical impacts and site capacity, evaluation of contaminant pathways, and evaluation of management actions and contaminant controls. The site selection is to avoid adverse impacts to the ecosystem, groundwater, and land use. Site selection also involves determining the capacity of the site and long-term physical impacts. The evaluation of contaminant pathways is performed using a tiered approach as outline in the framework for the "Comprehensive Analysis of Migration Pathways" (Brannon et al. 1990). Another guide for evaluating contaminant pathways and the effects of contaminant controls is "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments," ARCS Program, EPA 905-R96-001 (Myers et al. 1996). Contaminant control measures includes modifications of dredging and disposal operations, capping and containment, treatment, and monitoring.

The U.S. Army Engineer District, Norfolk, was originally authorized by the Rivers and Harbors Act of 1871 to maintain navigation in the Appomattox River Federal Navigation Channel. The channel is located in the cities of Petersburg and Hopewell, and Chesterfield and Prince George counties. Dredging has been used for maintaining the navigational depths in the river. Currently, the existing channel contains contaminated sediments that may require costly controls during dredging and disposal activities. One alternative that was evaluated for dealing with the contaminated sediment was to construct an alternate navigation channel parallel to the existing channel to by-pass the area of greatest contamination and dredge the remaining channel. However, this option was deemed impracticable because of costly engineering controls required to realign the channnel. The dredged material was then projected to be placed at the Puddledock site (proposed disposal site).

Currently, approximately 500,000 cu yd[1] of material must be dredged to restore and to maintain the navigation channel to the authorized depth of 10 ft below mean low water (with advance maintenance overdredging). Transporting the dredged material to the Puddledock site or other placement area is required. Therefore, it is necessary to evaluate the dredged material to be disposed of in a practicable, economical, and environmentally sound way. The disposal solution for the next few decades should enhance or maintain the viability of future plans for the Appomattox River Federal Navigation Channel.

Objective and Scope of Work

The overall objective was to support the Norfolk District in evaluating the primary effects of the disposal of contaminated dredged material at the Puddledock site or other upland CDF. The final objective was to evaluate the secondary effects of exposing nondredged contaminated material at the bottom of the channel to the water column of the Appomattox River navigation channel.

The specific study objectives were to:

a. Physically and chemically characterize the sediment.

b. Develop data for predicting the settling behavior of sediment when hydraulically or mechanically placed in a CDF site.

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[1] Factors for converting non-SI units to SI units are presented on page x.

c. Develop turbidity and total suspended solids (TSS) correlation to quickly estimate TSS by measuring turbidity.

d. Predict the quality of the effluent by accounting for the dissolved concentrations of contaminants and the solid contaminant fraction associated with TSS.

e. Collect subsurface soil and/or groundwater data at the Puddledock site.

f. Evaluate the integrity of the Puddledock site for disposal.

g. Evaluate the downstream impacts caused by the channel dredging.

h. Evaluate the water column impacts caused by dredging and the effects of exposing contaminated sediments in the channel bottom.

The scope of the study consists of two tasks.

i. Task 1 was to collect, to transport, and to conduct initial analysis of Appomattox River sediment and Puddledock tailing material samples.

j. Task 2 was to conduct appropriate environmental and engineering studies necessary to evaluate the dredging and disposal site.

The purpose of this report is to document Phases I and II testing. The report includes a review of contaminant loss pathways, case studies on environmental dredging, laboratory results for contaminat loss testing, and prediction of contaminant fluxes.

Phase I – Environmental and Engineering Studies

Appropriate environmental and engineering studies necessary to evaluate the dredging and disposal site are outlined in Table 1. The evaluation procedures listed below are by test and method. The column settling tests include flocculent, zone, and compression settling tests. The column settling tests were performed in accordance with the procedure described in Engineering Manual EM 1110-2-5027 (HQDOA 1987) and Environmental Effects of Dredging Program Technical Notes EEDP-02-5 (Palermo, Thackston, and Schroeder 1988). Technical Reports EL-88-15 (Wade 1988) and EL-94-9 (Wade 1994) describe case studies. The settling test data were evaluated using the Automated Dredging and Disposal Alternatives Management Systems (ADDAMS) model (Schroeder and Palermo 1995). TSS collected from the flocculent test was compared to turbidity of appropriate samples. Two sets of column settling tests were conducted. One set was on the Appomattox River channel material and the other set was on the appropriate composition percentage of Appomattox River dredged material with tailing material/sediment from the Puddledock site. The self-weight and conventional consolidation tests were performed in accordance with ASTM D-2435, “Test Method for One-Dimensional Consolidation Properties of Soils” (ASTM 1996). Material from the dredging and Puddledock sites was evaluated. The sediment classification tests include water content, organic content, grain

Table 1
Testing Requirements

Test	Method
Effluent	Flocculent settling and modified elutriate tests
Runoff	Simplified runoff extraction test
Plant Uptake	DPTA extract test
Animal Uptake	Bioaccumulation/toxicity test
Water Column Toxicity	Dredging elutriate test
Sedimentation	Zone and compression settling tests
Sediment Characterization	Atterberg limits, specific gravity, grain-size distribution, organic content, in situ moisture content, and bulk chemistry
Consolidation	Self-weight and standard oedometer consolidation tests
TCLP	EPA method for toxicity characteristics leaching procedure

size (hydrometer), specific gravity, Atterberg limits, and sieve analysis on the coarse-grained fraction of each sample.

The surface runoff test evaluated surface runoff water quality from contaminated dredged material prior to dredging and disposal. The test was used in conjunction with plant and animal bioassay and effluent tests to evaluate upland CDF. This test determined if engineered control methods were required before disposal. The plant uptake test evaluated the sediment for contaminants that were potentially phytotoxic and may be bioaccumulated by plants. The test determined which plant or plants might be used to control erosion. The animal uptake test evaluated the availability and animal uptake of contaminants from contaminated dredged material placed into the upland CDF site. The test predicted movement of contaminants into soil-dwelling animals colonizing the dredged material disposal site. The animal bioassay evaluated whether or not the sediment was toxic to the earthworm. The water column toxicity test evaluated the potential transport of toxicity of the contaminated sediment to the water column during and after dredging. The modified elutriate test predicted the quality of the effluent by evaluating the dissolved concentration of contaminants and that fraction associated with the total suspended solids. It accounted for possible geochemical changes that might occur during disposal operations.

Phase II – Volatilization and Case Studies

An additional environmental study necessary to evaluate the dredging and disposal site was conducted. Volatile emission of potential organic carbons during and after hydraulic dredging was evaluated for several emission pathways. Volatilization is a potential contaminant loss pathway from a CDF. Four emission routes such as dredged material transportation equipment, exposed sediment, ponded dredged material, and vegetation-covered dredged material were evaluated. Ponded dredged material and exposed sediment are expected to be the dominant emission routes. Theoretical chemodynamic models for volatile emission rates were performed using the Thibodeaux screening model. The approach is outlined in "Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediments" (Myers et al. 1996).

A literature search was warranted to provide the history of the USACE's environmental dredging operations. A summary of the findings is presented.

Sample Collection

Figure 1 shows the overall scope of the project including the proposed disposal facility location (Puddledock site). The volatilization test and tests listed in Table 1 were conducted on sediment samples collected from multiple locations within the Appomattox River Navigation channel (Figures 2 and 3) and the Puddledock site. These samples represented the "typical" and maximum petroleum hydrocarbon concentrations found. Samples for physical and chemical analysis were also collected from the Puddledock site (Figure 4) to assure the integrity of the disposal operation. The Puddledock site samples were collected at the proposed disposal facility location. Figure 5 shows the field activites at the Appomattox River Navigation Channel site. The Puddledock tailings material/sediment consist predominantly of extremely fine particles that are rejected from the grinding, screening, or processing of the raw material with a copious amount of water at the gravel pit. This material is generally uniform in character and size and usually consists of hard, angular siliceous particles with a high percentage of fines. Typically, mill tailings range from sand to silt-clay in particle size.

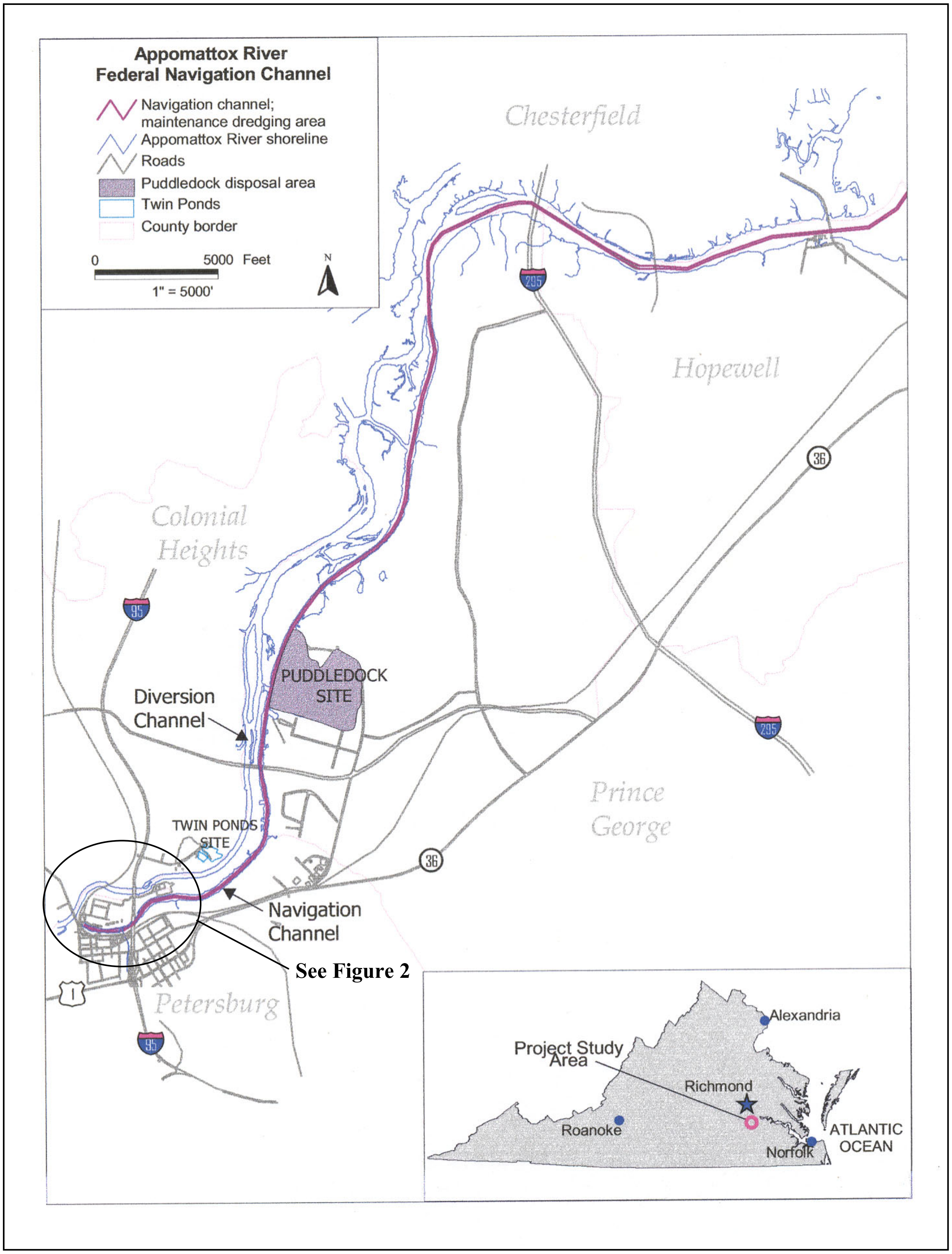


Figure 1. Project map

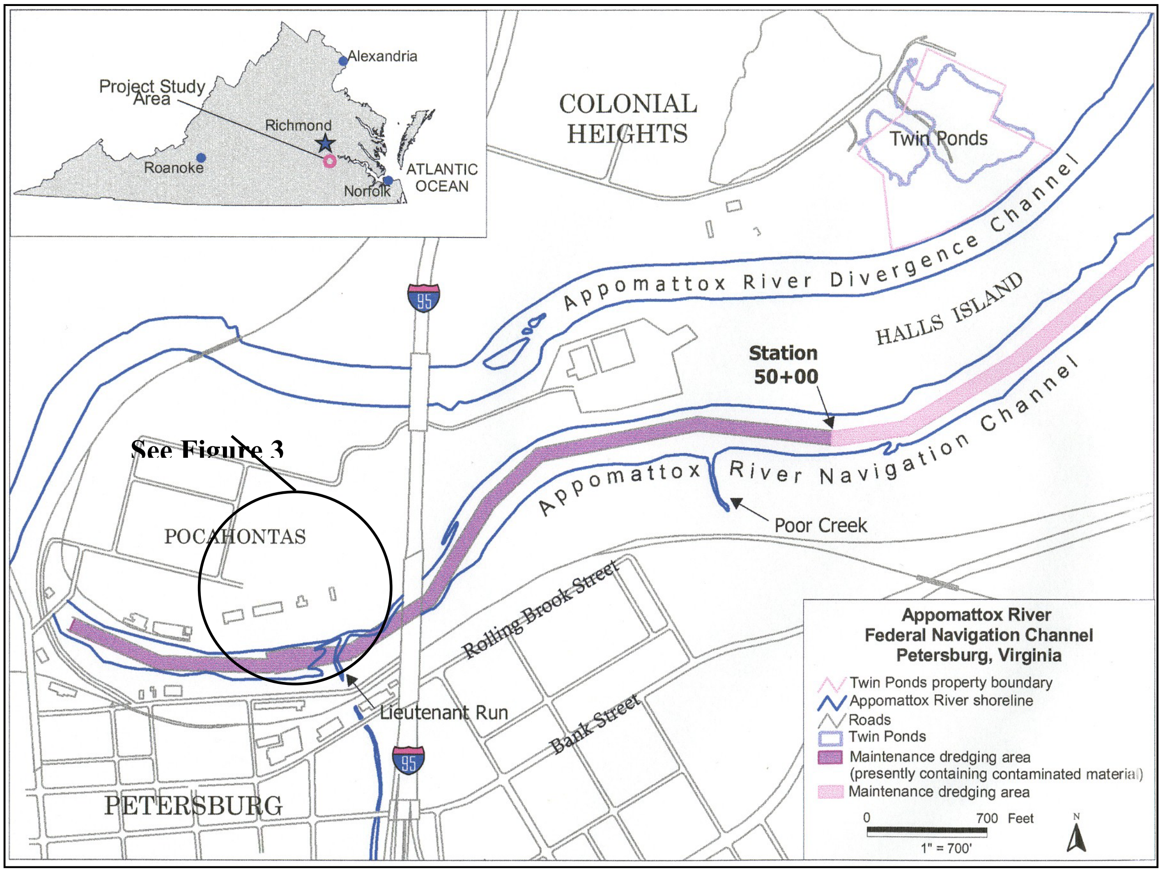


Figure 2. Site location

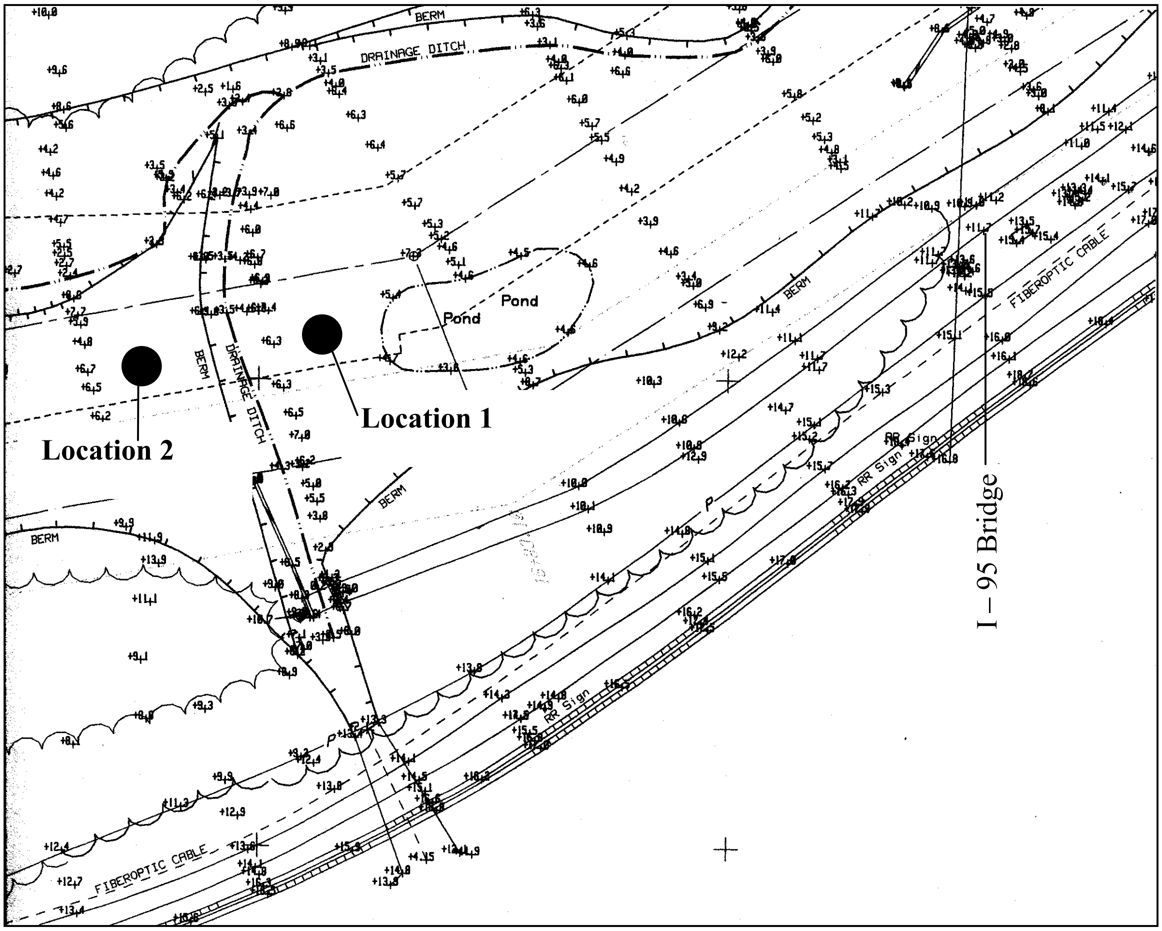


Figure 3. Appomattox River Navigation Channel sediment sample locations

Figure 4. Puddledock proposed site

Figure 5. Appomattox River Navigation Channel field sampling activities

3 Site Description

Project History

A tributary of the James River, the Appomattox River drains 1,300 sq miles. Because of sedimentation problems in the Navigational Channel, a second channel was constructed at the head of the tidal reach. The second channel (i.e., Diversion Channel) was constructed in the 1920's to divert the natural flow of the river, along with its heavy sediment load. The Diversion Channel rejoined the Navigation Channel 5 miles downstream in a naturally deep portion of the river (Figure 1).

During an October 1972 storm, the Appomattox River watershed experienced the worst flooding in the history of Petersburg. The river deposited tons of sediment into the upper reaches of the Navigation Channel. In 1990, the Norfolk District determined that to restore the project, the channel must be dredged; the wetlands which occupied the channel areas must be compensated for; and the breach connecting the diversion channel to the navigation channel at Halls Island must be repaired.

In 1991, a 5-mile reach was to be dredged and placed in a confined placement site (Puddledock) and an intertidal wetland creation site (Twin Pond) (Figure 1). During the restoration of the channels, petroleum hydrocarbons were detected in the sediments in the vicinity of the head of navigation. Other chemical parameters, such as polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, xylene, and total organic halogens were analyzed and detected (except for PCBs). TCLP was conducted and results were determined to be less than regulatory levels. The downstream portion of the channel was restored to project depth by placing suitable dredged material at the Puddledock site. This site is still being considered for the placement of dredged material, but it may require the construction of costly controls prior to acceptance of contaminated material.

Since the historical channel alignment has contaminated sediment, the realignment of the channel was proposed to bypass the areas of highest contamination. This would have allowed minimal interference with the operations of the navigation channel. This option would also have allowed the highly contaminated areas to remain buried and capped in the existing location of the navigation channel. The clean material from the realigned channel would have been placed as additional capping as well. However, the proposed channel realignment must be characterized to ensure other contamination problems do not exist.

Based upon the result of the environmental site investigation (Wade and Smith 1999), it was recommended that realignment of the channel was possible. Besides the contamination in the original navigation channel alignment, only one hot spot of petroleum hydrocarbon was detected in the re-aligned channel. Wade and Smith (1999) recommended that appropriate measures be taken when disposing this material. The noncontaminated material may be placed in dredged material disposal sites, placed in a debris landfills, and used as capping material or to create wetlands at the Twin Ponds or other sites. However, realignment of the channel was later deemed economically impracticable.

Introduction

The Appomattox River study involved the characterization of two sediments (Appomattox River and Puddledock) and site water. The Appomattox River and/or Puddledock sediment characterization included bulk sediment chemistry and TCLP test results. Physical characterization included sedimentation and consolidation test results for representative composite sediment samples. Water column chemical analysis was performed on the site water from the Appomattox River area where the sediment samples were collected.

The sediment characterizations defined the chemical and geotechnical properties of the sediment for assessing contaminant releases and design parameters. The TCLP test demonstrated that the potential beneficial use of the dredged material removed from the CDF would not be subject to Resource Conservation Recovery Act (RCRA) standards.

4 CDF Contaminant Loss Pathways

Description

Upland confined disposal is placement of dredged material within upland (diked) CDFs that are designed to retain dredged material solids. In the case of hydraulic dredging, CDFs are designed to provide adequate storage capacity, acceptable suspended solids and/or contaminant concentrations for discharges to receiving waters. Engineer Manual 1110-2-5027 (HQDOA 1987) provides basic guidance for design, operation, and management of CDFs. Confined disposal facilities 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 receiving waters. With such return flow, CDFs are regulated under Section 404 of the Clean Water Act (CWA).

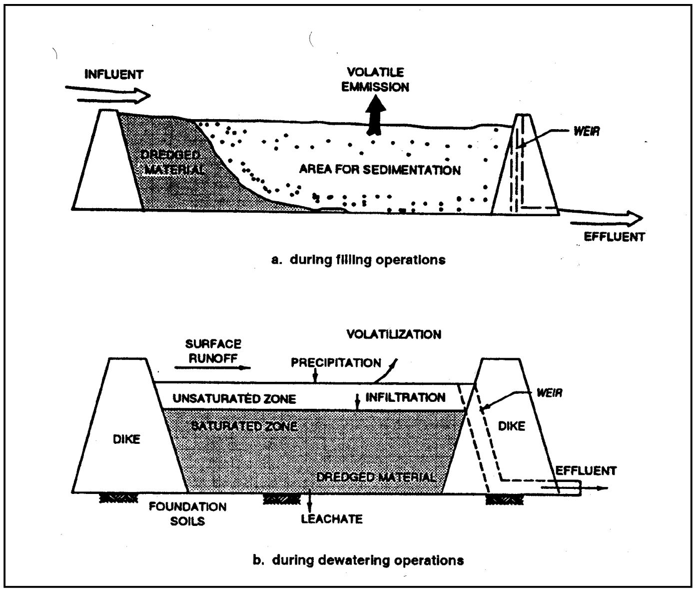
A principal design criterion of CDFs is to retain as high a percentage of the fine-grained sediment particles as practicable. This principle was based on the findings of the USACE Dredged Material Research Program (Saucier et al. 1978), which showed that most chemical contaminants associated with sediments 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 and are presented in this report. The descriptions and results of sedimentation and consolidation tests performed for clarification and storage designs are presented in Appendix A.

The proposed Puddledock site or CDF is expected to be used to store dredged material over the design life. Long-term storage capacity is therefore a major factor in design and management. If the 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.

Contaminant Migration Pathways

The possible migration pathways of contaminants from CDFs in the upland environment are illustrated in Figure 6. 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/USEPA 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 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 6. Upland CDF's contaminant pathways

Upland Geophysical 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 particulate. 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.

Predictions 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 (HQDOA 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.

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. Results of the effluent testing are in Appendix B.

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 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 SLRP.

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 be required. These controls may include placement of a surface cover or cap on the site, maintenance of ponded water, 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 NEPA process. Results of the surface runoff testing are in Appendix C.

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 evaluated 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 (DMF) 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 I, 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 an 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 II. Other considerations under a RAD are also an option prior to Tier II: (a) the number of DTPA extracted metals exceeding wet dredged material or reference sediment; (b) magnitude by which wet dredged material or reference sediment has exceeded; (c) toxicological importance of exceeding metals; and (d) 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 by Lee et al. (1991). Of particular importance is the evaluation of bioaccumulation. Contaminant concentrations are compared to available demonstrated effect levels, Food and Drug Administration (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 Technical Note (Folsom and Houck 1990) 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 content, and the dredged material pH in the condition of placement (wetland or upland). The DTPA test description and results for the Appomattox River dredged material composite and reference soils are presented in Appendix D. The analyses of the results using the PUP model are also presented in Appendix D.

Evaluation of the animal uptake is another pathway that should be addressed. Plant communities will colonize dredged material that has been dewatered. Plant colonization is accompanied by animal colonization. The potential for plants to mobilize contaminants from the dredged material, bioaccumulate, 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 and from plants to animals. The effects of soil invertebrate (earthworm) bioaccumulation from the test sediment are compared to the same from a reference sediment, or soil, location. The earthworm bioassay procedure conducted here was based on the current ASTM standard testing procedure (ASTM E 1676 (1997)). The results of the earthworm bioassay test are presented in Appendix E.

Volatile emission

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 and ponded CDF with a low-suspended solids concentration; and dredged material covered with vegetation.

In cases of highly contaminated sediments disposal, 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 were 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 Appomattox River dredged material are given in Appendix F.

5 Water Column Toxicity Test

Introduction

The water column toxicity test evaluated the dredged material impact on the water column. The test involved exposing test organisms to elutriate dilution series containing both dissolved and suspended components of the dredged material. The test organisms were added to the exposure chambers and exposed for a certain period. The surviving organisms were examined at specified intervals and/or at the end of the test to determine if the test material had an effect. The water column toxicity test used to evaluate the Appomattox River sediment was an acute 96-hr elutriate bioassay. The species were a fathead minnow called *Pimephales promelas*.

Laboratory Procedures

Elutriate bioassays (96-hr) using *Pimephales promelas* were conducted according to methods described in the Inland Testing Manual (USEPA/USACE 1998). The water column toxicity test was conducted as static exposure in precleaned glass chambers equipped with covers to minimize evaporation. The test was also conducted under nonstressful conditions to the test organisms. Dissolved oxygen concentration was maintained at 40 percent saturation for warm water species. The temperature, dissolved oxygen, pH, and other parameters such as ammonia were measured and recorded daily.

Elutriate preparation

The elutriate was prepared by homogenizing one part of composited Appomattox River sediment to four parts of Appomattox river site water at room temperature. The mixture was stirred vigorously for 30 min with a magnetic stirrer. After 30 min of mixing, the mixture was allowed to settle for 1 hr. The supernatant was carefully siphoned off, without disturbing the settled material, and immediately used for testing. The supernatant and any remaining suspended material after the settling period represents the 100-percent elutriate. The filtered elutriate was diluted with dechlorinated control water to yield the following concentrations: 0; 6.25; 12.5; 25; and 50 percent elutriate.

Experimental procedure

Each treatment was replicated five times with 10 organisms per replicate. The test was conducted using 4- to 5-day old *Pimephales promela,* which were fed newly hatched brine shrimp daily (0.2 mg). The *Pimephales promela* were of equal size and age and assigned randomly to the different treatments. Organisms exhibiting abnormal behavior were discarded. The organisms were free of any contamination. The control water was the same water that the organisms were stored prior to testing.

Each glass chamber was equipped with a trickle-flow aeration to maintain dissolved oxygen of 40 percent saturation. Each glass chamber was covered with a watch glass to minimize evaporation. The test chambers were randomly placed in a water bath.

The test duration was 96 hr in which survivability was determined. Care was taken to minimize any stress to the test organisms. Only the living organisms were counted. An organism was deemed dead if it did not move either after the water was gently swirled or after a sensitive part of its body was gently probed.

Results and Discussion

Survival (96-hr) of *Pimephales promelas* in the exposures ranged from 100 to 6 percent (Table 2). Survival met or exceeded the test acceptability criterion of 90 percent in the control treatment (USEPA/USACE 1998). Only the 100-percent elutriate treatment was significantly different from the control (P=<0.001) (Figure 7). The Trimmed Spearman-Karber method was used to calculate the LC_{50} value (Hamilton, Russo, and Thurston 1978). The Appomattox River elutriates had an LC_{50} value of 67.20 percent (59.99 lower - 75.27 upper confidence limit).

Table 3 shows the water quality data of the toxicity test. The pH, dissolved oxygen, and temperature levels were within an acceptable range for conducting toxicity studies with the test species. The initial and final ammonia levels (NH_3) in the 100-percent elutriate exposure ranged from 0.806 to 1.01 mg/L, respectively. These NH_3 levels closely approximate the LC_{50} of 1.24 mg/L for 5-day old *Pimephales promelas* (USEPA 1989).

Conclusion

The elutriate exposures of less than 50 percent did not adversely affect survival of the test species. However, the mortality observed in the 100-percent elutriate exposure may be attributed in part to the high level of NH_3.

Table 2
96-Hr Survival Data for *Pimephales Promelas* Exposed to Appomattox River Elutriates

Replicate	**Treatment**					
	Control	**100%**	**50%**	**25%**	**12%**	**6%**
1	10	1	10	10	9	10
2	10	2	9	10	10	10
3	9	1	7	10	10	10
4	10	1	8	10	10	10
5	10	0	7	10	10	10
Total Organism	49	5	41	50	49	50
Percent Survival	98	10	82	100	98	100
Standard Deviation	0.45	0.71	1.30	0.00	0.45	0.00

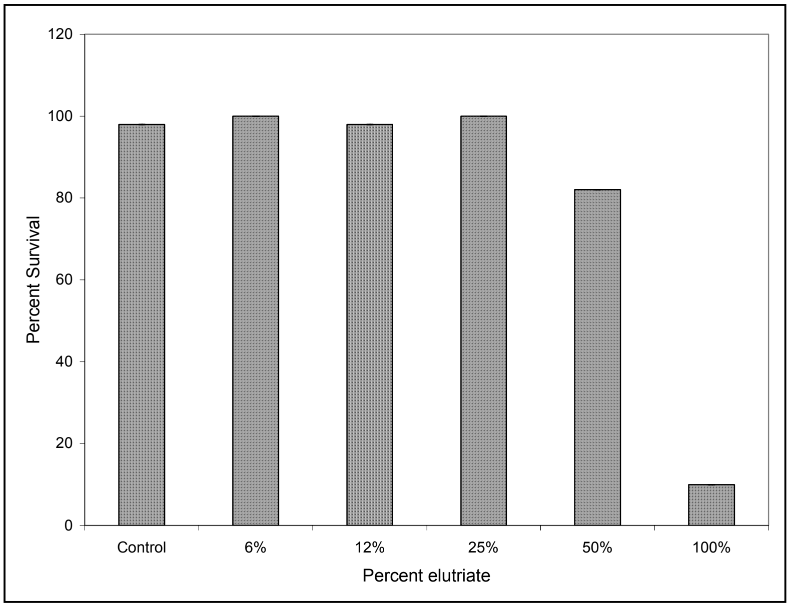


Figure 7. Survival of *Pimephales promelas*

Table 3
Water Quality Data for *Pimephales Promelas* Exposed to Appomattox River Elutriates

Treatment	Replicate	D.O. (mg/L)	pH	Temp. (ºC)	NH$_3$ (mg/L)*
Control (initial)	1	8.64	7.27	24.2	<0.102
(final)		8.23	7.36	24.4	0.102
(initial)	3	8.52	7.39	24.2	-----
(final)		8.32	7.44	24.4	-----
(initial)	5	8.68	7.40	24.2	-----
(final)		8.11	7.30	24.4	-----
6 % (initial)	1	8.48	7.25	24.2	<0.102
(final)		8.35	7.37	24.4	0.131
(initial)	3	8.42	7.33	24.2	-----
(final)		8.23	7.35	24.4	-----
(initial)	5	8.45	7.37	24.2	-----
(final)		8.26	7.44	24.4	-----
12 % (initial)	1	8.47	7.28	24.2	<0.102
(final)		8.31	7.46	24.4	0.171
(initial)	3	8.45	7.25	24.2	-----
(final)		8.31	7.42	24.4	-----
(initial)	5	8.45	7.29	24.2	-----
(final)		8.24	7.42	24.4	-----
25 % (initial)	1	8.36	7.32	24.2	0.201
(final)		8.28	7.43	24.4	0.232
(initial)	3	8.40	7.31	24.2	-----
(final)		8.27	7.39	24.4	-----
(initial)	5	8.41	7.35	24.2	-----
(final)		8.13	7.41	24.4	-----
50 % (initial)	1	8.29	7.27	24.2	0.403
(final)		8.31	7.36	24.4	0.504
(initial)	3	7.53	7.27	24.2	-----
(final)		8.10	7.46	24.4	-----
(initial)	5	8.14	7.29	24.2	-----
(final)		8.18	7.40	24.4	-----
100 % (initial)	1	8.29	7.07	24.2	0.806
(final)		8.26	7.36	24.4	1.01
(initial)	3	8.28	7.07	24.2	-----
(final)		8.27	7.32	24.4	-----
(initial)	5	8.35	7.05	24.2	-----
(final)		8.31	7.33	24.4	-----

[1] Denotes composite samples

6 Literature Review of Environmental Dredging Effectiveness

Environmental Dredging

Dredging for cleanup purposes has been considered for sometime as a primary means for managing contaminated sediments. Guidance for selection of dredging equipment and advantages and limitations of various types of dredges in the navigation-dredging context is available, and this information is generally applicable in the context of environmental dredging. However, resuspension of sediment and associated release of contaminants and removal precision are key environmental concerns when dealing with contaminated sediments.

All dredges resuspend some sediment during the dredging process. Some contaminants in the dissolved form and some contaminants associated with resuspended particles will be released and transported away from the dredging site. Removal precision refers to how accurately a given dredge can remove desired areas and thickness of contaminated sediment. Precision is important from the standpoint of removing the contaminated material layers while leaving behind as little residual contamination as possible. Also, precision is critical from the standpoint of not removing excessive amounts of clean sediment, since any sediments removed would likely be treated as contaminated material with the associated high cost of disposal and management.

Research supplemented by field demonstrations has resulted in general guidance for selection of equipment and techniques for dredging contaminated sediments. Much can be done to limit sediment resuspension from conventional dredges without substantial impact upon the efficiency of the dredging operation. Precautions in operation and/or minor plant modifications can be made with only a small increase in cost. In general, pipeline cutterhead dredges and hopper dredges without overflow generate less resuspended sediment than clamshell dredges or hopper dredges with overflow. It should be recognized, however, that other factors such as maneuverability requirements, hydrodynamic conditions, and location of the disposal site might dictate the type of dredge that must be used. The strategy then must be to minimize the resuspension levels generated by any specific dredge type. If conventional dredges are unacceptable, a special-purpose dredge may be required. These dredges generally resuspend less material than conventional dredges, but associated costs may be much greater. As in the case of conventional dredges, site-specific conditions, economics, and availability will likely dictate the selection of a special-purpose dredge.

Case Studies

A number of case studies and databases are available describing environmental dredging projects. One recent study has been completed in connection with the Fox River project in Wisconsin (ThermoRectec in press). This study examined 20 environmental dredging projects selected for evaluation based on the scale, availability of monitoring data, and other factors (Figure 8). The short- and long-term effectiveness of environmental dredging and the success of the projects in meeting remediation goals were assessed. The report is scheduled for publication as a supporting document for the Fox River feasibility study. Appendix G contains a description of each project extracted and summarized.

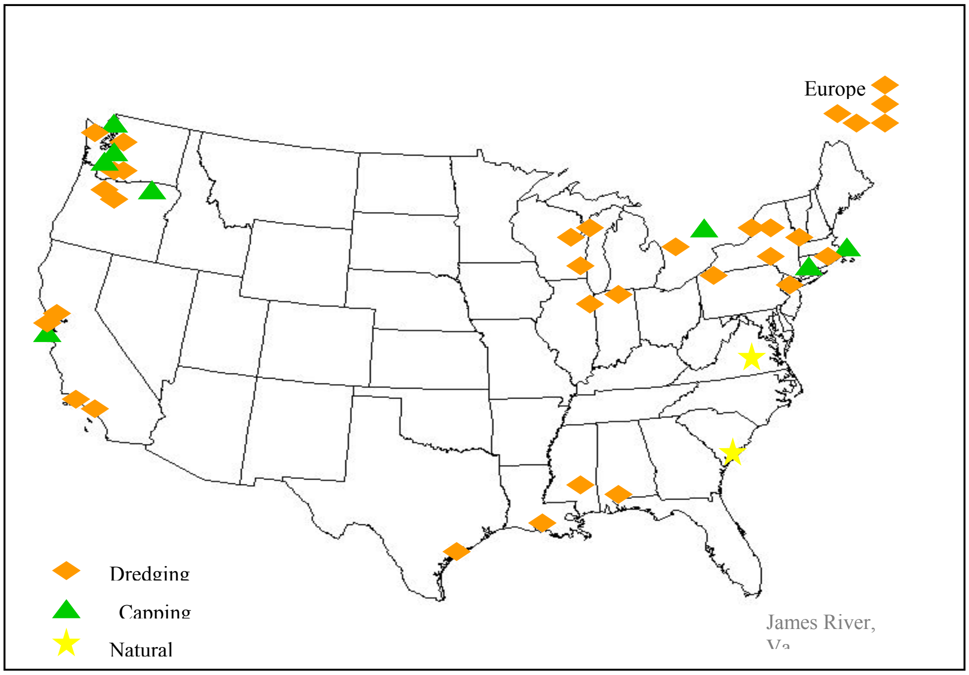


Figure 8. Locations of case studies for sediment remediation

A summary of the findings related to performance goals achieved for the 20 projects is given in Table 4. The evaluation indicated that 18 of 20 projects achieved the short-term goals related to removal of material as measured by a chemical criteria, mass removal, removal to a given horizon or elevation, or vertical depth. Long-term effectiveness is more difficult to measure. Table 5 summarizes the findings related to long-term effectiveness. Long-term goals

Table 4
Short-Term Effectiveness of Environmental Dredging

Short-Term Target Goal	No. of Projects	No. of Projects Achieving Performance-Based Criteria
Chemical Criteria	10	8
Mass Removal	3	3
Horizon (bedrock)	2	2
Elevation	2	2[1]
Vertical Depth	3	3
Total	20	18

[1] Denotes Sediment Management Unit (SMU) 56/57 did not target elevation during year 2000 dredging activities.

Table 5
Long-Term Effectiveness Of Environmental Dredging

RAO[1]	No. of Projects	Achieved[2]	Progress Towards[3]	Variable Results[4]
Protect Human Health	9	Bayou Bonfouca, Minamata Bay	GM Foundry, Lake Jarnsjon, Ford Outfall, Waukegan Harbor	Marathon Battery, Grasse River, Manistique River
Protect Environment	4	Black River, Collingwood Harbour, Sitcum Waterway Bay	Wyckoff/West Eagle Harbor	None
Physical/Source Control	7	None	Port of Portland, Port of Vancouver, Sheboygan River, Fox River Deposit N., Fox River SMU 56/57	Puget Sound Naval Shipyard, New Bedford Harbor
Total	20	5	10	5

[1] Remedial action objectives.
[2] Denotes fish consumption advisories have been removed, site restored to functional use, or the sites were delisted from regulatory status.
[3] Denotes some evidence of decreasing concentration in sediment and biota tissue, but no decision making action taken based on results.
[4] Denotes no discernible trends observed.

have been achieved for 5 projects, progress has been made toward attaining long-term goals for 10 projects, and results have been variable for 5 projects.

Overall, these results show that environmental dredging projects can be effective in attaining short-term goals related to removal. Attainment of longer-term goals is more difficult to evaluate and usually requires long-term monitoring data.

7 Summary of Results

Because of potential petroleum contamination in the Appomattox River, core samples were collected from two locations and composited to conduct various environmental and engineering studies and to characterize the sediment. Samples were also collected from the Puddledock site (potential disposal facility). The Puddledock samples were characterized to evaluate the integrity for disposal. If the Puddledock site is used, the dredged material will be flooded (i.e., not an upland site). However, if the Puddledock site is not used, environmental and engineering studies include surface runoff, plant and animal uptake, volatilization emission were required for evaluation. Water column toxicity, TCLP, modified elutriate, column settling, and geotechnical tests were also conducted.

The findings of Phase I and Phase II environmental and engineering studies can be summarized as follows:

k. Dredged material from the Appomattox River sediment was classified as gray silty sand with a trace of gravel. This sediment had a specific gravity of 2.64, a water content of 27.2 percent, and nonplastic. The Appomattox River sediment consisted of 88 percent coarse material and 12 percent fines. The Puddledock sediment was classified as brown, sandy, clayey silt. The Puddledock sediment had a specific gravity of 2.65, water content of 17.6 percent, and a plasticity index of 7. The Puddledock sediment consisted of 23 percent sand and 77 percent fines. Metals and some organic contaminants were present in the Appomattox River sediment, especially TRPH. The average TRPH concentration was 84 mg/kg from one location and 283 mg/kg from the other location. The maximum and predominant metals were aluminum, iron, and magnesium with average concentrations of 4,973, 9,007, and 555 mg/kg, respectively. The Puddledock sediment was characterized with predominant metals being aluminum, iron, and magnesium with average concentrations of 1,923, 1,890, and 117 mg/kg, respectively.

l. The TCLP results of the Appomattox River composited sediment passed the RCRA criteria. The TCLP results show that each analyte concentrations were below detection limits.

m. Based on zone settling test, the composited Appomattox River and 50/50 mixture sediments exhibited zone settling with a settling rate of 0.47 and 0.085 ft/hr, respectively.

n. Based on the flocculent settling test, clear effluent with low suspended solids and turbidity can be achieved. The modified elutriate test showed that effluent concentration for copper, lead, and zinc was slightly elevated as compared to the Federal water criteria. The modified elutriate effluent concentration was similar to the background site water concentration.

o. An SLRP was run on the Appomattox River composite sediment in its original, wet, unoxidized state and a dried, oxidized state. The SLRP shows that if the Appomattox dredged material is placed in an upland environment (i.e., not the Puddledock site), heavy metals in rainfall induced runoff from the wet unoxidized wet dredged material will be mostly insoluble and bound to suspended particulate in the surface water runoff, as will TRPH. Soluble metals were not predicted to exceed water quality standards during this period. Retention of suspended solids will significantly restrict all movement of metals and TRPH from the upland disposal site. Drying and oxidation of Appomattox sediment signifycantly increased the solubility of some metals. However, only copper and zinc were predicted to exceed the water quality standard during the dried conditions. However, the evaluation of Appomattox sediment does not indicate a major water quality concern from the release of rainfall-induced runoff into receiving waters. Based on the results of the RUNQUAL evaluation of Cu and Zn, a dilution factor of 2.6 is all that is required in a mixing zone to bring runoff water discharge into compliance with water quality standards.

p. If the Appomattox sediment is placed in an upland disposal facility (i.e., not the Puddledock site), the DTPA results predicted that Appomattox sediment might contribute to elevated levels of metals in leafy freshwater plants above levels from plants in an upland disposal facility. However, predicted levels were below levels of concern and should pose no significant adverse ecological effects. At this time, further evaluation using the Tier III testing is not necessary. If movement of metals into plants becomes a concern because of a decrease in dredged material pH or colonization by sensitive plant or animal species, management of dredged material pH or selection and management of certain plant species are options that can readily be deployed.

q. The earthworm bioassay conducted on Appomattox sediment and Puddledock site soil did not indicate excessive bioavailability of metals or TRPH. If plants and animals are permitted to colonize, retesting may be necessary to evaluate any movement of contaminants in the food web.

r. The potential for volatilization emission of organic carbons during and after hydraulic dredging was evaluated for several emission pathways. Results of these investigations reveal that the highest contaminant fluxes will occur with initial loading of the sediment. Results imply that changes in relative air humidity or sediment moisture will not result in an increase in emissions for the majority of compounds of interest. Flux rates for PAHs will be highest during initial sediment exposure (after placement). Changes in relative air humidity or sediment moisture following a rainfall will not result in increased fluxes. TRPH fluxes will be highest during initial exposure changes and increases in relative air humidity. Sediment moisture will result in increased emissions for a short period. Ammonium fluxes will be highest during initial exposure stages.

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Appendix A
Sediment Physical and Chemical Characterization

Introduction

The purpose of this appendix is to document and present the results of the Appomattox River study involving the characterization of two sediments (Appomattox River and 50 percent Appomattox/50 percent Puddledock mixture by weight) and site water. The Appomattox River and/or Puddledock sediment characterization included bulk sediment chemistry and toxicity characteristics leaching procedure (TCLP) test results. Physical characterization included sedimentation and consolidation test results for representative composite sediment samples. Water column chemical analysis was performed on the site water from the Appomattox River area where the sediment samples were collected. The water quality data are presented in Appendix B with the remaining effluent quality data.

The sediment characterizations were to define the chemical and geotechnical properties of the sediment for assessing contaminant releases and design parameters. The TCLP test demonstrated the potential beneficial use of the dredged material removed from the confined disposal facilities (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 sediments. 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 form the sediment under TCLP conditions. Other physical characteristics include grain-size distribution, specific gravity, Atterberg limits, self-weight and standard consolidation properties, and zone and compression settling properties.

Analytical Method

Environmental Chemistry Branch (ECB), Environmental Processes and Effects Division (EPED), Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, performed all chemical analysis. Appropriate quality assurance and quality controls were maintained to assure quality data. All chemical analyses were conducted according to SW-846 (U.S. Environmental Protection Agency (USEPA) 1986)[1] standard procedures (Table A1). Metals were analyzed using the Inductively Coupled Argon Plasma (ICP), Perkin-Elmer 5000 (Cold Vapor), or Zeeman 5100. Organic analyses were performed using gas chromatography/mass spectrometers (GC/MS).

Table A1
Laboratory Analytical Procedures

Parameter	Analytical Method	Reference
Base/Neutrals/Acid Extractable (BNA)	USEPA Method 8270	SW-846 (USEPA 1986)
Pesticides/PCBs	USEPA Method	SW-846 (USEPA 1986)
Total Organic Carbon (TOC)	USEPA Method	SW-846 (USEPA 1986)
Total Recoverable Petroleum Hydrocarbon (TRPH)	USEPA Method	SW-600 (USEPA 1979)
Volatile Organic Compounds (VOC)	USEPA Method	SW-846 (USEPA 1986)
Metals	USEPA Method USEPA 7000 Series/6010	SW-846 (USEPA 1986) SW-846 (USEPA 1986)

Bulk chemistry

Homogenized samples of the sediment and site water were sent to the Environmental Chemistry Branch (ECB) in triplicate to determine their chemical characteristics. The sediment and site water samples were analyzed for total metals, organic priority pollutants, and total recoverable petroleum hydrocarbon (TRPH). Tables A2 and A3 show results of those analyses for the sediments and site water, respectively.

TCLP test

The TCLP test was used to determine regulatory implications for reuse of the dredged material (40 CFR Part 261). The TCLP test was performed according to EPA Method 1311 (USEPA 1986). The TCLP test method consists of air-drying

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[1] References following Appendix A text.

Table A2
Bulk Chemistry Analysis Sediment Concentration

Semivolatiles	**Drum 1 (µg/kg)**			**Drum 2 (µg/kg)**			**Puddledock (µg/kg)**		
Phenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2-Chlorophenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2-Nitrophenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4-Dimethylphenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4-Dichlorophenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
4-Chloro-3-Methylphenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4,6-Trichlorophenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4-Dinitrophenol	<910	<920	<920	<850	<860	<810	<850	<880	<940
4-Nitrophenol	<910	<920	<920	<850	<860	<810	<850	<880	<940
2-Methyl-4,6-Dinotrophenol	<910	<920	<920	<850	<860	<810	<850	<880	<940
Pentachlorophenol	<910	<920	<920	<850	<860	<810	<850	<880	<940
Benzoic Acid	<910	<920	<920	<850	<860	<810	<850	<880	<940
2-Methylphenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
4-Methylphenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4,5-Trichlorophenol	<460	<460	<460	<430	<430	<410	<430	<440	<470
Benzyl Alcohol	<460	<460	<460	<430	<430	<410	<430	<440	<470
N-Nitrosodimethylamine	<460	<460	<460	<430	<430	<410	<430	<440	<470
Bis(2-Chloroisopropyl)Ether	<460	<460	<460	<430	<430	<410	<430	<440	<470
N-Nitroso-Di-N-Propylamine	<460	<460	<460	<430	<430	<410	<430	<440	<470
Nitrobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Isophorone	<460	<460	<460	<430	<430	<410	<430	<440	<470
Bis(2-Chloroethoxy)Methane	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,6-Dinitrotoluene	<460	<460	<460	<430	<430	<410	<430	<440	<470
2,4-Dinitrotoluene	<460	<460	<460	<430	<430	<410	<430	<440	<470
1,2-Diphenylhydrazine	<230	<230	<230	<210	<210	<200	<210	<220	<230
Benzidine	<910	<920	<920	<850	<860	<810	<850	<880	<940
3,3'Dichlorobenzidine	<460	<460	<460	<430	<430	<410	<430	<440	<470
Bis(2-Chloroethyl)Ether	<460	<460	<460	<430	<430	<410	<430	<440	<470
1,3-Dichlorobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
1,4-Dichlorobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
1,2-Dichlorobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Hexachloroethane	<460	<460	<460	<430	<430	<410	<430	<440	<470
Naphthalene	37,100	40,200	48,500	2,970	2,750	2,610	<430	<440	<470
1,2,4-Trichlorobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Hexachlorobutadiene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Hexachlorocyclopentadiene	<460	<460	<460	<430	<430	<410	<430	<440	<470

(Sheet 1 of 4)

Table A2 (Continued)

Semivolatiles	Drum 1 (µg/kg)			Drum 2 (µg/kg)			Puddledock (µg/kg)		
2-Chloronaphthalene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Acenaphthylene	660	694	943	260J	320J	<410	<430	<440	<470
Dimethyl Phthalate	<460	<460	<460	<430	<430	<410	<430	<440	<470
Acenaphthene	17,800	19,600	22,500	5,680	6,120	4,440	<430	<440	<470
Fluorene	9,320	10,100	12,000	2,780	2,910	2,100	<430	<440	<470
Diethyl Phthalate	<460	<460	<460	<430	<430	<410	<430	<440	<470
4-Chlorophenyl Phenyl Ether	<460	<460	<460	<430	<430	<410	<430	<440	<470
N-Nitrosodiphenyl Amine	<460	<460	<460	<430	<430	<410	<430	<440	<470
4-Bromophenyl Ether	<460	<460	<460	<430	<430	<410	<430	<440	<470
Hexachlorobenzene	<460	<460	<460	<430	<430	<410	<430	<440	<470
Phenanthrene	24,900	27,800	31,700	6,810	6,610	4,940	<430	<440	<470
Anthracene	7,750	8,540	9,800	1,500	1,340	1,070	<430	<440	<470
Dibutylphthalate	<460	<460	<460	<430	<430	<410	<430	<440	<470
Fluoranthene	10,800	12,300	13,400	3,760	3,800	1,950	<430	<440	<470
Pyrene	12,500B	15,800B	15,500B	4,870B	4,610B	2,660B	<430	<440	<470
Butylbenzylphthalate	<460	<460	<460	<430	<430	<410	<430	<440	<470
Chrysene	3,080B	3,050B	4,180B	1,640B	1,670B	826B	<430	<440	<470
Benzo(a)Anthracene	2,190	2,210	3,220	1,860	1,680	893	<430	<440	<470
Bis(2-Ethylhexyl)Phthalate	460	984	527	468	230J	<410	<430	<440	<470
Di-N-Octylphthalate	<460	<460	<460	<430	<430	<410	<430	<440	<470
Benzo(b)Fluoranthene	1,800	1,860	2,750	1,110	902	491	<430	<440	<470
Benzo(k)Fluoranthene	1,650	1,530	2,580	983	911	486	<430	<440	<470
Benzo(a)Pyrene	3,290	3,330	4,400	1,780	1,540	868	<430	<440	<470
Indeno(1,2,3-C,D)Pyrene	1,370	1,470	1,760	881	969	390J	<430	<440	<470
Dibenzo(A,H)Anthracene	330J	340J	410J	240J	230J	<410	<430	<440	<470
Benzo(G,H,I)Perylene	1,200	1,280	1,440	859	819	370J	<430	<440	<470
Aniline	<460	<460	<460	<430	<430	<410	<430	<440	<470
4-Chloroaniline	<460	<460	<460	<430	<430	<410	<430	<440	<470
Dibenzofuran	2,070	1,880	2,760	230J	210J	160J	<430	<440	<470
2-Methylnaphthalene	34,800	37,700	44,500	2,340	2,130	1,910	<430	<440	<470
2-Nitroaniline	<910	<920	<920	<850	<860	<810	<850	<880	<940
3-Nitroaniline	<910	<920	<920	<850	<860	<810	<850	<880	<940
4-Nitroaniline	<910	<920	<920	<850	<860	<810	<850	<880	<940

(Sheet 2 of 4)

J denotes estimated value below detection limit.

B denotes analyte found in the associated blank as well as in the sample.

Table A2 (Continued)

Pesticides/PCBs	Drum 1 (µg/kg) unless noted			Drum 2 (µg/kg)			Puddledock (µg/kg)		
Aldrin(ug/kg)	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
A-BHC	0.78	0.69	0.72	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
B-BHC	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
G-BHC	<0.625	<0.625	<0.625	1.67	1.83	1.41	<0.625	<0.625	<0.625
D-BHC	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
PPDDD	20.4	20.5	25.2	10.9	8.79	10.3	<1.25	<1.25	<1.25
PPDDE	12.2	12.2	13.8	2.88	2.98	3.46	<1.25	<1.25	<1.25
PPDDT	15.8	29.1	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25
Heptachlor	0.69	<0.625	<0.625	0.54J	0.28J	0.31J	<0.625	<0.625	<0.625
Dieldrin	2.30	<1.25	<1.25	2.00	1.38	1.92	<1.25	<1.25	<1.25
A-Endosulfan	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
B-Endosulfan	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25
Endosulfan sulfate	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25
Endrin	<1.25	<1.26	<1.27	<1.28	<1.25	<1.25	<1.25	<1.25	<1.25
Endrin Aldehyde	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25	<1.25
Heptachlor Epoxide	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625	<0.625
Methoxychlor	48.5	34.6	21.1	16.5	<6.25	<6.25	<6.25	<6.25	<6.25
Chlordane	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
Toxaphene	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1016	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1221	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1232	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1242	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1248	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1254	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
PCB-1260	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25	<6.25
TRPH (mg/kg)	290	250	310	87	67	98	<45	<45	<45

(Sheet 3 of 4)

Table A2 (Concluded)

Metals	**Drum 1 (mg/kg)**			**Drum 2 (mg/kg)**			**Puddledock (mg/kg)**		
Antimony	0.43	0.38	0.55	<0.30	<0.30	<0.30	<0.30	<0.30	<0.30
Arsenic	2.3	2.39	3.19	0.699	0.798	0.799	0.3	0.3	0.299
Beryllium	0.2	0.199	0.299	0.1	0.1	0.1	0.1	0.2	0.1
Cadmium	0.279	0.309	0.419	0.0699	0.0897	0.21	<0.020	<0.020	<0.020
Chromium	10.1	9.07	11.2	2.6	2.99	4.2	7.3	8.07	7.59
Copper	13.8	15.8	20.1	3	3.49	3.9	1.6	1.99	2
Lead	56.8	68.3	95.9	18.6	20.8	52.4	6.5	7.37	6.99
Mercury	0.258	0.282	0.402	<0.040	0.048	<0.040	<0.040	<0.040	<0.040
Nickel	3.99	3.49	4.49	1.1	1.2	1.6	0.6	0.5	0.599
Selenium	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
Silver	0.499	0.498	1.400	0.400	0.299	0.400	0.200	0.300	0.200
Thallium	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200	<0.200
Zinc	60.7	62.3	87.1	14.7	17.9	16.0	1.80	1.69	2.30
Alumium	4480	4580	5860	1560	1690	1650	1590	2010	2170
Barium	41.5	42	59.4	16.8	14.5	13.8	8.1	9.26	8.98
Calcium	1570	968	1090	478	356	435	124	162	191
Cobalt	2.5	2.39	3.29	1.2	1.2	1.5	0.4	0.4	0.399
Iron	8170	8860	9990	3550	3390	3240	1750	1920	2000
Magnesium	721	424	520	157	162	166	105	117	128
Manganesia	54.5	57.4	74.8	34.8	21.3	29.1	19.9	17.4	18.8
Potassium	436	457	553	194	207	186	293	319	340
Sodium	69.4	77.1	78.2	53.5	36.5	41.2	59.5	43.7	57.5
Vanadium	12.4	11.3	14.6	3.7	4.19	4.7	15.7	19.6	16.6

(Sheet 4 of 4)

Table A3
Site Water and Pore Water Analytical Results

Parameter	Concentration, ppb (unless noted)		
	Repl 1	Repl. 2	Pore Water
Naphthalene	<5	<5	1230
Acenaphthylene	<25	<25	17J
Acenaphthene	<5	<5	839
Fluorene	<5	<5	286
Phenanthrene	<5	<5	825
Anthracene	<5	<5	205
Fluoranthene	<5	<5	232
Pyrene	<5	<5	446
Chrysene	<5	<5	109
Benzo(a)Anthracene	<5	<5	121
Bis(2-Ethylhexyl)Phthalate	3.2J	3.3J	47.7
Benzo(b)Fluoranthene	<10	<10	53.2
Benzo(k)Fluoranthene	<10	<10	59.5
Benzo(a)Pyrene	<10	<10	117
Indeno(1,2,3-C,D)Pyrene	<10	<10	44.3
Dibenzo(A,H)Anthracene	<10	<10	9.3J
Benzo(G,H,I)Perylene	<10	<10	49.6
Dibenzofuran	<25	<25	23.0J
2-Methylnaphthalene	<5	<5	573
A-BHC	<0.025	<0.025	0.03
G-BHC	<0.025	<0.025	0.088
PPDDD	<0.050	<0.050	0.94
PPDDE	<0.050	<0.050	0.62
Heptachlor	<0.025	<0.025	0.026
B-Endosulfan	<0.025	<0.025	1.51
Endrin Aldehyde	<0.050	<0.050	0.22
PCB-1242	<0.25	<0.25	26.1
PCB-1260	<0.25	<0.25	28.9
TRPH (ppm)	<0.7	<0.7	49
Chromium	0.001	0.001	0.001
Copper	0.002	0.002	0.002
Lead	0.001	0.001	0.001
Nickel	0.002	0.002	0.002
Zinc	0.061	0.065	0.063
Aluminum	0.1	0.053	0.0765
Barium	0.033	0.033	0.033
Calcium	27.8	27.9	27.85
Iron	11.1	12.8	11.95
Magnesium	4.31	4.38	4.345
Manganese	0.144	0.149	0.1465
Potassium	5.02	0.508	2.764
Sodium	17.5	17.8	17.65

and crushing the sediment to pass a 9.5-millimeter (mm) standard sieve. The sample was placed in a 0.5 normal (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. The sediment and extract were placed in 1-gal[1] glass jars and tumbled end-over-end. After 18-hr of tumbling, the samples were filtered using a Whatman GF/F 0.75-micrometer filter. The filtered extracts were placed in preclean 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 test was performed on the Appomattox River sediment. The TCLP extracts were prepared using Method 1311 and were analyzed by ECB. The TCLP extract results shows that each analyte concentration was below detection limits. The TCLP concentrations and the regulatory limit from the Federal Register (Vol. 55, No. 61, 29 March 1990) are presented in Table A4. The Appomattox River TCLP concentrations were below the regulatory limits for all other parameters.

Table A4
TCLP Chemical Analysis

	Concentration (mg/L)				
Semivolatives	**Replicate 1**	**Replicate 2**	**Replicate 3**	**Blank**	**Regulatory Limit**
2,4,6-Trichlorophenol	<0.026	<0.026	<0.027	<0.026	2
Pentachlorophenol	<0.052	<0.052	<0.054	<0.052	100
2-Methylphenol	<0.026	<0.026	<0.027	<0.026	5
4-Methylphenol	<0.026	<0.026	<0.027	<0.026	200
2,4,5-Trichlorophenol	<0.026	<0.026	<0.027	<0.026	400
Nitrobenzene	<0.026	<0.026	<0.027	<0.026	2
2,4-Dinitrotoleune	<0.026	<0.026	<0.027	<0.026	0.13
1,4-Dichlorobenzene	<0.026	<0.026	<0.027	<0.026	7.5
Hexachloroethane	<0.026	<0.026	<0.027	<0.026	3
Hexachlorobutadiene	<0.026	<0.026	<0.027	<0.026	0.5
Hexachlorobenzene	<0.026	<0.026	<0.027	<0.026	0.13
Pyridine	<0.052	<0.052	<0.054	<0.052	5
Metals	**Concentration (mg/L)**				
Arsenic	<0.040	<0.040	<0.040	<0.040	5
Barium	1.2	1.78	1.18	0.058	100
Cadmium	<0.010	<0.010	<0.010	<0.010	1
Chromium	0.02	0.015	0.026	<0.004	5
Lead	0.48	0.411	0.463	<0.020	5
Mercury	<0.000200	<0.000200	<0.000200	<0.000200	0.2
Selenium	<0.100	<0.100	<0.100	<0.100	1
Silver	<0.010	<0.010	<0.010	<0.010	5

Physical Characteristics

The physical characteristics of the dredged material are important in the design of a CDF. Table A5 shows the results of the physical characteristics of

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[1] Factors for converting non-SI units to SI units is presented on page x.

Table A5
Sediment Physical Characteristics

Characteristic	Appomattox River Values	Puddledock Values
Specific Gravity	2.64	2.65
In Situ Solid Concentrations		
Water content	27.2%	17.6%
Void ratio	0.75	7.09
Solids concentration	1,512 g/L	281 g/L
Atterberg Limits		
Liquid limit	----	31
Plastic limit	----	24
Plasticity index	----	7
Grain-Size Distribution		
Percent gravel	4.4	0
Percent sand	83.1	22.9
Percent silt/clay	12.5	77.1
Classification	Silty sand (SM)	Sandy clayey silt (ML)

the Appomattox sediment and the Puddledock tailing material. Based on the Unified Soil Classification System (USCS), the Appomattox River sediment and the Puddledock tailing material were classified as a silty sand and sandy clayey silt, respectively.

Specific gravity

Specific gravity (SG) of the particulate in the sediment and tailing material were measured using the procedures given the Laboratory Soils Testing Engineering Manual (Headquarters, Department of the Army (HQDOA) 1970). The specific gravity of Appomattox sediment and Puddledock tailing material was 2.64 and 2.65, respectively.

Water content

The in situ water content (W) of fine-grained sediment samples is also an important parameter evaluating settling behavior and the volumetric changes occurring following dredging and disposal. It should be noted that the water content in this appendix is identical to the geotechnical engineering. This water content is defined as the ratio of weight of water to weight of solids expressed as percent, it can exceed 100 percent. The procedures are given in the Laboratory Soils Testing Engineering Manual, EM 1110-2-1906 (HQDOA 1970). Using the SG and W, the void ratio (e) and solids concentration (S) can be expressed as follows:

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

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

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 EM 1110-2-1906 (HQDOA 1970).

Plasticity

Liquid limit (LL) and plastic limit (PL) were determined for composite sediment samples using standard soils testing procedures as outlined in the Laboratory Soils Testing Engineer Manual EM 1110-2-1906 (HQDOA 1970). The plasticity index (PI) was then computed; PI = LL – PL.

Unified Soil Classification System classification

Visual classifications and classifications using results of the grain-size distribution and plasticity tests as described below were determined using the USCS as outlined in EM 1110-2-1906 (HQDOA 1970).

Column Settling Test Experimental Procedures

Sediment removal is required to maintain a navigable waterway in the Appomattox River. One disposal alternative that is being considered for the Appomattox dredged material is hydraulic placement into an upland CDF. The design of the CDF 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 result, the storage capacity of a CDF can be determined based on compression settling data.

Sample collection

The sediments and site water samples were collected from potential dredging areas and used to conduct the column settling tests. The samples were identified as Appomattox River sediment and Puddledock tailing material. The sediments and site water samples were delivered to the U.S. Army Engineer Research and Development Center (ERDC), Environmental Laboratory (EL), Vicksburg, MS, in 55-gal containers. Samples were stored in 4 ˚C coolers until tested. The EL personnel composited and homogenized two 55-gal containers of the Appomattox River sediment collected near previous borings in the vicinity of

Interstate-95 to obtain a representative sample for testing. Total solids analyses were run on the composite sample in triplicate to assure a homogenized sample. The composited samples were then replaced in a 4 ˚C cooler until tested.

Settling tests

The settling tests followed procedures found in Palermo, Montgomery, and Poindexter (1978), HQDOA (1987), and Palermo and Thackston (1988). The tests involved mixing sediment and site water to simulate a dredged material slurry, placing the material in a settling column, and observing each of several types of settling (i.e., zone, flocculent, and compression) behavior. The general procedures are described below.

Zone, compression, and flocculent settling tests were collected from two settling tests. The first settling test was conducted on the composite Appomattox River samples. The second settling test was conducted on a 50/50 by wet weight mixture of composite Appomattox River and Puddledock sediments. The selection of a 50/50 mix was based on a worst case scenerio. A small volume of Puddledock sediment mixed with the Appomattox sediment is not expected to hinder the settling of the dredged material when placed on site. However, a higher volume of Puddledock sediment might. Therefore, a 50/50 mix of Appomattox sediment/Puddledock sediments underwent a settling test. From henceforth, this mixture is labeled 50/50 Mix. The three types of settling data were collected from each settling test. The zone and compression settling tests are presented in this appendix while the flocculent settling test is presented in Appendix B.

Experimental approach

Slurry preparation. The target slurry concentration selected for the settling tests was dependent on the grain-size distribution of sample to simulate the solids concentration anticipated during production by a hydraulic dredge. However, if the grain-size distribution or influent concentration is not known, a suggested default value (150 g/L) for hydraulically dredged slurry is used. The target slurry was prepared by mixing the appropriate amount of sediment at its initial solids concentration and site water into a 130-L mixing chamber. The average solids content for the sediment sample prior to mixing was 1,512 and 281 g/L for Appomattox and 50/50 Mix, respectively. The salinity concentration of the site water was 0 parts per thousand (i.e., freshwater).

To achieve the target slurry concentration for the Appomattox composite material, approximately 11 kilograms of sediment were mixed with 69 L of site water. The mixture of sediment and site water was thoroughly blended using a lightning mixer for 30 min.

After completely mixing the slurry, the mixing intensity was decreased to allow the majority of the coarse-grained material to settle in the mixing chamber while keeping the fine-grained material in suspension. While mixing slowly, the fine-grained slurry was transferred from the 130-L mixing chamber to an 8-in.-diam, 7-ft-tall column with ports at 0.5-ft intervals starting at the 6.5-ft height

(Figure A1). Immediately after the loading, the column with the fine-grained slurry samples for total solids were extracted from the sampling ports at 1.0-ft intervals throughout the depth of the slurry in the column. The total solids concentrations for the slurry (representing the fine-grained fraction of the original slurry) as transferred into the columns are given in Table A6. The average suspended solids concentration was determined to be 62 and 187 g/L for Appomattox and 50/50 Mix, respectively. The difference between the target total solids concentration and the solids concentration of slurry as mixed is the result of sedimentation of the coarse fraction provided in the 130-L mixing chamber.

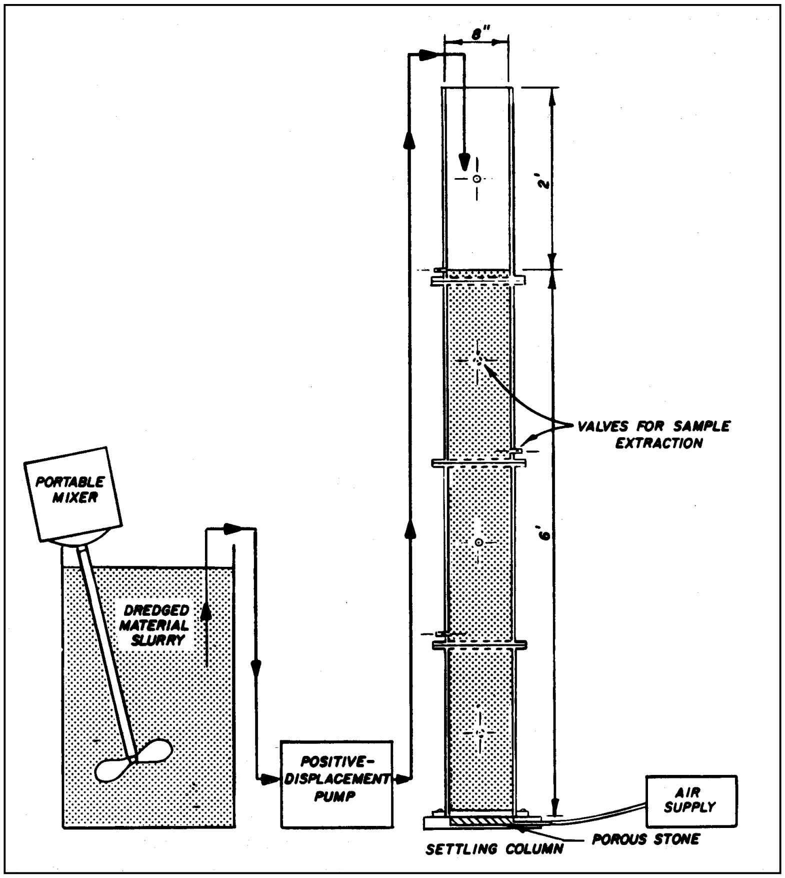

Figure A1. Schematic of settling column

Zone settling test. The zone settling test was performed concurrently with the compression settling test on the same slurry in the same column. The height of the interface was read at approximately 1-hr intervals for 8 hr. From the plot of the height of the interface (ft) versus time (hr), the zone settling velocity was determined from the slope of the straight-line portion of the curve. Photo of a settling test is shown in Figure A2.

Compression settling test. Following the zone-settling test (the first 13 hr immediately after the column was loaded with the slurry), the height of the

Table A6
Total Solids Concentration of Column Slurry Samples

Port Height (ft)	Appomattox concentration, g/L	50/50 Mix concentration, g/L
1.0	59.63	206.94
2.0	65.89	179.84
3.0	59.25	175.36
4.0	62.48	206.99
5.0	64.08	167.44
6.0	61.54	167.53
Average	61.59	187.38

interface was measured at approximately daily intervals for the next 15 days. The height of the interface, the initial height of the slurry, and the initial solids concentration of the slurry in the column are used to estimate the concentration of settled solids below the interface as a function of time as required in the compression settling analysis.

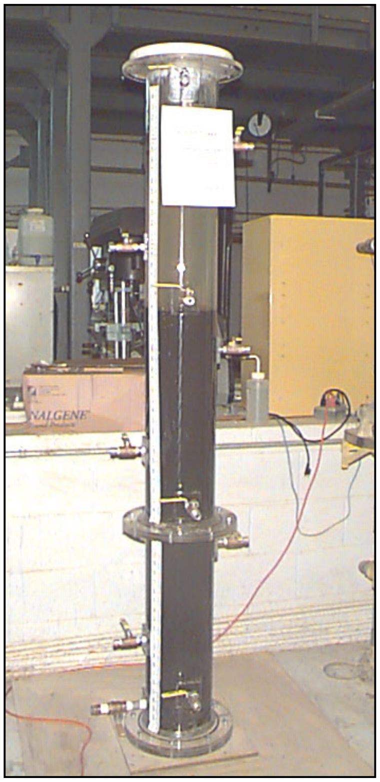

Figure A2. Photo of settling test

Data Analysis and Results

Compression settling tests

For the compression tests, the initial slurry concentration and height, and height of the interface versus time were entered (Table A7). The Automated Dredging and Disposal Alternative Management Systems (ADDAMS) SETTLE program (Schroeder and Palermo 1995, Hayes and Schroeder 1992) uses the initial slurry concentrations, the initial height, and the height of the interface 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) for each of the samples (Figure A3). SETTLE also generated a regression equation for the resulting power curve relating solids concentration to time. The composite sample regression equation may be used to determine the solid concentration at any given time. The equations are also given.

Zone settling tests

Zone settling velocities for the Appomattox River and 50/50 Mix sediment sample were determined using the zone settling test results in the ADDAMS SETTLE program. The height of the interface and their corresponding elapsed time from the start of the test when the height was measured were entered

Table A7
Compression Settling Test Results

Appomattox River					50/50 Mix				
Date	Time	Time Interval hr	Time interval days	Interface Depth ft	Date	Time	Time Interval hr	Time Interval days	Interface Depth ft
24 Oct 00	0825	0	0	6.31	11 Dec 00	0850	0	0	6.27
25 Oct 00	0825	24	1	2.32	12 Dec 00	0850	24	1	4.31
26 Oct 00	0825	48	2	2.17	13 Dec 00	0850	48	2	2.99
28 Oct 00	0825	96	4	2.01	15 Dec 00	0850	96	4	2.71
31 Oct 00	0825	168	7	1.89	18 Dec 00	0850	168	7	2.53
02 Nov 00	0825	216	9	1.82	20 Dec 00	0850	216	9	2.45
04 Nov 00	0900	264.5	11.02	1.77	21 Dec 00	0850	240	10	2.41
06 Nov 00	0825	312	13	1.73	22 Dec 00	0850	264	11	2.38
08 Nov 00	0825	360	15	1.57	24 Dec 00	1450	318	13.25	2.31
					26 Dec 00	0850	360	15	2.30

Notes:
The initial interface depth and slurry concentration was 6.31 ft and 61.59 g/L for the Appomattox River, respectively.
The initial interface depth and slurry concentration was 6.27 ft and 187.4 g/L for the 50/50 Mix, respectively.

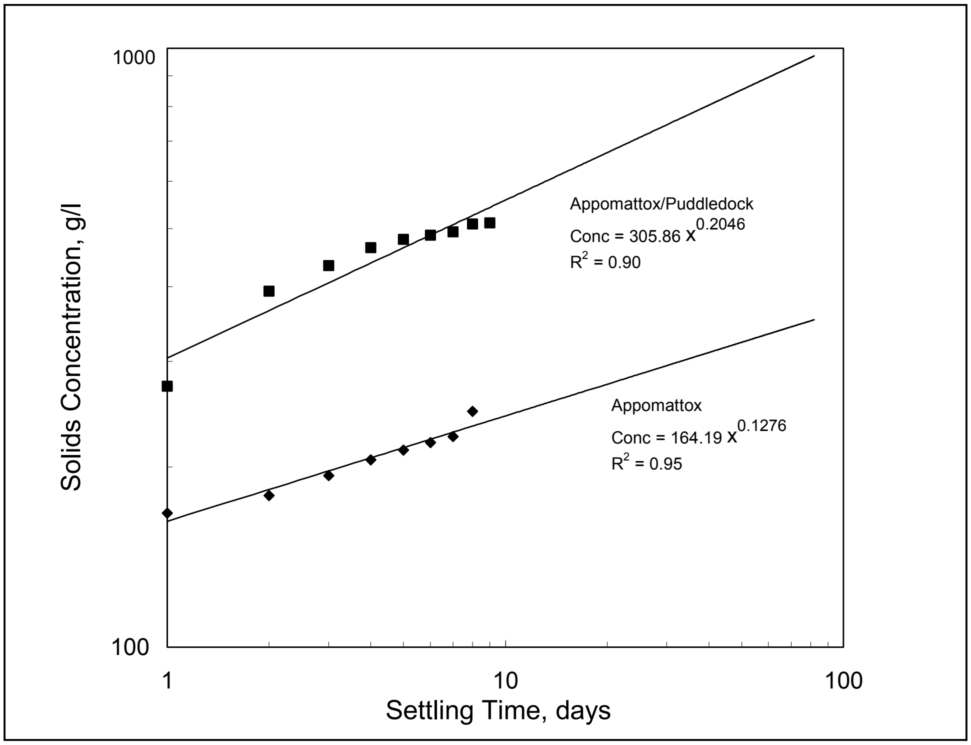

Figure A3. Compression settling curve

(Table A8) and plotted in the SETTLE program to determine the zone settling velocity (Figure A4). The zone settling velocity is the slope of the straight-line portion of the curve prior to transition. When the zone settling curve departs from the linear relationship, compression settling begins. The transition from zone to compression settling occurred between 10 and 12 hr. The zone settling velocity is adjacent to the plot of the zone settling data.

Table A8
Zone Settling Test Results

Appomattox River			50/50 Mix		
Military Time	Time Interval hr	Interface Depth ft	MilitaryTime	Time Interval hr	Interface Depth ft
0825 24 Oct 00	0.00	6.31	0850 11 Dec 00	0.00	6.27
0840	0.25	6.01	0907	0.28	6.24
0845	0.33	5.94	0920	0.50	6.22
0855	0.50	5.82	0935	0.75	6.20
0914	0.82	5.65	0950	1.00	6.18
0925	1.00	5.53	1005	1.25	6.15
0940	1.25	5.44	1020	1.50	6.14
0955	1.50	5.33	1035	1.75	6.12
1010	1.75	5.22	1050	2.00	6.10
1055	2.50	4.98	1105	2.25	6.09
1112	2.78	4.75	1127	2.62	6.06
1125	3.00	4.64	1135	2.75	6.05
1225	4.00	4.17	1150	3.00	6.03
1310	4.75	3.81	1235	3.75	5.98
1325	5.00	3.69	1250	4.00	5.95
1435	6.17	3.13	1320	4.50	5.91
1525	7.00	2.83	1350	5.00	5.88
2155	13.50	2.45	1450	6.00	5.80
			1650	8.00	5.64
			2050	12.00	5.26

Notes:
The initial interface depth and slurry concentration was 6.31 ft and 61.59 g/L for the Appomattox River, respectively.
The initial interface depth and slurry concentration was 6.27 ft and 187.4 g/L for the Appomattox River/Puddledock, respectively.

Consolidation tests

The consolidation tests provide data for evaluation of filling and settlement rates for a CDF. The test results are applicable for evaluation of both intertidal and an upland sites. The tests were conducted using standard oedometers and self-weight consolidation test procedures developed specially for soft sediments (Cargill 1983). The consolidation tests were performed using the Appomattox River and Puddledock sediments.

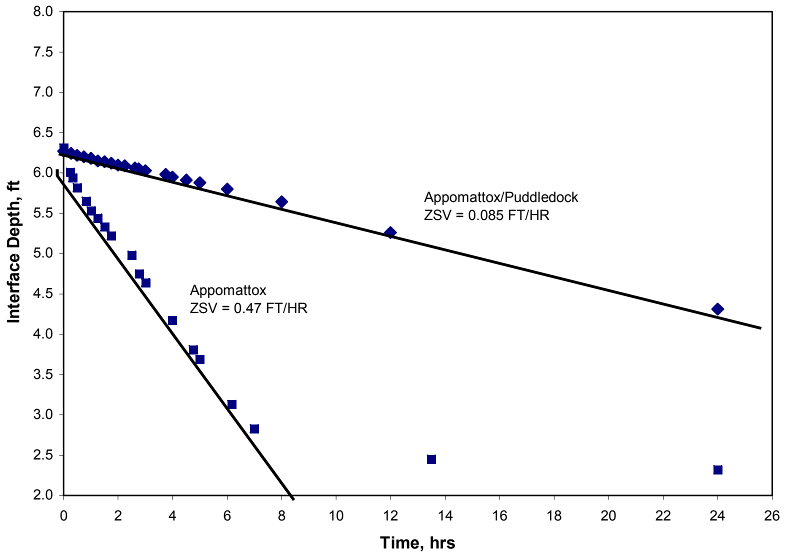

Figure A4. Zone settling curve

The results show that the Appomattox River sediment was classified as gray silty sand (SM) with trace of gravel. This sediment had a SG of 2.64, a W of 27.2 percent, and nonplastic. The Appomattox River sediment consisted of 88 percent coarse material and 12 percent fines. However, the results of the Puddledock sediment were different. This sediment was classified as brown sandy clayey silt (ML). The Puddledock sediment had a SG of 2.65, W of 17.6 percent, and a plasticity index of 7. The Puddledock sediment consisted of 23 percent sand and 77 percent fines.

The Appomattox River and Puddledock sediments grain-size distribution curves are shown in Figures A5 and A6. The self-weight consolidation test for the Puddledock sediment is shown in Figure A7 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. Because the Appomattox River sediment had 88 percent coarse material, the self-weight consolidation test was not conducted. The void ratio versus the effective stress relationship from the standard oedometer test is presented in Figures A8 and A9 for the Appomattox River and Puddledock sediments, respectively. The Appomattox River time curves from the standard oedometer consolidation tests for nine loading (0.05, 0.10, 0.25,0.50,1,2,4,8 and 16 tons per square feet) are presented in Figure A10. The Puddledock sediment time curves from standard oedometer consolidation tests for six loading (0.08, 0.16, 0.32, 0.64, 1.28, and 2.56 tons per square feet) are plotted in Figure A11. The standard oedometer test provides data for consolidation of thick layers or layers of dredged material with a desiccated crust. Figure A12 shows the combined relationship of void ratio versus the effective stress from the standard oedometer test and the self-weight test for the Puddledock sediment.

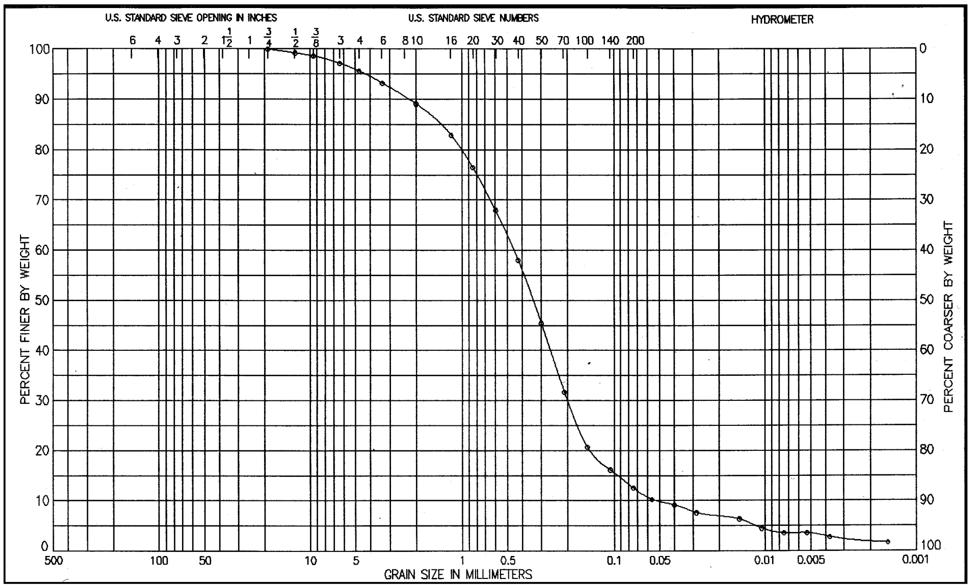

Figure A5. Appomattox River grain-size distribution curve

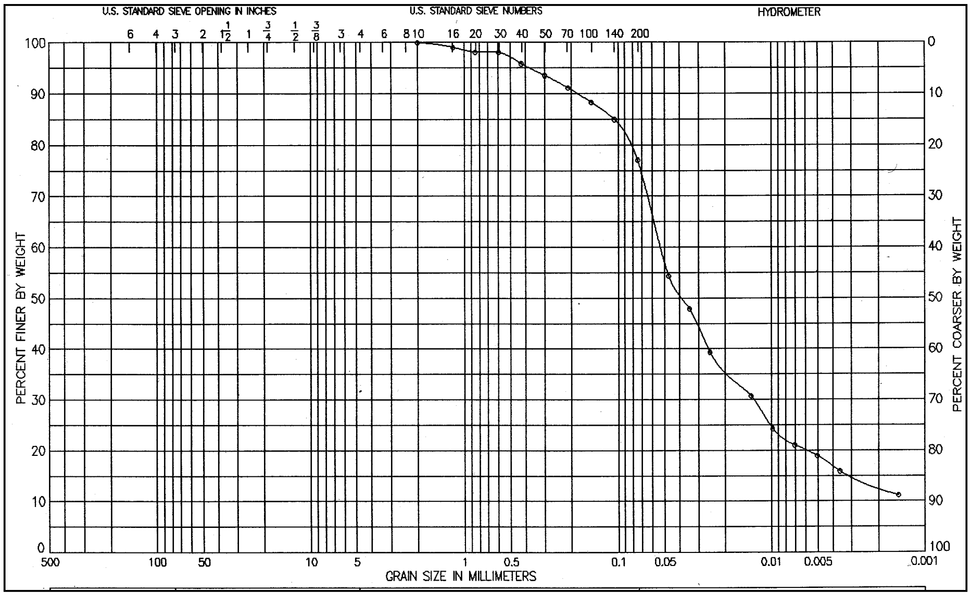

Figure A6. Appomattox River/Puddledock mixture grain-size distribution curve

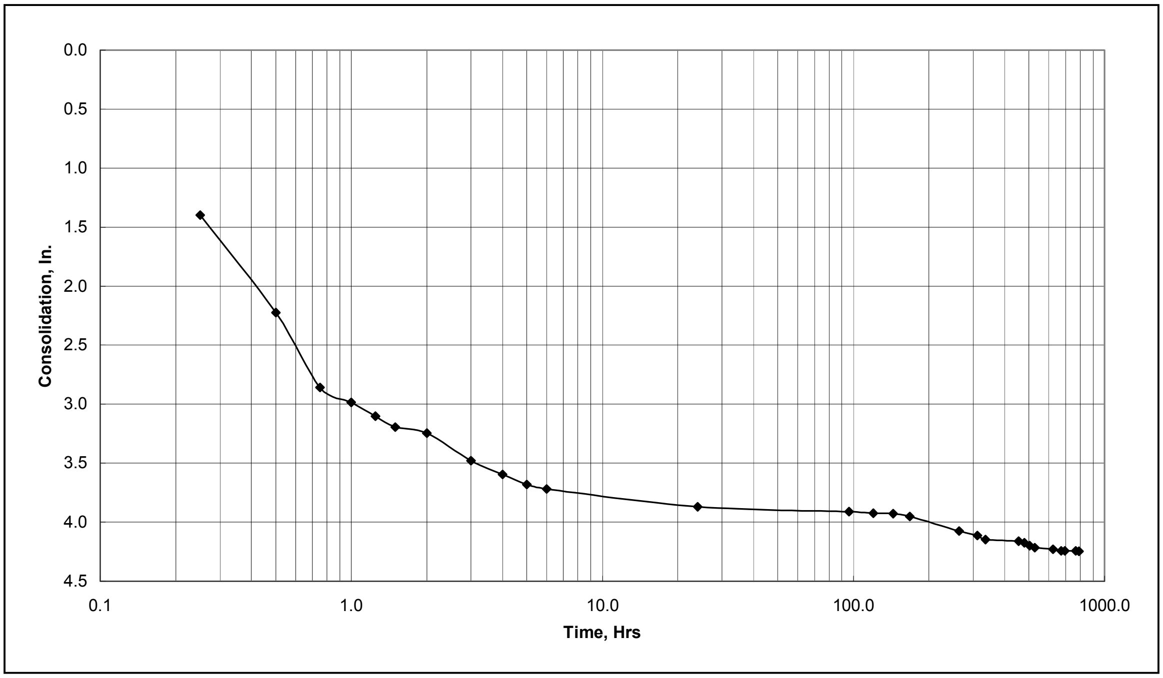

Figure A7. Self-weight consolidation test curve for Puddledock

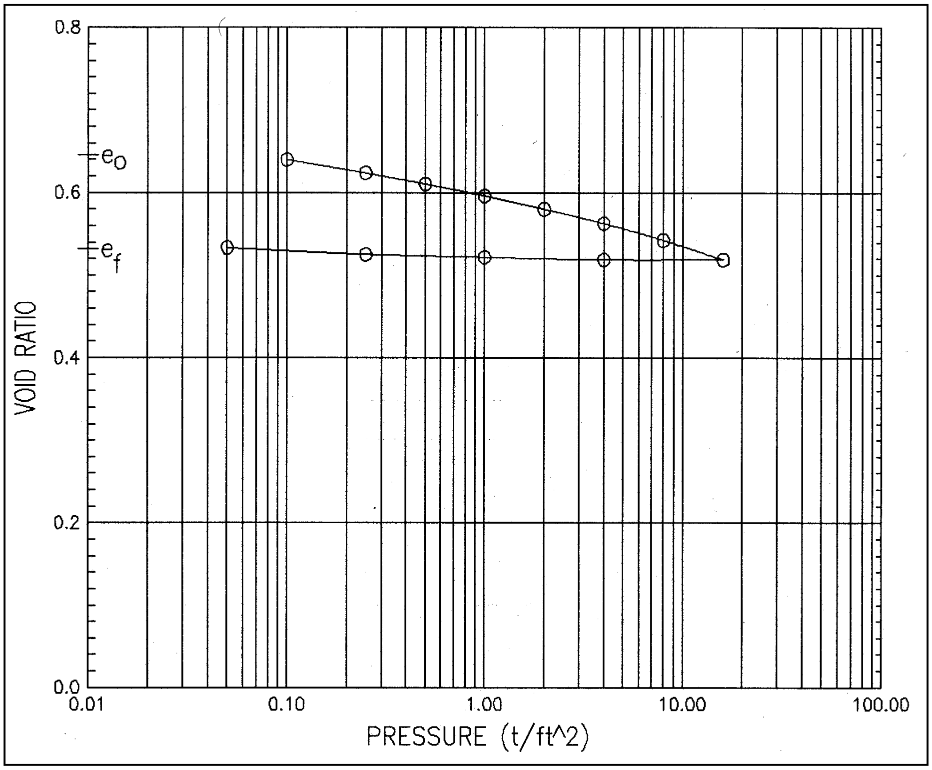

Figure A8. Void ratio-effective stress for Appomattox River sediment

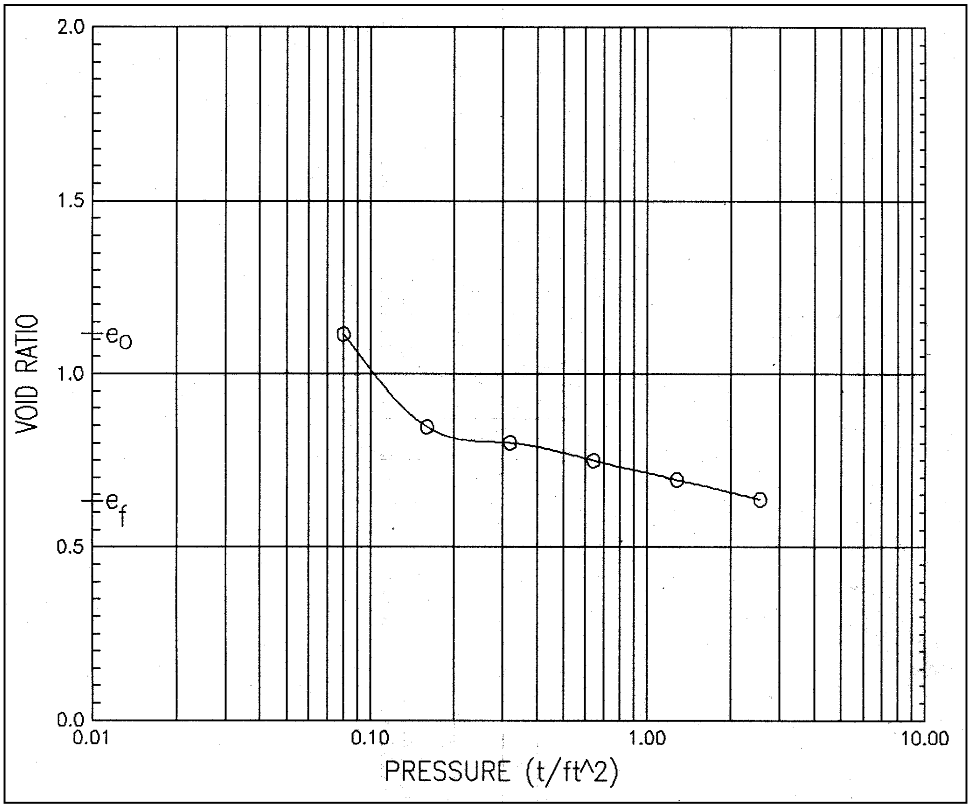

Figure A9. Void ratio-effective stress relationship for Puddledock

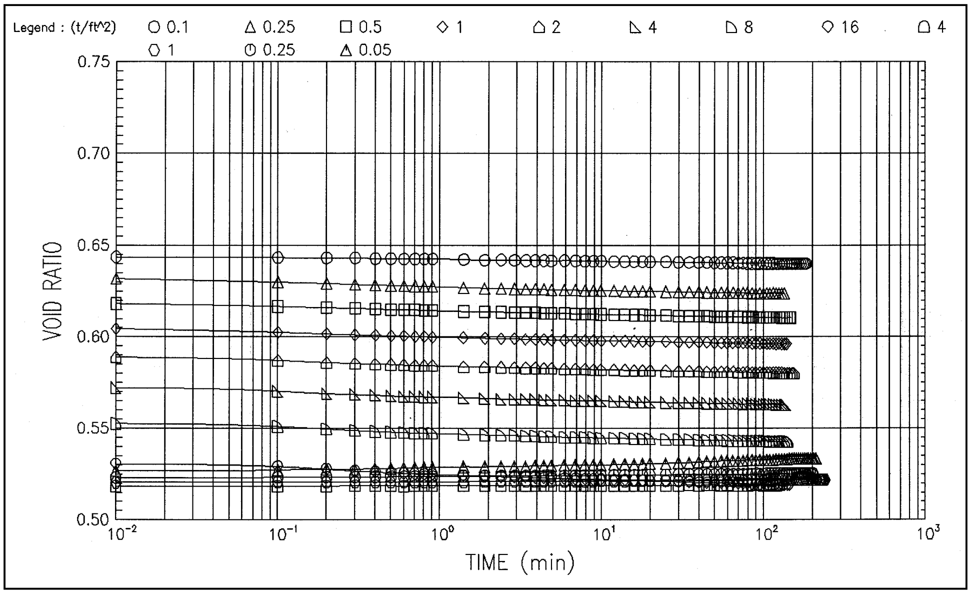

Figure A10. Time curve from standard oedometer consolidation test for Appomattox River sediment

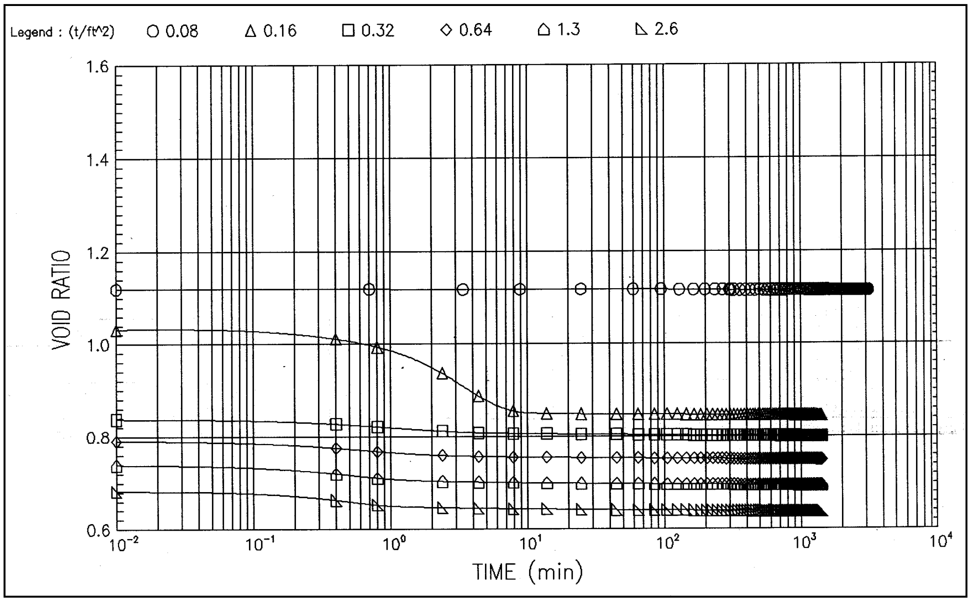

Figure A11. Time curves from standard oedometer consolidation test for Puddledock

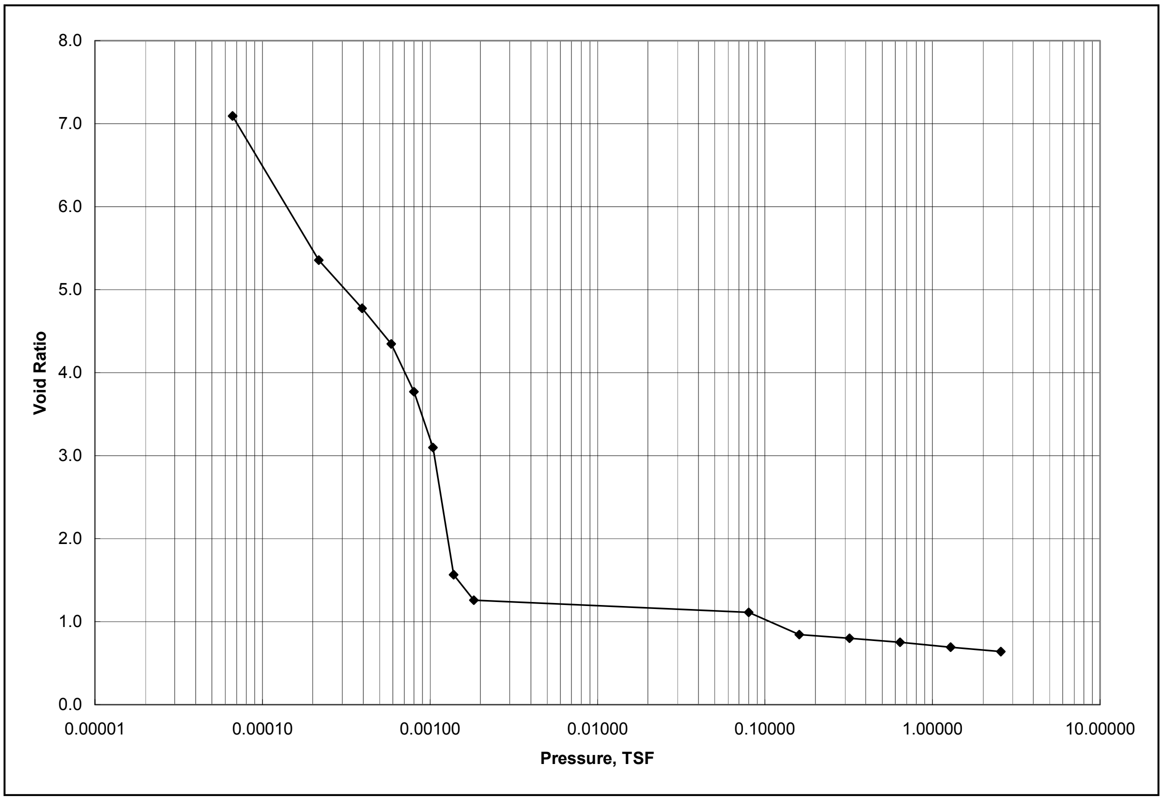

Figure A12. Self-weight and fixed ring consolidation test result for Puddledock

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40 CFR Part 261, Appendix II.

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Appendix B
Effluent Discharge Testing

Introduction

The purpose of this appendix is to document and present the results of the Appomattox River and 50/50 Mix column flocculent settling and modified elutriate tests. The modified elutriate test was conducted on the Appomattox River sediment only. These tests were performed to predict effluent quality from a combined disposal facility (CDF).

Testing objectives

The objective of the laboratory settling test was to predict the settling behavior of the Appomattox River sediment when placed and possibly mixed with Puddledock tailing material/sediment. The objective of the modified elutriate test was to predict the quality of effluent discharge from the proposed Puddledock 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 laboratory column settling tests on the homogenized Appomattox River and 50/50 Mix sediments. An initial screening for contamination was performed to determine if there was a reason to believe that 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 Procedure

Background

Sediment removal is required to restore a navigable waterway in the Appomattox River. One disposal alternative being considered for the Appomattox River is hydraulic dredging with temporary or permanent dredged material disposal in an upland CDF. The conceptual 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. 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)[1] were used to predict the concentration of suspended solids in the effluent for given operational conditions at the Appomattox River site. Modified elutriate tests (Thackston and Palermo 1990; Palermo 1985) were used to predict both the dissolved concentrations of contaminants in milligrams per liter and particle-associated contaminant fractions of the suspended solids in milligrams per kilogram of 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 was 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 from the site as effluent, which may contain 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 and 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.

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[1] A list of references follows Appendix B.

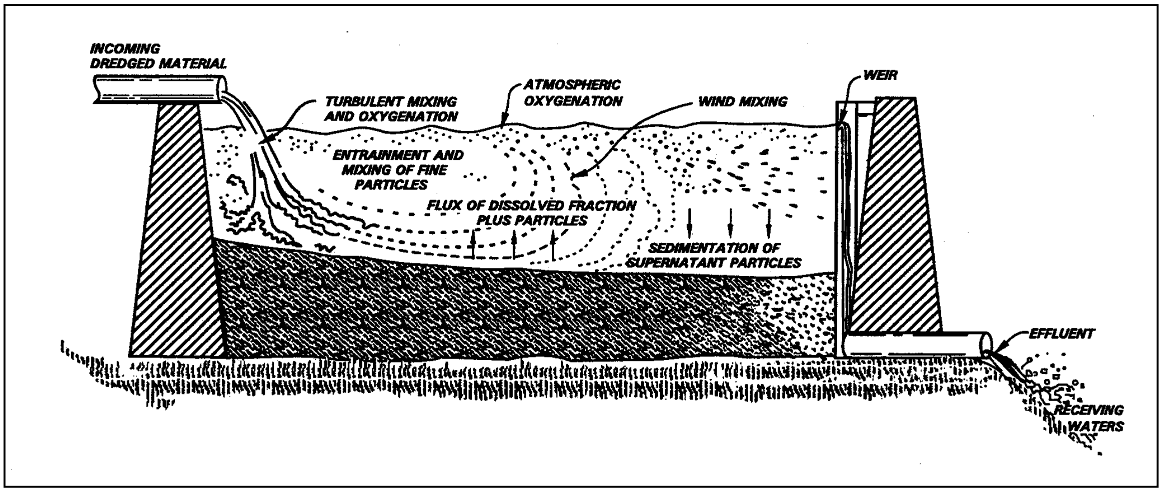

Figure B1. Schematic of an active CDF

Flocculent settling test experimental procedures

This part of the appendix describes laboratory testing conducted to predict effluent quality of the proposed CDF. Samples of sediment and water were collected and used to conduct the column settling and modified elutriate tests (see Chapter 2 of main text for details). Results from both of these tests were used to predict the total concentration of contaminants that may be present in the effluent. A flow chart illustrating the effluent quality prediction technique is shown in Figure B2.

Slurry preparation. The slurry preparation for the flocculent test was similar to the compression and zone settling tests. Each settling test was run at the same time for the Appomattox River sediment and 50/50 Mix (see Appendix A for details).

Flocculent settling test. 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, and 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 (Headquarters, Department of the Army 1987).

The flocculent settling test was performed concurrently with the zone and compression settling tests on the same slurry in the same column. Therefore, the initial slurry concentrations for the flocculent, zone, and compression settling tests were the same. Samples of the supernatant, if available, were extracted with a syringe at fixed ports located at heights of 6.0-, 5.5-, 5.0-, 4.5-, 4.0-, 3.5-, and

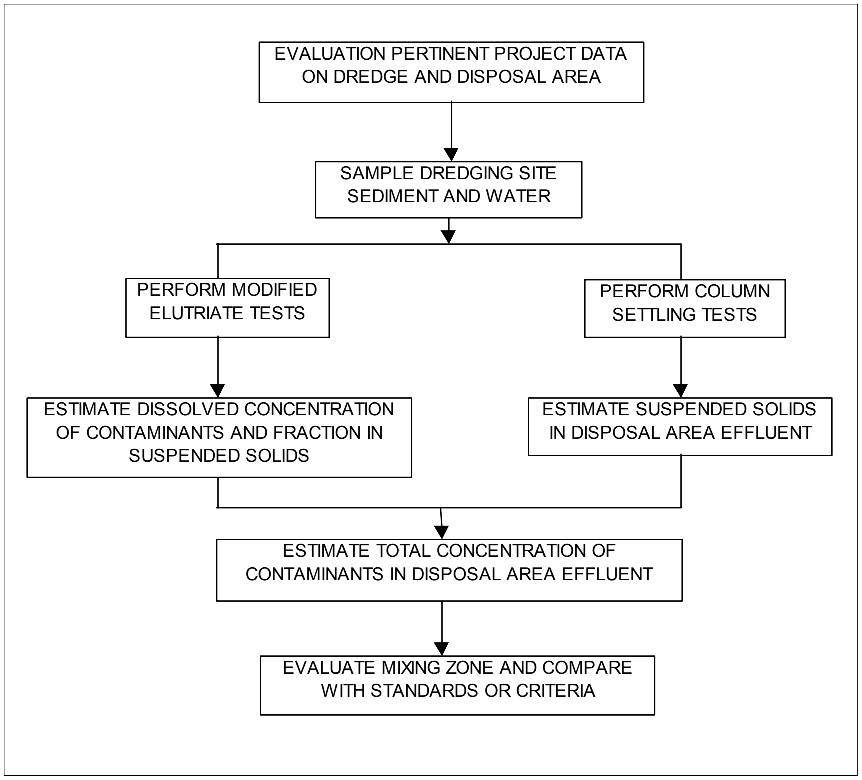

Figure B2.   Steps for predicting effluent water quality

3.0-ft[1] ports above the liquid-solid interface at different time intervals. Supernatant samples were appropriately collected at 1, 2, 4, 6, 8, 12, 24, 48, 72, 120, 168, 264, and 360 hr after loading the slurry. Samples were taken at all ports above the supernatant-settled solids interface where supernatant was available. Suspended solids concentrations were then determined on the supernatant samples by Standard Method 2540D (American Public Health Association (APHA)- American Water Works Association (AWWA)- Water Pollution Control Federation (WPCF) 1989). Turbidity of the supernatants were measured using a Hach Digital model 2100 turbidimeter and determined by Standard Method 2130B (APHA-AWWA-WPCF 1989).

Modified elutriate test procedure

The procedure for conducting a modified elutriate test, as shown in Figure B3, is described below.

Apparatus and testing procedure. 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 1 hr to

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[1] A table for converting non-SI units of measurement to SI units is presented on page x.

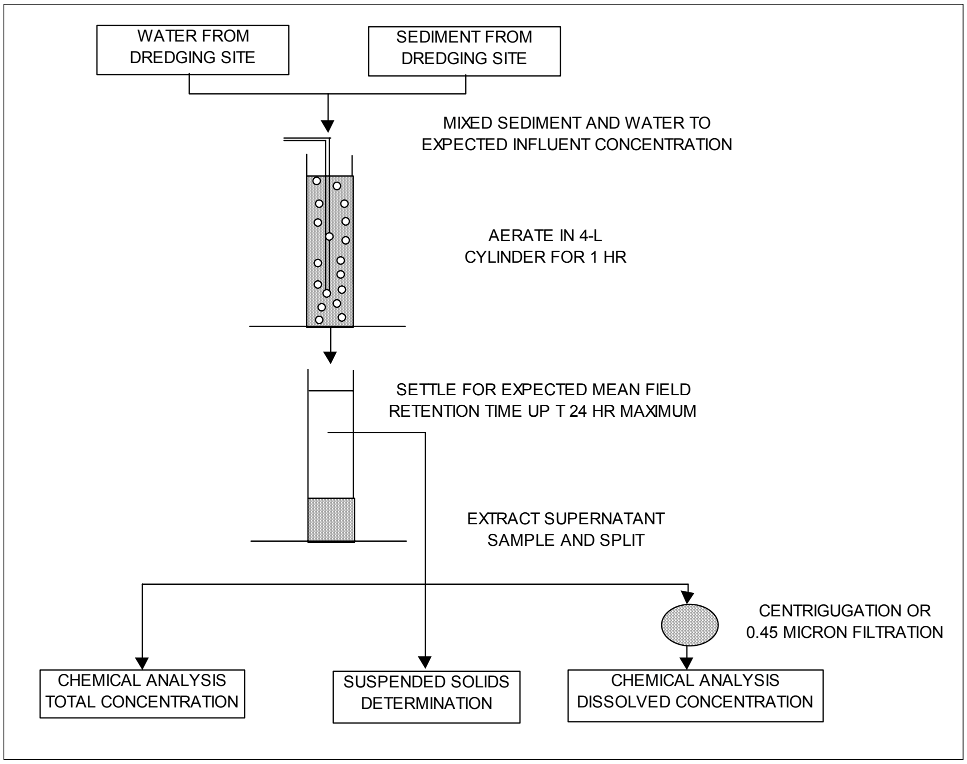

Figure B3. Modified elutriate test procedure

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 hr. The sample of the supernatant water is extracted for single analysis of dissolved and total contaminant concentrations. Detailed procedure for the modified elutriate test as conducted is presented below.

Sample preparation. The sediment and dredging site water were mixed to a target slurry concentration of 150 g/L. The composite sediment concentrations were 1,512 g/L. Each 4-L cylinder to be filled required a mixed slurry volume of 3.75 L. The slurries were prepared by adding 0.37 L of sediment to 3.38 L of site water. The volumes of sediment and dredging site water to be mixed in the cylinders were calculated using the following equations:

$$V_{sediment} = 3.75 \times \left(C_{slurry} / C_{sediment} \right) \tag{B1}$$

and

$$V_{water} = 3.75 - V_{sediment} \tag{B2}$$

where

$V_{sediment}$ = volume of sediment, L

3.75 = volume of slurry placed in a 4-L cylinder, L

C_{slurry} = desired concentration of slurry, g/L

$C_{sediment}$ = predetermined concentration of sediment, g/L

V_{water} = volume of dredging site water, L

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

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 1 hr.

Settling of the slurry. The tubing was then removed from the cylinder, thereby 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, samples of the supernatant water were 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 were homogenized, split, and analyzed for TSS 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 Appomattox River and 50/50 Mix sediments 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 ADDAMS (Schroeder and Palermo 1995) which is a family of computer programs developed at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, 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 (Appendix A, Table A1). 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 Spectrometer (GC/MS). The ECB at ERDC performed all analyses.

Flocculent settling tests

For the flocculent tests, an extension to this procedure is presented in Headquarters, Department of the Army (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 he showed that all gave essentially the same final result. Therefore, for simplicity, the concentration in the first sample taken at the highest sampling port was used as the initial concentration. SETTLE generated two curves based on the settling data in Tables B1 and B2: the concentration profile curves (Figures B4 and B5) and the supernatant suspended solids curves (Figures B6 and B7) for Appomattox River and 50/50 Mix, respectively. 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. Figure B8 shows that increasing the retention time beyond 150 and 100 hr for 2 ft of ponding depth provides little additional improvement in supernatant suspended solids concentration for Appomattox River and 50/50 Mix, respectively. 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 B3) is applied.

Table B1
Appomattox River 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
1	10,993[2]	BI[3]	BI	BI	BI	BI	BI	BI	BI
2	5,947	5,829	5,816	BI	BI	BI	BI	BI	BI
4	4,457	4,639	6,830	5,600	BI	BI	BI	BI	BI
6	3,933	3,992	4,009	3,990	3,962	4,029	BI	BI	BI
13.5	1,740	1,633	1,740	1,562	1,830	1,903	2,000	2,760	BI
24	1,100	1,150	1,250	1,160	1,410	1,409	1,250	1,230	BI
48	326	700	660	712	772	780	760	815	BI
96	BI	368	412	472	428	490	472	484	BI
168	BI	180	220	244	256	248	256	264	268
264.5	BI	48	88	140	152	152	160	156	176
360	BI	12.8	91.5	178	133	159	180	176	169

[1] The slurry concentration was 187 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.

Table B2
50/50 Mix 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
4	2,880[2]	BI[3]	BI	BI	BI	BI	BI	BI
6	1,984	BI	BI	BI	BI	BI	BI	BI
8	1,540	BI	BI	BI	BI	BI	BI	BI
12	1,057	1,530	BI	BI	BI	BI	BI	BI
24	483	581	661	1,513	BI	BI	BI	BI
48	204	239	278	325	378	502	BI	BI
96	15.1	77.9	73.8	113	131	129	123	BI
168	15.5	22.6	87.5	93	101	90	91	BI
264		1.17	1.22	51.5	53	56	55.6	46.7
360		10	18	17	7.1	15	13	14.7

[1] The slurry concentration was 62 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.

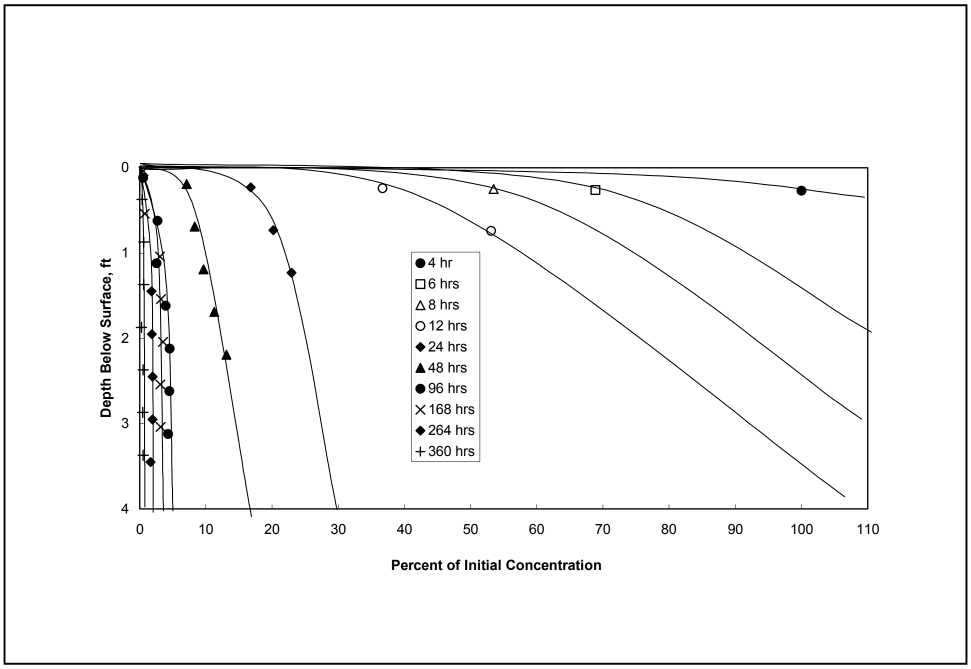

Figure B4. Appomattox River suspended solids relationship to time and depth below surface

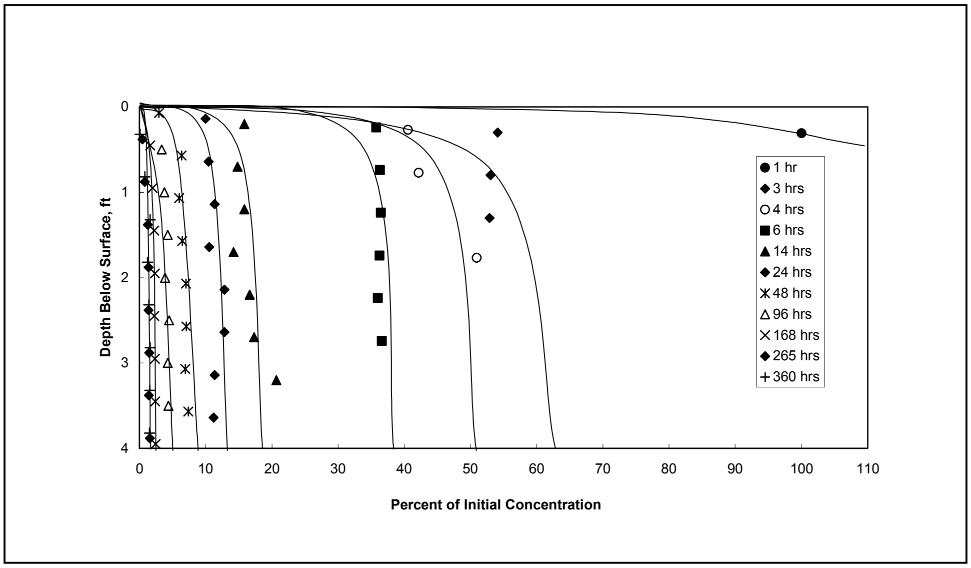

Figure B5. 50/50 Mix suspended solids relationship to time and depth below surface

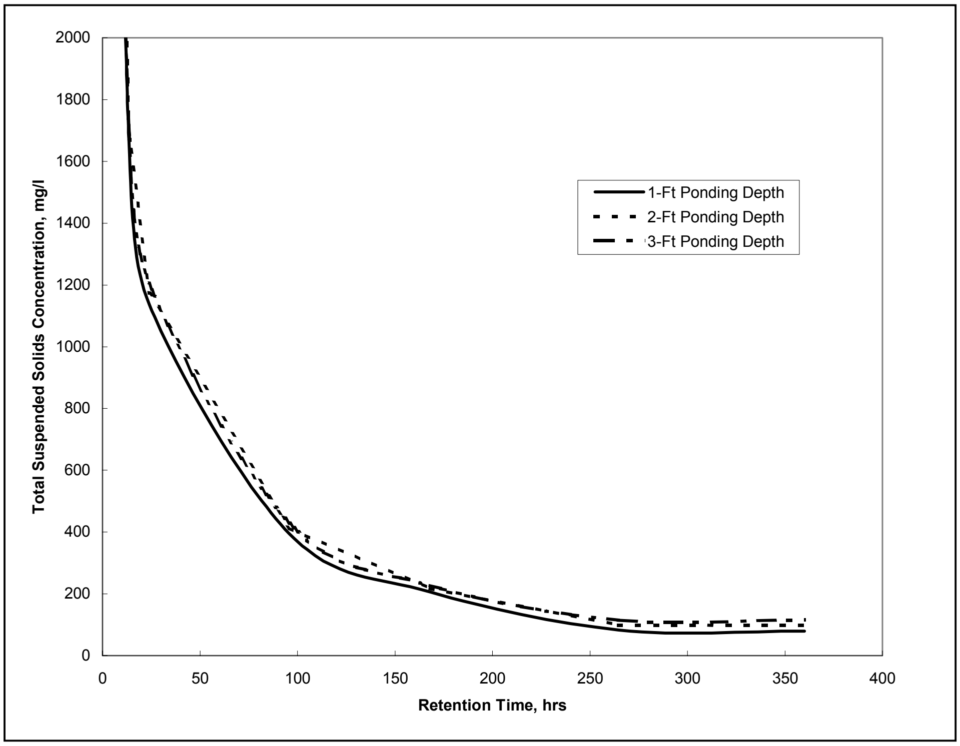

Figure B6. Appomattox River supernatant suspended solids curve

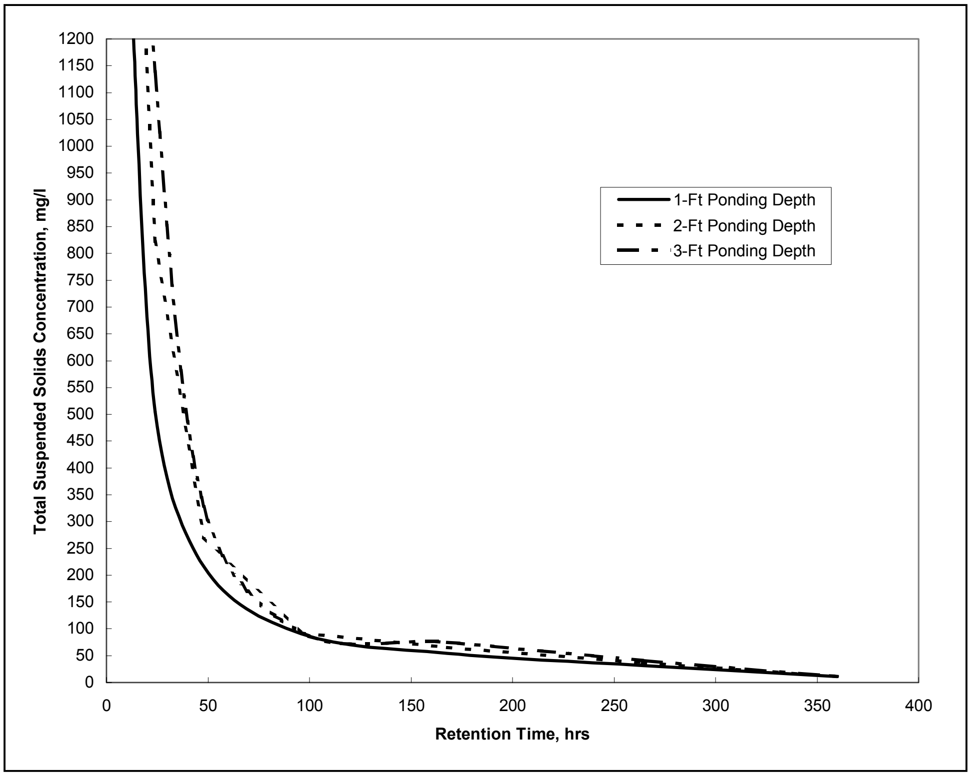

Figure B7. 50/50 Mix supernatant suspended solids curves

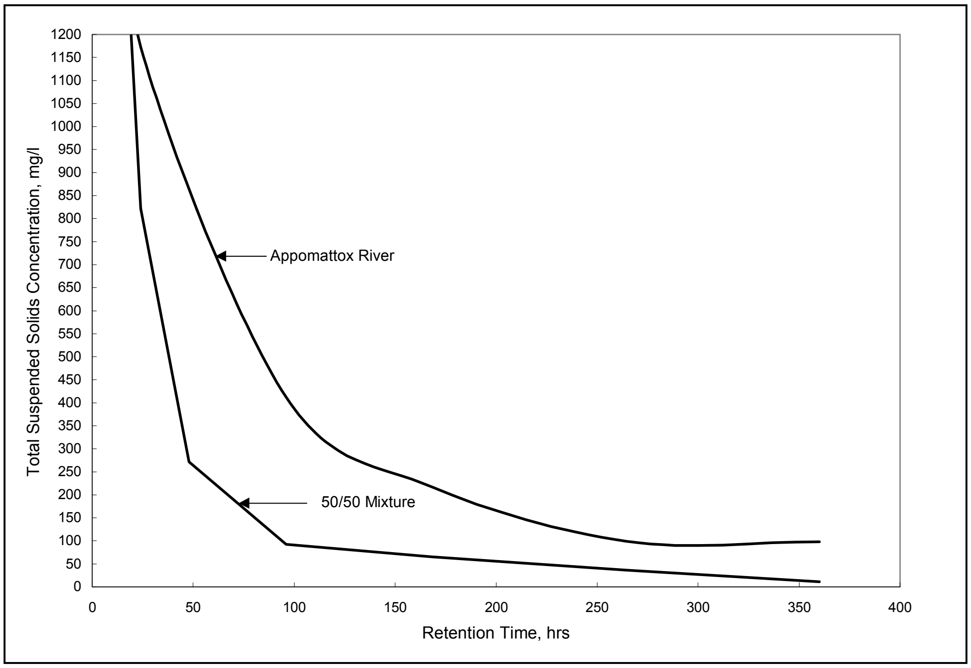

Figure B8. 2-ft ponding depth from supernatant suspended solids curve

Table B3
Recommended Resuspension Factors for Various Ponded Areas and Depths

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

Turbidity

Samples of the supernatant from the flocculent tests were split to measure turbidity of corresponding total suspended solids (TSS) concentration (Tables B4 and B5). TSS could be used as an indicator of overall performance of CDFs, both for solids retention and for most other contaminants, which are strongly associated by adsorption or ion exchange. Turbidity is much more easily measured than TSS and may be used instead of TSS during routine operational monitoring if approved by the regulatory agency.

Figure B9 compares the correlation curves between turbidity and TSS for the Appomattox River and 50/50 Mix, respectively. 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 concentration may ensure on-site compliance with state and/or Federal TSS standards. Samples for TSS measurement can be collected less frequently for compliance monitoring and to field verify the correlations for laboratory samples. Slopes of the correlation curve for Appomattox River and 50/50 Mix are similar.

Table B4
Appomattox River - Total Suspended Solids Concentrations and Turbidity Measurements from Settling Test Data

Time Hr	Port No.	Turbidity NTU[1]	TSS mg/L	Time Hr	Port No.	Turbidity NTU	TSS mg/L
13.5	6.0	3806	1740	96	3.5	775	490
13.5	5.5	3984	1633	96	3.0	750	472
13.5	5.0	4055	1740	96	2.5	768	484
13.5	4.5	4080	1562	168	5.5	311	180
13.5	4.0	4058	1830	168	5.0	394	220
13.5	3.5	4053	1903	168	4.5	447	244
13.5	3.0	4086	2000	168	4.0	475	256
24	6.0	2040	1100	168	3.5	464	248
24	5.5	2546	1150	168	3.0	456	256
24	5.0	2570	1250	168	2.5	467	264
24	4.5	2600	1160	168	2.0	471	268
24	4.0	2635	1410	264.5	5.5	132	48
24	3.5	2603	1409	264.5	5.0	214	88
24	3.0	2630	1250	264.5	4.5	302	140
24	2.5	2680	1230	264.5	4.0	301	152
48	6.0	474	326	264.5	3.5	291	152
48	5.5	1329	700	264.5	3.0	316	160
48	5.0	1399	660	264.5	2.5	295	156
48	4.5	1427	712	264.5	2.0	334	176
48	4.0	1422	772	360	5.5	35	12.8
48	3.5	1432	780	360	5.0	131	91.5
48	3.0	1430	760	360	4.5	204	178
48	2.5	1468	815	360	4.0	237	133
96	5.5	609	368	360	3.5	260	159
96	5.0	729	412	360	3.0	271	180
96	4.5	759	472	360	2.5	280	176
96	4.0	765	428	360	2.0	276	169

[1] Nephelometric turbidity units.

Table B5
50/50 Mixture - Total Suspended Solids Concentrations and Turbidity Measurements from Settling Test Data

Time Hr	Port No.	Turbidity NTU[1]	TSS mg/L	Time Hr	Port No.	Turbidity NTU	TSS mg/L
4	6.0	0[2]	2880	96	4.5	174	113
6	6.0	4211	1984	96	4.0	188	131
8	6.0	3327	1540	96	3.5	184	129
12	6.0	2068	1057	96	3.0	182	123
12	5.5	3239	1530	168	6.0	29.2	15.5
24	6.0	866	483	168	5.5	38.8	22.6
24	5.5	1075	581	168	5.0	127	87.5
24	5.0	1237	661	168	4.5	133	93
24	4.5	3327	1513	168	4.0	146	101
48	6.0	295	204	168	3.5	126	90
48	5.5	401	239	168	3.0	126	91
48	5.0	441	278	264	5.5	18.4	1.17
48	4.5	510	325	264	5.0	22	1.22
48	4.0	621	378	264	4.5	97.6	51.5
48	3.5	846	502	264	4.0	100	53
96	6.0	39.8	15.1	264	3.5	103	56
96	5.5	125	77.9	264	3.0	103	55.6
96	5.0	144	73.8	264	2.5	105	46.7

Notes: [1] Nephelometric turbidity units.
[2] Turbidity value greater than instrument maximum range.

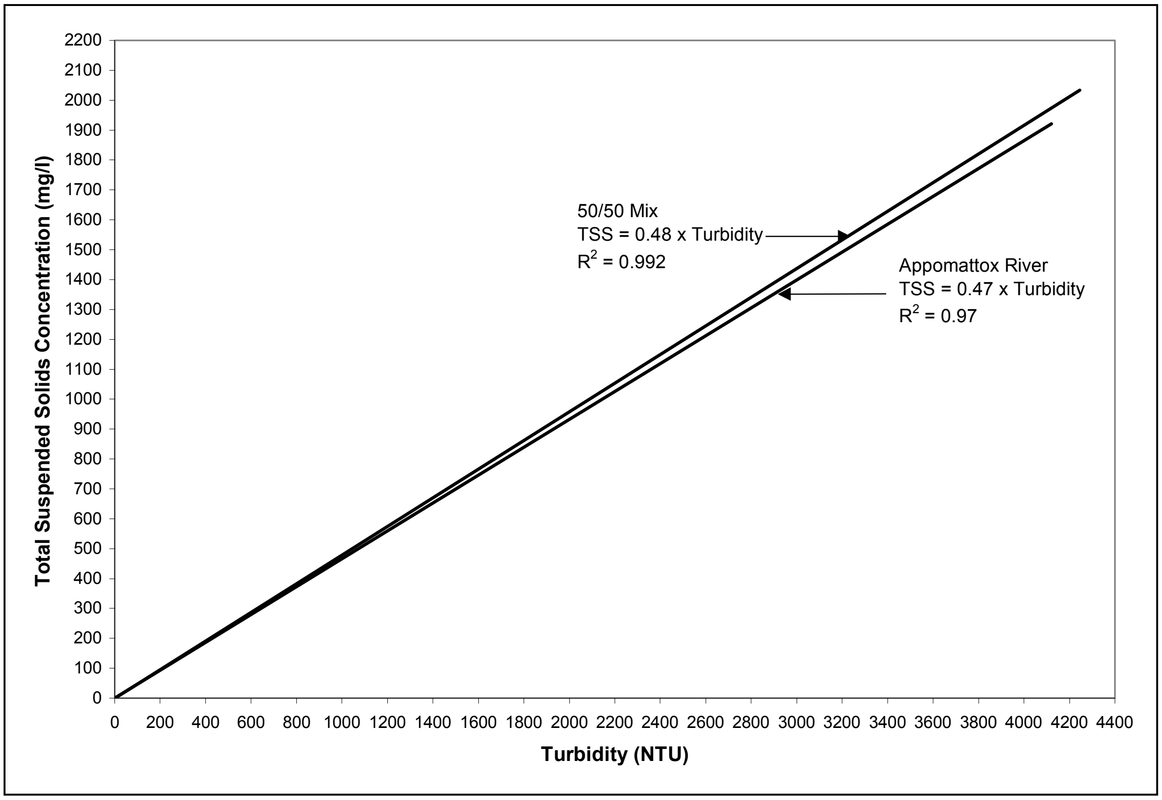

Figure B9. TSS versus turbidity curve

Modified elutriate test

Since the bulk chemistry results gave a "reason to believe" that the sediment may be contaminated, the modified elutriate test was conducted on the Appomattox River sediment to evaluate the potential for contaminant releases from the CDF during dredging operations. Results for all analytes are shown in Appendix A, Tables A2 and A3. The detected analytical results show total concentrations and dissolved concentrations of beryllium, antimony, and arsenic (Tables B6, B7, and B8).

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 TSS concentration was also determined. The average (in triplicate) TSS concentration was 1,657 mg/L and <4 mg/L for unfiltered and filtered samples, respectively. These elevated levels of TSS were not typical of similar sediment. A possible explanation is that little to no interface developed after 24 hr of settling.

Table B6
Modified Elutriate Semivolatile Organic Analyses

Semivolatiles	Site Water[1] mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl 1	Repl 2	Repl 3	Repl. 1	Repl. 2	Repl. 3
Phenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2-Chlorophenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2-Nitrophenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4-Dimetylphonel	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4-Dichlorophenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
4-Chloro-3-Methylphonel	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4,6-Trichlorophenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4-Dinitrophenol	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
4-Nitrophenol	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
2-Methyl-4,6-Dinotrophenol	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Pentachlorophenol	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Benzoic Acid	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
2-Methylphenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
4-Methylphenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4,5-Trichlorophenol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Benzyl Alcohol	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Bis(2-Chloroisopropyl)Ether	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
N-Nitroso-Di-N-Propylamine	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Nitrobenzene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Isophorone	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Bis(2-Chloroethoxy)Methane	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,6-Dinitrotoluene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2,4 Dinitrotoluene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Benzidine	<0.025	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026
3,3'Dichlorobenzidine	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
Bis(2-Chloroethyl)Ether	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
1,3-Dichlorobenzene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
1,4-Dichlorobenzene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
1,2-Dichlorobenzene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Hexachloroethane	<0.005	<0.0053	0.0053	0.0053	<0.0053	0.0053	0.0053
1,2,4-Trichlorobenzene	<0.005	<0.0053	0.0053	0.0053	<0.0053	0.0053	0.0053
Naphthalene	<0.005	0.0051J	.0059	.0047J	<0.0053	0.0053	0.0053
Hexachlorobutadiene	<0.005	<0.0053	0.0053	0.0053	<0.0053	0.0053	0.0053
Hexachlorocyclopentadiene	<0.005	<0.0053	0.0053	0.0053	<0.0053	0.0053	0.0053
2-Chloronaphthalene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Acenaphthylene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Dimethyl Phthalate	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Acenaphthene	<0.005	0.0648	0.0706	0.0753	0.0670	0.0580	0.0660
Fluorene	<0.005	0.0223	0.0208	0.0216	0.00971	0.00943	0.0111
Diethyl Phthalate	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
4-Chlorophenyl Phenyl Ether	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
N-Nitrosodiphenyl Amine	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
4-Bromophenyl Ether	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053

(Continued)

Note: [1] - Indicates average concentrations.
J – Indicates an estimated value below instrument detection limit.

Table B6 (Concluded)

Semivolatiles	Site Water[1] mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Hexachlorobenzene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Phenanthrene	<0.005	0.0711	0.0739	0.0797	0.0384	0.0370	0.0371
Anthracene	<0.005	0.0313	0.0319	0.0347	0.00907	0.00884	0.00879
Dibutylphthalate	<0.005	0.00732	0.00692	0.00629	<0.0053	<0.0053	<0.0053
Fluoranthene	<0.005	0.0471	0.0476	0.0485	0.00699	0.00551	0.0049J
Pyrene	<0.005	0.0646	0.0722	0.0747	0.00747	0.00695	0.00634
Butylbenzylphthalate	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Chrysene	<0.005	0.0181	0.0177	0.0191	<0.0053	<0.0053	<0.0053
Benzo(a)Anthracene	<0.005	0.0219	0.0222	0.0234	<0.0053	<0.0053	<0.0053
Bis(2-Ethylhexyl)Phthalate	0.0033J	0.00668BJ	0.0048BJ	0.0049BJ	<0.0053	<0.0053	<0.0053
Di-N-Octylphthalate	<0.005	0.0107J	<0.011	<0.011	<0.011	<0.011	<0.011
Benzo(b)Fluoranthene	<0.005	0.00920	0.00838	0.00861	<0.0053	<0.0053	<0.0053
Benzo(k)Fluoranthene	<0.005	0.0105	0.0113	0.0125	<0.0053	<0.0053	<0.0053
Benzo(a)Pyrene	<0.005	0.0171	0.0175	0.0189	<0.0053	<0.0053	<0.0053
Indeno(1,2,3-C,D)Pyrene	<0.005	0.00774	0.00725	0.00740	<0.0053	<0.0053	<0.0053
Dibenzo(A,H)Anthracene	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Benzo(G,H,I)Perylene	<0.005	0.00708	0.00677	0.00702	<0.0053	<0.0053	<0.0053
Aniline	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
4-Chloroaniline	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
Dibenzofuran	<0.005	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053	<0.0053
2-Methylnaphthalene	<0.005	0.0040J	0.0041J	0.0049J	0.0137	0.0116	0.0138
2-Nitroaniline	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
3-Nitroaniline	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011
4-Nitroaniline	<0.010	<0.011	<0.011	<0.011	<0.011	<0.011	<0.011

Note: [1] – Indicates average concentrations.
B – Indicates analyte is found in the associated blank as well as in the sample.
J – Indicates an estimated value below instrument detection limit.

Table B7
Modified Elutriate Test Pesticides/PCB Analyses

Pesticide/PCBs	Site Water[1] mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl. 1	Repl. 2	Repl. 3	Repl. 1	Repl. 2	Repl. 3
Aldrin	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
A-BHC	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
B-BHC	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
G-BHC	<0.000025	<0.000025	0.000014J	<0.000025	<0.000025	<0.000025	<0.000025
D-BHC	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
PPDDD	<0.000050	0.000102	0.000120	0.000167	<0.000050	<0.000050	<0.000050
PPDDE	<0.000050	0.000087	0.000096	0.000102	<0.000050	<0.000050	<0.000050
PPDDT	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Heptachlor	<0.000050	<0.000025	0.000072	<0.000025	<0.000025	<0.000025	0.000044
Dieldrin	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
A-Endosulfan	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
B- Endosulfan	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Endosulfan Sulfate	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Endrin	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Endrin Aldehyde	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050	<0.000050
Heptachlor Epoxide	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025	<0.000025
Methoxychlor	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
Chlordane	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025	<0.00025
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	0.00014J	0.00020J	<0.00025	<0.00025	<0.00025	<0.00025

Note: [1] – Indicates average concentrations.
J – Indicates an estimated value below instrument detection limit.

Table B8
Modified Elutriate Test Results for Metals, TOC, TSS, and TRPH[1] Analyses

Other Organics	Site Water[2] mg/L	Total Concentration, mg/L			Dissolved Concentration, mg/L		
		Repl 1	Repl 2	Repl 3	Repl 1	Repl 2	Repl 3
TRPH	<0.7	2.2	2.3	2.2	<0.7	<0.7	<0.7
TOC	3.2	18	19	19	16	17	17
TSS	<4	1,826	1,473	1,672	<4	<4	<4
Metals							
Antimony	<0.003	0.015J	0.015J	0.015J	0.012J	0.013J	0.013J
Arsenic	<0.002	0.040	0.039	0.019	<0.015	<0.015	<0.015
Beryllium	<0.001	0.0052	0.0051	0.0051	<0.0020	<0.0020	<0.0020
Cadmium	<0.0002	0.0036	0.0036	0.0037	<0.0025	<0.0025	<0.0025
Chromium	0.001	0.158	0.153	0.156	0.0027J	0.0022J	0.0021J
Copper	0.002	0.189	0.188	0.188	0.0043J	0.0033J	0.0028J
Lead	0.001	0.889	0.891	0.888	0.0079J	0.0077J	0.0078J
Mercury	<0.0002	0.00242	0.00246	0.00243	<0.00020	<0.00020	<0.00020
Nickel	0.002	0.0539	0.0523	0.0543	0.0030J	<0.010	<0.0021J
Selenium	<0.002	<0.020	<0.020	<0.020	<0.020	<0.020	<0.020
Silver	<0.001	0.0049J	0.0047J	0.0047J	<0.005	<0.005	<0.005
Thallium	<0.002	<0.030	<0.030	<0.030	<0.030	<0.030	<0.030
Zinc	0.063	1.02	1.02	1.02	0.111	0.107	0.105
Aluminum	0.075	109	104	108	1.68	1.6	1.6
Barium	0.033	0.73	0.724	0.726	0.554	0.558	0.552
Boron	---	0.099	0.099	0.098	0.069	0.069	0.068
Calcium	27.9	22.9	23	22.9	11.5	11.5	11.5
Cobalt	<0.001	0.005J	0.005J	0.005J	<0.015	<0.015	<0.015
Iron	12.0	107	105	106	1.02	1.01	1.01
Magnesium	4.35	7.4	7.17	7.33	1.79	1.8	1.77
Manganese	0.1470	0.5240	0.5200	0.5200	0.0448	0.0452	0.0447
Potassium	5.05	11.1	10.8	11	6.41	6.45	6.31
Sodium	17.7	20.3	20.5	20.1	15.8	15.7	15.7
Vanadium	<0.001	0.208	0.202	0.206	<0.020	<0.020	<0.020

Note: [1] – Total recoverable suspended petroleum hydrocarbon.
[2] – Indicates average concentrations.
J – Indicates an estimated value below instrument detection limit.

To predict the total concentration of each contaminant in the effluent, it was necessary to first calculate the fraction of each contaminant associated with the TSS in the elutriate samples using the following equation:

$$Fss = \left(1 \times 10^6\right) \times \frac{C_{total} - C_{diss}}{SS} \tag{B3}$$

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 B3 are summarized in Table B9 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.

Table B9
Modified Elutriate Test – Summary Results

Parameter	Avg. Total Concentration, mg/L	Avg. Dissolved Concentration, mg/L	Fraction of TSS, mg/kg of TSS
PPDDD	0.00013	0[1]	0.078
PPDDE	0.000095	0	0.057
Heptachlor	0.000044	0	0.027
Naphthalene	5.88	0	3,549
Acenaphthene	0.0702	0.0638	3.88
Fluorene	0.0216	0.0101	6.93
Phenanthrene	0.0749	0.0375	22.6
Anthracene	0.0326	0.0089	14.3
Dibutylphthalate	0.0068	0	4.130
Fluoranthene	0.0477	0.0058	25.3
Pyrene	0.0705	0.0069	38.4
Chrysene	0.0183	0	11.0
Benzo(a)Anthracene	0.0225	0	13.6
Bis(2-Ethylhexyl)Phthalate	5.46	0	3,295
Benzo(b)Fluoranthene	0.0087	0	5.27
Benzo(k)Fluoranthene	0.0114	0	6.90
Benzo(a)Pyrene	0.0178	0	10.8
Indeno(1,2,3-C,D)Pyrene	0.0075	0	4.50
Benzo(G,H,I)Perylene	0.00696	0	4.198
Antimony	0.015	0.0127	1.41
Arsenic	0.0327	0	19.7
Beryllium	0.0051	0	3.09
Cadmium	0.0036	0	2.19
Chromium	0.1557	0.0023	92.6
Copper	0.1883	0.0034	111.6
Lead	0.8893	0.0077	532.1
Mercury (ppm)	0.0024	0	1.47
Nickel	0.0535	0	32.3
Silver	0.0048	0	2.90
Zinc	1.02	0.1077	550.6
Aluminum	107	1.63	63,593
Barium	0.7267	0.5547	103.8
Boron	0.0987	0.0687	18.1
Calcium	22.9	11.5	6,900
Cobalt	0.005	0	3.018
Iron	106	1.01	63,359
Magnesium	7.30	1.79	3,327
Manganese	0.5213	0.0449	287.5
Potassium	10.97	6.39	2,762
Sodium	20.3	15.7	2,756
Vanadium	0.2053	0	123.92
TRPH	2.2333	0	1,348

[1] - "<" values were assigned zero.

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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) [1] 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 into a CDF, contaminant movement from the wet, unoxidized material will be mainly associated with suspended solids. As the material dries and oxidizes, the 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, Price, and Brandon (1988), has been applied to dredged material from a number of locations including Indiana Harbor (U.S. Army Engineer Waterways Experiment Station (USAEWES), Environmental Laboratory (EL) 1987); Black Rock Harbor (Skogerboe et al. 1987); New Bedford Harbor (Skogerboe, Price, and Brandon 1988); Oakland Harbor (Lee et al. 1992a, 1992b, 1993a, 1993b), and others. Contaminants have included heavy metals, PAHs, PCBs, pesticides, organics, and dioxins. The procedure uses the RSLS in the laboratory (Figure C1). The RSLS requires a minimum of eleven 208-L drums of sediment, representative of the proposed dredging site. After placing the sediment in a soil lysimeter, surface runoff tests are conducted on the wet, unoxidized sediment. The lysimeter is then moved outside, covered with a ventilated top, and allowed to naturally dry for 6 months. The runoff tests are then repeated on the dry, oxidized sediment.

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[1] Reference information is presented at the end of Appendix C.

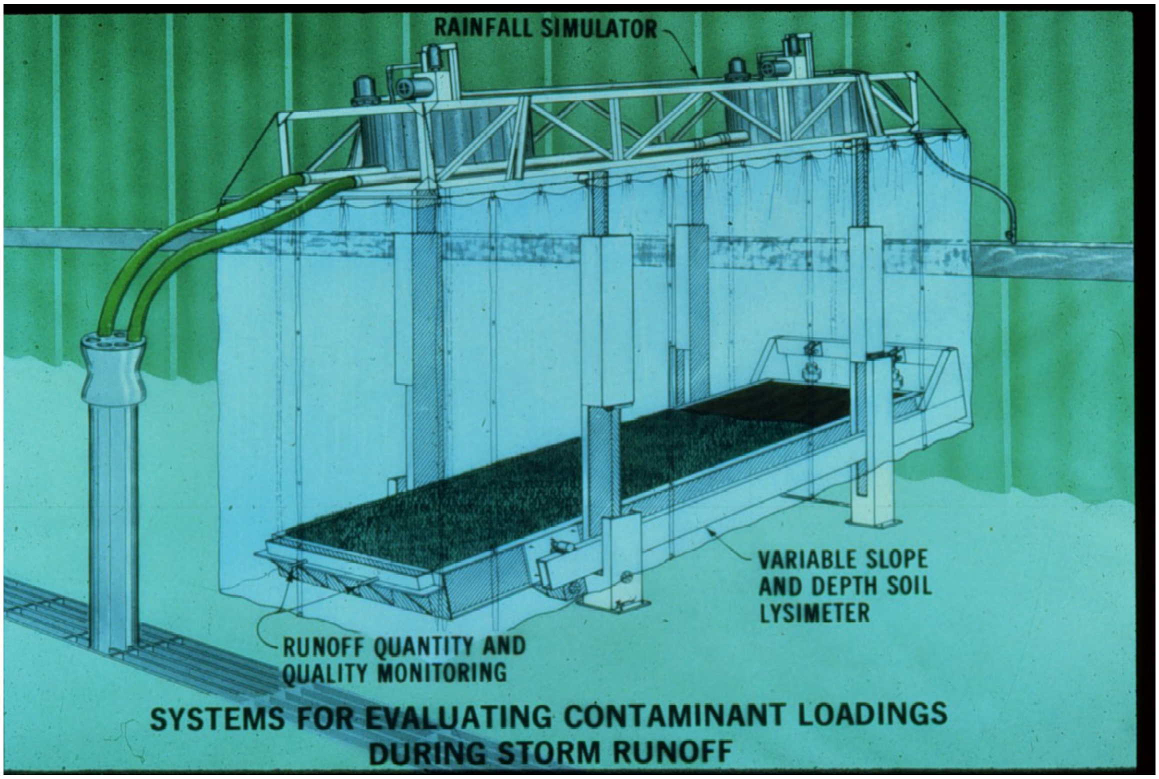

Figure C1. Schematic of RSLS system

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 the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. 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) 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 RSLS tests of the same material (USAEWES 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, Skogerboe, and Lee 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 Material

Simplified laboratory runoff procedure

Appomattox sediment was thoroughly mixed in a 19-L plastic bucket with a lightning mixer to ensure homogeneity and samples were collected for the determination of sediment physical and chemical characteristics. 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 Appomattox 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, soluble refers to filtered samples and total refers to unfiltered samples.

Table C1
Sediment-to-Water Ratios and Corresponding Suspended Solids Concentrations

Sediment Condition	Sediment:Water Ratio			
	1:20 (DF=0.05)	1:200 (DF=0.005)	1:2,000 (DF=0.0005)	1:20,000 (DF=0.00005)
	Suspended Solids Concentration, mg/L			
Wet	50,000	5,000	500	---
Dry	---	5,000	500	50

DF=Dilution Factor

Wet, unoxidized sediment. 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 ranging from 500 to 50,000 mg/L. After thorough mixing, sediment was removed from the bucket, placed in 4-L glass jugs 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 1 hr to ensure adequate suspension and dissolution of the sediment. In previous studies, half of the samples were divided into separate sample containers for analysis of contaminants of concern (COC). These represent the total contaminants in unfiltered water. Since this can be determined by simply multiplying the bulk sediment concentration by the dilution factor and total concentrations are not used to determine water quality, it is no longer done. This reduced some of the cost of chemical analyses. After allowing some settling time, the samples are filtered through the appropriate filters for each class of COC. These samples represent the soluble contaminants in runoff water. Total contaminants are determined by simply multiplying the bulk sediment concentration for each COC by the dilution factors in Table C1.

Dry, unoxidized 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 flat and allowed to air dry in a greenhouse for 3 weeks or until the sediment had reached a moisture content of less than 5 percent. After drying was complete, the sediment was ground in a mechanical soil grinder and half was collected for oxidation with hydrogen peroxide. The addition of H_2O_2 simulates quickly the long-term effects natural oxidation has on the solubility of metals. A pretest was necessary to determine the amount of H_2O_2 necessary to fully oxidize the Appomattox sediment. Ten grams of dried sediment was placed in a 500-mL glass bowl and 30 percent H_2O_2 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 H_2O_2 used was recorded, and the resulting H_2O_2 per gram of sediment was used in the SLRP procedure. Half of the air-dried sediment was oxidized with H_2O_2 and then mixed with RO water to the sediment: water ratios indicated previously in Table C1. The remaining air-dried sediment was also prepared by mixing with RO water in the same manner. The samples were shaken for 1 hr and then filtered through a 0.45-μm membrane filter for metals and through a 0.7-μm glass fiber filter for total recoverable petroleum hydrocarbon (TRPH). Samples for both the wet and dry sediment were submitted for chemical analysis of As, Cd, Cr, Cu, Hg, Pb, Ni, Ag, Zn, and TRPH using the methods described by USEPA (1986).

Prediction of surface runoff water quality

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 5,000 mg/L in surface runoff during the initial wet stage after filling the CDF with Appomattox dredged material. If 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 chemical data obtained is compared to the Clean Water Act (CWA) Section 304(a) Environmental Protection Agency (EPA) water quality criteria. Generally, the chronic criteria for the protection of aquatic life are the most appropriate values upon which to compare the SLRP results. Comparison of SLRP results to these values provides a conservative evaluation on the side of environmental protection. Where SLRP results do not exceed the chronic criteria at the highest suspended solids ratio for each test condition, there is no need for further evaluation of runoff water quality for that particular COC. When the SLRP results exceed the criteria, there will be a need to consider mixing zones and/or runoff management. When a COC exceeds the criteria at the lowest suspended solids concentration for each test condition, additional quantitative testing using the RSLS may be required. Where no protection of aquatic life

Table C2
Suspended Solids Concentrations from other Sediments Evaluated Using the RSLS

Sediment	Suspended solids concentration, mg/L	
	Wet	Dry
Indiana Harbor	6,600	56
Blackrock 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

criteria exists, results are compared to human health criteria for the consumption of aquatic organism.

To receive a State 401 water quality certification, results must meet the water quality standards for the jurisdiction in which the discharge will occur. In the absence of state water quality standards, the EPA criteria will apply. Some states will have more stringent water quality standards than the EPA criteria. Comparison of the SLRP results to these standards may be required. In the absence of state standards or if specific water quality standards are not specified, it is assumed the EPA criteria for the protection of marine life (USEPA and USACE 1998) 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.

The evaluation of surface runoff water quality from Appomattox sediment did not include the RSLS procedure; therefore, 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 5,000 mg/L in surface runoff during the initial wet stage after filling the CDF with Appomattox dredged material. If 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 chemical data obtained from the SLRP was for dissolved contaminants from wet and dry sediment conditions. The dissolved constituents were compared to the USEPA freshwater chronic criteria. When soluble contaminant concentrations exceeded the criteria, the SLRP data were input into the RUNQUAL module (Schroeder, Gibson, and Dardeau 1995) of the ADDAMS. RUNQUAL provides a statistical comparison of the predicted runoff concentrations to the standards and calculates a dilution factor to meet the standard.

The total concentration of contaminants in unfiltered runoff was calculated by diluting the bulk sediment chemical data to reflect the various suspended solids concentrations. Since water quality standards are based upon soluble (filtered) runoff contaminants, the total (unfiltered) runoff is not needed for comparison to water quality standards. This was provided to determine solubility as a percent of the total concentration.

Results and Discussion

Effects of drying and oxidation on contaminant levels in sediment

Contaminant concentrations of bulk, air-dried, and oxidized sediments are shown in Table C3. Air-drying and oxidation with peroxide had little effect on total metals in the Appomattox sediment. Generally, the effects of drying and oxidation do not significantly change the total concentration of most metals but do significantly change the solubility of some metals. In many cases, pH is the controlling factor and the reduction of pH is controlled significantly by the oxidation of sulfides, and, to a lesser degree, oxidation of ammonium and decomposition of organic wastes into organic acids. The oxidation reactions are rapidly simulated through the use of hydrogen peroxide. This effectiveness of peroxide to provide a rapid estimation on the effects of oxidization on some metals in runoff water has been verified in the field (Price, Skogerboe, and Lee 1998). However, the effects peroxide oxidation has on organic contaminants and other metals are still being evaluated in field studies. This is why the SLRP currently uses both air-dried and oxidized sediment in the evaluation. As Table C3 shows, TRPH was only slightly reduced as a result of air-drying but was significantly reduced after oxidation with peroxide. Organic contaminants are generally more subject to degradation and are more likely to be bound to soil and organic particles in runoff.

Table C3
Effects of Drying and Oxidation on Sediment Contaminants

Parameter	Concentration, mg/kg		
	Wet (Bulk Sediment)	Air-Dry	Oxidized
As	1.69	1.77	1.73
Cd	0.229	0.177	0.16
Cr	6.69	10.2	7.16
Cu	10.0	11.1	10.9
Pb	52.1	43.7	49.1
Hg	0.178	0.143	0.124
Ni	2.65	6.13	2.93
Ag	0.583	0.433	0.2
Zn	43.1	39.6	36.8
TRPH	184	146.7	22.3

Surface runoff from wet dredged material

Tables C4 and C5 show results of water quality estimations for runoff. Table C4 shows predicted total release of contaminants based on dilution ratios for each sediment condition and suspended solids load. The numbers provide a very conservative estimate of total release assuming no retention of rainfall generated runoff before discharge. Since retention of rainfall to allow suspended solids settling is normally provided, release of indicated suspended solids loads and associated contaminants would be minimized. Soluble contaminant loads in discharged runoff water would then be of concern. However, as shown in Table C5, even at the overly conservative suspended solids concentration of 50,000 mg/L, soluble Sb, As, Pb, Hg, Ni, and Zn were detectable but below the USEPA and State of Virginia Water Quality Standard (WQS). TRPH was not detectable in filtered runoff. The results indicate that while the sediment is in a

Table C4
Predicted Total Contaminant Load in Runoff Water

Sediment Condition	SS mg/L	Contaminant, µg/L													
		Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn	TRPH
Wet	50,000	18.83	84.8	8.32	11.5	334	500	2606	8.92	132.20	10	29.1	10	2156	9183
Wet	5,000	1.88	8.48	0.832	1.15	33.4	50	260	0.892	13.2	1	2.91	1	215.6	918.3
Wet	500	0.188	0.848	0.083	0.115	3.34	5	26	0.089	1.32	0.1	0.291	0.1	21.6	91.8
Air Dry	5,000	1.88	8.48	0.832	1.15	33.4	50	260	0.892	13.2	1	2.91	1	215.6	918.3
Air Dry	500	0.188	0.848	0.083	0.115	3.34	5	26	0.089	1.32	0.1	0.291	0.1	21.6	91.8
Air Dry	50	0.019	0.085	0.008	0.012	0.334	0.5	2.6	0.009	0.132	0.01	0.029	0.01	2.16	9.18
Oxidized	5,000	1.88	8.48	0.832	1.15	33.4	50	260	0.892	13.2	1	2.91	1	215.6	918.3
Oxidized	500	0.188	0.848	0.083	0.115	3.34	5	26	0.089	1.32	0.1	0.291	0.1	21.6	91.8
Oxidized	50	0.019	0.085	0.008	0.012	0.334	0.5	2.6	0.009	0.132	0.01	0.029	0.01	2.16	9.18

Table C5
Predicted Soluble Contaminant Load in Runoff Water

Sediment Condition	SS mg/L	Contaminant, µg/L													
		Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn	TRPH
Wet	50,000	9.00	4.00	*1.00*	*0.200*	*1.00*	*1.00*	2.333	0.03	1.333	*2.00*	*1.00*	*2.00*	25.0	800
Wet	5,000	*3.00*	*2.00*	*1.00*	*0.200*	*1.00*	*1.00*	1.667	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	*10.0*	*733*
Wet	500	*3.00*	*2.00*	*1.00*	*0.200*	*1.00*	*1.00*	1.667	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	*10.0*	*767*
Air Dry	5,000	*3.00*	*2.00*	*1.00*	*0.200*	*1.00*	*1.00*	*1.00*	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	10.0	*800*
Air Dry	500	*3.00*	*2.00*	*1.00*	*0.200*	*1.00*	*1.00*	*1.00*	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	*10.0*	*767*
Air Dry	50	*3.00*	*2.00*	*1.00*	*0.200*	*1.00*	*1.00*	*1.00*	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	*10.0*	*700*
Oxidized	5,000	*3.00*	*2.00*	*1.00*	0.667	6.33	**26.0**	*1.00*	*0.025*	3.0	*2.00*	*1.00*	*2.00*	**219**	*733*
Oxidized	500	*3.00*	*2.00*	*1.00*	0.467	1.00	2.00	*1.00*	*0.025*	1.00	*2.00*	*1.00*	*2.00*	73.3	*700*
Oxidized	50	*3.00*	*2.00*	*1.00*	0.233	*1.00*	0.33	*1.00*	*0.025*	*1.00*	*2.00*	*1.00*	*2.00*	17.7	*700*
WQS		14 c	150 a	NS	2.2 a	11 a	9 a	2.5 a	0.77 a	52 a	5 a	3.4 b	1.7 c	120 a	NS

Note; Italic numbers were not detectable at the indicated value
Bold numbers exceed WQS.
a - freshwater chronic
b - freshwater acute
c - human health for consumption of water + organism

wet, unoxidized, state, movement of metals will be associated with the suspended solids, as most of the metals were not very soluble or sediment concentrations were low.

Table C6 provides some estimate of solubility where concentrations could be determined. While the sediment remains wet and anaerobic, detectable concentrations were indicating solubility rates in the order of Sb, Se, Zn, Ni, Hg, and Pb. Where concentrations were below detection limits, solubility was not determined.

Table C6
Solubility of Contaminants in Runoff Water

Sediment Condition	SS mg/L	Contaminant, %													
		Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Ni	Se	Ag	Tl	Zn	TRPH
Wet	50,000	**47.8**	NA	NA	NA	NA	NA	**0.09**	**0.34**	**1.0**	**20**	NA	NA	**1.2**	NA
Wet	5,000	NA	NA	NA	NA	NA	NA	**0.64**	NA	NA	NA	NA	NA	NA	NA
Wet	500	NA	NA	NA	NA	NA	NA	**6.4**	NA	NA	NA	NA	NA	NA	NA
Air Dry	5,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**4.6**	NA
Air Dry	500	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Air Dry	50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Oxidized	5,000	NA	NA	NA	**58.1**	**18.9**	**51.9**	NA	NA	**22.7**	NA	NA	NA	**102**	NA
Oxidized	500	NA	NA	NA	**407**	**29.9**	**39.9**	NA	NA	NA	NA	NA	NA	**340**	NA
Oxidized	50	NA	NA	NA	**2,034**	NA	**66.6**	NA	NA	NA	NA	NA	NA	**819**	NA

The results of SLRP evaluation on wet Appomattox sediment indicate that immediately after placement of dredged material, discharge of runoff water after allowing for adequate settling of suspended solids will not contribute to unacceptable contaminant releases.

Surface runoff from dry sediment

Drying and oxidation typically results in physicochemical changes to sediment that effects the solubility of metals. Generally, total metals will be reduced in runoff from dry sediment as the suspended solids will be reduced. However, many factors, including vegetative cover and physical structure of the dredged material surface may affect this. Solubility of many metals tends to increase as the dredged material is dried and oxidized. Solubility increased significantly for Cd, Cr, Cu, Ni, and Zn compared to solubility in runoff from wet sediment (Table C6). The increase in solubility is higher under the oxidizing conditions that the SLRP is designed to simulate. As shown in Table C6, solubility increases as the suspended solids are reduced. This result of limits in the solution phase as the water column becomes saturated from the higher concentration of suspended solids. After drying and oxidation, soluble Cu is predicted to exceed the USEPA water quality criteria of 9 µg/L and the Virginia WQS of 12 µg/L for the protection of aquatic life when rainfall generates suspended solids concentrations approaching 5,000 mg/L. Soluble copper was 26.0 µg/L in runoff from the oxidized sediment. Soluble Zn will also exceed the USEPA and State of Virginia WQS of 120 and 110 µg/L, respectively.

Results indicate that only Cu and Zn are of concern before allowing for mixing. Results of the SLRP evaluation for Cu and Zn were input into the RUNQUAL module (Schroeder, Gibson, and Dardeau 1995) of ADDAMS. The RUNQUAL comparisons of predicted water quality to standards determined that a dilution ratio of 2.6 is the maximum required for Cu and Zn water quality standards (Table C7).

Table C7
Runoff Quality Comparisons with Water Quality Standards (from RUNQUAL)

Contaminant	Detection Limit µg/L	Background Conc. (B) µg/L	Predicted Conc. (P) µg/L	Standard Conc. µg/L	Required Dilution Ratio (D) and Remarks	Results And Confidence Level %
Copper	1.0	2.0	27	9.0	D = 2.6 meets S	P > S = 99.8
Zinc	10	63.5	257.3	120	D = 2.4 meets S	P > S = 96.2

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 Appomattox dredged material is placed in an upland environment, heavy metals in rainfall induced runoff from the wet unoxidized wet dredged material will be mostly insoluble and bound to suspended particulate in the surface water runoff as will TRPH. Soluble metals are not predicted to exceed water quality standards during this period. Retention of suspended solids will significantly restrict all movement of metals and TRPH from the upland disposal site. Drying and oxidation of Appomattox sediment significantly increased the solubility of some metals. However, only copper and zinc were predicted to exceed the water quality standard during the dried conditions.

Based on the results of the RUNQUAL evaluation of Cu and Zn, a dilution factor of 2.6 is all that is required in a mixing zone to bring runoff water discharge into compliance with water quality standards.

The SLRP is being developed as a screening procedure to determine the need for more expensive evaluations of surface water runoff from dredged material using the RSLS.

At this point, it is not a totally stand-alone evaluation. Where the SLRP predicts failure of water quality standards, the RSLS may be sometimes be required as a means of providing a more quantitative evaluation of surface runoff water quality from the sediment in question. Using the SLRP results alone may lead to incorporation of excessive and/or costly engineering controls and treatments in the final CDF design. However, the evaluation of Appomattox sediment does not indicate a major water quality concern from the release of rainfall induced runoff into receiving waters.

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Appendix D
Tier II Screening of Plant Uptake of Heavy Metals from Dredged Material in an Upland Environment

Plant Uptake Pathway

Purpose and scope

The placement of dredged material in upland or nearshore environments requires that a number of pathways be evaluated to determine the potential for adverse impacts. Lee et al. (1991)[1] describes these pathways including the Decision Making Framework (DMF) for Management of Dredged Material. 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 CDF and dewatered. The potential for plants to mobilize contaminants from the dredged material, bioaccumulate, 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 procedure, as described by Folsom and Price (1989) for freshwater plants, and Lee et al. (1992), and 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 a wetland/flooded condition 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

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[1] Reference information is presented at the end of Appendix D.

used for freshwater upland, freshwater wetland, and leached saltwater upland conditions. The procedure calls for sediment exposure through maturity of the plant or 45 days in an environmentally controlled greenhouse. Aboveground plant tissues are harvested and analyzed for contaminant concentrations. These 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 exist and 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 by plants 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, Lee, and Bates (1981) and is based on the procedure of Lindsay and Norvell (1978). The DTPA procedure has been used in a number of studies to successfully predict plant uptake from dredged material placed in upland environments (Lee, Folsom, and Engler 1982; 1983; and Lee et al. 1991; and U.S. Army engineer Waterways Experiment Station 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 metal 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 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 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 II. 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 the plant bioassay evaluation in Tier III. Other considerations under a RAD are also an option prior to Tier II, such as: (a) the number of DTPA extracted metals exceeding wet sediment or reference sediment; (b) magnitude by which wet sediment or reference sediment is exceeded; (c) toxicological importance of exceeding metals; and (d) 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 by 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 by Lee et al. (1991). Of particular importance is the evaluation of bioaccumulation. Contaminant concentrations are normally compared to available demonstrated effect levels, FDA type action levels, or other human health levels. These provide for some rational in determining restrictions to prevent adverse environmental impacts as a result of plant uptake of contaminants or movement of contaminants to surface soils or into animals through plant uptake. There are no regulatory standards for concentrations of contaminants in ecosystem plants.

Objective

The objective of this study was to determine the DTPA extractable metals from the Appomattox River sediment placed in an upland environment and compare to DTPA extractable metals from the existing material in the proposed Puddledock disposal site and to appropriate limitations.

Approach

The plant uptake pathway was evaluated using the DTPA and computer simulation protocol described in the Technical Note by Folsom and Houck (1990). Appomattox composite sediment and Puddledock disposal site material (Puddledock) was provided. The proposed placement of Appomattox dredged material allows for upland creation so only the upland portion of the DTPA procedure was conducted; no wetland conditions were considered. Normally the DTPA procedure compares the flooded test sediment to the upland test sediment. This is to verify the phenomenon that occurs to most plant available metals when sediment conditions change from anaerobic to aerobic: Metals become more soluble and plant available. In this case, verifying that phenomenon was not necessary.

Methods and Materials

Sediment preparation and DTPA extraction

Sediment preparation. Both the Appomattox sediment and Puddledock soil was thoroughly mixed in a 19-L plastic bucket 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 ºC until needed. The barrel of Puddledock material was dumped into a 1.2 × 4.6-m aluminum lysimeter, mixed thoroughly, allowed to air-dry and then placed back in the barrel until needed.

Sediment pH. Ten grams (oven-dry weight (ODW) to nearest 0.001 g) of original wet, dried, and dried + peroxide sediment were weighed into a tall 50-mL Pyrex glass beaker. Twenty (20) mL of distilled water was 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 a total of 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, Lee, and Bates 1981).

Organic matter. Organic matter (OM) was determined by weight loss on ignition at 550 ºC on air-dried (AD) and air-dried wash (ADW) 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 ºC until constant weight (48 hr). Five grams of the oven-dried sediment is weighed to the nearest 0.001 g and combusted at 550 ± 5 ºC 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:

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

DTPA extract. The DTPA extraction was conducted on the dry sediment following the methods by Folsom and Houck (1990). An extraction solution was prepared using 0.005 Molar (M) of DTPA + 0.01 M calcium chloride + 0.1 M triethanolamine buffered at pH 7.3 (Lee et al. 1978; Lee, Folsom, and Bates 1983). Three replicate 50-g samples of AD Appomattox and Puddledock (ODW equivalent) were placed in a 500-mL polycarbonate centrifuge bottle to which 250 mL of the DTPA solution was added. The bottles were shaken for 24 hr on a mechanical shaker and then centrifuged at 4 ˚C and 9,500 rpm (13,700 g) for 30 min. The supernatant from each bottle was poured into a polyethylene sample bottle and preserved at 4 ˚C until chemical analysis for metals.

Prediction of plant uptake

The mean DTPA and total sediment metal concentrations (from bulk sediment analysis) were input along with pH and organic matter content into the PUP as described in Folsom and Houck (1990). DTPA metal concentrations below the analytical method detection limit (MDL) were entered as the MDL value times. Blank DTPA concentrations were subtracted from sediment DTPA concentrations prior to entering data into PUP. Results are presented as plant metals concentration in mg/kg and as total plant uptake in µg on an ODW basis.

Plant growth and appearance

Some concern was noted about the potential for plant growth in the Appomattox dredged material. A plant bioassay was conducted following the procedures by Folsom and Price (1989). Four replicates of 4.5-kg samples each of Appomattox air-dried and Puddledock sediments were placed in the double container bioassay unit (Figure D1) and planted with five sprouted tubers of *Cyperus esculentus*. The plants were grown in a controlled environment greenhouse simulating a summer environment and after 45 days the aboveground plant tissue was harvested, dried, and weighed to determine total dry weight yields.

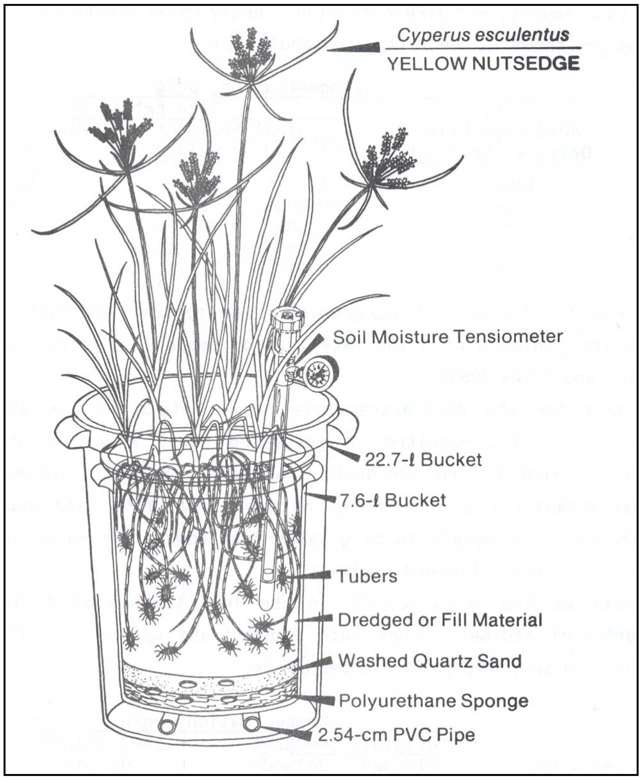

Figure D1. Schematic diagram of plant bioassay unit

Results and Discussion

Effects of drying and oxidation

As dredged material dries and oxidizes, one of the most important physicochemical changes that may occur is the reduction of pH. The solubility and plant uptake of many metals may increase as the pH is reduced to near pH 5.0. Table D1 shows that air-drying reduced pH from 6.9 to 5.2. Compared to the Puddledock sediment pH of 5.5, the difference was negligible. The organic matter results were derived from a method that has been used throughout the development of the PUP procedure but has been shown to overestimate organic matter. Nelson and Sommers (1982) state that procedures based on combustion overestimate organic matter as both organic and inorganic carbon lose weight on

Table D1
Selected Properties of Appomattox and Puddledock Sediments

Parameter	Puddledock	Appomattox Wet	Appomattox Dry
pH	5.5	6.9	5.2
Moisture, %	8.9	34.8	2.75
EC, mmhos/cm	0.387	0.207	1.031
OM, %	8.6	NA	5.1

ignition at high temperatures. The total organic carbon analysis of the bulk sediment can be used to estimate actual organic mater by the value by the universally acceptable conversion factor of 2 (Nelson and Sommers 1982).

DTPA extractable metals and predicted plant uptake

The DTPA and PUP results are summarized in Table D2 along with the total metals from the bulk sediment (DM) analysis from Appendix A. Table D2 shows mean DTPA results for Appomattox and Puddledock. These data were input into PUP to generate estimated plant concentrations (EST Plant) and estimated total plant uptake (EST Plant Total). Results indicate that except for Cr, total metals were higher in Appomattox than in the Puddledock as were all DTPA metals. In fact, Puddledock DTPA metals were mostly the result of low-level metals in the DTPA extracting solution. PUP generated estimates of plant concentration of metals indicate that the higher total sediment concentration in Appomattox sediment may not contribute to equally higher plant concentrations. PUP generates a prediction of plant concentration based on the total sediment concentration, DTPA concentration, sediment pH, and percent organic matter. Results will vary depending on the input variables. PUP may also generate negative numbers in the estimation process. These numbers generally mean that the estimation value is close to zero or the input variables are sufficiently different than those used in the calibration of the estimation equation and the estimates are unreliable.

Table D2
Mean Sediment (DM), Sediment DTPA Concentrations, and PUP Predicted Plant Metals

Metal	Appomattox Concentration (mg/kg)				Puddledock Concentration (mg/kg)			
	DM	DTPA	Est Plant	Est Plant Total	DM	DTPA	Est Plant	Est Plant Total
As	1.99	0.31	0.79	0.915	0.299	0.003	-0.743	0.199
Cd	0.315	0.053	0.842	-14.82	0.02	0.000	1.37	24.72
Cr	7.70	0.034	1.48	11.71	7.65	0.000	-2.85	19.06
Cu	12.0	3.12	5.98	-9.59	1.86	0.068	3.97	-49.54
Pb	74.15	16.61	2.09	0.264	6.95	0.058	2.07	2.35
Hg	0.221	0.00	0.003	-0.007	0.04	0.000	0.0007	-0.0063
Ni	3.05	0.221	1.12	16.97	0.566	0.003	1.75	60.53
Zn	51.55	11.05	39.01	-602.45	1.93	0.243	29.68	2.47

The confidence intervals generated by PUP are provided in Table D3 and show the same level of confidence between sediments for each metal. The wide range of values indicates a high degree of uncertainty as to possible metal concentrations in plant tissues. This is likely a result of the limited range of data used to generate the estimation equations and the low sediment DTPA concentrations input into the program.

Table D3
Estimated Plant Concentration (90% Confidence Interval)

Metal	Appomattox Concentration (mg/kg)	Puddledock Concentration (mg/kg)
As	-2.22 to 3.80	-3.75 to 2.27
Cd	-4.79 to 6.48	-4.26 to 7.01
Cr	-21.6 to 24.6	-25.9 to 20.2
Cu	-4.72 to 16.7	-6.73 to 14.7
Pb	-13.0 to 17.2	-13.0 to 17.1
Hg	-0.029 to 0.034	-0.031 to 0.033
Ni	-6.24 to 8.47	-5.62 to 9.11
Zn	-37.5 to 115.5	-46.85 to 106.2

Decision criteria

Table D4 shows the results of the PUP comparison of Appomattox and Puddledock. In each case (1a, 2a, and 3a), where sufficient data were available for comparison, upland Appomattox sediment exceeded the Puddledock sediment. For Cd and Cr, no comparison could be conducted, since sediment DTPA was less than analytical detection limits for all in Puddledock and for Hg in Appomattox. Testing of Appomattox sediment did not include a DTPA extraction of the wet sediment, therefore cases 1b, 2b, and 3b were not included in Table D4. Generally, plant uptake of most metals of concern will increase in upland vs. flooded conditions, particularly when the pH drops from neutrality to acidic conditions. In this case, the last decision criteria would apply: *air-dried sediment is greater than the reference and greater than the saturated sediment*.

Table D4
Results of Decision Comparison Cases for Upland Appomattox and Puddledock

Case	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	NO. EXCD
1a	EXCD	--	--	EXCD	EXCD	EXCD	EXCD	EXCD	6
2a	EXCD			EXCD	EXCD	EXCD	EXCD	EXCD	6
3a	EXCD			EXCD	EXCD	EXCD	EXCD	EXCD	6

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

a. DTPA extractable concentrations of all metals from the air-dried sediment are *less than or equal to* the reference sediment (Case 1a) and *less than or equal to* the saturated sediment (Case 1b). This leads to a **DECISION OF NO RESTRICTIONS** to protect against contaminant impacts on plants colonizing the dredged material.

b. DTPA extractable concentrations of any metal from the air-dried sediment is *less than or equal to* the reference (Case 2a) and *greater than* the saturated sediment (Case 2b).

c. DTPA extractable concentration of any metal from the air-dried sediment is *greater than* the reference (Case 3a) and *less than or equal to* the saturated sediment (Case 3b). Condition b and c lead to a **LOCAL AUTHORITY DECISION** as discussed in paragraph B49 of the DMF.

d. DTPA extractable concentration of any metal from the air-dried sediment is *greater than* the reference (Case 3a) and *greater than* the saturated sediment (Case 2b). This leads to a **DECISION FOR FURTHER EVALUATION** by conducting a plant bioassessment as discussed in paragraph B50 in the DMF.

Comparison to phytotoxic effects and action levels

The results of the plant screening evaluation show that all of the DTPA extractable metals exceed those of the Puddledock sediment. PUP predicted plant uptake fails the test sediment to reference sediment comparison. This generally requires that a plant bioassessment be performed as discussed in paragraph B50 of the DMF. However, the results of the PUP can also be compared to demonstrated effects levels or FDA type action levels as an alternative. Leaf tissue concentrations of plants exhibited normal to phytotoxic response to metals (Table D5). Phytotoxic response can be a good indicator that elevated levels of metals have accumulated in plant tissues, although some plants can accumulate a significant level of metals with no visible effects. The predicted concentrations of metals from PUP are within the normal leaf concentration for all metals and well below the phytotoxic concentrations. Table D6 provides limited action levels for metals in foodstuffs from various countries. Predicted Cu (0.79) and Cd (0.842) are below the action levels of 20 and 1.0 mg/kg for animal feed. Predicted Hg (0.003) is below the 1.0-mg/kg action level for wheat seed. Predicted Pb (2.09) is also below the action levels of 5 mg/kg for single animal feed and 12 mg/kg for leafy vegetables.

There are currently no regulatory standards limiting specific levels of metals in plants in the environment. However, limitations on soil concentrations to prevent unacceptable levels of metals in crops are provided under the USEPA 503 Rule (USEPA 1995) for the application of biosolids to cropland. A comparison of Appomattox dredged material to the 503 acceptable soil concentration and background soil concentration is provided in Table D7. Metals in Appomattox sediment were compared to the 50th percentile background soil concentrations and were below those concentrations for As, Cu, Ni, and Zn. Appomattox Cd and Hg were slightly above the background levels, and Pb was

Table D5
Demonstrated Effects of Metal Uptake by Plants

Metal	Leaf Concentration, mg/kg			
	Normal [1] Leaf	Critical Content [2] Leaf	25% Yield Reduction [3] Leaf	Phytotoxic [1] Leaf
As	0.1-1.0	---	---	3-10
Cd	0.1-1.0	8	varies	5-700
Cr (III) oxides	0.1-1.0	---	---	20
Cu	3-20	20	20-40	25-40
Ni	0.1-5	11	50-100	500-1,000
Pb	2-5	---	---	---
Zn	15-150	200	500	500-1500

[1] Leaf tissue content from Chaney (1983).
[2] Leaf tissue content from Davis, Beckett, and Wollan (1978); Davis and Beckett (1978); Beckett and Davis (1977).
[3] Leaf tissue content from Chaney et al. (1978).

Table D6
Action Levels for Metals in Foodstuffs Used by Various Countries

Metal	Source	Commodity	Concentration	References
Cu	Dutch	Animal Feed	20.0 (DW)	DMAFCMN (1973)
Cd	World Health Organization Dutch (unofficial)	Root Vegetable Leafy Vegetables Potatoes, Cereal Single animal Feed Mixed Animal Feed Roughage	0.05 (FW) 0.10 (FW) 0.10 (FW) 0.50 (DW) 1.00 (DW) 1.00 -2.00 (FW)	WHO (1972) European Community (1974)
Hg	FDA	Wheat Seed	1.00 (DW)	USFDA (1987)
Pb	World Health Organization Britain European Economic Community	Root Vegetable Cereal Leafy Vegetables	0.10 (FW) 0.10 (FW) 1.20 (FW)	WHO (1972)
		All Foods	1.00 (FW)	USAEWES (1972)
		Single animal Feed Mixed Animal Feed Roughage	10.0 (DW) 5.0 (DW) 1.0 - 2.0 (FW)	Van Driel, Smilde and Van Luit (1983)

Table D7
Comparison of EPA 503 Rule, Background Soils and Risk Assessment Acceptable Soil

Metal	Concentrations, mg/kg		
	Appomattox Bulk Sediment	50th Percentile Background Soil[1]	Risk Assessment Acceptable Soil[1]
As	1.99	3	23.5
Cd	0.315	0.2	19.7
Cr	7.70	----	----
Cu	12.0	19	769
Pb	74.15	11	161
Hg	0.221	0.1	8.6
Ni	3.05	18	228
Zn	51.55	54	1454

[1] From USEPA (1995), Table 18.

nearly seven times the background level. However, when the Appomattox sediment metals are compared to the acceptable soil concentrations under the 503 rule, all metals are well below the limitation. The 503 rule limitations included assessment of ecological risks, including animals eating plants grown on biosolids amended soils and earthworms living in and consuming biosolids amended soils as well as phytotoxic effects on plants. Chromium was removed from the 503 rule as a result of a court decision that determined the biosolids risk assessment did not identify any chromium level associated with risk to human or environmental health (USEPA 1995). Based on comparison of the Appomattox metals concentrations to the 503 rule limitations, there should be no unacceptable ecological risks associated with plant growth on Appomattox dredged material in a upland environment.

One must be aware that the 503 rule limitations are based on metals applied in biosolids. Some conditions that reduce risks are discussed in EPA Guide (1995). First is the insoluble and strongly adsorbed condition of metals like Cr and Pb that prevents translocation into edible portions of plants. Second is the pH factor that allows phytotoxic levels of Cu and Ni to be taken up by plants at pH levels below 5.5. The assumption here is that the stunted, less desirable plants would provide less consumable quantities of plant tissues reducing exposure of animals to plants with elevated levels of metals. The EPA (USEPA 1995) recognized that metals such as Cd might be accumulated in excessive levels by plants without causing phytotoxicity and that excessive levels in tissues could be toxic to animals ingesting them. Adverse health effects were found in Japan where farm families consumed rice containing high levels of Cd. It was determined that the low intake of calcium, iron, and zinc (sufficient levels reduce Cd absorption in the intestine) was responsible for the increased toxicity of Cd. Elevated levels of Cd are a concern if metals that inhibit Cd absorption are deficient. The USEPA (1995) noted studies by Strehlow and Barltrop (1988) and the Agency for Toxic Substances and Disease Registry (ATSDR) (1994) of Cd contaminated sites in Shipham, England, and Palmerton, Pennsylvania, respectively. In Shipham, the Cd concentration was 360 mg/kg and no adverse health effects were found in the local population consuming vegetables grown in the contaminated soils. Similar findings of no increased adverse effects were noted in Palmerton from the long-term consumption of vegetables grown in soils containing 100 mg/kg Cd. In both cases, the Cd:Zn ratios were high 1:200 and 1:100, respectively. The USEPA (1995) notes that soil amended with biosolids usually contain Cd and Zn at a ratio of 1:100 as well as iron and calcium and would not contribute to adverse effects. Appomattox sediment has a Cd to Zn ratio of 1:160.

The use of the 503 rule limitations to screen the upland placement of dredged material for plant and animal risks is appropriate, particularly when metal concentrations are near background levels and well below the acceptable limitations as they are in the case of Appomattox dredged material. However, it should only be used for guidance and not for regulatory purposes.

Plant growth and appearance

Results of the plant bioassay indicate that plant growth will be higher in the Appomattox than in the Puddledock sediment (Figures D2 and D3). The yield of *C. esculentus* grown in Appomattox sediment was over five times the yield from the Puddledock sediment (Table D8). Lower yields in the Puddledock sediment were not a surprise, considering the origin of the material. Appomattox dredged material with higher nutrient levels and low concentrations of metals should produce adequate plant growth. Although the plant pathway did not evaluate uptake of TRPH, the presence of TRPH at the tested concentrations should have little effect on plant growth. With time, TRPH should be reduced because of biodegradation.

Figure D2. Appearance of *C. esculentus* in Puddledock sediment

Figure D3. Harvested aboveground tissues from Puddledock (top) and Appomattox (bottom)

Table D8
Yield of *C. esculentus*

Sediment	Fresh Weight, g[1]	Dry Weight, g[1]	% Moisture[2]
Appomattox	23.98	6.30	73.8
Puddledock	4.96	1.15	77.5

[1] Grams per pot
[2] Wet weight basis 4.96

Conclusion

The purpose of the Tier II PUP procedure is to screen sediments for potential problems relating to plant uptake of heavy metals. Failure of the decision criterion may invoke the Tier III testing protocol, the Plant Bioassay Procedure. Tier II testing predicted that Appomattox sediment might contribute to elevated levels of metals in leafy freshwater plants above levels from plants in the Puddledock sediment. However, predicted levels were below levels of concern and should pose no significant adverse ecological effect. At this time, further evaluation using the Tier III testing is not necessary. If movement of metals into plants becomes a concern because of decrease in dredged material pH or colonization by sensitive plant or animal species, management of dredged material pH or selection and management of certain plant species are options that can readily be deployed.

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Appendix E
Earthworm Bioassay Tests

Upland Animal Bioaccumulation

Another pathway for evaluation is animal uptake. Unless adverse conditions exist (excessively low pH, high phytotoxic contaminant concentrations, etc.), plant communities will colonize dredged material that has been dewatered. Plant colonization is accompanied by animal colonization. The potential for plants to mobilize contaminants from the dredged material, bioaccumulate, 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 and from plants to animals. Under Tier III (in the proposed Corps of Engineers Upland Testing Manual), effects of soil invertebrate (earthworm) bioaccumulation from the test sediment are compared to the same from a reference sediment or soil location. The earthworm bioassay procedure conducted here was based on the current American Society for Testing Materials (ASTM) standard testing procedure, ASTM E 1676 (ASTM 1997).[1] This procedure, at its current level of development and interpretation, can only provide an evaluation of materials as they currently exist, not as they may be in the future when plants and animals do colonize.

Laboratory Procedures

Experimental conditions

Culture of test organisms. Earthworms were obtained through culture procedures onsite at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS.

Age. All tests with *E. fetida* used sexually mature fully clitellate earthworms.

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[1] Reference information is presented at the end of Appendix E.

Test specifications

Experimental design. Decisions concerning the various aspects of experimental design, such as the number of replicates (Table E1), the number of test containers, and the mass of earthworms selected were based on the amount of tissue material needed for appropriate detection levels during chemical analysis.

Table E1
Test Specifications for the 28-day *Eisenia fetida* Bioaccumulation Test

Test Duration	**28 days**
Biological Endpoint	Contaminant accumulation
Temperature	Same as field condition if within 10-29 °C
Photo period	24 hr/ 100-1080 lx
pH	Same as field condition if within 4-10
% moisture	Same as field condition
Salinity	Same as field condition
Test Containers	Plexiglass cylinders

Test material. Test materials were sediment from the Appomattox River, soil from the potential disposal location (Puddledock Site), and a negative control of earthworm culture media for evaluation of test acceptability.

Test containers. Test material was placed in transparent Plexiglas cylinders 30 cm deep and 15 cm in diameter. One of the cylinder ends was closed with a 17-cm PVC band and cotton muslin cloth. The bottom end was then placed in a 20-cm-diam plastic dish of reverse osmosis (RO) water to allow water movement into the substrate and allow earthworms to move into areas of optimum moisture.

Day 0 test initiation. Prior to testing, earthworms are rinsed with test water and placed on paper towels to remove excess water. On day 0, the mass of earthworms needed for the particular chemical analysis procedures for the contaminants of concern (COC) were added to each of the test cylinders. Test containers accommodated up to 30 g (~75 earthworms)/cylinder (Skogerboe et al. 1996). Weights and numbers of earthworms in each test cylinder are presented in Table E1.

Day 28 test breakdown. On day 28, earthworms were removed, rinsed with test water, blotted, counted, and weighed. Depuration of the earthworms was as recommended for 24 hr on moist filter paper. Earthworms were then rinsed and frozen in preparation for chemical analysis.

Feeding. Test materials that are primarily nutrient enriched dredged materials do not require an additional food source (Marquenie, Simmers, and Kay 1987; Macdonald 1983; Marquenie and Simmers 1988; Simmers et al. 1986; Stafford et al. 1991; Lee et al. 1992, 1986, 1991; Skogerboe et al. 1996). Soils with less nutrients tested with this procedure may require added food due to test length (Belfroid et al. 1995). As a result of the 28-day duration of the test and the lack of plant material in the Puddledock Site substrate, a surface application of moistened rolled oats from a local grocery was used as supplemental food in all test cylinders.

Quality control parameters. Temperature, pH, and percent moisture were controlled and monitored throughout the test. Ideally, these parameters should be the same as in the field and within the range of the earthworms' temperature and pH requirements. Acceptable temperature range is from 10 to 29 ºC with a recommended range of 19 to 25 ºC. Acceptable pH range is between 4 and 10 (Greene et al. 1989). Recommended photo period is 24 hr within 100-1080lx. The photo period is recommended to prevent earthworm escape, encourage maximum exposure to test material, and to discourage contact with container sides (Table E1).

Analytical procedures. The earthworm tissues from the five replicates of each substrate were composited, homogenized, and divided into three equal samples for chemical analyses. Tissues were analyzed for As, Cd, Cr, Cu, Pb, Hg, Ni, Ag, Zn, and TRPH. Analyses were conducted by the appropriate standard methods.

Statistical procedures. Initial and final weights and all contaminant concentrations were evaluated using the same sequence of statistical procedures. The Statistical Analysis System (SAS) release 6.12 was used to perform the data analysis (SAS Institute Inc. 1989a, b). The normality and equality of variance assumptions were evaluated. PROC UNIVARIATE with the NORMAL option was used to test normality of residuals using the Shapiro-Wilk's Test (Conover 1980). This test provides a test statistic W that compared to values of W expected from a normal distribution. Because normality is desired, one looks for a high value of W with an associated probability greater than 0.05. An associated probability less than 0.05 indicates the inappropriateness of the normality assumption. Data from three exposure media (i.e., Control, Puddledock, Appomattox) were used. Levene's Test was used to evaluate the equality of variance assumption (Snedecor and Cochran 1980). Levene's Test was accomplished using the HOVTEST feature of PROC GLM at alpha = 0.05. If neither the normality nor equality of variances assumption was rejected, PROC GLM with MEANS options LSD LINES was used to compare weight and contaminant concentration means for the respective exposure media. The LSD option performs pairwise t-tests, equivalent to Fisher's least-significant-difference in the case of equal cell sizes (SAS Institute Inc. 1989b). This test performs all pairwise comparisons of means. However, the F test of treatments was performed first. The statistical differences identified by LSD were reported only if the F test was significant. This procedure is often referred to as Fisher's (protected) LSD (Steel and Torrie 1980). Statistical differences are indicated by different alphabets.

Results and Discussion

Survival was acceptable in all the test cylinders (Table E2). Weight gain was greatest in the five replicates composed of the earthworm culture media, while there was little weight change in the Appomattox River and Puddledock replicates. The increase in earthworm numbers in some of the test cylinders was the result of small animals that adhered to larger animals selected for the procedure. The small earthworms then grew large enough to be counted by day 28. There was insufficient time for reproduction to account for any population increase. There was a loss of 50 percent of the earthworms in Appomattox River replicate cylinder number 3 that cannot be easily explained. One possible explanation is injury to animals during the test setup.

Table E2
Survival and Weights for the 28-day *Eisenia fetida* Bioaccumulation Test

Substrate Replicate	Weight of Worms, g day 0	Number of Worms day 0	Weight of Worms, g day 28	Number of Worms day 28
Appomattox 1	30.13	160	31.97	161
Appomattox 2	30.00	185	29.06	198
Appomattox 3	30.04	100	21.45	50
Appomattox 4	30.00	165	40.34	165
Appomattox 5	30.00	101	31.77	101
Mean	30.03	142.2	30.91	135
Puddledock 1	30.01	103	42.71	114
Puddledock 2	30.15	96	39.91	102
Puddledock 3	30.10	100	37.74	112
Puddledock 4	30.11	130	35.04	130
Puddledock 5	30.13	155	29.54	185
Mean	30.10	116.8	36.99	128.6
Reference 1	30.05	81	37.14	81
Reference 2	30.30	91	41.70	97
Reference 3	30.00	100	41.59	102
Reference 4	30.09	94	39.68	94
Reference 5	30.08	95	37.80	105
Mean	30.10	92.2	39.58	95.8

Total weight of worm tissue recovered from the Appomattox sediment was significantly less that that of the reference (Table E2). The test animals in the Appomattox and Puddledock substrates did gain weight but not to the extent of those worms in the optimum conditions of the Reference substrate.

Table E3 shows the comparison of the analytical replicates. The variation addressed by the statistical treatment of the analytical replicates as employed here does not reflect the variation between individual bioassay units, rather it addresses the analytical variation. Tissue concentrations of selected metal contaminants and total recoverable petroleum hydrocarbon (TRPH) are

Table E3
Concentrations of Contaminants in the 28-day *Eisenia fetida* Bioaccumulation Test

Contaminant	Concentration, mg/kg by dry weight		
	Reference	Puddledock	Appomattox
As	0.37	0.37	0.43
Cd	0.47 b	0.38 c	0.53 a
Cr	0.67 a	0.68 a	0.47 a
Cu	0.98 c	2.26 a	1.42 b
Pb	0.09 b	0.05 b	0.75 a
Hg	0.01 b	0.01 b	0.02 a
Ni	0.09 b	0.25 a	0.21 a
Ag	0.23 a	0.14 a	0.05 a
Zn	9.74 b	12.27 a	10.40 b
TRPH	36.33 a	38.00 a	18.33 a

Means in a row followed by the same letter are not significantly different.

summarized in relation to the concentrations previously reported in Appendix D from analyses of substrates and diethylene triamine pentaacetic acid (DTPA) extractions. As and Cd concentrations in earthworm tissues exposed to Appomattox sediment were significantly higher than Puddledock, greater than DTPA, and less than Appomattox sediment levels. Lead and mercury tissue concentrations from the Appomattox sediment were significantly greater than Puddledock tissue concentrations, less than DTPA, and less than Appomattox sediment levels. Chromium and Silver in the Appomattox earthworm tissues were not significantly different from those of Puddledock or Reference tissues, greater than DTPA, and less than levels in the Appomattox sediment. Copper in the tissues from the Puddledock substrate was significantly greater than Appomattox earthworm tissues, greater than DTPA, and less than Appomattox sediment concentration. Nickel concentrations in tissues from the Appomattox bioassay cylinders were not significantly different from Puddledock, greater than DTPA, and greater than Appomattox sediment levels. Silver in the Appomattox tissues was not significantly different from Puddledock, greater than DTPA, and less than concentrations in the Appomattox sediment. Zinc concentration in tissues from the Appomattox sediment were significantly less than Puddledock, greater than DTPA, and less than Appomattox sediment itself. TRPH concentrations were not significantly different across the earthworm tissue from the three substrates.

It is important to conduct bioassay procedures, since the bioavalability of a contaminant is not necessarily related directly to the concentration in the dredged material. In fact, the levels of contaminants detected in earthworms may increase as vegetation develops and the dredged material becomes more like a soil with leaf litter incorporated. Stafford et al. (1991) documents the increased bioaccumulation by earthworms exposed to leaf litter, even when the contaminant levels were lower than the underlying dredged material. For example, 3.3 mg/kg of Cd in dredged material resulted in 5.6 mg/kg in Cottonwood tree leaf litter and 57 mg/kg in earthworm tissues. This level of bioaccumulation is also typical for Zn but has not been reported for Cu, Ni, or Pb. In the case of the Appomattox sediment, the contaminant levels in the sediment and in the bioassay earthworms are quite low, but any likelihood that there would be any food web impact in any ecosystem that might develop cannot be predicted.

Conclusions

The earthworm bioassay conducted on Appomattox sediment and Puddledock site soil as provided did not indicate excessive bioavability of metals or TRPH. If plants and animals are permitted to colonize the disposal site, retesting may be necessary to evaluate any movement of contaminants in the food web.

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Appendix F
Laboratory Assessment of Volatilization from Appomattox River Sediment

Background

The loss of volatile contaminants from dredged sediments is an increasingly recognized environmental concern. Dredging, disposal, and storage operations associated with dredged material placement in a confined disposal facility (CDF) can increase the potential for volatile organic compound (VOC) emissions. There are several pathways for chemicals to enter the atmosphere from sediment stored in a CDF. In previous work, Valsaraj, Thibodeaux, and Reible (1995) surveyed the various pathways that include exposed sediment, sediment covered with ponded water, resuspended sediment in the water column, and vegetated covered sediment. They concluded that the most significant local for air emissions was from exposed material. The emission of volatile and semi-volatile compounds is known to depend upon a variety of factors, including contaminant sediment concentrations, sediment moisture content, temperature, and relative air humidity. In an upland CDF, sediments are subject to cyclic wet and dry conditions, variations in relative air humidity, and temperature fluctuations.

Appomattox River sediment contains polyaromatic hydrocarbons (PAHs), petroleum hydrocarbons, and ammonia (Table F1). This study evaluated volatile emissions from Appomattox River sediment in order to determine possible volatile losses during disposal of the material in a settling pond. Volatile emissions of organic contaminants and other odorous compounds that potentially reduce air quality are a concern. This appendix summarizes the laboratory results and includes all PAH, total recoverable petroleum hydrocarbon (TRPH), and ammonia fluxes from the sediment sample. Emphasis is placed on trends in the volatile emissions as a function of evaporative sediment drying, sediment moisture content, and the effects of varying relative air humidity on compound fluxes.

Table F1
Sediment Loading of PAHs and TRPH

Compound		Average Sediment Concentration, mg/kg
Naphthalene	(NAPHTH)	22.4
Acenaphthylene	(ACENAY)	0.575
Acenaphthene	(ACENAP)	12.7
Fluorene	(FLUORE)	6.54
Phenanthrene	(PHENAN)	17.1
Anthracene	(ANTRAC)	5.0
Fluoranthene	(FLANTHE)	7.67
Pyrene	(PYRENE)	9.32
Chrysene	(CHRYSE)	2.41
Benzo(a)Anthracene	(BANNTHR)	2.01
Benzo(b)Fluoranthene	(BBFLANT)	1.49
Benzo(k)Fluoranthene	(BKFLANT)	1.36
Benzo(a)Pyrene	(BAPYRE)	2.54
Indeno(1,2,3-CD)Pyrene	(I123PYR)	1.14
Dibenzo(A,H)Anthracene	(DBAHANT)	0.310
Benzo(G,H,I)Perylene	(BGHIPY)	0.995
2-Methylnaphthalene	(2MeNAPH)	20.6
Total Recoverable Petroleum Hydrocarbons	(TRPH)	220

Method and Material

Flux chamber

Laboratory investigations were conducted using VOC flux chambers designed by personnel at Louisiana State University and constructed at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS, (Figure F1) (Valsaraj et al. 1997; Price et al. 1997).[1] The two-piece anodized aluminum chambers are devised to hold sediment at a depth of 10 cm with a surface area of 375 cm^2. The top portions of the chambers contain channels designed to distribute airflow uniformly across the sediment surface. A glass window in the top portion of the chamber is provided to allow for visual monitoring of the sediment surface. The chambers were sealed with an O-ring and threaded fasteners for an airtight fit. Sediment moisture content was measured prior to and following the test.

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[1] Reference information is presented at the end of Appendix F.

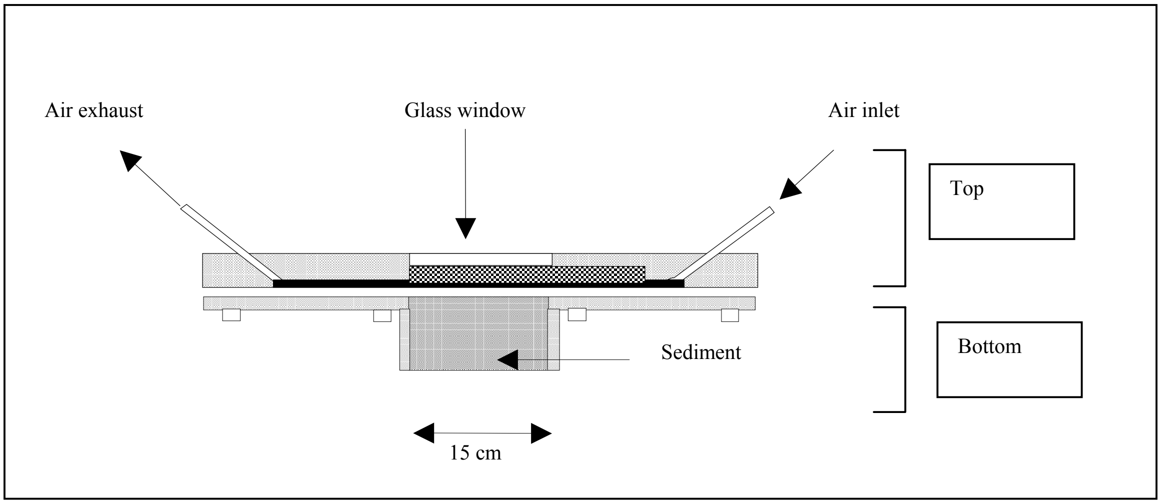

Figure F1. Laboratory flux chamber

Experimental design

Flux chambers were filled with a known volume (~6 grams by wet weight) of Appomattox River sediment and sealed. Air was passed over the sediment surface at 1.7 L/min. This rate was used based upon earlier investigations conducted with flow rates in the flux chamber (Valsaraj et al. 1997). The flow rate was chosen to eliminate fluxes controlled by airside resistance, thereby maximizing contaminant fluxes that are sediment-side controlled. Increasing the flow rate past 1.7 L/min did not result in increased flux rates, signifying that sediment-side resistance became the controlling factor. If airside resistance dominates, fluxes would be low and at a constant rate; whereas, sediment-side resistance fluxes show high initial values (maximum flux) followed by steady decreases as sediment-side diffusion takes over. At this stage, increases in airflow rate would not affect contaminant flux. The relative humidity of the air passing over the sediment in the chambers was controlled and maintained by using an in-line bubble trap as needed. A thermohygrometer (Cole Parmer, IL) was connected to the exit port to monitor air temperature and relative air humidity.

Contaminant specific sampling tubes (Supelco Inc., PA) were attached to the chamber exit ports. PAHs and TRPHs were trapped on XAD-2 glass sampling tubes (Orbo-44), and analyses were conducted according to U.S. Environmental Protection Agency (USEPA) method 8270 (USEPA 1982). Ammonia was trapped on H_2SO_4-coated silica gel (Orbo 554) and analyzed according to OSHA method 6015.

The experiments were designed to provide information on maximum contaminant fluxes expected upon initial disposal and under different air humidity and sediment moisture conditions. The sample schedule consisted of three continuous runs simulating various conditions. Run 1 was designed to give maximum initial fluxes from wet sediment during dredging and disposal operations. Dry air was passed over the sediment surface for a period of 10 days until visual monitoring of the sediment surface revealed a drying front across the sediment. Samples were taken 6, 24, 72 hr, 7 and 10 days after dry air was applied over the sediment surface. Run 2 gives maximum fluxes during a humid air event from the sediment after surface drying has taken place. The dry air was changed to humid air for this run, and samples were taken 6, 24, 72 hr and 7 days after air was applied across the sediment. Run 3 was designed to give maximum fluxes after a rain event. Water was added to the chambers to bring the sediment back to original moisture content or as nearly as possible, and dry air was again applied with samples being taken at 6, 24, 72 hr and 7 days.

Results and Discussion

PAH fluxes

The majority of hydrocarbon fluxes reached a peak emission rate 24 hr after addition of dry air over the sediment surface (Figures F2 and F3). The only exception was for pyrene, a low volatile compound, where emissions peaked 72 hr after application of dry air over the sediment surface. No increase in hydrocarbon flux rates was noted when humid air was passed over the sediment in Run 2 as experienced in earlier investigations with laboratory-spiked sediment (Valsaraj et al. 1997) and experiments conducted with New York Harbor dredged material (Price et al. 1998). The sorptive capacity of sediments is strongly affected by sediment moisture; decreasing sediment moisture results in increased sediment sorptive capacity (Valsaraj and Thibodeaux 1988). The capacity of the surface sediment layer for contaminants should therefore be higher than the deeper layers. When the sediment surface is dry, there is little competition for adsorption sites for organics on the surface since the moisture content of the carrier air is zero. Application of humid air would result in the water molecules in the air displacing the sorbed PAHs from the sediment surface and hence increases in fluxes are seen. This behavior was not noted in these investigations and is possibly a result of the lack of decrease in sediment moisture during the test. Visual observations during Run 1 indicated a drying layer at the sediment surface by day 10. However, sediment moisture fluxes, which were monitored during the course of the test, showed no decrease in relative humidity, which would account for the lack of an increase in flux rates when humid air was passed over the sediment. These results are similar to those seen in studies conducted with sediment from the Grand Calumet River and Indiana Harbor Canal (Price et al. 1999; Ravikrishna et al. 1998; Valsaraj et al. 1999). Naphthalene, 2-Methylnaphthalene, and Acenaphthene showed the highest 24-hr volatilization rates of 15.3, 13.5, and 19.6 ng/cm^2/hr, respectively. All other detectable PAH compounds showed initial volatilization rates of less than 12 ng/cm^2/hr (Table F2). Ten (10) days after application of dry air over the sediment surface, all hydrocarbon fluxes were below 0.3 ng/cm^2/hr or were below detection limits (Table F2).

Emission trends during these investigations indicated that PAH fluxes were highest during the initial exposure stages after disposal. Increased relative air humidity or sediment moisture would not result in increased emissions.

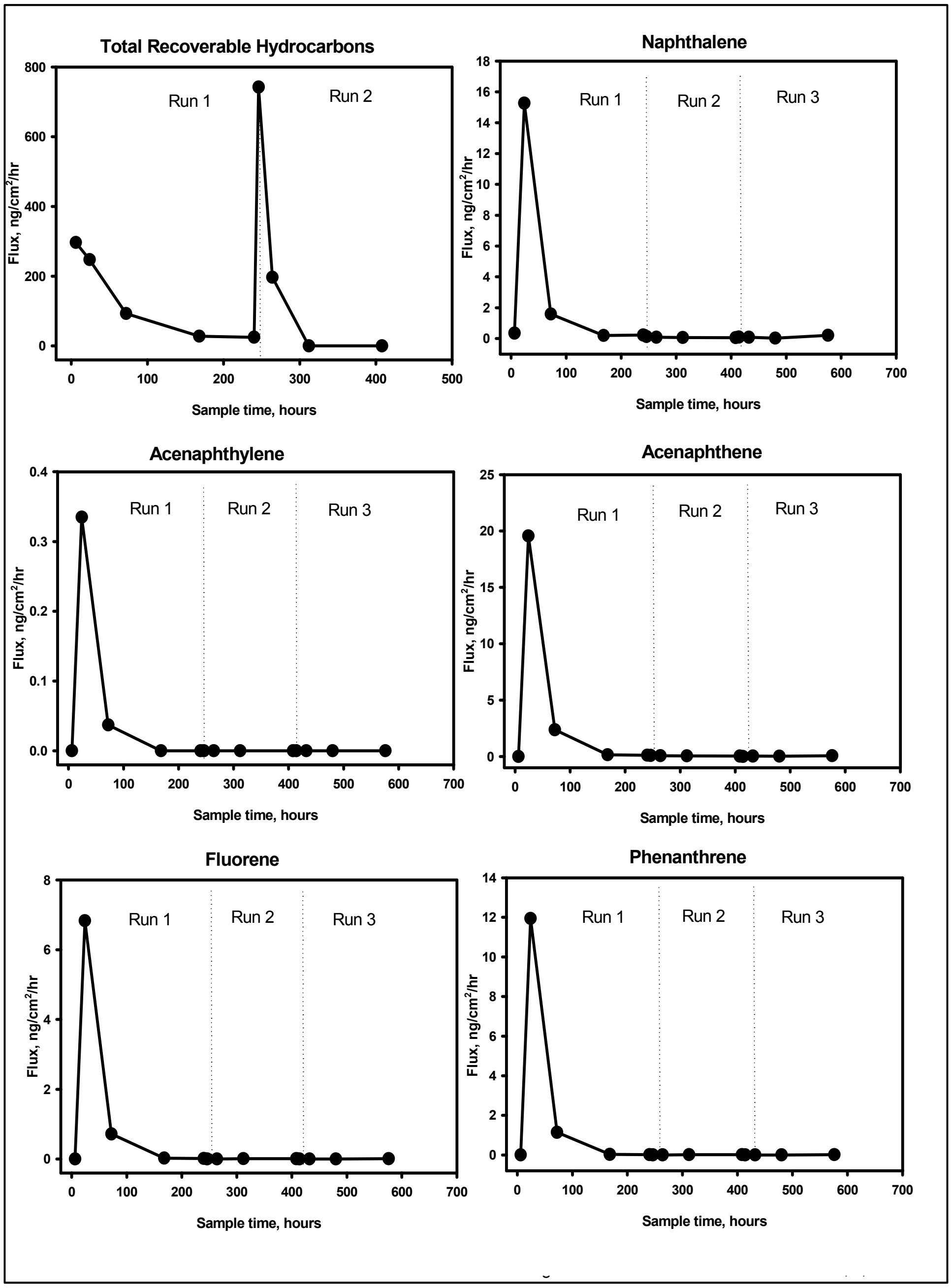

Figure F2. TRPH and PAH fluxes

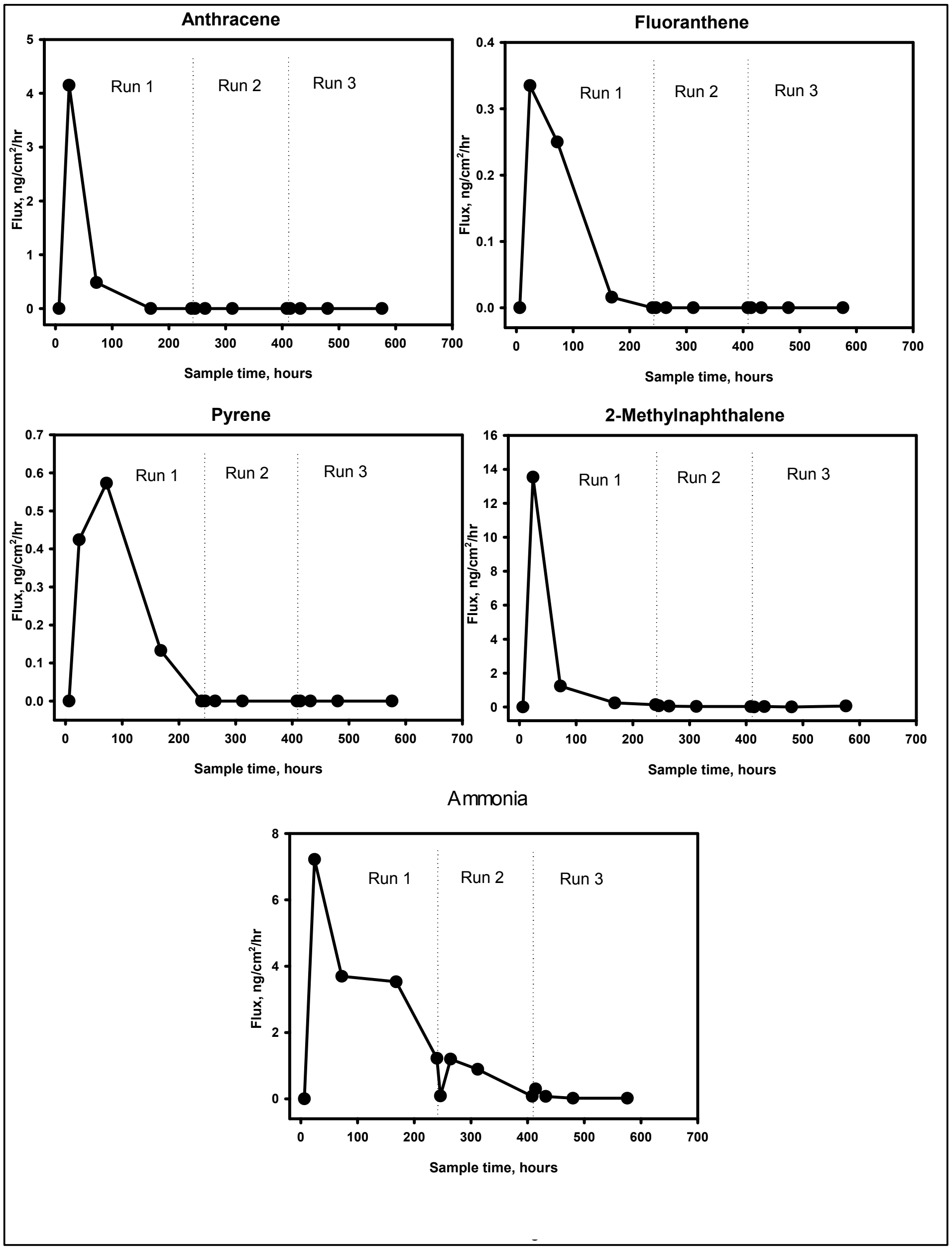

Figure F3. PAHs and ammonia fluxes

Total recoverable hydrocarbon emissions

The TRPH flux rate decreased from 296 to 25 ng/cm^2/hr in 240 hr followed by an increase in rate to 742 ng/cm^2/hr upon application of humid air (Table F2 and Figure F2). During Run 1, water loss from the surface would create a drier surface layer, which would have a higher sorption capacity for the compounds. The increase in relative humidity would result in an increase in contaminant pore-air concentration and water would displace the sorbed TRPHs from the sediment surface. The response to humid air by TRPH fluxes indicates that the

Table F2
TRPH and PAHs Fluxes (ng/cm^2/hr) for Appomattox River Sediment

Time	TRPH	NAPHTH	ACENAY	ACENAP	FLUORE	PHENAN	ANTRAC	FLANTHE	PYRENE
Run 1. (Dry air over wet sediment surface)									
6 hours	296	0.351	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
24 hours	247	15.3	0.335	19.6	6.83	11.9	4.15	0.335	0.424
72 hours	92.8	1.59	0.037	2.36	0.716	1.14	0.482	0.25	0.573
7 days	27.8	0.120	<1.0	0.149	0.026	0.023	<1.0	0.016	0.133
10 days	24.7	0.225	<1.0	0.101	0.016	0.011	<1.0	<1.0	<1.0
Run 2. (Humid air over dry sediment surface)									
6 hours	742	0.124	<1.0	0.080	<1.0	<1.0	<1.0	<1.0	<1.0
24 hours	197	0.079	<1.0	0.059	<1.0	<1.0	<1.0	<1.0	<1.0
72 hours	<330	0.068	<1.0	0.053	0.013	0.012	<1.0	<1.0	<1.0
7 days	<330	0.059	<1.0	0.032	0.0094	0.0094	<1.0	<1.0	<1.0
Run 3. (Dry air over wet sediment surface (after rewetting))									
6 hours	<330	0.089	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
24 hours	99.3	0.079	<1.0	0.033	<1.0	<1.0	<1.0	<1.0	<1.0
72 hours	<330	0.028	<1.0	0.017	<1.0	<1.0	<1.0	<1.0	<1.0
7 days	<330	0.209	<1.0	0.059	0.0094	0.0086	<1.0	<1.0	<1.0

Time	CHRYSE	BAANTHR	BBFLANT	BKFLANT	BAPYRE	I123PYR	DBAHANT	BGHIPY	2MeNAPH
Run 1. (Dry air over wet sediment surface)									
6 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
24 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	13.5
72 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.23
7 days	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.246
10 days	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.145
Run 2. (Humid air over dry sediment surface)									
6 hours	0.16	0.143	0.173	0.191	0.200	0.116	<1.0	0.084	0.076
24 hours	<1.0	<1.0	0.030	0.102	0.036	<1.0	<1.0	<1.0	0.049
72 hours	<1.0	<1.0	0.011	0.013	0.012	<1.0	<1.0	<1.0	0.040
7 days	<1.0	<1.0	<1.0	0	0.0056	<1.0	<1.0	<1.0	0.031
Run 3. (Dry air over wet sediment surface (after rewetting))									
6 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
24 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.030
72 hours	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.011
7 days	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.067

change in relative humidity of the carrier air in Run 2 decreased the sediment sorptive capacity for TRPHs, allowing for increased volatilization. The increased flux suggests that factors affecting volatilization of TRPHs differ fundamentally from those affecting PAHs. The higher initial flux in Run 2 as compared to Run 1 is probably a result of the release of petroleum hydrocarbons, which had diffused to the surface and were being held in the drier top surface layer until being displaced by the humidity in the air. Rewetting the sediment resulted in a slight increase in emissions followed by a rapid decrease to below detection limits (Figure F2). The increased emissions as a result of increases in air and sediment moisture are similar to results seen in previous investigations conducted with Indian Harbor Canal and Grand Calumet River sediments; where TRPH fluxes increased to initial emissions under identical experimental conditions (Price et al. 1999).

Ammonia fluxes

Ammonia fluxes exhibited an initial increase in flux rate to 7.21 ng/cm^2/hr following 24 hr of application of dry air over the sediment surface in Run 1. Emission rates decreased to 1.22 ng/cm^2/hr in 10 days (Table F3 and Figure F3). Table F3 shows ammonia emissions increased slightly with increased relative air humidity and sediment moisture content, followed by a rapid decrease in emissions to less than 1.0 ng/cm^2/hr. These data indicate that ammonia fluxes will be highest during initial sediment exposure stages.

Table F3
Ammonia Flux (ng/cm^2/hr) for Appomattox River Sediment

Sample Time	Ammonia
Run 1. (Dry air over wet sediment surface)	
6 hours	<0.0004
24 hours	7.21
72 hours	3.69
7 days	3.53
10 days	1.22
Run 2. (Humid air over dry sediment surface)	
6 hours	0.089
24 hours	1.2
72 hours	0.889
7 days	0.078
Run 3. (Dry air over sediment after rewetting)	
6 hours	0.297
24 hours	0.074
72 hours	0.016
7 days	0.019

Conclusions

Results of these investigations reveal that the highest contaminant fluxes will occur with initial loading of the sediment. Results imply that changes in relative air humidity or sediment moisture will not result in an increase in emissions for the majority of compounds of interest. These flux trends are consistent with trends observed in earlier studies conducted with Indian Harbor Canal and Grand Calumet River sediments (Price et al. 1998, 1999, and Ravikrishna et al. 1998).

Flux rates for PAHs will be highest during initial sediment exposure (after placement). Changes in relative air humidity or sediment moisture following a rainfall will not result in increased fluxes. TRPH fluxes will be highest during initial exposure changes and increases in relative air humidity. Sediment moisture will result in increased emissions for a short period. Ammonium fluxes will be highest during initial exposure stages.

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Appendix G
Environmental Dredging Case Studies

Project: Bayou Bonfouca
Slidell, Louisiana

Major Contaminant: PAHs

Receiving Water Body: Lake Pontchartrain

Site Description: Contaminated sediment found from 2.6 to 17 ft[1] thick along 4,000-ft-long stretch of the bayou. Very shallow with standing water.

Statement of Problem: Designated as a Superfund site from former wood treating facility. Observed impact to fish; posted fish consumption advisories, but partially rescinded in 1998.

Removed Volume: 169,000 cubic yards (cy)

Project Design and Implemented Remedy: Wet excavation using a mechanical custom-designed crane-mounted clamshell buckets on a barge. Material was pipelined to a holding pond then to an onsite incineration system. Leftover ash was placed in an onsite landfill. Full-scale remediation of the 4,000-ft-long project area.

Problem Encountered: Sheet-pile walls surrounding the areas were left in place to minimize disturbance of sediments and house foundation.

Factors Influencing Outcome: Sheet-pile walls surrounding the area were left in place to minimize disturbance of sediments and house foundations.

Lessons Learned: The incineration costs were hugely expensive and the majority of the $55 million costs was dredging ($125/cy). Adequate sediment investigation accurately defined volume of contaminated materials and site conditions prior to remediation.

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[1] A table for converting non-SI units of measurement to SI units is presented on page x.

Project: Black River
Northwest Ohio

Major Contaminant: PAHs

Receiving Water Body: Southern Lake Erie

Site Description: Freshwater tributary to Southern Lake Erie.

Statement of Problem: Designated as a Great Lakes area of concerns (AOC) from former steel facility and effluent waste. Observed impact in aquatic organisms. Fish consumption advisories rescinded in 1997.

Removed Volume: 49,700 cy

Project Design and Implemented Remedy: Wet excavation using a mechanical clamshell bucket and hydraulic cutterhead dredge. Material was placed into an onsite CDF and capped. Full-scale remediation of study area.

Problem Encountered: Switched to a cutterhead dredge when bucket could not close from presence of debris.

Factors Influencing Outcome: Dredged to hard bottom. Switched to a cutterhead dredge when bucket could not close from presence of debris.

Lessons Learned: Although PAH concentrations postproject were similar to baseline levels (after plant closure) the incidence of fish liver tumors were <1 percent after dredging compared to 32 percent prior to dredging (but after plant closure). Fish consumption advisories lifted.

Project: Collingwood Harbour
Ontario, Canada

Major Contaminant: Copper

Receiving Water Body: Lake Huron

Site Description: Dredge area is 2.45 acres surrounded by wetlands and shipyards. Shallow water and soft silts (2 ft thick) over the clay bedrock.

Statement of Problem: Soft surface sediments exceeded Ontario's chemical guidelines for protection of sediment quality. Moderately contaminated, but no open water disposal.

Removed Volume: 3,896 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic Pneuma airlift pump. Material was pipelined to an onshore CDF. Dredged the contaminated surficial soft silt overlying a blue clay layer. Full-scale remediation of project area after an initial pilot study was conducted.

Problem Encountered: Large debris would plug the Pneuma pump cylinder

Factors Influencing Outcome: Large debris would plug the Pneuma pump cylinder

Lessons Learned: A pilot study was useful in predicting dredging effectiveness. Site was delisted.

Project: Ford Outfall/River Raisin
Monroe, Michigan

Major Contaminant: PCBs

Receiving Water Body: River Raisin to Lake Erie

Site Description: The hotspot around Ford Outfall is located within the larger River Raisin AOC. It is moderately sloped down to the main navigation channel with very soft silt (2 ft thick) over stiff clay (9 ft thick) over hardpan.

Statement of Problem: Designated as a Great Lakes AOC from motor plant industrial discharges. Observed impact to sediments and biota; posted fish consumption advisories. Emergency Superfund removal for source control of hotspot.

Removed Volume: 28,500 cy

Project Design and Implemented Remedy: Wet excavation using mechanical closed clamshell buckets with a barge and scow. Material was treated and transported to an onsite CDF. This was a focused removal project of hotspot sediments near the Ford Outfall. Cleanup criteria designed to be protective of biota. Remedy of the River Raisin is planned.

Problem Encountered: Passing cargo vessel generated prop wash and disturbed silt curtains. Sediment resuspension/settling on top of hardpan.

Factors Influencing Outcome: Passing cargo vessel disturbed silt curtains. Mechanical Cable Arm dredged below depth of navigational channel resulting in side slope sloughing. Sediment resuspension/settling on top of hardpan.

Lessons Learned: Dredged to hardpan/bedrock. Eighty percent of dredge cells met chemical criteria. Need to look at design depths relative to surrounding elevations and the potential for sloughing/recontamination of dredge area.

Project: Fox River Deposit N
Kimberly, Wisconsin

Major Contaminant: PCBs

Receiving Water Body: Fox River to Green Bay

Site Description: The hotspot deposit is contained with the larger 28-mile Fox River AOC. Dredge area is 3 acres, avg. 8-ft water depth, and 3-ft-thick soft sediments over bedrock.

Statement of Problem: Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.

Removed Volume: 8,175 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic cutterhead dredge. Material pipelined to an onsite treatment area. Dewatered material transported to offsite landfills. Only a pilot demonstration project to assist selection of remedial technologies for Lower Fox River project.

Problem Encountered: Winter shutdown conditions

Factors Influencing Outcome: Target goal was to dredge down to within 3 in. of bedrock.

Lessons Learned: Development of realistic target goals helped maximize achievement of risk reduction for a reasonable cost.

Project: Fox River SMU 56/57
Wisconsin

Major Contaminant: PCBs

Receiving Water Body: Fox River to Green Bay

Site Description: The demonstration project is contained within the larger 28-mile Fox River AOC. Dredge area is 9 acres, avg. water depth 2 to 14 ft, and avg. 10-ft soft sediment over clay.

Statement of Problem: Designated as a Great Lakes AOC from paper mill discharges. Observed impact to sediments and biota; posted fish consumption advisories.

Removed Volume: 31,346 cy

Project Design and Implemented Remedy: Wet excavation using hydraulic cutterhead and horizontal auger dredge. Material was dewatered and placed in offsite landfill. Was a demonstration project to gather information for Lower Fox River projects?

Problem Encountered: Winter shutdown conditions.

Factors Influencing Outcome: Demobilized from site before reaching target depth from onset of winter conditions. Actual sediment removal rates were one-third of targeted goal.

Lessons Learned: Elevated surface sediment verification samples were the result of incomplete dredging (did not reach target depth below PCB hotspot).

Project: GM Foundry/St. Lawrence River
Massena, New York

Major Contaminant: PCBs

Receiving Water Body: St. Lawrence River

Site Description: Entire study area includes 62,000 cy of sediments from the St. Lawrence River, Raquette River, and Turtle Cove. This focused St. Lawrence River project dredged approx. 13,800 cy (11 acres) located on a shallow shelf of the St. Lawrence River consisting of soft silt/sand over hardpan. Remediation of the Raquette River and Turtle Cove are planned.

Statement of Problem: Designated as a Superfund site from industrial discharges. Observed impacts to sediment and biota; posted fish consumption advisories.

Removed Volume: 13,800 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic horizontal auger dredge (dry excavation of nearshore areas). Boulders and debris were excavated before dredging. Material was pipelined to a settling basin and stored temporarily. Treated material will be sent to an on/offsite CDF depending upon the levels. Turtle Cove was not dredged; possible continued source. Full-scale remediation project of the St. Lawrence AOC. Remediation of Raquette River and Turtle Cove discussed in 1999 Record of Decision. Capped residuals.

Problem Encountered: River currents required switch from silt curtains to sheet-pile walls. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove.

Factors Influencing Outcome: River currents required switch from silt curtains to sheet-pile walls. The silt curtain was poorly designed for river conditions, may have been implementable with different design. A sand cap was required over Quadrant 3 from elevated residual concentrations. No permission to access Turtle Cove. Dredged to hardpan.

Lessons Learned: Despite multiple attempts, elevated concentrations remained in Quadrant 3 requiring a sediment cap. PCB contaminant in the underlying glacial till was suspected. Other quadrants (5 of 6) averaged 5 ppm PCBs postproject (10-fold reduction) but did not achieve target goal of 1 ppm PCBs.

Project: Grasse River
Massena, New York (pilot)

Major Contaminant: PCBs

Receiving Water Body: St. Lawrence River

Site Description: Entire study area (AOC) encompasses an 8.5-mile stretch of river. The pilot dredge project was a hotspot of approximately 1 acre, with water depths of 2 to 14 ft within a larger study area. Substrate consists of soft sediment with loose cobbles over hardpan.

Statement of Problem: Designated as voluntary cleanup by ALCOA under Superfund from aluminum plant discharges. Sediments determined as unacceptable risk to environment. Posted fish consumption advisories.

Removed Volume: 3,175 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic auger dredge (dry excavation around ALCOA outfall). Boulders were excavated prior to dredging. Material was dewatered and transferred to an upland landfill. Voluntary dredge cleanup project of hotspot area around outfall by ALCOA (25 percent of total mass).

Problem Encountered: 550 cy of sediment left in place because of boulders and cobbles. The extent of these materials was not anticipated. Silt curtain switched from screws to bottom weights.

Factors Influencing Outcome: 550 CY of sediment left in place because of boulders and cobbles. The extent of these materials was not anticipated. Silt curtain switched from screws to bottom weights.

Lessons Learned: Horizontal auger did not work well with cobbles. Caged fish located along/outside the perimeter of contaminant system showed elevated PCBs during dredging, but significantly reduced immediately postproject.

Project: Lake Jarnsjon
Sweden

Major Contaminant: PCBs

Receiving Water Body: Eman River to Baltic Sea

Site Description: Entire study area (and dredge area) is a shallow 63-acre lake located along the Eman River (5-to 8-ft depth). Contamination was found across the lake in soft sediments up to 6 ft thick.

Statement of Problem: The Swedish EPA designated the lake as a continuing source of contamination to the river sediments from historic paper mills and other industries. Sediments were an unacceptable risk to aquatic organisms.

Removed Volume: 157,000 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic auger dredge and mechanical bucket for denser material. Material was dewatered and placed in nearby landfill. Full-scale remediation of lake sediments.

Problem Encountered: Pockets of dense sand and gravel required switch of dredge equipment.

Factors Influencing Outcome: Pockets of dense sand and gravel required switch of dredge equipment (from auger to bucket). Higher sand content required addition of more water for the suction dredge (lower percent solids). Designed 0.5 ft of overdredging.

Lessons Learned: Not available

Project: Manistique River
Manistique, Michigan

Major Contaminant: PCBs

Receiving Water Body: Lake Michigan

Site Description: Entire study area extends 1.7 miles of river and a 97-acre harbor. Dredge area was a 15-acre hotspot in the harbor and several nearshore areas of the river in water depths of 15 to 20 ft.

Statement of Problem: Designated as a Superfund site from paper mills and other industrial discharges. Observed impact to fish; posted fish consumption advisories.

Removed Volume: 120,000 cy

Project Design and Implemented Remedy: Wet excavation using hydraulic cutterhead dredges customized for the project. Material was pipelined to onsite treatment and settling tanks, then transported to offsite landfills. Full-scale remediation to 95 percent mass removal of sediments above chemical criteria.

Problem Encountered: Many site conditions compromised implementation: buried slab-wood and debris, winter weather and wind, and excavation to bedrock.

Factors Influencing Outcome: Many site conditions compromised implementation: Buried slab-wood and debris, winter weather and wind, and excavation to bedrock.

Lessons Learned: Repeated dredging to remove residuals on bedrock.

Project: Marathon Battery
Massena, New York (Areas I and III)

Major Contaminant: Cadmium

Receiving Water Body: Hudson River

Site Description: Entire study area includes 340 acres of marshes and tidal flats, and over 200 acres of coves designated in three operable units. Areas are very shallow (5-ft depth) and tidally influenced. Substrate is soft clay (1 ft thick) over clayey hardpan.

Statement of Problem: Designated as a Superfund site from battery manufacturing discharges. Observed impact to sediments and biota; posted fish consumption advisories.

Removed Volume: 100,200 cy

Project Design and Implemented Remedy: Wet excavation of coves and ponds using a hydraulic horizontal auger and mechanical clamshell dredges (dry excavation of marshes). Material was placed in an onsite settling basin, fixated, and then transported to offsite landfills. Full-scale remediation to 95 percent mass removal of sediment above chemical criteria.

Problem Encountered: Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.

Factors Influencing Outcome: Coarse sand and gravel required switch to clamshell bucket. Tidal conditions slowed progress.

Lessons Learned: Discrete samples exceeded chemical criteria, however, the average concentrations met target goals. Background concentrations were 10 ppm.

Project: New Bedford Harbor
Bristol County, Massachusetts

Major Contaminant: PCBs

Receiving Water Body: Buzzards Bay

Site Description: Entire study area includes 17,950 acres of Acushnet River, upper and lower harbor, and Buzzards Bay sediments. The dredge area was a 5-acre hotspot removal project in the upper harbor. Substrate consists of soft sandy silt up to 4 ft thick.

Statement of Problem: Designated as a Superfund site from electronics manufacturing discharges. Observed impacts to sediments and biota; posted fish consumption advisories.

Removed Volume: 14,000 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic cutterhead dredge. Material pipelined 1 mile to a temporary CDF. Only a partial mass removal project of upstream sediments (45 percent) to control ongoing source and prevents downstream transport during storm events. Modeled for the most benefit for the least cost. Remediation of lower harbor and Buzzards Bay planned.

Problem Encountered: Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains.

Factors Influencing Outcome: Submerged power lines prevented access to a few areas. Tides/currents compromised silt curtains. Sampled the upper 2-cm for verification.

Lessons Learned: Designated as a mass removal project for source control (remove sediments >4,000 ppm PCBs) to prevent downstream transport. Target goal selected based on cost/benefit analysis. Target goal easily achieved.

Project: Port of Portland T4 Pencil Pitch
Portland, Oregon

Major Contaminant: PAHs

Receiving Water Body: Willamette River to Columbia River

Site Description: Terminal 4 is an active port facility along the shorelines of the Willamette River. Area is acquiescent with limited disturbance from currents. Dredge area was in Slip 3 and under pier areas, with pencil pitch contained within the upper 15 cm.

Statement of Problem: Designated for cleanup as source control from off-loading spills of pencil pitches (coal tar) from vessels. Observed sediment concentrations and toxicity above state standards. Entire River is an AOC and currently under investigation; posted fish consumption advisories.

Removed Volume: 35,000 cy

Project Design and Implemented Remedy: Wet excavation using shrouded clamshell bucket and bottom-dump scows. Nearshore areas excavated with airlift pump. Material transported to an in-water CDF. Capping not considered. Full-scale remediation to 100 percent mass removal of spilled pencil pitch (coal tar).

Problem Encountered: Difficult to access and dredge underpier and riprapped areas.

Factors Influencing Outcome: Difficult to access and dredge underpier and riprapped areas. Combined with navigational dredge project. Designed for 1 ft of overdredging.

Lessons Learned: Even with overdredging designed into project, exceeded chemical criteria in most cells, likely because of contaminated nondredged areas.

Project: Port of Vancouver Copper Spill
Vancouver, Washington

Major Contaminant: Copper

Receiving Water Body: Columbia River

Site Description: Dredge area covers 0.8 acre along the shore slopes of the river in 5 to 40 ft of water. Substrate consists of slightly silty sand with contamination contained in the upper 18 cm.

Statement of Problem: Designated for cleanup as source control from copper spill associated with off-loading activities. Observed sediment concentrations and toxicity above state standards. Posted fish consumption advisories for Lower River.

Removed Volume: 5,000 cy

Project Design and Implemented Remedy: Wet excavation using a hydraulic cutterhead dredge, with diver assistance in underpeir areas. Material pipelined to an onsite settling pond then transported to disposal sites located on port property. Full-scale remediation project of 100 percent mass removal to eliminate source (spilled copper).

Problem Encountered: The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind.

Factors Influencing Outcome: The heavier weight of copper concentrate prevented complete entrainment by dredge. Residuals redeposited and left behind. Designed 0.5-ft overdredging. No silt curtains installed because of deep water.

Lessons Learned: The postproject concentration averaged among all dredge cells met the 1,300 ppm copper chemical criteria, although some discrete dredge cell measurements exceeded 1,300 ppm.

Project: Puget Sound Naval Shipyard Pier D
Bremerton, Washington

Major Contaminant: PAHs, PCBs

Receiving Water Body: Sinclair Inlet to Puget Sound

Site Description: Dredge project area is approx. 7.2 acres to 9-ft depth below mudline in 43 ft of water. Substrate consists of soft silt and sand over dense sand (no hardpan). Area is tidally influenced with weak tidal currents.

Statement of Problem: Project area designated for cleanup under MTCA and CERCLA from shipyard construction activities. Selected sediments within the operable unit needed immediate removal to expand vessel draft depths; however, sediment concentrations and toxicity measured above state standards.

Removed Volume: 105,000 cy

Project Design and Implemented Remedy: Wet excavation using clamshell buckets and dump scows. Material transported to either open-water disposal or offsite landfill. Only a partial cleanup of larger study area implemented by need to increase navigational depths near berths.

Problem Encountered: None specified.

Factors Influencing Outcome: Designed 1 ft of overdredging.

Lessons Learned: Combined navigational and source control dredging project. Chemical criteria were not met in numerous dredge cells, suspect recontamination from areas not dredged but in the AOC.

Project: Sheboygan River and Harbor
Sheboygan Falls, Wisconsin (pilot)

Major Contaminant: PCBs

Receiving Water Body: Lake Michigan

Site Description: Entire study area includes 13 miles of upper, lower, and middle river sections and the harbor. Dredge area encompassed 18 small hotspots in the upper river section with avg. water depth of 2 to 4 ft.

Statement of Problem: Designated as a Superfund site from die-casting and other activities. Observed impact to sediments and biota; posted fish consumption advisories.

Removed Volume: 3,800 cy

Project Design and Implemented Remedy: Wet excavation of 18 hotspots using clamshell buckets and land-based backhoes. Material placed in onsite CTF, some hotspots capped. A pilot study with main objective to assist future selection of full-scale remedial alternatives. Mass removal of hotspot sediments above 686 ppm PCBs. Also placed a pilot cap.

Problem Encountered: Winter shutdown and strong currents. Very shallow area required backhoes. Restricted permission to access areas from shoreline residents.

Factors Influencing Outcome: Winter shutdown and strong currents. Very shallow area required backhoes. Strong currents toppled the silt curtains. Access restrictions from shoreline residents. A pilot cap was placed over residuals in hotspot areas (designed into project).

Lessons Learned: Sediment probing techniques used to assess sediment thickness underestimated actual volumes of material requiring removal. Dredge equipment was versatile and mobile.

Project: Sitcum Waterway Commencement Bay/Nearshore Tideflats
Tacoma, Washington

Major Contaminant: Arsenic

Receiving Water Body: Commencement Bay to Puget Sound

Site Description: Project area is 52 acres with avg. water depth of 25 ft. Substrate consists of soft silty sand with renewed deposition from Puyallup River. Area is tidally influenced.

Statement of Problem: Designated a problem area within the Commencement Bay/Nearshore Tideflat Superfund Site from multiple sources. Observed impact to sediments and biota; posted fish consumption advisories. Remedy was a partial cleanup and navigational dredging project.

Removed Volume: 425,000 cy

Project Design and Implemented Remedy: Wet excavation using hydraulic cutterhead dredges and clamshell buckets for specialized areas. Material placed in an onsite, nearshore CDF used to expand port facilities. Full-scale remediation of waterway combined with a navigational dredge project caused by rapid sedimentation.

Problem Encountered: Significant debris on underpier armored slopes. Tide swings required horizontal and vertical control maintenance.

Factors Influencing Outcome: Tide swings required horizontal and vertical control maintenance. Combined with a navigational project. Designed 1-ft overdredging.

Lessons Learned: Underpier areas had significant debris, cables, concrete, and boulders, which proved difficult to access and dredge effectively.

Project: Waukegan Harbor/Outboard Marine
Waukegan, Illinois (Upper Harbor)

Major Contaminant: PCBs

Receiving Water Body: Lake Michigan

Site Description: The harbor is approx. 37 acres with avg. water depths of 14 to 25 ft. A 20-ft sheet-pile wall surrounds the harbor. Substrate consists of soft silt (7 ft thick) over sand (4 ft thick) over hardpan.

Statement of Problem: Designated as a Great Lakes AOC from die-casting discharges. Observed impact to sediments, biota, and community structure. Fish consumption advisories rescinded in 1996.

Removed Volume: 38,300 cy

Project Design and Implemented Remedy: Wet excavation using hydraulic cutterhead dredge. Material <500 ppm placed directly in nearshore CDF located over the area of highest contamination (Slip3) minimizing volume requiring excavation. Material >500 ppm stabilized then returned to containment cell. Full-scale remediation of upper harbor.

Problem Encountered: Activities halted during boating season. CDF required 2 years to consolidate before closure.

Factors Influencing Outcome: Activities halted during boating season. Slip 3 sediments (<500 ppm) were left in place. (CAD site). CDF required 2 years to consolidate before closure.

Lessons Learned: Additional baseline sediment data needed (right before sampling) for comparison to postproject samples. Fish tissue samples collected yearly (although few samples) and variability is high.

Project: Wyckoff/West Eagle Harbor Operable Unit
Bainbridge Island, Washington (OU-3)

Major Contaminant: Mercury

Receiving Water Body: Puget Sound

Site Description: Entire study area is a marine embayment of three operable units totaling 500 acres and avg. water depths of 10 to 20 ft. Dredge area for OU-3 included tidally-influenced soft silt to gravelly sand with buried timber piles (minimal currents). OU-2 was capped.

Statement of Problem: Designated as a Superfund site from historical shipbuilding and wood treatment activities. Observed impacts to sediment and biota; posted fish consumption advisories.

Removed Volume: 3,650 cy

Project Design and Implemented Remedy: Wet excavation using clamshell buckets and backhoes for underpier areas. Dredged material barged to onsite CDF used to expand ferry terminal facilities. Capped remaining sediments below state cleanup criteria, but still had exposure risk. Cap used to enhance natural recovery. Full-scale remediation of OU-3.

Problem Encountered: Tide swings sloughed exposed sediment; armored areas for protection.

Factors Influencing Outcome: Design plan called for capping of nondredged areas for enhanced natural recovery. Designed 1 ft overdredging. Tide swings sloughed exposed sediment, armored areas for protection.

Lessons Learned: Compliance with state sediment management standards chemical criteria is assumed to be protective of the benthic community based on Apparent Effects Thresholds tests.

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14. ABSTRACT

This report documents Phases I and II to evaluate the testing and analysis of upland disposal of dredged material from the Appomattox River, Petersburg, VA. Phase I of this study evaluated the environmental and engineering effect of dredging and placing the Appomattox River sediment in the proposed Puddledock site. Phase II of this study evaluated screening of potential contaminate release to atmosphere and evaluated environmental dredging case studies conducted by the U.S. Army Corps of Engineers. The Phase I 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. Phase II testing included tests that predict the potential emission release of volatiles during and after dredging.

Physical characterization included a number of geotechnical tests including grain-size analyses, 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

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15. SUBJECT TERMS

Animal uptake
Bioassay
Contaminant
Dredged material
Elutriate
Environmental dredging
Pathway testing
Plant uptake
Sediment
Settling behavior
Surface runoff

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procedure (SLRP) for runoff quality, diethylene triamine pentaacetic acid (DTPA) extraction for plant uptake, earthworm bioassay for animal uptake, and 96-hr elutriate bioassay for water column toxicity. Using characterization data, leachate quality was predicted based on equilibrium partitioning of the contaminants between the soil and water.

The results of Phases I and II show that disposal of Appomattox River dredged material is technically feasible. Disposal in the Puddledock site poses no significant impacts on human health. Potential contaminant releases by effluent, runoff, dredging, 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 Virginia toxicity standards but are similar to the contaminant concentrations in the background sediment and 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 the Puddledock site may colonize after flooding. The predicted levels of contaminants were below levels of concern and should not pose any significant adverse ecological effect. The water column downstream should be of little concerns during dredging operation because elutriate exposures of less than 50 percent (i.e., elutriates mixed with site water during dredging) did not adversely affect survival of the fathead minnows.