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September 1993

Management Plan for the Disposal of Contaminated Material in the Craney Island Dredged Material Management Area

by Tommy E. Myers, Anthony C. Gibson,
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Final report

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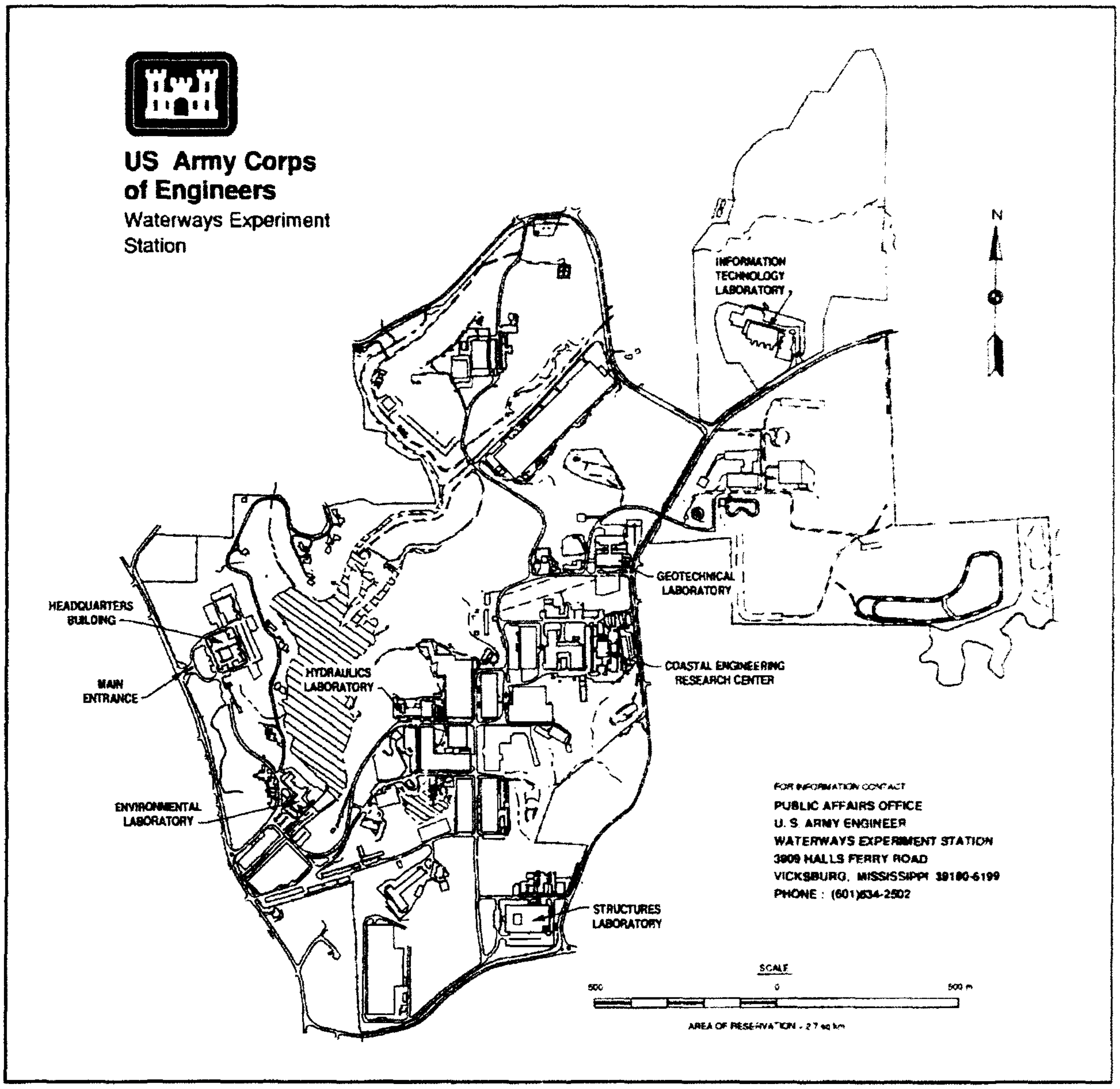

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Preface

The work described herein was conducted under Interdepartmental Purchase Request CA 91-3025 by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for the U.S. Army Engineer District, Norfolk, in support of the Craney Island Management Plan. Project tasks addressing the results of an investigation of the service life of the Craney Island Dredged Material Management Area (CIDMMA) (Chapter 2) and the Comprehensive Analysis of Migration Pathways (CAMP) (Chapter 3) are included in this document. In addition, an Introduction (Chapter 1) and Conclusions and Recommendations (Chapter 4) are also presented.

Chapter 2 presents the results of an investigation of the CIDMMA service life under the proposed Restricted Use Program to satisfy Task 1 of the Revised Scope of Work for the Norfolk District. The Restricted Use Program involves ocean disposal suitable material and the other material being placed in the CIDMMA. This chapter contains an assessment of the service of life of the CIDMMA because of its storage capacity using the microcomputer program PCDDF, Primary Consolidation and Desiccation of Dredged Fill. PCDDF performs simulations of consolidation and desiccation of dredged material for designing, maximizing, and managing the long-term storage capacity of confined dredged material disposal facilities. The results of the analysis indicate that the proposed Restricted Use Program will significantly extend the service life of the CIDMMA.

Research associated with Chapter 2 was performed under Contract No. DACW39-92-M-4901 between WES and Dr. Timothy D. Stark, Department of Civil Engineering, University of Illinois at Urbana-Champaign. Technical guidance at WES was provided by Dr. Jack Fowler, Geotechnical Laboratory, the contracting officer's representative. Dr. Stark supervised the analysis and prepared this chapter. Technical information was provided by Mr. M. T. Byrne, Norfolk District, and by Mr. D. A. Pezza, Chief, Geotechnical Branch, Norfolk District. Mr. Ivan Contreras, Graduate Research Assistant, University of Illinois at Urbana-Champaign, performed the analysis.

Chapter 3 describes a priori CAMP for the proposed Restricted Use Program at the CIDMMA. Mr. Tommy E. Myers, Environmental Restoration Branch, ERB, Environmental Engineering Division (EED), Environmental Laboratory (EL), WES, prepared this chapter to satisfy Tasks 2 through 4 of the Revised Scope of Work for the Norfolk District. Dr. Paul R. Schroeder, Environmental Applications Branch (EAB), EED, provided technical guidance for Hydrologic Evaluation of Landfill Performance (HELP) computer model simulations. Ms. Melody Currie assisted with tabular and graphical presentation of results.

This report was prepared by Mr. Myers, Dr. Stark, and Messrs. Anthony C. Gibson and Elba A. Dardeau, Jr., and Dr. Schroeder, EAB. Project manager and point of contact at the Norfolk District was Mr. Samuel E. McGee. Technical Reviews were provided by Drs. Michael R. Palermo, EED, and James M. Brannon, Environmental Processes and Effects Division, EL.

Work progressed under the general WES administrative supervision of Dr. John J. Ingram, Chief, EAB; Mr. Norman R. Francingues, Chief, ERB; Dr. Raymond L. Montgomery, Chief, EED; and Dr. John Harrison, Director, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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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	4046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
pounds (mass) per square foot	4.882428	kilograms per square meter
square feet	0.09290304	square meters
tons (force) per square foot	95.76052	kilopascals
tons (2,000 pounds mass)	907.1847	kilograms

1 Introduction

Background

At the request of the U.S. Army Engineer District, Norfolk, the U.S. Army Engineer Waterways Experiment Station (WES) developed the Craney Island Management Plan (CIMP) to extend the useful life of the Craney Island Dredged Material Management Area (CIDMMA). The CIDMMA is used for disposal of maintenance and new work dredged material from the project area. The initial goals of the CIMP included maximization of storage capacity by dewatering and densification of the confined dredged material and maintenance of an acceptable effluent water quality (Palermo, Shields, and Hayes 1981). Since that time, the management approach as recommended in the CIMP has been generally implemented. With current practices, the CIDMMA is expected to reach its ultimate capacity around the year 2000 (Palermo and Schaefer 1990). The useful life of the CIDMMA may, however, be extended if suitable material is barged to sea and unsuitable (i.e., contaminated) material is placed in the facility; thus, the Restricted Use Program was formulated. The Norfolk District has, therefore, requested that WES investigate the feasibility of the proposed Restricted Use Program for extending the useful life of the CIDMMA.

Objectives and Scope

The objectives of the work presented in this report were those addressed under Phase 1, Tasks 1 through 4 of the Revised Scope of Work, (WES 1992) as follows:

a. Investigate the service life of the CIDMMA under the proposed Restricted Use Program (Task 1).

b. Determine the contaminant losses that are expected to occur under the proposed Restricted Use Program, and then conduct a priori Comprehensive Analysis of Migration Pathways (CAMP) for the proposed Restricted Use Program (Tasks 2 through 4).

Task *a* was accomplished by assembling available geotechnical data, simulating the 1959-1992 disposal history under the proposed Restricted Use Program to use in the microcomputer program, Primary Consolidation and Desiccation of Dredged Fill (PCDDF). Once calibrated, PCDDF was used to estimate the service life of the CIDMMA under the proposed Restricted Use Program. Task *b* involved performance of a CAMP evaluation to estimate losses in the effluent during hydraulic disposal; losses in the leachate, volatile emission, and runoff following disposal; and losses by uptake and migration by plants and animals. The Hydrologic Evaluation of Landfill Performance (HELP) model was used to estimate leachate and runoff production.

Site Description

The CIDMMA is a 2,500-acre[1] confined dredged material disposal site located near Norfolk, VA. Plans for the site were developed in the early 1940s to provide a long-term disposal area for material dredged from the channels and ports in the Hampton Roads area. Hampton Roads, including the ports of Norfolk, Portsmouth, Chesapeake, Newport News, and Hampton, comprises Virginia's greatest port complex. Hampton Roads is generally recognized as the southernmost boundary of the Boston-New York-Washington industrial, commercial, residential, and recreational complex. Commercial, agricultural, and industrial development in the Hampton Roads area, along with the movement of naval vessels, is dependent upon maintaining project depths in the Hampton Roads channels. Prior to and during World War II, dredged material removed from these channels was primarily disposed of in open water sites. As these open water sites neared capacity at the end of the war, Congress authorized a study to determine a more permanent and lasting means for disposing of dredged material from the Hampton Roads area. As a result, development of the Craney Island Disposal Area was recommended and approved by Congress under the River and Harbor Act of 1946. Actual construction of Craney Island was completed in 1957. Since that time, this site has received maintenance, private, and permit dredged material from numerous dredging projects in the Hampton Roads area (U.S. Army Engineer District (USAED), Norfolk 1974).

Figure 1-1 is a site location map, and Figure 1-2 shows a layout of the CIDMMA. The CIDMMA has been divided into three subcontainment areas, designated as north, center, and south cells. Dredged material inflow is directed to the east side of a given cell or subcontainment. The effluent flow passes over the weirs of a cell into the receiving waters of Hampton Roads Harbor. These weirs are located at the west corners of each subcontainment area (Figure 1-2). Average surface elevations at mean low water (MLW)

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

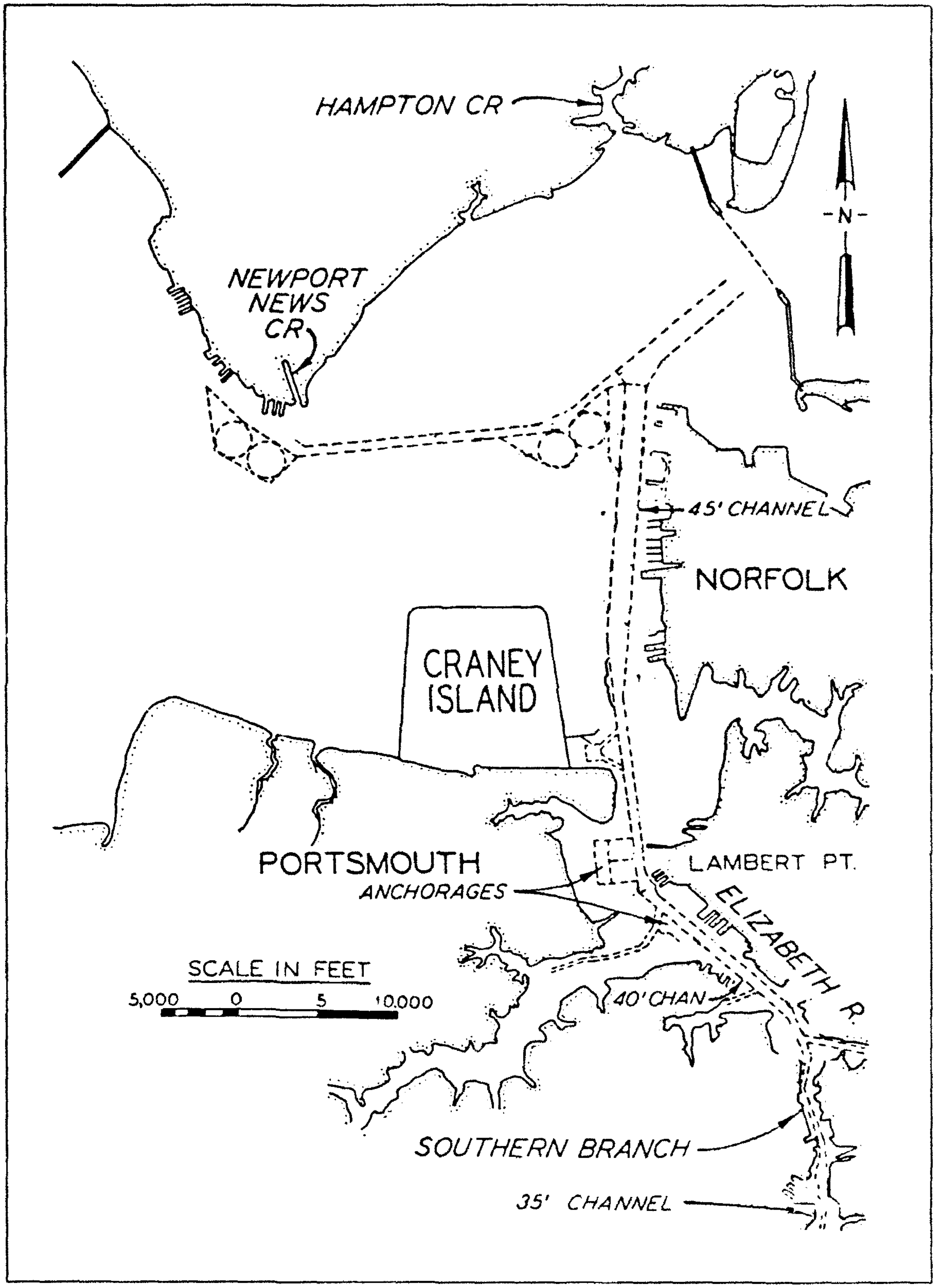

Figure 1-1. Craney Island Dredged Material Management Area and vicinity

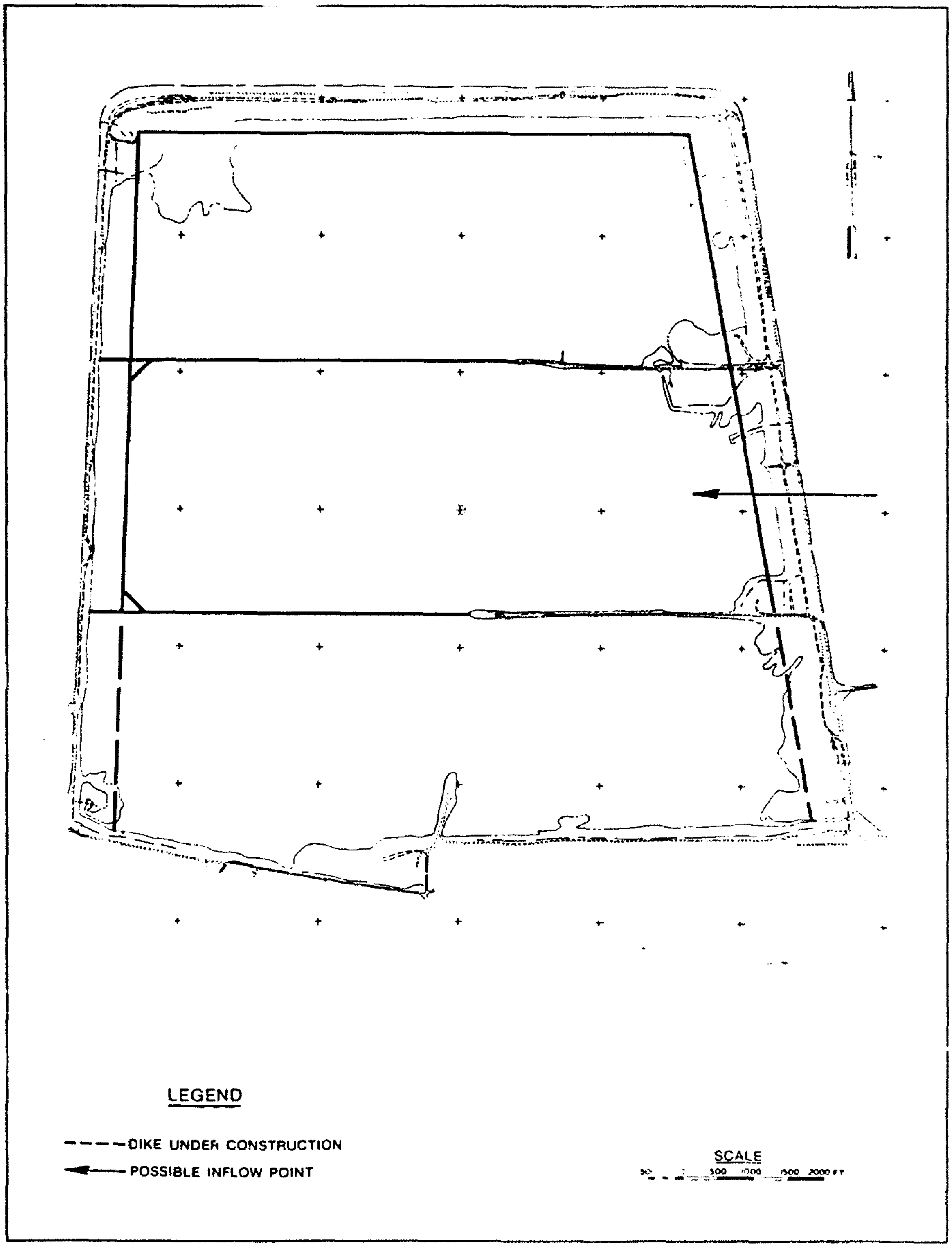

Figure 1-2. Layout of Craney Island Dredged Material Management Area

(based on aerial surveys) of the north, center, and south cells in August 1989 were 24.7, 21.8, and 21.2 ft, respectively (Dozier, Palermo, and Ingram 1992).

2 Service Life of Craney Island Dredged Material Management Area Under Proposed Restricted Use Program

Description of Study

The storage capacity of the CIDMMA was evaluated by comparing simulations of past filling rates with field monitoring data and projections of future filling rates with the ultimate surface elevation of +30 ft MLW. The future filling rates were estimated using PCDDF (Stark 1991), which considers both consolidation and desiccation of the dredged material and consolidation of the compressible foundation. The field monitoring data used were the average fill elevations based on periodic aerial surveys, as given in Table 2-1.

Three filling simulations were performed. First, a simulation of the filling history from 1956 to 1984 was compared with field monitoring data. This simulation served as a verification of the PCDDF microcomputer model for conditions existing prior to subdivision of the site and implementation of dewatering operations as outlined in the CIMP. Second, simulations of filling history from 1984 (the time of cross-dike closure) to 1992 were conducted for each of the three subcontainments. Third, simulations of projected filling rates from 1992 (McGee 1992) were used to determine the service life of the CIDMMA under the proposed Restricted Use Program. The service life is the time at which the fill elevation (el) reaches a limit of +30 ft MLW (Craney Island datum) in each of the three subcontainments, the maximum fill elevation along the west side of Craney Island. The maximum fill elevation along the east side of Craney Island is +36 ft MLW. Because material is pumped in on the east side, capacity could also be defined using an average surface elevation of +33 ft MLW. However, a conservative estimate of the service life can be obtained if a surface elevation of +30 ft MLW is used as the maximum fill elevation.

Table 2-1
Average Surface Elevations[1] (ft) Based on Aerial Surveys

Date	Entire Site	North Cell	Center Cell	South Cell
Oct 56	-10.0	--	--	--
Dec 64	-0.7	--	--	--
Aug 65	0.4	--	--	--
Oct 68	4.6	--	--	--
Dec 75	13.0	--	--	--
Oct 77	14.2	--	--	--
Mar 80	15.4	--	--	--
Sep 84[2]	18.39	19.13	16.95	19.10
Sep 85	18.82	19.91	16.39	20.16
Oct 86	19.90	19.95	19.71	20.03
Sep 87	20.42	20.00	19.41	21.86
Oct 88	22.17	25.8	19.50	21.10
Aug 89	22.67	24.7	21.80	21.20

[1] Reference elevation, mean low water - 0.0 ft.
[2] Initial reading following settlement plate installation.

The projected filling rates under the proposed Restricted Use Program were estimated by the Norfolk District (McGee 1992). The following four dredging scenarios were proposed for the Restricted Use Program: (a) Baseline Maintenance, (b) Worst Case Maintenance, (c) New Work (Deepening), and (d) Long-Term Maintenance. The Baseline Maintenance Dredging Scenario assumes that current trends and situations with respect to maintenance of Federal navigation channels will continue and that the maintenance material in the Southern and Eastern Branch of the Elizabeth River is contaminated. Its volume is estimated to be typical of past volumes and uniformly distributed in time such that disposal can rotate between compartments in 1-ft lifts. The Worst Case Maintenance Dredging Scenario is similar to the Baseline Maintenance Scenario except that periods of overlapping high-quantity dredging and larger volumes are assumed, thus decreasing the efficiency of consolidation and desiccation. The New Work (Deepening) Scenario assumes that the contaminated reaches of the Southern Branch of the Elizabeth River will be deepened in 1996 and 1997 and disposed in conjunction with the baseline volumes. The Long-Term Maintenance Dredging Scenario assumes that the contamination sources are controlled or eliminated and the volumes of contaminated sediments will decrease in the future. The last two cases are not explored in detail in this report. Analysis of the Baseline Maintenance Dredging Scenario (described in the following paragraphs) showed that a small amount of material would be placed in Craney Island under this dredging scenario and the current storage capacity would not be exceeded by the year 2130. Therefore, the four dredging scenarios were combined to determine the service life of the CIDMMA under the most extreme dredging scenario. Therefore, this report presents the PCDDF results for the Baseline Maintenance Dredging Scenario and the summation of four dredging scenarios, termed the Worst Case Dredging Scenario.

The mathematical model PCDDF was used for the storage capacity evaluations in this study. The model was initially developed by Cargill (1985) and subsequently modified by Stark (1991). The model considers consolidation and desiccation parameters for the dredged material, initial thicknesses of dredged material applied as a function of time, consolidation of foundation soils, and precipitation and evaporation rates. Stark (1991) modified the model to account for 25 different dredged material and compressible foundation properties, thus allowing alternating layers of different dredged fill and foundation materials to be considered. Because consolidation and desiccation data are unavailable for each layer of dredged material placed in the CIDMMA since 1956 and the different soil layers in the compressible foundation, only the set of soil properties used by Palermo and Schaefer (1990) for the compressible foundation and the dredged material was used in this study.

CIDMMA Study Objective

The objective of the work presented in this chapter was to investigate the service life of the CIDMMA under the proposed Restricted Use Program. Under this program, only material unsuitable for ocean disposal will be placed in the CIDMMA. The following steps were followed to accomplish this study objective:

a. Assemble available geotechnical data and disposal history of Craney Island from conferences with WES and Norfolk District personnel and from existing documentation, both published and unpublished.

b. Approximate the 1956-1992 Craney Island disposal history and the estimated disposal histories under the proposed Restricted Use Program for use in the microcomputer program PCDDF.

c. Assemble the consolidation and desiccation properties of the compressible foundation and dredged material from conferences with WES and Norfolk District personnel and from existing literature for use in PCDDF.

d. Calculate the surface elevation of Craney Island from 1956 to 1992 using PCDDF and compared with field measurements to calibrate the PCDDF computer model.

e. After calibration, use the PCDDF model to estimate the service life of the CIDMMA under the proposed Restricted Use Program. This is accomplished by comparing the calculated surface elevations of the north, center, and south compartments of Craney Island to the ultimate surface elevation of +30 ft MLW.

Procedures

Selection of model parameters

The consolidation parameters shown in Table 2-2 were used to evaluate the service life of the CIDMMA under the proposed Restricted Use Program. These parameters were the same as those used by Palermo and Schaefer (1990) and Dozier, Palermo, and Ingram (1992) for estimating the current storage capacity of Craney Island. The void ratio-effective stress and void ratio-permeability relations were obtained from the results of self-weight and large strain, controlled rate of strain (LSCRS) consolidation tests (Cargill 1986). The self-weight test yields void ratio relations from an effective stress of approximately 10^{-5} tsf to 10^{-2} tsf, and the LSCRS test covers the effective stress range of 10^{-2} tsf to 10 tsf. The results of the self-weight and LSCRS tests are combined to define the void ratio relationships over the range of effective stresses encountered in a confined disposal area.

The self-weight and LSCRS tests were performed on one channel sediment, four samples obtained from the disposal area (Cargill 1983), and a composite sample of the dredged material (Cargill 1985). The composite sample was used because the initial version of PCDDF (Cargill 1985) allowed only one dredged fill and foundation material type. The boundary conditions used in the analysis are shown in Figure 2-1, which shows that the site is doubly drained and the dredged material is underlain by soft marine clay. The compressible foundation option was used to model the marine clay in the analysis.

Conventional odometer tests were also conducted on samples of dredged material in 1985 and 1987 to verify the self-weight and LSCRS test results. The self-weight, LSCRS, and odometer test results were used to develop the average void ratio relationships shown in Table 2-2. Field measurements were used to calibrate the input parameters; therefore, average void ratio relations could be initially used.

The desiccation parameters used in PCDDF, rate of precipitation, pan evaporation efficiency, maximum crust thickness, and drainage efficiency, were the same desiccation parameters used by Palermo and Schaefer (1990) and Dozier, Palermo, and Ingram (1992) and represent an active dewatering condition (Table 2-3). The precipitation and evaporation rates that were used for the simulations are shown in Table 2-4 and were obtained from Palermo and Schaefer (1990). The precipitation and evaporation rates were originally obtained from Brown and Thompson (1977) and the National Climatic Center (1980).

Table 2-2
Consolidation Characteristics of the Foundation and Dredged Material

Foundation			Dredged Material		
Void Ratio	Effective Stress psf	Coefficient of Permeability ft/day	Void Ratio	Effective Stress psf	Coefficient of Permeability ft/day
3.00	0.00	8.6OE-04	10.50	0.00	9.36E-01
2.90	8.80	1.03E-03	10.40	0.08	8.21E-01
2.80	19.60	8.85E-04	10.20	0.15	6.62E-01
2.70	32.00	7.61E-04	10.00	0.22	5.26E-01
2.60	48.00	6.39E-04	9.80	0.30	4.18E-01
2.50	70.00	5.22E-04	9.60	0.40	3.31E-01
2.40	104.00	4.23E-04	9.40	0.50	2.59E-01
2.30	154.00	3.45E-04	9.20	0.62	2.09E-01
2.20	232.00	2.73E-04	9.00	0.76	1.66E-01
2.10	344.00	2.16E-04	8.80	0.92	1.30E-01
2.00	510.00	1.40E-04	8.60	1.10	1.05E-01
1.90	780.00	1.32E-04	8.40	1.30	8.35E-02
1.80	1,160.00	1.03E-04	8.20	1.54	6.48E-02
1.70	1,700.00	7.70E-05	8.00	1.80	5.18E-02
1.60	2,540.00	5.80E-05	7.80	2.10	4.10E-02
1.50	3,750.00	4.30E-05	7.60	2.44	3.24E-02
1.40	5,540.00	3.10E-05	7.40	2.80	2.59E-02
1.30	8,500.00	2.70E-05	7.20	3.20	2.02E-02
1.25	10,400.00	1.90E-05	7.00	3.70	1.61E-02
0.87	50,000.00	1.00E-05	6.80	4.60	1.28E-02
0.80	60,000.00	5.00E-06	6.60	5.80	1.01E-02
			7.40	7.80	7.99E-03
			6.20	10.60	6.31E-03
			6.00	14.60	5.03E-03
			5.80	20.00	3.96E-03
			5.60	28.00	3.15E-03
			5.40	39.00	2.46E-03
			5.20	55.00	1.94E-03

(Continued)

Table 2-2 (Concluded)					
Foundation			Dredged Material		
Void Ratio	Effective Stress psf	Coefficient of Permeability ft/day	Void Ratio	Effective Stress psf	Coefficient of Permeability ft/day
			5.00	75.60	1.56E-03
			4.80	105.00	1.23E-03
			4.60	139.00	9.72E-04
			4.40	183.00	7.63E-04
			4.20	240.00	6.05E-04
			4.00	316.00	4.75E-04
			3.80	618.00	2.46E-04
			3.00	1,240.00	1.11E-04
			2.50	2,420.00	3.80E-05
			2.00	4,740.00	1.00E-05
			1.00	17,000.00	5.00E-06
			0.50	60,000.00	5.00E-06

Simulation of dredged material disposal

Thicknesses of dredged material for each disposal operation were determined from the actual dredging volumes and the surface areas available for placement in the disposal area. Table 2-5 (updated from Palermo and Schafer (1990), Appendix A) shows the disposal history at Craney Island. Because PCDDF applies an entire lift instantaneously, the disposal history had to be subdivided and applied at the midpoint of each subdivision. The volume of in-channel material applied in each PCDDF lift is shown in Table 2-5. The height of each lift was obtained by dividing the in-channel disposal volume (Table 2-5) by the surface area of the entire site prior to subdivision. After subdivision, the height of each lift was obtained by dividing the in-channel disposal volume (Table 2-5) by the surface area of the subcontainment being utilized. The surface area used for the entire site prior to subdivision was 2,189 acres, with the areas of the north, center, and south subcontainments after subdivisions being 689, 766, and 734 acres, respectively.[1] For example, the first in-channel disposal volume was 3,699,276 cu yd (Table 2-5), and the height of the first lift was 1.05 ft (Table 2-6) based on a storage area of 2,189 acres. Each lift was placed at the time corresponding to the midpoint of the

[1] Personal Communication, 1992, D. A. Pezza, U.S. Army Engineer District, Norfolk, Norfolk, VA.

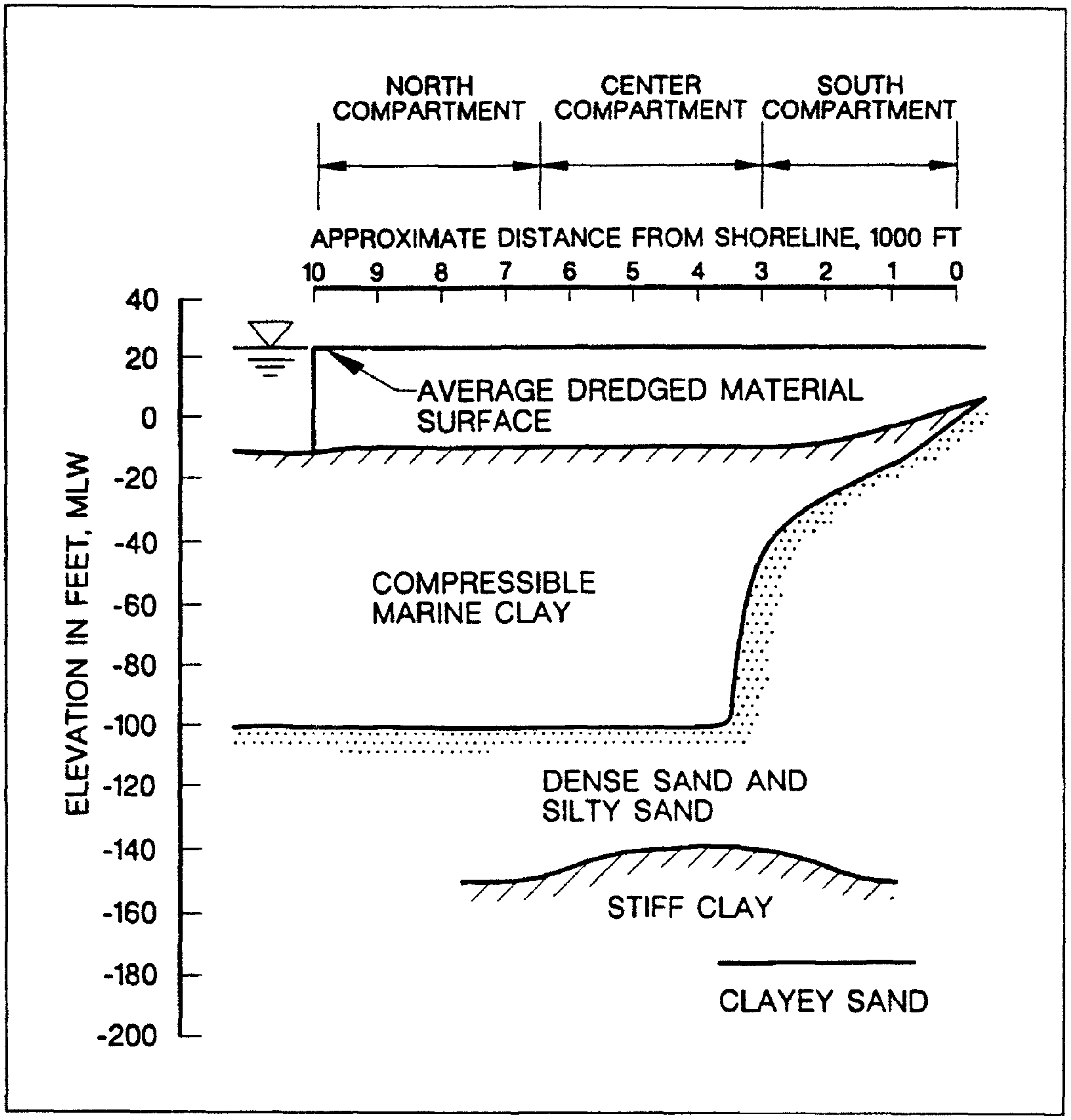

Figure 2-1. Generalized subsurface profile of Craney Island

disposal operation except for the first lift, which was placed at October 1956 to start the simulation.

Dredged material was placed using two different filling criteria. In the Baseline Maintenance Dredging Scenario, dredged material was placed in a compartment until a thickness of approximately 1 ft was obtained. After reaching that thickness, dredged material was placed in the next compartment. A 1-ft lift was used to investigate the consolidation and desiccation characteristics of thin lifts. In previous years, the filling schedule involved an annual rotation of the compartments, resulting in a large amount of dredged material

Table 2-3
Desiccation Parameters for Filling Simulations

Parameter	Active Dewatering
Surface drainage efficiency, percent	100
Maximum evaporation efficiency percent	100
Saturation at end of desiccation, percent	80
Maximum crust thickness, ft	1.0
Time to desiccation after filling, days	30
Elevation of fixed water table, ft, MLW	1.5
Void ratio at saturation limit	6.5
Void ratio at desiccation limit	3.2
In-channel void ratio	5.93
Void ratio at zero effective stress	10.50
Void ratio of incompressible foundation sand	0.65
Permeability of incompressible foundation sand, ft/day	3.0E-04

Table 2-4
Precipitation and Evaporation Rates at Craney Island Dredged Material Management Area

			Excess Evaporation, in.	
Month	Precipitation in.	Pan Evaporation in.	100-Percent Infiltration	75-Percent Infiltration
January	3.4	0.0	--	--
February	3.3	0.6	--	--
March	3.4	1.0	--	--
April	2.7	4.5	1.8	2.4
May	3.3	7.0	3.7	4.5
June	3.6	7.7	4.1	5.0
July	5.7	7.7	2.0	3.4
August	5.9	6.6	0.7	2.2
September	4.2	4.9	0.7	2.2
October	3.1	3.6	0.5	1.3
November	2.9	1.2	--	--
December	3.1	0.0	--	--
Total	44.6	44.8	13.5	21.0

Table 2-5
Craney Island Disposal History

Location and Type	Beginning Date	Ending Date	In-Channel Volume, cu yd			
			USACE	Other Federal	Commercial	Total
Permit	Oct 56	Dec 56			982,566	
RE Basin,NW	Jan 57	Aug 57	2,414,467			
RE Basin,maint	Feb 57	May 57	302,243			3,699,276
NH, maint, HD	Oct 57	Nov 57	1,468,894			1,468,894
NH, NW widen	Jul 58	Dec 58	4,708,210			
RE Basin,maint	Jul 58	Sep 58	371,090			5,079,300
NH, SB, maint & NW	Jan 59	Apr 59	5,159,218			5,159 218
NOB Approach	Jun 59	Aug 59		1,964,503		
RE Basin,maint	Aug 59	Sep 59	940,351			2,904,854
NH, maint & NM	27 Nov 59	1 Jan 60	2,099,627			2,099,627
CI ANCH, nw	25 Nov 59	22 May 60	4,643,020			
N&W Piers A&B	10 Dec 59	27 Dec 59			127,630	
NAVY,DEGAUS	11 May 60	20 May 60		41,368		4,812,018
NH,SB,maint,HD	4 Oct 60	10 Nov 60	674,431			
RE Basin,maint	20 May 61	20 Aug 61	1,042,693			1,717,124
N&W Piers, NW	2 May 61	30 Sep 61			687,634	
D&S Piers, maint	1 Aug 61	17 Nov 61		817,673		1,505,307
N&W Piers, NW	1 Oct 61	2 Mar 62			825,161	
S of N&W	24 Mar 62	2 Apr 62			119,740	
NH, maint, HD	3 Apr 62	25 Apr 62	1,258,530			2,203,431
ESCI, barge reha	31 Aug 62	5 Sep 62			55,939	
CNN, maint, HD	5 Sep 62	22 Sep 62	766,893			
N&W Piers, maint	14 Sep 62	10 Oct 62			156,645	
NH, maint, HD	22 Sep 62	21 Oct 62	1,910,338			
NNSY	15 Oct 62	21 Oct 62		26,376		2,916,191
RE Basin,maint	5 Jan 63	1 Apr 63	795,559			
N&W Piers	11 Feb 63	24 Feb 63			67,924	
NNSB	24 Feb 63	2 Mar 63			26,500	
NOB & D&S Piers	2 Mar 63	13 Jun 63		521,419		1,411,402
NOB, maint	14 Jan 64	12 Mar 64		357,575		
NH, maint, HD	7 May 64	29 Jun 64	1,579,115			
RE Basin, maint	2 Jun 64	30 Sep 64	603 878			
Thimble Shoals, HD	23 Jun 64	2 Jul 64	63,920			2,604,488
NOB, maint	27 Jul 64	12 Sep 64		371,275		
N&W, maint	10 Sep 64	2 Oct 64			148,853	
RE Basin,maint	1 Oct 64	5 Jan 65	603,878			1,124,006
NH 40, maint, HD	3 Mar 65	2 Jun 65	2,618,550			2,618,550
NNSY, maint, HD	14 May 65	22 May 65		107,900		
ESCI, BR	12 Jul 65	24 Jul 65			64,755	
NOB, maint	26 Jul 65	7 Oct 65		602,060		780,581

(Sheet 1 of 6)

Table 2-5 (Continued)

Location and Type	Beginning Date	Ending Date	In-Channel Volume, cu yd USACE	Other Federal	Commercial	Total
HRSD, TP	3 Aug 65	31 Aug 65			1,096	
N&W, maint	11 Sep 65	12 Sep 65			4,770	
N&W Piers, maint	8 Oct 65	12 Oct 65			28,613	
NOB, D&S Piers	10 Oct 65	7 Dec 65		466,515		
NH45 maint, HD	3 Sep 65	1 Dec 65	2,333,940			2,829,068
NH45, maint	6 Apr 68	25 Jul 68	1,508,336			1,508,336
CNN45, NW	8 Sep 68	1 Oct 68	230,630			
NOB & D&S Piers	14 Sep 68	28 Nov 68		538,103		768,733
NH40&45, maint, HD	29 Jan 69	3 May 69	2,305,462			
CI FUEL DEPOT, NW	16 Feb 69	17 Apr 69	583,635			2,889,097
CNN45, NW	13 May 69	30 Dec 69	1,898,300			1,898,300
D&S Piers, maint	6 Nov 69	13 Feb 70		225,500		
NIT, VPA	6 Nov 69	18 Nov 69			115,925	
N&W, maint	23 Oct 69	5 Nov 69			180,967	522,392
NNSY, maint, HD	2 Jan 70	3 Feb 70		71,200		
NH40&45, maint	2 Jan 70	10 May 70	1,978,980			
CNN, maint	10 May 70	16 May 70	188,610			
NP&IA	9 Jan 70	11 Feb 70			493,425	2,732,215
NH45, nw	23 Mar 66	30 Sep 66	2,931,330			2,931,330
CI Fuel Depot	20 Aug 66	19 Nov 66		360,815		
NH45, NW	1 Oct 66	16 Jan 67	1,465,600			
RE Basin, maint	24 Sep 66	21 Apr 67	1,032,198			
NH45, NW	26 Oct 66	22 Dec 66	176,575			
NH40, Maint, HD	29 Oct 66	19 Dec 66	1,197,650			
N&W, NW	20 Nov 66	11 Jan 67			281,960	4,514,798
PMT, VPA, na	17 Jan 67	17 Apr 67			1,004,959	1,004,959
CNN45, NW	25 Mar 67	30 Sep 67	3,258,490			
NH45, NW	22 Apr 67	22 Aug 67	3,588,859			
C&O, NW, NW	27 Aug 67	22 Oct 67			420,710	7,268,059
CNN45, nw	1 Oct 67	11 Jan 68	1,629,245			1,629,245
ATLAS CEMENT	15 Jan 68	20 Jan 68			46,590	
NP&IA	12 Jan 68	13 Feb 68			811,471	
NOB, maint	20 Feb 68	27 Apr 68		715,366		
NH45, maint, HD	26 Jan 68	8 Feb 68	236,247			
NH40, maint, HD	4 Feb 68	2 Mar 68	716,262			
NNSY, maint, HD	7 Feb 68	24 Feb 68		72,193		2,598,129
RE Basin, maint	7 Mar 70	11 May 70	800,407			
N&W, maint	30 Mar 70	19 May 70			112,476	
DEGAUS RANGE	24 May 70	25 Aug 70		327,401		
NOB, Pier 12	11 Jul 70	11 Aug 70		226,775		
N&W, maint	23 Sep 70	1 Oct 70			71,672	
NAVY POL, NW	1 Aug 70	22 Sep 70		525,183		2,063,869
SPA, NW	31 Aug 70	30 Sep 71	8,039,700			8,039,700

(Sheet 2 of 6)

Table 2-5 (Continued)

Location and Type	Beginning Date	Ending Date	In-Channel Volume, cu yd USACE	Other Federal	Commercial	Total
CNN, maint, HD	29 Sep 70	29 Oct 70	370,690			
NIT, VPA, maint	3 Oct 70	12 Oct 70			131,988	
NH40, maint	29 Oct 70	27 Nov 70	890,285			1,392,963
NH45, maint	11 Dec 70	16 May 71	1,852,999			
EXXON Piers	13 Mar 71	19 Mar 71			50,104	
NOB, maint	5 Apr 71	22 Jun 71		485,175		2,388,278
NNA40, NW	16 Jul 71	22 Nov 71	4,828,174			
USCG, CI CR, NW	16 Aug 71	20 Nov 71		671,202		5,499,376
SPA, NW	1 Oct 71	1 Feb 72	2,679,887			
PMT, VPA, maint	16 Oct 71	14 Nov 71			322,389	3,002,276
N&W, maint	20 Nov 71	9 Dec 71			166,698	
NH40&45, maint	2 Nov 71	4 Jan 72	1,489,000			1,655,698
USCG, CI CR, maint	9 Feb 72	1 Aug 72		288,507		
RE Basin, maint	25 Jun 72	19 Sep 72	892,487			1,180,994
NOB & D&S Piers	8 Aug 72	5 Sep 72		239,032		
ATLAS CEMENT	6 Sep 72	11 Sep 72			23,050	
NH45, maint	12 Sep 72	29 Oct 72	606,717			868,799
NIT, VPA, NW	27 Jan 73	3 May 73			1,264,045	
NH40, maint, HD	7 Feb 73	28 Mar 73	862,800			
CNN, maint, HD	23 Feb 73	28 Mar 73	238,060			
NNSY, maint, HD	17 Feb 73	22 Mar 73		57,950		
HRBT, VDOT, NW	27 Apr 73	5 May 73			183,406	
N&W, maint	9 May 73	23 May 73			152,170	
NNSB, maint	23 May 73	26 May 73			15,907	
C&O Piers, maint	8 Jul 73	23 Jul 73			70,552	2,844,890
NNSB, NW	7 Aug 73	30 Sep 73			324,976	
NNSB, NW	2 Oct 73	31 Dec 73			956,776	1,281,752
NOB & D&S, maint	10 Oct 73	1 Apr 74		916,885		
NH40 & SB35, M, HD	13 Dec 73	29 Jan 74	852,544			
NNSY, maint, HD	19 Dec 73	29 Dec 73		54,823		1,824,222
NNSB, NW	1 Jan 74	26 May 74			659,742	
NNSB, nw	1 Jan 74	26 May 74			769,928	
PMT, VPA	9 Jun 74	22 Aug 74			674,820	
NOB, maint	25 Jun 74	18 Sep 74		207,855		
D&S Piers, maint	19 Jul 74	9 Sep 74		199,710		
NIT, VPA, maint	8 Dec 74	24 Dec 74			199,174	2,711,229
NH45, maint	29 Jan 75	16 Mar 75	1,622,300			
DEGAUS RANGE	15 Feb 75	23 Feb 75		36,825		
CARGILL GRAIN, BR	15 Feb 75	14 Mar 75			103,324	
NNSB, maint, BR	1 Mar 75	4 Mar 75			14,625	
YELLOW RIVER (LIM)	18 Mar 75	22 Mar 75			11,728	1,788,802

(Sheet 3 of 6)

Table 2-5 (Continued)

Location and Type	Beginning Date	Ending Date	In-Channel Volume, cu yd USACE	Other Federal	Commercial	Total
NNSB, maint	22 Apr 75	30 May 75			263,948	
SO. BLOCK, SB	30 May 75	1 Jun 75			7,156	
US GYPsum, SB	1 Jun 75	2 Jun 75			4,316	
NOB, maint	28 Jun 75	16 Sep 75		530,995		
RE Basin, maint	7 Aug 75	17 Nov 75	770,254			1,576,669
NNSY, maint, HD	6 Oct 75	27 Oct 75		79,695		
NH40, maint, HD	3 Oct 75	30 Oct 75	476,270			
CNN, maint, HD	3 Oct 75	30 Oct 75	120,863			
NNSB, NW	10 Oct 75	14 Dec 75			433,649	
C&O Coal Pier, BR	14 Dec 75	18 Dec 75			26,532	
NH45, maint	18 Nov 75	21 Jan 76	539,132			1,676,141
NOB, 12, maint	8 Feb 76	13 Mar 76		386,425		
N&W, maint	7 Mar 76	6 Apr 76			102,916	
NORSHIPCO	7 Apr 76	6 Jul 76			334,220	
NOB,25, NW & maint	3 Jun 76	3 Jul 76		622,180		
VDOT,W NOR.BR	29 May 76	15 Jul 76			12,924	1,458,665
HH45, maint	17 Jul 76	4 Oct 76	2,455,287			
N&W, maint	25 Aug 76	24 Sep 76			384,679	
NOB, Boat Basin	27 Jul 76	17 Sep 76		67,200		
NNSB, maint	28 Nov 76	3 Jan 77			110,307	
NNSB, WAY5&6, maint	23 Nov 76	30 Nov 76			37,205	3,054,678
C&O Coal Pier	14 Feb 77	20 Feb 77			20,045	
VDOT, JRB	14 Feb 77	20 Feb 77			6,071	
NNSY, maint, BR	8 Feb 77	23 Feb 77		39,645		
NOB, 20, maint	12 Feb 77	4 May 77		528,325		
NNSB, NW, BR	26 Apr 77	17 Jun 77			333,900	
SPA, maint	5 May 77	20 Jun 77	743,476			
Vdot, JRB	6 May 77	21 May 77			5,528	
WILLOUGHBY BAY	18 May 77	20 May 77	2,400			
DEGAUS RANGE	21 May 77	21 Jun 77		130,480		
Deep CR, NN, M, BR	25 Jun 77	15 Jul 77	42,862			
NORSHIPCO	1 Oct 77	25 Jan 78			222,230	
NNSB, W EXT, NW	17 Dec 77	31 Dec 77			53,646	2,128,608
NOB, 2&4, maint	30 Jan 78	21 Feb 78		211,245		
RE Basin, maint	21 Feb 78	5 Jan 79	1,231,637			
NH40&SB35, M, HD	2 Mar 78	29 Mar 78	303,786			1,746,668
NIT, VPA, NW	15 Mar 78	13 Aug 78			954,180	
CNN, maint, HD	16 Mar 78	1 Apr 78	129,160			
CNG, nw, BR	21 Mar 78	14 May 78			108,389	
NOB, 12, maint	4 Apr 78	1 Jun 78		345,990		
NOB, 12, NW	4 Apr 78	1 Jun 78		146,090		1,683,809

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Table 2-5 (Continued)						
			In-Channel Volume, cu yd			
Location and Type	**Beginning Date**	**Ending Date**	**USACE**	**Other Federal**	**Commercial**	**Total**
Fuel Line Trench	12 May 78	11 Jun 78		8,458		
C&O Pier14, BR	24 May 78	10 Jun 78			59,400	
NIT, VPA, maint	3 Jun 78	7 Jul 78			457,370	
NH45, maint	6 Jun 78	1 Nov 78	2,147,368			
ERT, maint, BR	12 Jun 78	15 Jun 78			2,250	
PMT, VPA, NW	15 Jun 78	17 Nov 78			601,176	
EXXON PIER	15 Oct 78	24 Oct 78			76,091	
NOB, Pier 24, NW	12 Dec 78	14 Feb 79		475,435		3,827,548
NOB, D&S Piers	6 Jan 79	20 Mar 79		337,630		
YORKTOWN NWS, HD	2 Jan 79	6 Mar 79		400,971		
NIT, VPA, maint	15 Jul 79	29 Jul 79			111,255	
VDOT, JRB, NW	16 Oct 79	24 Oct 79			9,068	
Deep CR, NN, maint	25 Oct 79	18 Jan 80	296,375			1,155,299
SPA, maint	15 Aug 79	18 Nov 79	1,477,626			
NH45, maint	10 Nov 79	18 Jun 80	2,016,563			
NOB, Piers, maint	21 Nov 79	22 Feb 80		204,007		3,698,196
NNA, maint	12 Apr 70	29 May 80	1,087,166			
NOB, 3 7, 22, 25m	21 Apr 80	18 Jun 80		407,375		
CONT Grain, NW & M	17 Jun 80	6 Aug 80			159,350	
N&W, nw&m	7 Jul 80	2 Aug 80			230,354	1,884,245
NOB, 12, maint	12 Aug 80	3 Sep 80		251,738		
RE Basin, maint	20 Feb 80	14 Oct 80	1,637,381			
NOB, 7, maint	4 Sep 80	6 Sep 80		25,092		
NIT, VPA, maint	19 Feb 80	22 Feb 80			14,823	1,929,034
NOB, AFDL, maint	12 May 81	5 Jul 81		247,155		
NOB Piers, maint	23 Jul 81	14 Nov 81		651,882		
CI Fuel Depot, m	14 Sep 81	14 Oct 81		35,997		
NH45, maint	14 Sep 81	22 Jan 82	2,228,076			
N&W, maint	19 Nov 81	1 Dec 81			96,024	3,259,134
RE Basin, maint	9 Jan 92	30 Sep 82	1,414,988			
CNN, maint	24 Apr 82	23 Jun 82	648,722			
DOMINION TER, nw	25 Jul 82	30 Sep 82			330,000	
NOB, maint	22 Jan 82	19 Mar 82		891,629		3,285,339
RE Basin, maint	1 Oct 82	8 Jun 83	1,414,988			
DOMINION TER, nw	1 Oct 82	9 Jun 83			989,925	
NH45, maint	14 Nov 82	24 May 83	2,183,692			
NOB Piers, maint	28 Sep 82	11 Apr 83		366,479		4,955,084
NOB, ADFL, maint	3 May 83	24 May 83		114,005		
NIT, VPA, maint	12 Jun 83	5 Jul 83			363,098	506,153
NOB Piers, maint	19 Oct 83	26 Nov 83 N[1]		392,148		
NH45, maint	6 Apr 84	30 Sep 84 N	1,752,340			2,115,438
NOB Pier 11, m	22 May 84	6 Jul 84 N		469,639		
SPA, maint	4 Feb 84	29 Sep 84 N	2,451,377			2,921,016

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[1] Site Subdivided Oct. 1983, N=North Compartment, C=Center Compartment, S=South Compartment.

Table 2-5 (Concluded)

Location and Type	Beginning Date	Ending Date	In-Channel Volume, cu yd USACE	Other Federal	Commercial	Total
NH45, maint	1 Oct 84	14 Dec 84 N	876,171			
NOB Piers, maint	16 Sep 84	28 Nov 84 N		775,448		
N&W, maint	23 Oct 84	24 Nov 84 N			121,457	1,773,076
NNA, maint, HD	2 Feb 85	7 Mar 85 N	183,546			
NOB Piers, maint	7 Mar 85	1 May 85 N		610,386		
EXXON PIERS, maint	16 May 85	22 May 85 N			77,150	
LEHIGH CEMENT, m	22 May 85	24 May 85 N			45,400	
NNA, maint	31 Jul 85	11 Aug 85 N		251,987		1,168,469
	1 Nov 87	17 Nov 87 N	280,615			280,615
	1 Dec 87	30 Mar 88 N	1,770,000			1,770,000
	1 Oct 87	18 Jul 88 N	3,412,714			3,412,714
	7 Aug 88	15 Sep 88 N	624,764			
	1 May 88	20 Jul 88 N	616,387			
	5 Jul 88	30 Sep 88 N	540,586			1,781,737
	1 May 88	3 Dec 88 N	1,590,267			1,590,267
Rehandling Basin	11 Jan 90	26 Apr 90 N	1,838,231			1,838,231
NIT, maint & nw	3 Feb 85	2 Apr 85 C			600,095	600,095
	7 Jan 86	19 Mar 86 C	997,142			
	2 Feb 86	22 Mar 86 C	150,431			1,147,573
	22 May 86	22 Jun 86 C	1,618,841			
	1 Jun 86	22 Jun 86 C	185,365			1,804,206
	15 Jul 86	14 Aug 86 C	192,055			
	15 Jul 86	30 Aug 86 C	529,325			721,380
	19 Apr 89	25 May 89 C	1,353,460			
	15 Apr 89	30 Jun 89 C	103,610			1,457,070
	16 Aug 89	31 Oct 89 C	916,834			916,834
Norfolk Harbor	1 Aug 91	29 Dec 91 C	2,068,369			2,068,369
RE Basin, maint	1 Apr 84	30 Sep 84 S	869,433			869,433
RE Basin, maint	1 Oct 84	16 May 85 S	1,391,094			1,391,094
	9 Jun 87	1 Aug 87 S	978,250			
	20 Jun 87	8 Aug 86 S	153,474			
	6 May 87	23 Aug 87 S	1,681,024			2,812,748
RE Basin, maint	19 Apr 89	25 May 89 S	1,353,460			
US NAVY	15 Apr 89	30 Jun 89 S		103,610		1,457,070
NH45&50, maint	16 Aug 89	31 Oct 89 S	916,834			916,834

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Table 2-6
Approximated Disposal History in Craney Island Dredged Material Management Area, 1956 to 1984

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Bulked Disposal Height ft
Oct 1956	0	3,699,276	1.05	N/A	N/A	1.74
Oct 1957	365	1,468,894	0.42	365	9	0.63
Sep 1958	695	5,079,300	1.44	695	9	2.15
Feb 1959	850	5,159,218	1.46	1,000	6	2.18
Jul 1959	1,000	2,904,854	0.82	1,000	6	1.22
Nov 1959	1,120	2,099,627	0.59	1,120	11	0.88
Feb 1960	1,215	4,812,018	1.36	1,395	6	2.03
Jul 1960	1,395	1,717,124	0.49	1,395	6	0.73
Aug 1961	1,760	1,505,307	0.43	1,760	8	0.64
Feb 1962	1,945	2,203,431	0.62	2,095	6	0.93
Sep 1962	2,155	2,916,191	0.83	2,155	9	1.24
Feb 1963	2,310	1,411,402	0.40	2,430	6	0.60
May 1964	2,765	2,604,488	0.74	2,795	6	1.10
Oct 1964	2,915	1,124,006	0.32	2,915	0	0.48
Mar 1965	3,070	2,618,550	0.74	3,160	6	1.10
Jul 1965	3,195	780,581	0.22	3,195	7	0.33
Nov 1965	3,315	2,829,068	0.80	3,315	11	1.19
May 1966	3,495	2,931,330	0.83	3,525	6	1.24
Oct 1966	3,645	4,514,798	1.28	3,645	10	1.91
Feb 1967	3,770	1,004,959	0.28	3,890	6	0.42
May 1967	3,860	7,268,059	2.06	3,890	6	3.08
Oct 1967	4,010	1,629,245	0.46	4,010	10	0.69
Feb 1968	4,135	2,598,129	0.72	4,255	6	1.07
Jun 1968	4,255	1,508,336	0.43	4,255	6	0.64
Oct 1968	4,375	768,733	0.22	4,375	10	0.33
Mar 1969	4,530	2,889,097	0.82	4,620	6	1.22
Aug 1969	4,650	1,898,300	0.54	4,650	8	0.81
Dec 1969	4,800	522,392	0.15	4,800	12	0.22

(Continued)

Note: N/A = Not required in PCDDF analysis.

Table 2-6 (Concluded)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Dessication Start Time	Month Desiccation Starts	Bulked Disposal Height ft
Apr 1970	4,925	2,732,215	0.77	4,985	6	1.15
Jun 1970	4,985	2,063,869	0.58	4,985	6	0.87
Aug 1970	5,045	8,039,700	2.28	5,045	8	3.40
Oct 1970	5,105	1,392,963	0.39	5,105	10	0.58
Mar 1971	5,260	2,388,278	0.68	5,350	6	1.02
Sep 1971	5,440	5,499,376	1.56	5,440	9	2.33
Dec 1971	5,530	3,002,276	0.85	5,530	12	1.27
Jan 1972	5,565	1,655,698	0.47	5,715	6	0.70
Jul 1972	5,745	1,160,994	0.33	5,745	7	0.49
Sep 1972	5,805	868,799	0.25	5,805	9	0.37
Feb 1973	5,960	2,844,890	0.81	6,080	6	1.21
Oct 1973	6,200	1 281,752	0.36	6,200	10	0.54
Dec 1973	6,260	1,824,222	0.52	6,260	12	0.78
Apr 1974	6,385	2,711,229	0.77	6,445	6	1.15
Feb 1975	6,690	1,788,802	0.51	6,810	6	0.76
Aug 1975	6,870	1,576,669	0.45	6,870	8	0.67
Oct 1975	6,930	1,676,141	0.47	6,930	10	0.70
Jun 1976	7,175	1,458,665	0.41	7,175	6	0.61
Aug 1976	7,235	3,054,678	0.86	7,235	8	1.28
May 1977	7,510	2,128,608	0.60	7,540	6	0.90
Jan 1978	7,755	1,746,668	0.49	7,905	6	0.73
May 1978	7,875	1,683,809	0.48	7,905	6	0.72
Sep 1978	7,995	3,827,548	1.08	7,995	9	1.61
Feb 1979	8,150	1,155,299	0.33	8,270	6	0.49
Nov 1979	8,450	3,698,196	1.05	8,450	11	1.57
Apr 1980	8,575	1,884,245	0.53	8,635	6	0.79
Jun 1980	8,635	1,929,034	0.55	8,635	6	0.82
May 1981	8,970	3,259,134	0.92	9,000	6	1.37
Oct 1981	9,120	3,285,339	0.93	9,120	10	1.39
Jun 1982	9,365	4,955,084	1.40	9,365	6	2.09
Mar 1983	9,640	506,153	0.14	9,730	6	0.21

Total in-channel disposal volume = 149,567,046 cu yd
Total CIDMMA disposal volume = 223,453,167 cu yd

being placed in a compartment (i.e., lift thicknesses of 3 to 6 ft). Such placement may have slowed the rate of consolidation and desiccation. The quantities and frequencies of dredging for this case are shown below:

Source of Material	Assumed Quantity, cu yd
*Southern Branch and N.H. 40-ft	200,000 to 250,000
Eastern Branch	100,000
All other dredging (annual)	400,000

* Southern Branch is dredged every 5 years, and the buffer area of the Norfolk Harbor 40-ft channel is dredged every 10 years.

For comparison purposes, an annual rotation of the compartment was used for the Worst Case Dredging Scenario because of the large anticipated quantity of material. After the actual dredging rates for the Restricted Use Program become available, PCDDF analysis can be conducted to determine the lift thickness that maximizes the consolidation and desiccation in the three compartments. The quantities and frequencies of dredging for this case are as follows:

Source of Material	Assumed Quantity, cu yd
Southern Branch	300,000
Eastern Branch	150,000
Other maintenance dredging (peak annual)	500,000
Other new work dredging	100,000

The PCDDF model initiates consolidation calculations for an initial material thickness corresponding to a void ratio at zero effective stress. The in-channel disposal volumes shown in Table 2-6 correspond to dredged material at the in-channel void ratio. Palermo and Schaefer (1990) reported that the average in-channel void ratio of the Craney Island sediment is 5.93 and the void ratio at zero effective stress immediately following deposition is 10.50. Therefore, the void ratio increases from 5.93 to 10.50 during dredging, which results in a significant increase in the disposal volume. Therefore, the dredged or bulked height of each lift is obtained by multiplying the in-channel disposal height by 1.66. Table 2-6 shows the bulked lift thicknesses and the times at which they were applied in the computer simulation for 1956 to 1984. Tables 2-7 through 2-12 show the bulked lift thicknesses and the times at which they were applied in the north, center, and south compartments for the Baseline Maintenance Dredging Scenario and the Worst Case Dredging Scenario, respectively. The bulked lift thicknesses for the Worst Case Dredging Scenario were based on the summation of the four dredging scenarios proposed by the Norfolk District and represent an extreme worst case situation. The four dredging scenarios for the Restricted Use Program are described in the beginning of this chapter.

Table 2-7
Approximated Disposal History for Baseline Maintenance Dredging Scenario in North Compartment from 1984 to 2069

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 1984	9,945	2,115,438	1.89	10,095	6	2.83
Jun 1984	10,095	2,921,016	2.61	10,095	6	3.90
Oct 1984	10,215	1,773,076	1.59	10,215	10	2.38
Mar 1985	10,370	1,168,469	1.05	10,460	6	1.57
Nov 1987	11,340	280,615	0.24	11,340	11	0.35
Dec 1987	11,370	1,770,000	1.59	11,370	12	2.38
Feb 1988	11,435	3,412,000	3.06	11,555	6	4.57
Jul 1988	11,585	1,781,737	1.59	11,585	7	2.37
Sep 1988	11,645	1,590,267	1.41	11,645	8	2.11
Jan 1990	12,135	1,838,231	1.65	12,285	6	2.47
Baseline Maintenance Dredging Scenario in the Restricted Use Program (McGee 1992)						
Jan 1997	14,690	200,000	0.18	14,840	6	0.27
May 1997	14,810	200,000	0.18	14,840	6	0.27
Jan 1998	15,055	200,000	0.18	15,205	6	0.27
May 1998	15,175	200,000	0.18	15,205	6	0.27
Jan 2003	16,880	200,000	0.18	17,030	6	0.27
May 2003	17,000	200,000	0.18	17,030	6	0.27
Sep 2003	17,120	200,000	0.18	17,120	9	0.27
Jan 2004	17,245	200,000	0.18	17,395	6	0.27
Jan 2008	18,945	250,000	0.22	18,945	6	0.34
Jan 2009	19,070	166,666	0.15	19,220	6	0.22
May 2009	19,190	166,666	0.15	19,220	6	0.22
Sep 2009	19,310	166,666	0.15	19,310	9	0.22
Sep 2013	20,740	200,000	0.18	20,740	9	0.27
Jan 2014	20,895	200,000	0.18	21,045	6	0.27
May 2014	21,015	200,000	0.18	21,045	6	0.27
Jan 2015	21,260	200,000	0.18	21,410	6	0.27
Jan 2019	22,720	200,000	0.18	22,870	6	0.27

(Sheet 1 of 3)

Table 2-7 (Continued)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2019	22,840	200,000	0.18	22,870	6	0.27
Jan 2020	23,085	200,000	0.18	23,235	6	0.27
May 2020	23,205	200,000	0.18	23,235	6	0.27
Sep 2024	24,785	200,000	0.18	24,785	9	0.27
Jan 2025	24,910	200,000	0.18	25,060	6	0.27
May 2025	25,030	200,000	0.18	25,060	6	0.27
Jan 2026	25,275	200,000	0.18	25,425	6	0.27
Jan 2030	26,735	200,000	0.18	26,885	6	0.27
May 3030	26,855	200,000	0.18	26,885	6	0.27
Jan 2031	27,100	200,000	0.18	27,250	6	0.27
May 2031	27,220	200,000	0.18	27,250	6	0.27
Sep 2035	27,340	200,000	0.18	27,340	9	0.27
Jan 2036	28,925	200,000	0.18	29,075	6	0.27
May 2036	29,045	200,000	0.18	29,075	6	0.27
Jan 2037	29,290	200,000	0.18	29,440	6	0.27
Jan 2041	30,750	200,000	0.18	30,900	6	0.27
May 2041	30,870	200,000	0.18	30,900	6	0.27
Jan 2042	31,115	200,000	0.18	31,265	6	0.27
May 2042	31,235	200,000	0.18	31,265	6	0.27
May 2046	32,695	200,000	0.18	32,725	6	0.27
Jan 2047	32,940	200,000	0.18	33,090	6	0.27
May 2047	33,060	200,000	0.18	33,090	6	0.27
Jan 2048	33,305	200,000	0.18	33,455	6	0.27
Jan 2052	34,765	200,000	0.18	34,915	6	0.27
May 2052	34,885	200,000	0.18	34,915	6	0.27
Jan 2053	35,130	200,000	0.18	35,280	6	0.27
May 2053	35,250	200,000	0.18	35,280	6	0.27
Sep 2057	35,370	200,000	0.18	35,370	9	0.27
Jan 2058	36,955	325,000	0.29	37,105	6	0.44

(Sheet 2 of 3)

Table 2-7 (Concluded)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2058	37,075	325,000	0.29	37,105	6	0.44
Jan 2063	38,780	300,000	0.27	38,930	6	0.40
May 2063	38,900	300,000	0.27	38,930	6	0.40
Jan 2064	39,145	200,000	0.18	39,295	6	0.27
May 2068	39,265	225,000	0.20	40,755	6	0.30
Sep 2068	39,385	225,000	0.20	39,385	9	0.30
Jan 2069	40,970	500,000	0.45	41,120	6	0.67

Total in-channel disposal volume for north compartment = 30,000,847 cu yd
Total CIDMMA disposal volume in north compartment = 44,821,268 cu yd

(Sheet 3 of 3)

Palermo, Shields, and Hayes (1981) tabulated the index properties of 32 samples of in-channel dredged material that were to be placed in the CIDMMA. The index properties showed that approximately 90 percent of the dredged material consisted of fine-grained material. Because coarse-grained material does not undergo consolidation, the bulked lift thickness in Table 2-6 was reduced by 10 percent to obtain the bulked lift thickness of fine-grained material that was placed in the CIDMMA.

Results

Craney Island filling simulation, 1956 to 1984

Figure 2-2 presents simulations for the filling history from 1956 to 1984. The simulation incorporated the effects of desiccation, and the results are in excellent agreement with the field surface elevations. The main objective of this simulation was to calculate the void ratio and effective stress profiles in the dredged fill and compressible foundation in October 1983 (the time of cross-dike closure). For discussion purposes, the time of cross-dike closure is referred to as 1984 even though October 1983 was actually used in the analysis (Figure 2-2). The calculated void ratio and effective stress profiles reflect the consolidation and desiccation that occurred between 1956 and 1984 and were used as a starting point for the subsequent simulations using the restart option in PCDDF. The excellent agreement with field surface elevations indicates that the input parameters are representative of field conditions and can be

Table 2-8
Approximated Disposal History for Baseline Maintenance Dredging Scenario in Center Compartment from 1984 to 2131

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Mar 1985	10,370	600,095	0.48	10,460	6	0.72
Feb 1986	10,705	1,147,573	0.93	10,825	6	1.39
Jun 1986	10,825	1,804,206	1.46	10,825	6	2.18
Aug 1986	10,885	721,380	0.58	10,885	8	0.87
Apr 1989	11,860	1,457,070	1.17	11,920	6	1.74
Sep 1989	12,010	916,834	0.74	12,010	9	1.11
Sep 1991	12,470	2,068,369	1.67	12,740	9	2.44
Baseline Maintenance Dredging Scenario in the Restricted Use Program (McGee 1992)						
Jan 1993	13,230	200,000	0.16	13,380	6	0.24
May 1993	13,350	200,000	0.16	13,380	6	0.24
Sep 1993	13,470	200,000	0.16	13,470	9	0.24
Jan 1994	13,595	300,000	0.24	13,745	6	0.36
Sep 1998	15,295	250,000	0.20	15,295	9	0.30
Jan 1999	15,420	200,000	0.16	15,570	6	0.24
May 1999	15,540	200,000	0.16	15,570	6	0.24
Jan 2000	15,785	300,000	0.24	15,935	6	0.36
May 2004	17,365	200,000	0.16	17,395	6	0.24
Jan 2005	17,610	200,000	0.16	17,760	6	0.24
May 2005	17,730	200,000	0.16	17,760	6	0.24
Jan 2006	17,975	200,000	0.16	18,125	6	0.24
May 2006	18,095	200,000	0.16	18,125	6	0.24
Jan 2010	19,435	200,000	0.16	19,585	6	0.24
May 2010	19,555	200,000	0.16	19,585	6	0.24
Jan 2011	19,800	200,000	0.16	19,950	6	0.24
May 2011	19,920	200,000	0.16	19,950	6	0.24
Jan 2015	21,260	200,000	0.16	21,410	6	0.24
Jan 2016	21,625	200,000	0.16	21,775	6	0.24

(Sheet 1 of 5)

Table 2-8 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2016	21,745	200,000	0.16	21,775	6	0.24
Jan 2017	21,990	200,000	0.16	22,140	6	0.24
Jan 2021	23,450	200,000	0.16	23,600	6	0.24
May 2021	23,570	200,000	0.16	23,600	6	0.24
Jan 2022	23,815	200,000	0.16	23,965	6	0.24
May 2022	23,935	200,000	0.16	23,965	6	0.24
May 2026	25,395	200,000	0.16	25,425	6	0.24
Jan 2027	25,640	200,000	0.16	25,790	6	0.24
May 2027	25,760	200,000	0.16	25,790	6	0.24
Jan 2028	26,005	300,000	0.24	26,155	6	0.36
Jan 2032	27,465	200,000	0.16	27,615	6	0.24
May 2032	27,585	200,000	0.16	27,615	6	0.24
Jan 2033	27,830	200,000	0.16	27,980	6	0.24
May 2033	27,950	200,000	0.16	27,980	6	0.24
Jan 2037	29,290	200,000	0.16	29,440	6	0.24
Jan 2038	29,655	216,666	0.14	29,805	6	0.26
May 2038	29,775	216,666	0.14	29,805	6	0.26
Sep 2038	29,895	216,666	0.14	29,895	9	0.26
Jan 2043	31,480	200,000	0.16	31,630	6	0.24
May 2043	31,600	200,000	0.16	31,630	6	0.24
Sep 2043	31,720	200,000	0.16	31,720	9	0.24
Jan 2044	31,845	200,000	0.16	31,995	6	0.24
May 2048	33,425	225,000	0.18	33,455	6	0.27
Sep 2048	33,545	225,000	0.18	33,545	9	0.27
Jan 2049	33,670	166,666	0.13	33,820	6	0.20
May 2049	33,790	166,666	0.13	33,820	6	0.20
Sep 2049	33,910	166,666	0.13	33,910	9	0.20
Sep 2053	35,370	200,000	0.16	35,370	9	0.24
Jan 2054	35,495	200,000	0.16	35,645	6	0.24

(Sheet 2 of 5)

Table 2-8 (Continued)						
Date	**Elapsed Time days**	**In-Channel Disposal Volume cu yd**	**In-Channel Disposal Height ft**	**Desiccation Start Time**	**Month Desiccation Starts**	**Initial Disposal Thickness at Craney Island ft**
May 2054	35,615	200,000	0.16	35,645	6	0.24
Jan 2055	35,860	200,000	0.16	36,010	6	0.24
Jan 2059	37,320	200,000	0.16	37,470	6	0.24
May 2059	37,440	200,000	0.16	37,470	6	0.24
Jan 2060	37,685	200,000	0.16	37,835	6	0.24
May 2060	?7,805	200,000	0.16	37,835	6	0.24
May 2064	39,265	200,000	0.16	39,295	6	0.24
Jan 2065	39,510	200,000	0.16	39,660	6	0.24
May 2065	39,630	200,000	0.16	39,660	6	0.24
Jan 2066	39,875	200,000	0.16	40.025	6	0.24
Jan 2070	41,335	200,000	0.16	41,485	6	0.24
May 2070	41,455	200,000	0.16	41,485	6	0.24
Jan 2071	41,700	200,000	0.16	41,850	6	0.24
May 2071	41,820	200,0ↄ0	0.16	41,850	6	0.24
Jan 2074	42,795	200,000	0.16	42,945	6	0.24
May 2074	42,915	200,000	0.16	42,945	6	0.24
Jan 2075	43,160	200,000	0.16	43,310	6	0.24
May 2075	43,280	200,000	0.16	43,310	6	0.24
Jan 2078	44,255	325,000	0.26	44,405	6	0.39
May 2078	44,375	325,000	0.26	44,405	6	0.39
Jan 2079	44,620	200,000	0.16	44,770	6	0.24
May 2079	44,740	200,000	0.16	44,770	6	0.24
Jan 2082	45,715	200,000	0.16	45,865	6	0.24
May 2082	45,835	200,000	0.16	45,865	6	0.24
Jan 2c83	46,080	300,000	0.24	46,230	6	0.36
May 2083	46,200	300,000	0.24	46,230	6	0.36
Jan 2086	47,175	200,000	0.16	47,325	6	0.24
May 2086	47,295	200,000	0.16	47,325	6	0.24
Jan 2087	47,540	200,000	0.16	47,690	6	0.24
						(Sheet 3 of 5)

Table 2-8 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2087	47,660	200,000	0.16	47,690	6	0.24
Jan 2090	48,635	200,000	0.16	48,785	6	0.24
May 2090	48,755	200,000	0.16	48,785	6	0.24
Jan 2091	49,000	200,000	0.16	49,150	6	0.24
May 2091	49,120	200,000	0.16	49,150	6	0.24
Jan 2094	50,095	200,000	0.16	50,245	6	0.24
May 2094	50,215	200,000	0.16	50,245	6	0.24
Jan 2095	50,460	200,000	0.16	50,610	6	0.24
May 2095	50,580	200,000	0.16	50,610	6	0.24
Jan 2098	51,555	325,000	0.26	51,705	6	0.39
May 2098	51,675	325,000	0.26	51,705	6	0.39
Jan 2099	51,920	200,000	0.16	52,070	6	0.24
May 2099	52,040	200,000	0.16	52,070	6	0.24
Jan 2102	53,015	200,000	0.16	53,165	6	0.24
May 2102	53,135	200,000	0.16	53,165	6	0.24
Jan 2103	53,380	300,000	0.24	53,530	6	0.36
May 2103	53,500	300,000	0.24	53,530	6	0.36
Jan 2106	54,475	200,000	0.16	54,625	6	0.24
May 2106	54,595	200,000	0.16	54,625	6	0.24
Jan 2107	54,840	200,000	0.16	54,990	6	0.24
May 2107	54,960	200,000	0.16	54,990	6	0.24
Jan 2110	55,935	200,000	0.16	56,085	6	0.24
May 2110	56,055	200,000	0.16	56,085	6	0.24
Jan 2111	56,300	200,000	0.16	56,450	6	0.24
May 2111	56,420	200,000	0.16	56,450	6	0.24
Jan 2114	57,395	200,000	0.16	57,545	6	0.24
May 2114	57,515	200,000	0.16	57,545	6	0.24
Jan 2115	57,760	200,000	0.16	57,910	6	0.24
May 2115	57,880	200,000	0.16	57,910	6	0.24

(Sheet 4 of 5)

Table 2-8 (Concluded)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 2118	58,855	325,000	0.26	59,005	6	0.39
May 2118	58,975	325,000	0.26	59,005	6	0.39
Jan 2119	59,220	200,000	0.16	59,370	6	0.24
May 2119	59,340	200,000	0.16	59,370	6	0.24
Jan 2122	60,315	200,000	0.16	60,465	6	0.24
May 2122	60,435	200,000	0.16	60,465	6	0.24
Jan 2123	60,680	300,000	0.24	60,830	6	0.36
May 2123	60,800	300,000	0.24	60,830	6	0.36
Jan 2126	61,775	200,000	0.16	61,925	6	0.24
May 2126	61,895	200,000	0.16	61,925	6	0.24
Jan 2127	62,140	200,000	0.16	62,290	6	0.24
May 2127	62,260	200,000	0.16	62,290	6	0.24
Jan 2130	63,235	200,000	0.16	63,385	6	0.24
May 2130	63,355	200,000	0.16	63,385	6	0.24
Jan 2131	63,600	200,000	0.16	63,750	6	0.24
May 2131	63,720	200,000	0.16	63,750	6	0.24
Total in-channel disposal volume for center compartment = 34,815,523 cu yd Total CIDMMA disposal volume in center compartment = 52,014,391 cu yd						
						(Sheet 5 of 5)

used to estimate the service life of the CIDMMA under the proposed Restricted Use Program.

Craney Island filling simulations, 1984 to 1992

Simulations for the filling history from 1984 to 1992 for the north, center, and south subcontainments are shown in Figures 2-3, 2-4, and 2-5, respectively. The void ratio and effective stress profiles calculated in the previous simulation were input using the restart option and the surface elevation shown in Figure 2-2 at October 1983 was the starting elevation. Figures 2-3, 2-4, and 2-5 illustrate that the calculated surface elevations are in excellent agreement with the field data for all three subcontainments. As a result, these input

Table 2-9
Approximated Disposal History for Baseline Maintenance Dredging Scenario in South Compartment from 1984 to 2132

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Apr 1984	10,035	869,433	0.73	10,095	6	1.09
Sep 1984	10,185	1,391,094	1.17	10,185	9	1.75
Jun 1987	11,190	2,812,748	2.37	11,190	6	3.54
May 1989	12,255	1,457,070	1.23	12,285	6	1.84
Sep 1989	12,375	916,834	0.77	12,375	9	1.16
Jan 1992	12,865	689,456	0.58	13,015	6	0.88
May 1992	12,985	689,456	0.58	13,015	6	0.88
Sep 1992	13,105	689,456	0.58	13,015	6	0.88
Baseline Maintenance Dredging Scenario in the Restricted Use Program (McGee 1992)						
May 1994	13,715	100,000	0.08	13,745	6	0.13
Jan 1995	13,960	200,000	0.17	14,110	6	0.25
May 1995	14,080	200,000	0.17	14,110	6	0.25
Jan 1996	14,325	200,000	0.17	14,475	6	0.25
May 1996	14,445	200,000	0.17	14,475	6	0.26
May 2000	15,905	100,000	0.08	15,935	6	0.13
Jan 2001	16,150	200,000	0.17	16,300	6	0.25
May 2001	16,270	200,000	0.17	16,300	6	0.25
Jan 2002	16,515	200,000	0.17	16,665	6	0.25
May 2002	16,635	200,000	0.17	16,665	6	0.25
Jan 2007	18,340	200,000	0.17	18,490	6	0.25
May 2007	18,460	200,000	0.17	18,490	6	0.25
Jan 2008	18,705	200,000	0.17	18,855	6	0.25
May 2008	18,825	200,000	0.17	18,855	6	0.25
Jan 2012	20,165	200,000	0.17	20,315	6	0.25
May 2012	20,285	200,000	0.17	20,315	6	0.25
Jan 2013	20,530	200,000	0.17	20,680	6	0.25
May 2013	20,650	200,000	0.17	20,680	6	0.25

(Sheet 1 of 5)

Table 2-9 (Continued)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2017	22,110	200,000	0.17	22,140	6	0.25
Jan 2018	22,355	216,666	0.18	22,505	6	0.27
May 2018	22,475	216,666	0.18	22,505	6	0.27
Sep 2018	22,595	216,666	0.18	22,595	9	0.27
Jan 2023	24,180	200,000	0.17	24,330	6	0.25
May 2023	24,300	200,000	0.17	24,330	6	0.25
Sep 2023	24,420	200,000	0.17	24,420	9	0.25
Jan 2024	24,545	200,000	0.17	24,695	6	0.25
May 2028	26,125	175,000	0.15	26,155	6	0.22
Sep 2028	26,245	175,000	0.15	26,155	9	0.22
Jan 2029	26,370	250,000	0.21	26,520	6	0.32
May 2029	26,490	250,000	0.21	26,520	6	0.32
Sep 2033	28,070	200,000	0.17	28,070	9	0.26
Jan 2034	28,195	200,000	0.17	28,345	6	0.25
May 2034	28,315	200,000	0.17	28,345	6	0.25
Jan 2035	28,560	200,000	0.17	28,710	6	0.25
Jan 2039	30,020	200,000	0.17	30,170	6	0.25
May 2039	30,140	200,000	0.17	30,170	6	0.25
Jan 2040	30,385	200,000	0.17	30,535	6	0.25
May 2040	30,505	200,000	0.17	30,535	6	0.25
May 2044	31,965	200,000	0.17	31,995	6	0.25
Jan 2045	32,210	200,000	0.17	32,360	6	0.25
May 2045	32,330	200,000	0.17	32,360	6	0.25
Jan 2046	32,575	200,000	0.17	32,725	6	0.25
Jan 2050	34,035	200,000	0.17	34,185	6	0.25
May 2050	34,155	200,000	0.17	34,185	6	0.25
Jan 2051	34,400	200,000	0.17	34,554	6	0.25
May 2051	34,520	200,000	0.17	34,550	6	0.25
May 2055	35,980	200,000	0.17	36,010	6	0.25

(Sheet 2 of 5)

Table 2-9 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 2056	36,225	200,000	0.17	36,375	6	0.25
May 2056	36,345	200,000	0.17	36,375	6	0.25
Jan 2057	36,590	200,000	0.17	36,740	6	0.25
Jan 2061	38,050	200,000	0.17	38,200	6	0.25
May 2061	38,170	200,000	0.17	38,200	6	0.25
Jan 2062	38,415	200,000	0.17	38,565	6	0.25
May 2062	38,535	200,000	0.17	38,565	6	0.25
May 2066	39,995	200,000	0.17	40,025	6	0.25
Jan 2067	40,240	200,000	0.17	40,390	6	0.25
May 2067	40,360	200,000	0.17	40,390	6	0.25
Jan 2068	40,605	200,000	0.17	40,755	6	0.25
Jan 2072	42,065	200,000	0.17	42,215	6	0.25
May 2072	42,185	200,000	0.17	42,215	6	0.25
Jan 2073	42,430	300,000	0.25	42,580	6	0.38
May 2073	42,550	300,000	0.25	42,580	6	0.38
Jan 2076	43,525	200,000	0.17	43,675	6	0.25
May 2076	43,645	200,000	0.17	43,675	6	0.25
Jan 2077	43,890	200,000	0.17	44,040	6	0.25
May 2077	44,010	200,000	0.17	44,040	6	0.25
Jan 2080	44,985	200,000	0.17	45,135	6	0.25
May 2080	45,105	200,000	0.17	45,135	6	0.25
Jan 2081	45,350	200,000	0.17	45,500	6	0.25
May 2081	45,470	200,000	0.17	45,500	6	0.25
Jan 2084	46,445	200,000	0.17	46,595	6	0.25
May 2084	46,565	200,000	0.17	46,595	6	0.25
Jan 2085	46,810	200,000	0.17	46,960	6	0.25
May 2085	46,930	200,000	0.17	46,960	6	0.25
Jan 2088	47,905	325,000	0.27	48,055	6	0.41
May 2088	48,025	325,000	0.27	48,055	6	0.41
						(Sheet 3 of 5)

Table 2-9 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 2089	48,270	250,000	0.21	48,420	6	0.32
May 2089	48,390	250,000	0.21	48,420	6	0.32
Jan 2092	49,365	250,000	0.21	49,515	6	0.32
May 2092	49,485	250,000	0.21	49,515	6	0.32
Jan 2093	49,730	300,000	0.25	49,880	6	0.38
May 2093	49,850	300,000	0.25	49,880	6	0.38
Jan 2096	50,825	200,000	0.17	50,975	6	0.25
May 2096	50,945	200,000	0.17	50,975	6	0.25
Jan 2097	51,190	200,000	0.17	51,340	6	0.25
May 2097	51,310	200,000	0.17	51,340	6	0.25
Jan 2100	52,285	200,000	0.17	52,435	6	0.25
May 2100	52,405	200,000	0.17	52,435	6	0.25
Jan 2101	52,650	200,000	0.17	52,800	6	0.25
May 2101	52,770	200,000	0.17	52,800	6	0.25
Jan 2104	53,745	200,000	0.17	53,895	6	0.25
May 2104	53,865	200,000	0.17	53,895	6	0.25
Jan 2105	54,110	200,000	0.17	54,260	6	0.25
May 2105	54,230	200,000	0.17	54,260	6	0.25
Jan 2108	55,205	325,000	0.27	55,355	6	0.41
May 2108	55,325	325,000	0.27	55,355	6	0.41
Jan 2109	55,570	250,000	0.21	55,720	6	0.32
May 2109	55,690	250,000	0.21	55,720	6	0.32
Jan 2112	56,665	250,000	0.21	56,815	6	0.32
May 2112	56,785	250,000	0.21	56,815	6	0.32
Jan 2113	57,030	300,000	0.25	57,180	6	0.38
May 2113	57,150	300,000	0.25	57,180	6	0.38
Jan 2116	58,125	200,000	0.17	58,275	6	0.25
May 2116	58,245	200,000	0.17	58,275	6	0.25
Jan 2117	58,490	200,000	0.17	58,640	6	0.25

(Sheet 4 of 5)

Table 2-9 (Concluded)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2117	58,610	200,000	0.17	58,640	6	0.25
Jan 2120	59,585	200,000	0.17	59,735	6	0.25
May 2120	59,705	200,000	0.17	59,735	6	0.25
Jan 2121	59,950	200,000	0.17	60,100	6	0.25
May 2121	60,070	200,000	0.17	60,100	6	0.25
Jan 2124	61,045	200,000	0.17	61,195	6	0.25
May 2124	61,165	200,000	0.17	61,195	6	0.25
Jan 2125	61,410	200,000	0.17	61,560	6	0.25
May 2125	61,530	200,000	0.17	61,560	6	0.25
Jan 2128	62,505	325,000	0.27	62,655	6	0.41
May 2128	62,625	325,000	0.27	62,655	6	0.41
Jan 2129	62,870	250,000	0.21	63,020	6	0.32
May 2129	62,990	250,000	0.21	63,020	6	0.32
Jan 2132	63,965	250,000	0.21	64,115	6	0.32
May 2132	64,085	250,000	0.21	64,115	6	0.32
Total in-channel disposal volume for south compartment = 35,365,545 cu yd Total CIDMMA disposal volume in south compartment = 52,836,124 cu yd						
(Sheet 5 of 5)						

parameters were used to predict the surface elevation of the CIDMMA under the Restricted Use Program.

Review of the void ratio and effective stress profiles in 1992 showed that the majority of the calculated consolidation occurred in the dredged fill. However, large excess pore water pressures, and thus low effective stresses, were calculated in the compressible marine clay foundation (Figure 2-1), which suggest that the compressible foundation (90 to 100 ft thick) is underconsolidated because of the large drainage path. Piezometers recently installed in the perimeter dikes also indicate excess pore water pressure levels in February 1991 that exceed the ground surface elevation by 25 ft in some locations.

Dissipation of these excess pore water pressures would result in substantial consolidation settlement and thus increased storage capacity. Vertical strip drains could significantly reduce the drainage path by allowing both radial and vertical flow. Radial flow will decrease the time required to consolidate the

Table 2-10
Approximated Disposal History for Worst Case Dredging Scenario in North Compartment from 1984 to 2031

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2129	62,990	250,000	0.21	63,020	6	0.32
Jan 2132	63,965	250,000	0.21	64,115	6	0.32
May 2132	64,085	250,000	0.21	64,115	6	0.32
Jan 1984	9,945	2,115,483	1.89	10,095	6	2.83
Jun 1984	10,095	2,921,016	2.61	10,095	6	3.90
Oct 1984	10,215	1,773,076	1.59	10,215	10	2.38
Mar 1985	10,370	1,168,469	1.05	10,460	6	1.57
Nov 1987	11,340	280,615	0.24	11,340	11	0.35
Dec 1987	11,370	1,770,000	1.59	11,370	12	2.38
Feb 1988	11,435	3,412,000	3.06	11,555	6	4.57
Jul 1988	11,585	1,781,737	1.59	11,585	7	2.37
Sep 1988	11,645	1,590,267	1.41	11,645	8	2.11
Jan 1990	12,135	1,838,231	1.65	12,285	6	2.47
Worst Case Dredging Scenario in Restricted Use Program (McGee 1992)						
Jan 1995	13,960	200,000	0.17	14,110	6	0.25
May 1995	14,080	200,000	0.17	14,110	6	0.25
Sep 1995	14,230	200,000	0.17	14,230	9	0.25
Jan 1998	15,055	766,666	0.69	15,205	6	1.03
May 1998	15,175	766,666	0.69	15,205	6	1.03
Sep 1998	15,295	766,666	0.69	15,295	9	1.03
Jan 2001	16,150	133,333	0.12	16,300	6	0.18
May 2001	16,270	133,333	0.12	16,300	6	0.18
Sep 2001	16,390	133,333	0.12	16,390	9	0.18
Jan 2004	17,245	133,333	0.12	17,395	6	0.18
May 2004	17,365	133,333	0.12	17,395	6	0.18
Sep 2004	17,485	133,333	0.12	17,485	9	0.18
Jan 2007	18,340	133,333	0.12	18,490	6	0.18

(Continued)

Table 2-10 (Concluded)						
Date	**Elapsed Time days**	**In-Channel Disposal Volume cu yd**	**In-Channel Disposal Height ft**	**Desiccation Start Time**	**Month Desiccation Starts**	**Initial Disposal Thickness at Craney Island ft**
May 2007	18,460	133,333	0.12	18,490	6	0.18
Sep 2007	18,580	133,333	0.12	18,580	9	0.18
Jan 2010	19,435	133,333	0.12	19,585	6	0.18
May 2010	19,555	266,666	0.24	19,585	6	0.36
Jan 2013	20,530	200,000	0.17	20,680	6	0.25
May 2013	20,650	200,000	0.17	20,680	6	0.25
Sep 2013	20,740	200,000	0.17	20,740	9	0.25
Jan 2016	21,625	766,666	0.69	21,775	6	1.03
May 2016	21,745	766,666	0.69	21,775	6	1.03
Sep 2016	21,865	766,666	0.69	21,865	9	1.03
Jan 2019	22,720	133,333	0.12	22,870	6	0.18
May 2019	27,840	133,333	0.12	22,870	6	0.18
Sep 2019	22,960	133,333	0.12	22,960	9	0.18
Jan 2022	23,815	133,333	0.12	23,965	6	0.18
May 2022	23,935	133,333	0.12	23,965	6	0.18
Sep 2022	24,055	133,333	0.12	24,055	9	0.18
Jan 2025	24,910	133,333	0.12	25,060	6	0.18
May 2025	25,030	133,333	0.12	25,060	6	0.18
Sep 2025	25,150	133,333	0.12	25,150	9	0.18
Jan 2028	26,005	516,666	0.46	26,155	6	0.69
May 2028	26,125	516,666	0.46	26,155	6	0.69
Sep 2028	26,245	516,666	0.46	26,245	9	0.69
Jan 2031	27,100	133,333	0.12	27,250	6	0.18
May 2031	27,220	133,333	0.12	27,250	6	0.18
Sep 2031	27,340	133,333	0.12	27,340	9	0.18

Total in-channel disposal volume for north compartment = 29,200,835 cu yd
Total CIDMMA disposal volume in north compartment = 43,626,048 cu yd

Table 2-11
Approximated Disposal History for Worst Case Dredging Scenario in Center Compartment from 1984 to 2080

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Mar 1985	10,370	600,095	0.48	10,460	6	0.72
Feb 1986	10,705	1,147,573	0.93	10,825	6	1.39
Jun 1986	10,825	1,804,206	1.46	10,825	6	2.18
Aug 1986	10,885	721,380	0.58	10,885	8	0.87
Apr 1989	11,860	1,457,070	1.17	11,920	6	1.74
Sep 1989	12,010	916,834	0.74	12,010	9	1.11
Sep 1991	12,470	2,068,369	1.67	12,740	9	2.44
Worst Case Dredging Scenario in Restricted Use Program (McGee 1992)						
Jan 1993	13,320	200,000	0.16	13,380	6	0.24
May 1993	13,350	200,000	0.16	13,380	6	0.24
Sep 1993	13,470	200,000	0.16	13,470	9	0.24
Jan 1996	14,325	766,666	0.62	14,475	6	0.93
May 1996	14,445	766,666	0.62	14,475	6	0.93
Sep 1996	14,565	766,666	0.62	14,565	9	0.93
Jan 1999	15,420	133,333	0.11	15,570	6	0.16
May 1999	15,54[illegible]	133,333	0.11	15,570	6	0.16
Sep 1999	15,660	133,333	0.11	15,660	9	0.16
Jan 2002	16,515	133,333	0.11	16,665	6	0.16
May 2002	16,635	133,333	0.11	16,665	6	0.16
Sep 2002	16,755	133,333	0.11	16,755	9	0.16
Jan 2005	17,610	133,333	0.11	17,760	6	0.16
May 2005	17,730	133,333	0.11	17,760	6	0.16
Sep 2005	17,850	133,333	0.42	17,850	9	0.63
Jan 2008	18,750	516,667	0.42	18,855	6	0.63
May 2008	18,825	516,667	0.42	18,855	6	0.63
Sep 2008	18,945	516,667	0.42	18,945	9	0.63
Jan 2011	19,800	133,333	0.11	19,950	6	0.16

(Sheet 1 of 5)

Table 2-11 (Continued)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2011	19,920	266,666	0.22	19,950	6	0.33
Jan 2014	20,895	133,333	0.11	21,045	6	0.16
May 2014	21,015	133,333	0.11	21,045	6	0.16
Sep 2014	21,135	133,333	0.11	21,135	9	0.16
Jan 2017	21,990	766,666	0.62	22,140	6	0.93
May 2017	22,110	766,666	0.62	22,140	6	0.93
Sep 2017	22,230	766,666	0.62	22,230	9	0.93
Jan 2020	23,085	133,333	0.11	23,235	6	0.16
May 2020	23,205	133,333	0.11	23,235	6	0.16
Sep 2020	23,325	133,333	0.11	23,325	9	0.16
Jan 2023	24,180	200,000	0.16	24,330	6	0.24
May 2023	24,300	200,000	0.16	24,330	6	0.24
Sep 2023	24,420	200,000	0.16	24,420	9	0.24
Jan 2026	25,275	133,333	0.11	25,425	6	0.16
May 2026	25,395	133,333	0.11	25,425	6	0.16
Sep 2026	25,515	133,333	0.11	25,515	9	0.16
Jan 2029	26,370	166,666	0.13	26,520	6	0.20
May 2029	26,490	166,666	0.13	26,520	6	0.20
Sep 2029	26,610	166,666	0.13	26,610	9	0.20
Jan 2032	27,465	133,333	0.11	27,615	6	0.16
May 2032	27,585	133,333	0.11	27,615	6	0.16
Sep 2032	27,705	133,333	0.11	27,705	9	0.16
Jan 2034	28,195	200,000	0.16	28,345	6	0.24
May 2034	28,315	200,000	0.16	28,345	6	0.24
Sep 2034	28,435	200,000	0.16	28,435	9	0.24
Jan 2036	28,925	200,000	0.16	29,075	6	0.24
May 2036	29,045	200,000	0.16	29,075	6	0.24
Sep 2036	29,165	200,000	0.16	29,165	9	0.24
Jan 2038	29,655	766,666	0.62	29,805	6	0.93

(Sheet 2 of 5)

Table 2-11 (Continued)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2038	29,775	766,666	0.62	29,805	6	0.93
Sep 2038	29,895	766,666	0.62	29,895	9	0.93
Jan 2040	30,385	133,333	0.11	30,535	6	0.16
May 2040	30,505	133,333	0.11	30,535	6	0.16
Sep 2040	30,625	133,333	0.11	30,625	9	0.16
Jan 2042	31,115	133,333	0.11	31,265	6	0.16
May 2042	31,235	133,333	0.11	31,265	6	0.16
Sep 2042	31,355	133,333	0.11	31,355	9	0.16
Jan 2044	31,845	200,000	0.16	31,995	6	0.24
May 2044	31,965	200,000	0.16	31,995	6	0.24
Sep 2044	32,085	200,000	0.16	32,085	9	0.24
Jan 2046	32,575	133,333	0.11	32,725	6	0.16
May 2046	32,695	133,333	0.11	32,725	6	0.16
Sep 2046	32,815	133,333	0.11	32,815	9	0.16
Jan 2048	33,305	133,333	0.11	33,455	6	0.16
May 2048	33,425	133,333	0.11	33,455	6	0.16
Sep 2048	33,545	133,333	0.11	33,545	9	0.16
Jan 2050	34,035	166,666	0.13	34,185	6	0.20
May 2050	34,155	166,666	0.13	34,185	6	0.20
Sep 2050	34,275	166,666	0.13	34,275	9	0.20
Sep 2052	35,005	133,333	0.11	35,005	9	0.16
Sep 2054	35,735	200,000	0.16	35,735	9	0.24
May 2056	36,345	200,000	0.16	36,375	6	0.24
Sep 2056	36,465	200,000	0.16	36,465	9	0.24
Jan 2058	36,955	766,666	0.62	37,105	6	0.93
May 2058	37,075	766,666	0.62	37,105	6	0.93
Sep 2058	37,195	766,666	0.62	37,195	9	0.93
Jan 2060	37,685	133,333	0.11	37,835	6	0.16
May 2060	37,805	133,333	0.11	37,835	6	0.16

(Sheet 3 of 5)

Table 2-11 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Sep 2060	37,925	133,333	0.11	37,925	9	0.16
Jan 2062	38,415	133,333	0.11	38,565	6	0.16
May 2062	38,535	133,333	0.11	38,565	6	0.16
Sep 2062	38,655	133,333	0.11	38,655	9	0.16
Jan 2064	39,145	200,000	0.16	39,295	6	0.24
May 2064	39,265	200,000	0.16	39,295	6	0.24
Sep 2064	39,385	200,000	0.16	39,385	9	0.24
Jan 2066	39,875	133,333	0.11	40,025	6	0.16
May 2066	39,995	133,333	0.11	40,025	6	0.16
Sep 2066	40,115	133,333	0.11	40,115	9	0.16
Jan 2068	40,605	133,333	0.11	40,755	6	0.16
May 2068	40,725	133,333	0.11	40,755	6	0.16
Sep 2068	40,845	133,333	0.11	40,845	9	0.16
Jan 2070	41,335	166,666	0.13	41,485	6	0.20
May 2070	41,455	166,666	0.13	41,485	6	0.20
Sep 2070	41,575	166,666	0.13	41,575	9	0.20
Jan 2072	42,065	133,333	0.11	42,215	6	0.16
May 2072	42,185	133,333	0.11	42,215	6	0.16
Sep 2072	42,305	133,333	0.11	42,305	9	0.16
Jan 2074	42,795	200,000	0.16	42,945	6	0.24
May 2074	42,915	200,000	0.16	42,945	6	0.24
Sep 2074	43,035	200,000	0.16	43,035	9	0.24
Jan 2076	43,525	200,000	0.16	43,675	6	0.24
May 2076	43,645	200,000	0.16	43,675	6	0.24
Sep 2076	43,765	200,000	0.16	43,765	9	0.24
Jan 2078	44,255	766,666	0.62	44,405	6	0.93
May 2078	44,375	766,666	0.62	44,405	6	0.93
Sep 2078	44,495	766,666	0.62	44,495	9	0.93
Jan 2080	44,985	133,333	0.11	45,135	6	0.16
						(Sheet 4 of 5)

Table 2-11 (Concluded)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2080	45,105	133,333	0.11	45,135	6	0.16
Sep 2080	45,225	133,333	0.11	45,225	9	0.16

Total in-channel disposal volume for center compartment = 36,865,493 cu yd
Total CIDMMA disposal volume in center compartment = 55,077,047 cu yd

(Sheet 5 of 5)

dredged fill and foundation clay and provide a rapid increase in storage capacity. Consolidation of the dredged fill and foundation clay would also cause a significant increase in the undrained shear strength of these materials, allowing the perimeter dikes to be constructed to higher elevations without setbacks or stability berms. The height to which the dikes could be constructed after consolidation with vertical strip drains is currently being investigated. The effect of vertical strip drains on the service life of the CIDMMA is beyond the scope of this report.

Based on the void ratio and effective stress profiles in 1992, Stark and Fowler (In Preparation) proposed that vertical strip drains be installed throughout the disposal area and subsequently the perimeter dikes. The strip drains should accelerate consolidation of the foundation clay and dredged fill and allow a new disposal area to be constructed on top of the existing area, thus prolonging the service life of the CIDMMA and saving the cost of ocean disposal. A 450-ft-by-400-ft strip drain test section was completed in February 1993 in the north compartment of the CIDMMA to evaluate the effectiveness of strip drains in increasing storage capacity. Early results showed that the dredged fill and foundation clay underlying the test section are undergoing substantial settlement (2 to 2.5 ft in 3 months). The strip drains were designed and spaced to promote consolidation, and thus settlement, for an additional 9 months. Analysis of the results of the test section are beyond the scope of this study.

Baseline maintenance filling simulations, 1992 to 2132

The Baseline Maintenance simulations for the filling history from 1992 to 2132 under the proposed Restricted Use Program are also shown in Figures 2-3, 2-4, and 2-5 for the north, center, and south subcontainments, respectively. Dredged material was initially placed in the center compartment. After approximately 1 ft of material was placed in the center compartment, dredged material was placed in the south compartment. Placement was moved to the

Table 2-12
Approximated Disposal History for Worst Case Dredging Scenario in South Compartment from 1984 to 2080

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Apr 1984	10,035	869,433	0.73	10,095	6	1.09
Sep 1984	10,185	1,391,094	1.17	10,185	9	1.75
Jun 1987	11,190	2,812,748	2.37	11,190	6	3.54
May 1989	12,255	1,457,070	1.23	12,285	6	1.84
Sep 1989	12,375	916,834	0.77	12,375	9	1.16
Jan 1992	12,865	689,456	0.58	13,015	6	0.88
May 1992	12,985	689,456	0.58	13,015	6	0.88
Sep 1992	13,105	689,456	0.58	13,015	9	0.88
Worst Case Dredging Scenario in Restricted Use Program (McGee 1992)						
Jan 1994	13,595	133,333	0.11	13,745	6	0.16
May 1994	13,715	133,333	0.11	13,745	6	0.16
Sep 1994	13,835	133,333	0.11	13,835	9	0.16
Jan 1997	14,690	766,666	0.65	14,840	6	0.97
May 1997	14,810	766,666	0.65	14,840	6	0.97
Sep 1997	14,930	766,666	0.65	14,930	9	0.97
Jan 2000	15,785	133,333	0.11	15,935	6	0.16
May 2000	15,905	133,333	0.11	15,935	6	0.16
Sep 2000	16,025	133,333	0.11	16,025	9	0.16
Jan 2003	16,880	200,000	0.17	17,030	6	0.25
May 2003	17,000	200,000	0.17	17,030	6	0.25
Sep 2003	17,120	200,000	0.17	17,120	9	0.25
Jan 2006	17,975	133,333	0.11	18,125	6	0.16
May 2006	18,095	133,333	0.11	18,125	6	0.16
Sep 2006	18,215	133,333	0.11	18,215	9	0.16
Jan 2009	19,070	166,666	0.14	19,220	6	0.21
May 2009	19,190	166,666	0.14	19,220	6	0.21
Sep 2009	19,310	166,666	0.14	19,310	9	0.21

(Sheet 1 of 5)

Table 2-12 (Continued)

Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 2012	20,165	133,333	0.11	20,315	6	0.16
May 2012	20,285	266,666	0.22	20,315	6	0.33
Jan 2015	21,260	200,000	0.17	21,410	6	0.25
May 2015	21,380	200,000	0.17	21,410	6	0.25
Sep 2015	21,500	200,000	0.17	21,500	9	0.25
Jan 2018	22,355	516,666	0.44	22,505	6	0.65
May 2018	24,300	516,666	0.44	22,505	6	0.65
Sep 2018	24,420	516,666	0.44	24,420	9	0.65
Jan 2021	23,450	133,333	0.11	23,600	6	0.16
May 2021	23,570	133,333	0.11	23,600	6	0.16
Sep 2021	23,690	133,333	0.11	23,690	9	0.16
Jan 2024	24,545	133,333	0.11	24,695	6	0.16
May 2024	24,665	133,333	0.11	24,695	6	0.16
Sep 2024	24,785	133,333	0.11	24,785	9	0.16
Jan 2027	25,640	133,333	0.11	25,790	6	0.16
May 2027	25,760	133,333	0.11	25,790	6	0.16
Sep 2027	25,880	133,333	0.11	25,880	9	0.16
Jan 2030	26,735	133,333	0.11	26,885	6	0.16
May 2030	26,855	133,333	0.11	26,885	6	0.16
Sep 2030	26,975	133,333	0.11	26,975	9	0.16
Jan 2033	27,830	133,333	0.11	27,980	6	0.16
May 2033	27,950	133,333	0.11	27,980	6	0.16
Sep 2033	28,070	133,333	0.11	28,070	9	0.16
Jan 2035	28,560	133,333	0.11	28,710	6	0.16
May 2035	28,680	133,333	0.11	28,710	6	0.16
Sep 2035	28,800	133,333	0.11	28 800	9	0.16
Jan 2037	29,290	766,666	0.65	29,440	6	0.97
May 2037	29,410	766,666	0.65	29,440	6	0.97
Sep 2037	29,530	766,666	0.65	29,530	9	0.97

(Sheet 2 of 5)

Table 2-12 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Jan 2039	30,020	516,666	0.44	30,170	6	0.65
May 2039	30,140	516,666	0.44	30,170	6	0.65
Sep 2039	30,260	516,666	0.44	30,260	9	0.65
Jan 2041	30,750	133,333	0.11	30,900	6	0.16
May 2041	30,870	133,333	0.11	30,900	6	0.16
Sep 2041	30,990	133,333	0.11	30,990	9	0.16
Jan 2043	31,480	133,333	0.11	31,630	6	0.16
May 2043	31,600	133,333	0.11	31,630	6	0.16
Sep 2043	31,720	133,333	0.11	31,720	9	0.16
Jan 2045	32,210	133,333	0.11	32,360	6	0.16
May 2045	32,330	133,333	0.11	32,360	6	0.16
Sep 2045	32,450	133,333	0.11	32,450	9	0.16
Jan 2047	32,940	133,333	0.11	33,090	6	0.16
May 2047	33,060	133,333	0.11	33,090	6	0.16
Sep 2047	33,180	133,333	0.11	33,180	9	0.16
Jan 2049	33,670	516,666	0.44	33,820	6	0.65
May 2049	33,790	516,666	0.44	33,820	6	0.65
Sep 2049	33,910	516,666	0.44	33,910	9	0.65
Jan 2051	34,400	133,333	0.11	34,550	6	0.16
May 2051	34,520	133,333	0.11	34,550	6	0.16
Sep 2051	34,640	133,333	0.11	34,640	9	0.16
Jan 2053	35,130	133,333	0.11	35,280	6	0.16
May 2053	35,250	133,333	0.11	35,280	6	0.16
Sep 2053	35,370	133,333	0.11	35,370	9	0.16
Jan 2055	35,860	133,333	0.11	36,010	6	0.16
May 2055	35,980	133,333	0.11	36,010	6	0.16
Sep 2055	36,100	133,333	0.11	36.100	9	0.16
Jan 2057	36,590	766,666	0.65	36,740	6	0.97
May 2057	36,710	766,666	0.65	36,740	6	0.97

(Sheet 3 of 5)

Table 2-12 (Continued)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
Sep 2057	36,830	766,666	0.65	36,830	9	0.97
Jan 2059	37,320	516,666	0.44	37,470	6	0.65
May 2059	37,440	516,666	0.44	37,470	6	0.65
Sep 2059	37,560	516,666	0.44	37,560	9	0.65
Jan 2061	38,050	133,333	0.11	38,200	6	0.16
May 2061	38,170	133,333	0.11	38,200	6	0.16
Sep 2061	38,290	133,333	0.11	38,290	9	0.16
Jan 2063	38,780	133,333	0.11	38,930	6	0.16
May 2063	38,900	133,333	0.11	38,930	6	0.16
Sep 2063	39,020	133,333	0.11	39,020	9	0.16
Jan 2065	39,510	133,333	0.11	39,660	6	0.16
May 2065	39,630	133,333	0.11	39,660	6	0.16
Sep 2065	39,750	133,333	0.11	39,750	9	0.16
Jan 2067	40,240	133,333	0.11	40,390	6	0.16
May 2067	40,360	133,333	0.11	40,390	6	0.16
Sep 2067	40,480	133,333	0.11	40,480	9	0.16
Jan 2069	40,970	516,666	0.44	41,120	6	0.65
May 2069	41,090	516,666	0.44	41,120	6	0.65
Sep 2069	41,210	516,666	0.44	41,210	9	0.65
Jan 2071	41,700	133,333	0.11	41,850	6	0.16
May 2071	41,820	133,333	0.11	41,850	6	0.16
Sep 2071	41,940	133,333	0.11	41,940	9	0.16
Jan 2073	42,430	133,333	0.11	42,580	6	0.16
May 2073	42,550	133,333	0.11	42,580	6	0.16
Sep 2073	42,670	133,333	0.11	42,670	9	0.16
Jan 2075	43,160	133,333	0.11	43,310	6	0.16
May 2075	43,280	133,333	0.11	43,310	6	0.16
Sep 2075	43,400	133,333	0.11	43,400	9	0.16
Jan 2077	43,890	766,666	0.65	44,040	6	0.97
						(Sheet 4 of 5)

Table 2-12 (Concluded)						
Date	Elapsed Time days	In-Channel Disposal Volume cu yd	In-Channel Disposal Height ft	Desiccation Start Time	Month Desiccation Starts	Initial Disposal Thickness at Craney Island ft
May 2077	44,010	766,666	0.65	44,040	6	0.97
Sep 2077	44,130	766,666	0.65	44,130	9	0.97
Jan 2079	44,620	516,666	0.44	44,770	6	0.65
May 2079	44,740	516,666	0.44	44,770	6	0.65
Sep 2079	44,860	516,666	0.44	44,860	9	0.65

Total in-channel disposal volume for south compartment = 39,315,051 cu yd
Total CIDMMA disposal volume in south compartment = 58,737,359 cu yd

(Sheet 5 of 5)

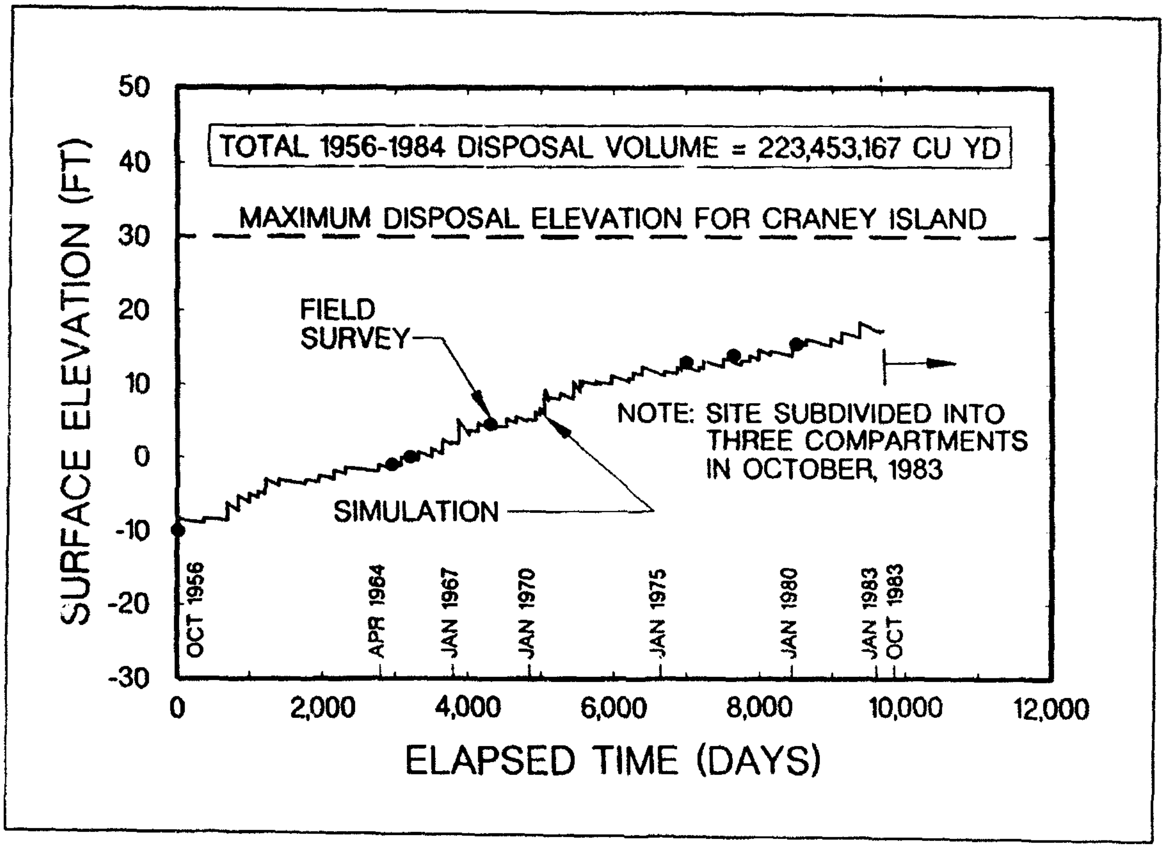

Figure 2-2. Fill rates for Craney Island from 1956 to 1984

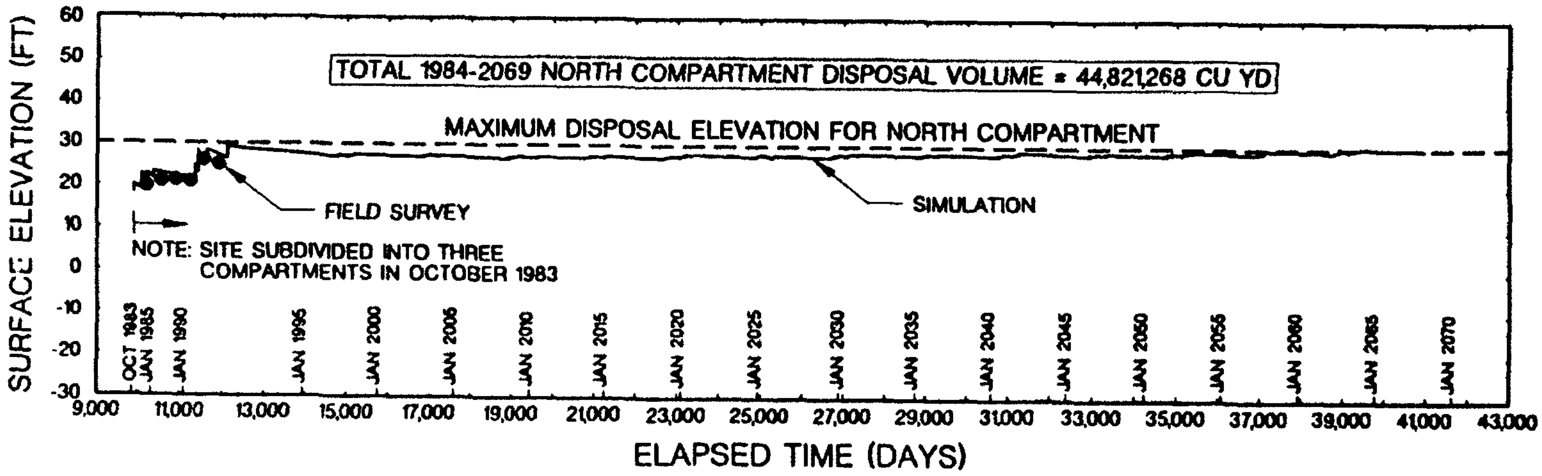

Figure 2-3. Simulation of fill rates for Baseline Maintenance Dredging Scenario in north compartment from 1984 to 2069

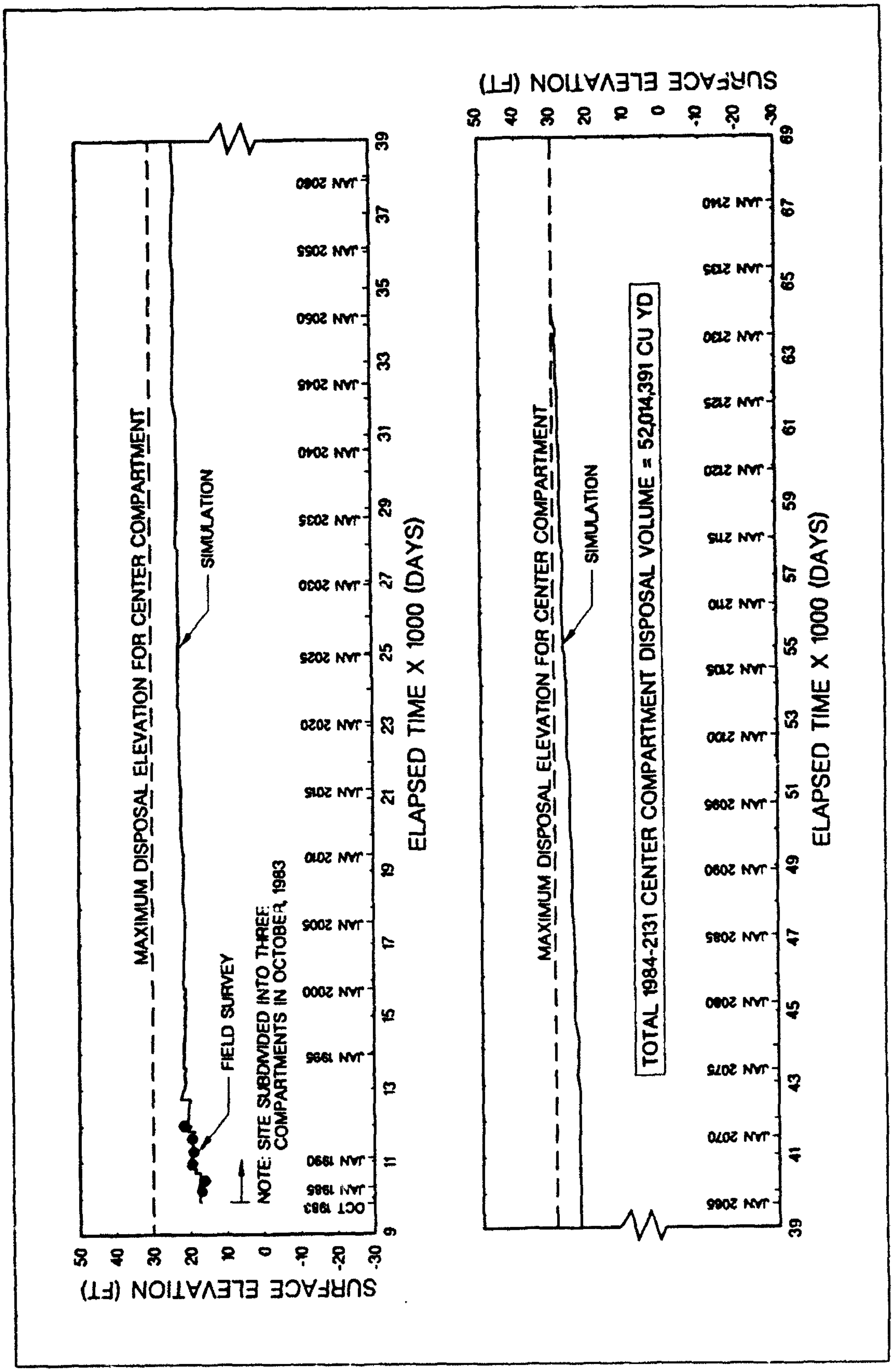

Figure 2-4. Simulation of fill rates for Baseline Maintenance Dredging Scenario in center compartment from 1984 to 2131

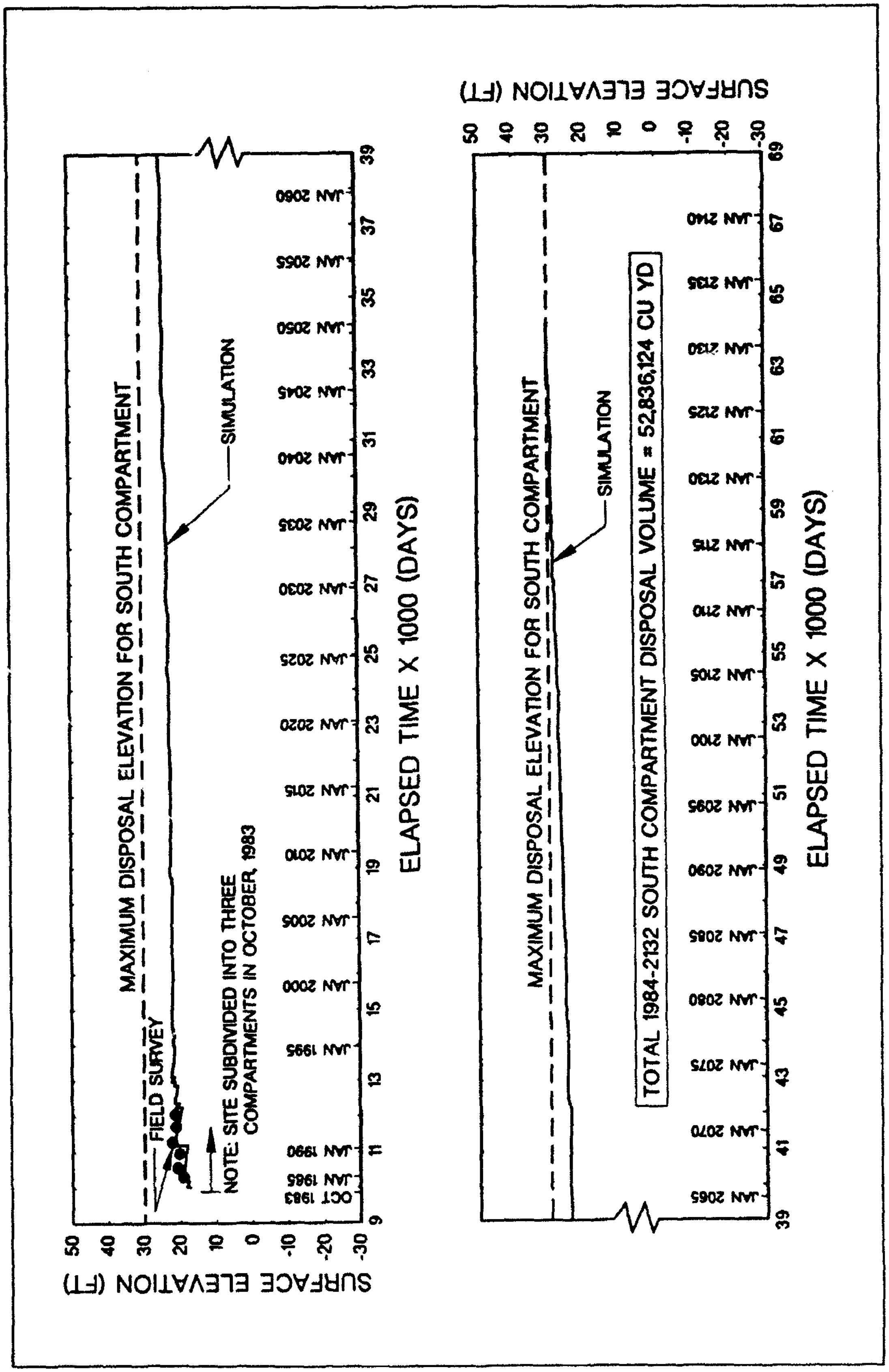

Figure 2-5. Simulation of fill rates for Baseline Maintenance Dredging Scenario in south compartment from 1984 to 2132

north cell after a 1-ft lift was placed in the south cell, and this cycle was repeated until an elevation of +30 ft MLW was obtained in all three compartments. As shown in Figure 2-2, the north compartment reached capacity in January 2069. After January 2069, all of the dredged material was placed in the center and south compartments using 1-ft lifts. Figure 2-3 shows that the center compartment reached capacity in May 2131. After May 2131, all of the Baseline Maintenance dredged material was placed in the south compartment; as a result, this compartment reached capacity in May 2132. Therefore, the service life of the CIDMMA would be extended to the year 2130 under the proposed Baseline Maintenance Dredging Scenario of the proposed Restricted Use Program.

The north compartment reached capacity earlier than the center and south compartments because the current surface elevation is approximately +27 ft MLW, whereas the surface elevation in the center and south compartments is about +20 ft MLW. If the Restricted Use Program is instituted, some of the material projected for the north compartment could be distributed to the center and south compartments to reduce the possibility that the north compartment will reach capacity more quickly than the other two compartments.

This analysis predicts that the CIDMMA has a service life of approximately 140 years under the Baseline Maintenance Dredging Scenario of the Restricted Use Program. Clearly, this prediction is a planning level estimate and should only be used to determine if the Restricted Use Program deserves further consideration. This prediction involves many assumptions that may not pertain to the CIDMMA around the year 2130. For example, the precipitation and evaporation rates will be different, which may lead to a change in the quantity and character of the dredged material. The contaminants entering the Norfolk Harbor and Channels will also change, altering the quantity and character of the dredged material placed in the CIDMMA. In summary, the results of the Baseline Maintenance Dredging Scenario clearly show that reducing the amount of dredged material placed in Craney Island in the Restricted Use Program will significantly extend the service life of this facility.

Worst Case filling simulations, 1992 to 2081

The Worst Case simulations for the filling history from 1992 to 2081 under the proposed Restricted Use Program are shown in Figures 2-6, 2-7, and 2-8 for the north, center, and south subcontainments, respectively. The volume of material placed in this scenario corresponds to a summation of the four dredging scenarios presented by the Norfolk District (McGee 1992).

Simulation of dredged material placement was accomplished using an annual rotation starting with the center compartment and ending with the north compartment. As shown in Figure 2-6, the north compartment reached capacity (i.e., el +30 ft MLW) by September 2031. After September 2031, dredged material would be placed only in the center and south compartments using an annual rotation schedule. As shown in Figure 2-8, the south compartment

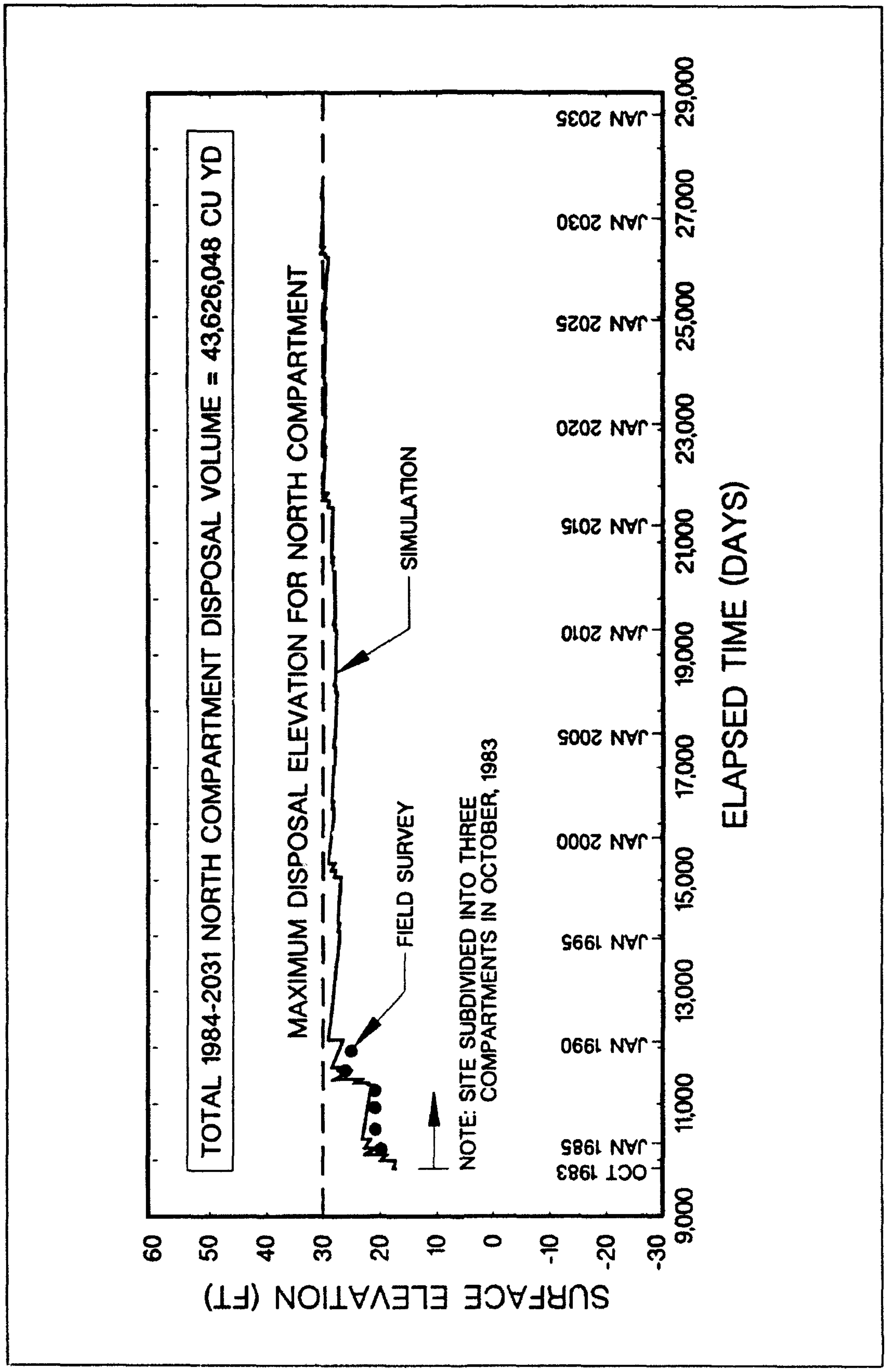

Figure 2-6. Simulation of fill rates for Worst Case Dredging Scenario in north compartment from 1984 to 2031

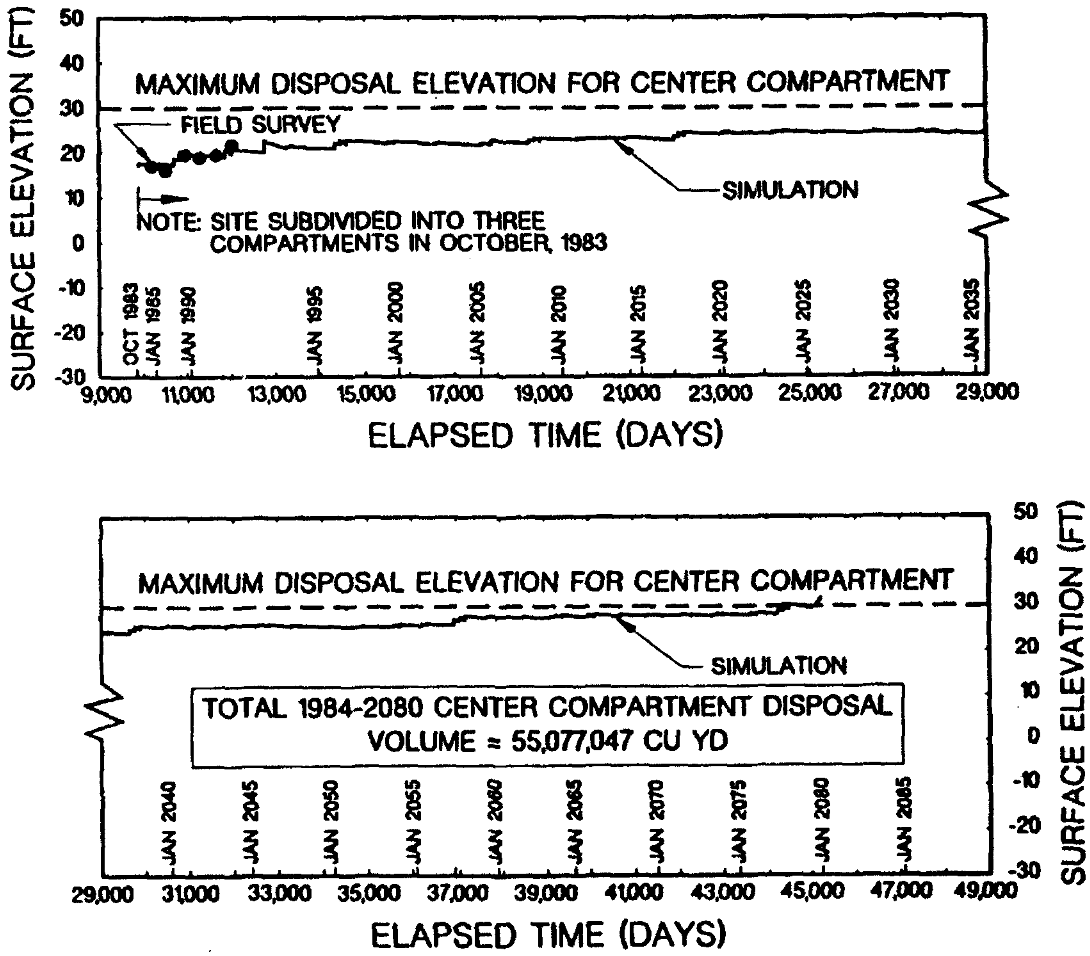

Figure 2-7. Simulation of fill rates for Worst Case Dredging Scenario in center compartment from 1984 to 2080

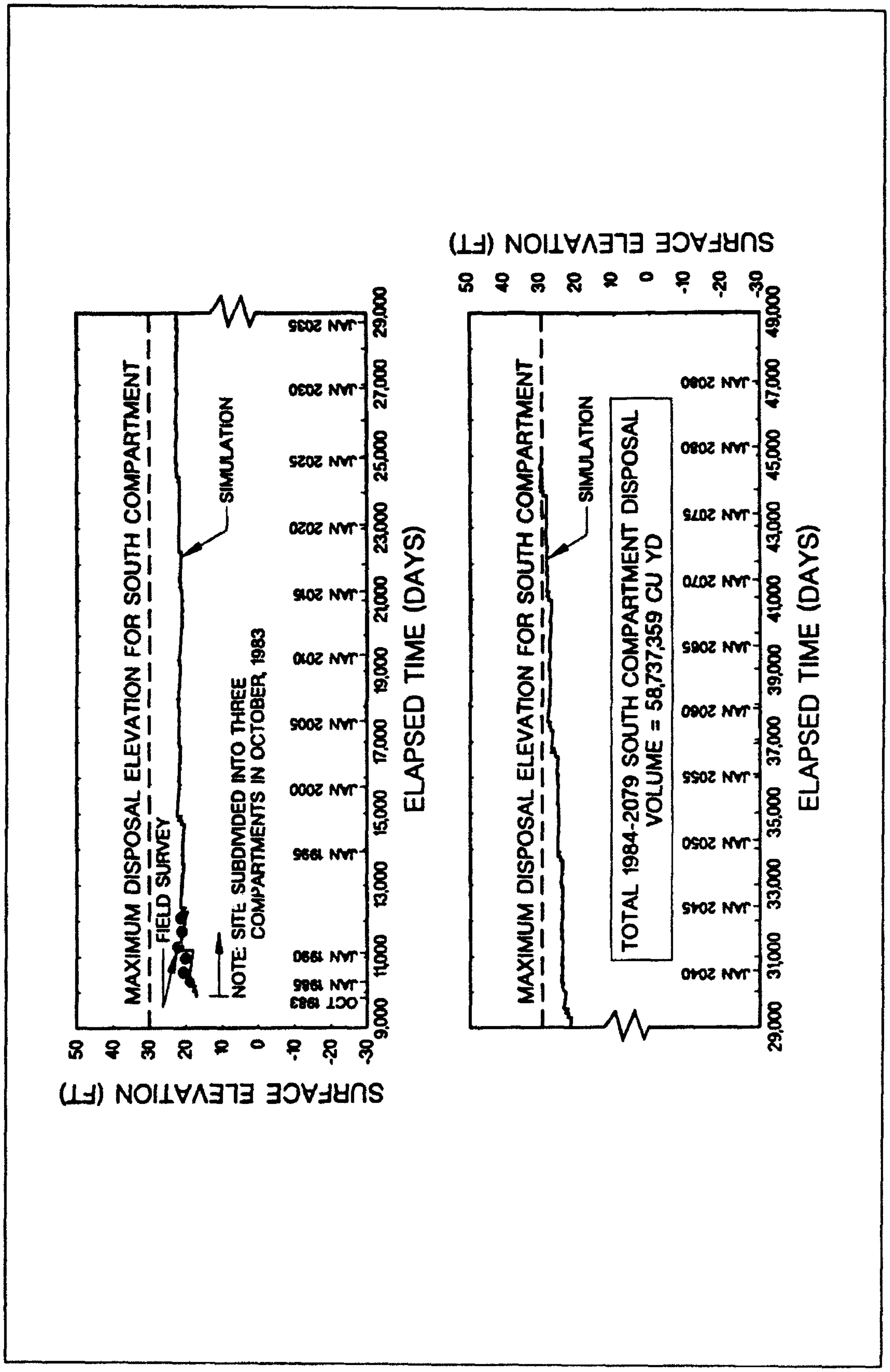

Figure 2-8. Simulation of fill rates for Worst Case Dredging Scenario in south compartment from 1984 to 2079

would reach capacity in May 2079. After May 2079, all dredged material would be placed in the center compartment, causing this compartment to reach capacity in September 2080. Therefore, even under the Worst Case Dredging Scenario (i.e., the summation of the four dredging cases presented by the Norfolk District), the service life of the CIDMMA will be extended to the year 2081 under the proposed Restricted Use Program.

3 Comprehensive Analysis of Migration Pathways (CAMP)

Introduction

When contaminated dredged material is placed in a confined disposal facility (CDF), contaminants can be mobilized and transported away from the CDF by a variety of physical, chemical, and biological processes (Figure 3-1).

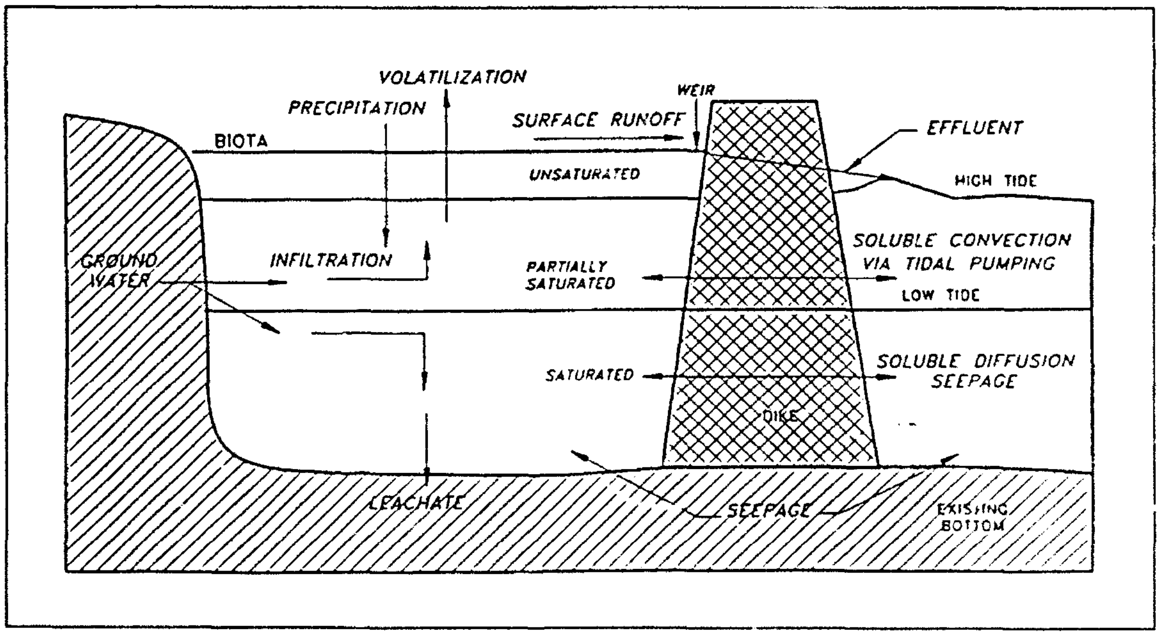

Figure 3-1. Nearshore disposal site migration pathways (from Brannon et al. 1990)

Pathways involving movement of large masses of water have the greatest potential for transporting significant quantities of contaminants out of CDFs (Brannon et al. 1990). Water-related migration pathways include effluent discharge during hydraulic filling, seepage of leachate through dikes, seepage of leachate into foundation soils, and surface runoff. Pathways such as volatilization and plant and animal uptake may also transport contaminants at certain stages in the life of a CDF.

The computational elements of Comprehensive Analysis of Migration Pathways (CAMP) are structured around mass balance concepts. For any given contaminant, the rate of contaminant mass into a CDF minus the rate of contaminant mass out of the CDF is the rate of contaminant mass retention. Overall containment efficiency factor (CEF) is defined as follows (Myers 1991):

$$CEF = \left(\frac{1}{n+m}\right) \sum_{j=1}^{m} \sum_{i=1}^{n} \frac{\left[Rate\ of\ mass\ in\right]_{i,j} - \left[Rate\ of\ mass\ out\right]_{i,j}}{\left[Rate\ of\ mass\ in\right]_{i,j}} \tag{3-1}$$

where

n = number of contaminants included in the pathway analysis

m = number of pathways

j = pathway index

i = contaminant index

The CEF is a simple indicator of containment efficiency that is useful for comparing alternatives or sites in a relative manner.

Thus, the basic concept of CAMP is simple. Implementation of this concept presents two types of challenges—appropriate definition of spatial and temporal scales and estimation of contaminant transfer rates along pathways.

The spatial scale of the CIDMMA is relatively straightforward, consisting of the confining dikes, the interface between foundation soils and dredged material, and the surface of the CDF. The temporal scale, on the other hand, is not so easily defined. First, the relative importance of various pathways is time dependent. For example, effluent is an important pathway during filling operations; but after the CIDMMA is filled, this contaminant loss pathway no longer exists. In addition, the overall time scale must be considered because the CIDMMA is permanently maintained and some pathways persist indefinitely

The availability of techniques and test procedures for estimating contaminant losses is another problem for CAMP because the availability of contaminant loss estimation techniques is highly pathway dependent. For some pathways, such as effluent, established procedures can be adapted for estimating contaminant losses. For other pathways, such as volatile emissions, theoretical models are the only tools available, and for some pathways, procedures are unavailable. Since most of the predictive techniques available are still developmental, descriptions of the CAMP techniques used for the CIDMMA are included in this report.

Two levels of predictive techniques are described as techniques based on laboratory testing and a priori techniques requiring no laboratory testing other than bulk chemical analysis of sediments. After the predictive techniques are described, contaminant losses are estimated using a priori estimation techniques for selected restricted use scenarios.

Priority pollutant data (Table 3-1) from the Virginia State Water Control Board Toxics Database Report (VSDR) for sediments in the Hampton Roads Harbor area were used to prepare a priori estimates of contaminant losses. Four metals (copper, chromium, lead, and zinc) were identified as contaminants of concern in the VSDR. Five organic contaminants were also identified. The organic compounds listed are polycyclic aromatic hydrocarbons (PAHs). PAHs comprise a class of chemicals that are mutagenic and carcinogenic, some being more potent mutagens and carcinogens than others (Cooke and Dennis 1983).

Table 3-1
Priority Pollutant Concentrations Identified in the 1985-1989 Virginia State Water Control Board Toxics Database Report for Sediments in the Hampton Roads Area[1]

Chemical[2]	Sediment Area						
	CI	NH	PN	TP	EB	WB	NN
Benzofluoranthene	710	2,140	7,860	2,860	8,570	1,000	860
Pyrene	710	7,860	12,300	2,140	17,900	1,000	2,000
Chrysene	430	16,000	6,430	1,430	8,140	860	710
Fluoranthene	710	12,100	17,900	1,430	27,100	860	2,140
Phenanthrene	290	12,300	20,100	710	14,300	290	430
Copper	70	110	70	NA	180	70	60
Chromium	55	44	52	NA	67	55	33
Lead	80	42	180	NA	290	130	70
Zinc	220	245	780	NA	490	645	220

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port of Norfolk, TP = Town Point, EB = Elizabeth River, East Branch, WB = Elizabeth River, West Branch, NN = Newport News.

[1] Concentrations read from bar graphs supplied by Norfolk District.

[2] Organic Concentrations in μg/kg and metals concentrations in mg/kg.

Effluent Losses During Hydraulic Filling

Standard Corps of Engineers procedures

Effluent quality during hydraulic filling is predicted on the basis of data from column settling and modified elutriate tests and disposal facility design (Headquarters, U.S. Army Corps of Engineers 1987). Data requirements for using standard Corps of Engineers techniques for estimating effluent quality during hydraulic filling are listed in Table 3-2. As indicated in Table 3-2, information on facility design and influent flow and quality are needed to estimate effluent flow and quality.

Table 3-2
Data Requirements for Predicting Effluent Quality During Hydraulic Disposal Using Standard Corps of Engineers Procedures[1]

Data Required	Source of Data
Dredge inflow	Project information, site design
Influent solids concentration	Project information
Average ponding depth	Project information, site design
Hydraulic efficiency factor	Dye tracer study or theoretical retention time
Effluent suspended solids concentration	Column settling tests
Contaminant dissolved concentrations in effluent	Modified elutriate test
Fraction of contaminant in effluent suspended solids	Modified elutriate test

[1] Source: Headquarters, U.S. Army Corps of Engineers (1987).

In addition to column settling tests, the standard Corps of Engineers procedure uses data from modified elutriate tests. This test was developed specifically for estimating effluent quality from CDFs (Palermo 1986). Particulate contaminant concentrations can be calculated from modified elutriate data as follows:

$$C_{p,i} = \frac{C_{ww,i} - C_{w,i}}{S_{me}} \tag{3-2}$$

where

$C_{p,i}$ = predicted effluent particulate contaminant concentration for the ith contaminant, mg/kg

$C_{ww,i}$ = whole water contaminant concentration in the modified elutriate for the ith contaminant, mg/ℓ

$C_{w,i}$ = dissolved contaminant concentration in the modified elutriate for the ith contaminant, mg/ℓ

S_{me} = suspended solids concentration in the modified elutriate, kg/ℓ

Predicted total contaminant concentrations in the effluent during hydraulic filling is estimated using the particulate and dissolved contaminant concentrations from the modified elutriate test and predicted suspended solids concentration. Effluent suspended solids concentration is predicted using data from the column settling test and facility design and dredge production information. The total contaminant mass concentration in the effluent is given by

$$C_{total} = \sum_{i=1}^{n} C_{w,i} + C_{p,i} S \qquad (3\text{-}3)$$

where S = the predicted effluent suspended solids concentration (kg/ℓ). Contaminant loss rate is the product of concentration and flow, so that, the "rate of mass out" term in Equation 3-1 for the effluent pathway is given by

$$W_E = Q_d C_{Total} \qquad (3\text{-}4)$$

where

W_E = mass rate of contaminant loss, mg/day

Q_d = volumetric dredge production rate for water, ℓ/day

A priori technique

Column settling and modified elutriate data are not available for materials from the sampling areas listed in Table 3-1. This report describes, for the first time, an a priori technique for estimating effluent quality when modified elutriate and column settling data are not available. The approach used in this study was to apply Equation 3-1 and CEFs from previous studies to estimate effluent quality. Application of Equation 3-1 to the effluent pathway yields

$$C_{total} = \rho_I C_{p,i} (1 - CEF) \qquad (3\text{-}5)$$

where ρ_I = solids concentration in the influent, kg/ℓ. Palermo (1988) measured CEFs at five field sites including the CIDMMA. The five-site average CEF for metals was 0.986 (98.6 percent). Organic contaminants were not investigated except for polychlorinated biphenyls (PCBs) at one site. The one-site CEF for PCBs was 0.99 (99 percent). In this study, a CEF of 0.98 (98 percent) for hydraulic disposal in the CIDMMA was used for all contaminants. A CEF value lower than the previously measured CEFs is appropriate since the settling characteristics of dredged materials included in a Restricted Use Program may differ from the characteristics for those materials for which CEF data are available.

Predicted total contaminant concentrations in effluent for hydraulic disposal of dredged materials from the sampling areas listed in Table 3-1 are provided in Table 3-3. For these calculations, influent solids concentration was 0.122 kg/ℓ. The total contaminant concentrations listed in Table 3-3 include particulate and dissolved contaminant concentrations. Marine water acute and chronic toxicity criteria are also listed in Table 3-3 for comparison. The criteria for chromium are for hexavalent chromium. Because toxicity criteria are not available for individual PAHs, the concentrations listed for PAHs is the sum of the individual PAHs listed in Table 3-1.

Table 3-3
Predicted Effluent Quality (Total Concentrations (μg/ℓ)) for Dredged Material from Sampling Areas Identified in the 1985-1989 Virginia State Water Control Board Toxics Database Report for Sediments in the Hampton Roads Area

Chemical	Sediment Area							Criteria[1]	
	CI	NH	PN	TP	EB	WB	NN	Acute	Chronic
PAHs	3	123	157	21	185	10	15	150	NA
Cooper	170	270	170	NA	440	170	150	2.9	2.9
Chromium	130	110	130	NA	160	130	80	1,100	50
Lead	200	100	440	NA	710	320	170	140	5.6
Zinc	530	600	1,900	NA	1,200	1,600	530	95	86

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port of Norfolk, TP = Town Point, EB = Elizabeth River, East Branch, WB = Elizabeth River, West Branch, NN = Newport News.
[1] Marine waters toxicity criteria (U.S. Environmental Protection Agency 1986).

Effluent summary

Predictions of total contaminant concentrations indicate that PAHs should not be a problem in the effluent. There may, however, be a problem with some of the metals. Predicted total chromium exceeded the chronic toxicity criterion for hexavalent chromium but did not exceed the acute toxicity criterion. Predicted copper, lead, and zinc total concentrations exceeded acute and chronic criteria. The maximum dilution or attenuation required is for the East Branch sediment, requiring a dilution of about 150 for several metals.

Other sediments and contaminants require much smaller reductions. In some circumstances, this level of dilution may be achieved by mixing.

Contaminant concentrations in the effluent from the CIDMMA for a Restricted Use Program may be lower than the concentrations predicted in this report for several reasons. First, the dredged material contaminant concentrations may be lower than those indicated in Table 3-1, or the CEF during disposal in the CIDMMA may be higher than the CEF value used to develop a priori predictions. In addition, disposal operations could be managed to increase retention times thereby increasing CEFs. Such management options would include raising the boards on the weir to pond more water, use of multiple discharge points to utilize as much surface area as possible, and slowing the discharge rate of the dredge. Because the reliability of the estimates is unknown, refined estimates of effluent quality based on the modified elutriate and companion column settling tests performed on sediments representative of a Restricted Use Program are recommended.

Leachate Losses

When contaminated dredged material is placed in a CDF, contaminants may be mobilized and transported beyond the facility boundaries by leaching. Leachate is contaminated pore water, and leachate generation is the combination of interphase transfer of contaminants from dredged material solids to pore water and movement of contaminated pore water. Thus, leaching involves coupling of sediment chemistry and porous-media fluid mechanics. Techniques for estimating leachate flow and quality are discussed in this section.

Leachate flow

Immediately after filling, dredged material in a CDF is in a saturated condition (all voids are filled with water). As evaporation and seepage removes water from the voids in the dredged material, the amount of water stored in the voids and available for gravity drainage decreases. After some time, usually several years, a quasi-equilibrium is reached in which water that seeps or evaporates is replenished by infiltration through the surface. Thus, leachate flow from CDFs is time varying and highly dependent on local climatology, dredged material properties, and facility design factors. To predict time-varying leachate flow, all these factors must be considered.

Projected estimation of leachate flow, therefore, requires coupled simulation of local weather (precipitation, temperature, and humidity), surface processes (snowmelt, infiltration, surface runoff, and evaporation), and subsurface processes (evaporation from dredged material voids and unsaturated and saturated flow). A simulation model is available to couple climatic events, surface hydrologic processes, and subsurface hydraulics that is applicable to dredged material in a containment facility. This model, HELP (Schroeder et al. 1988), is a water budget model that accounts for the effects of surface storage, runoff, infiltration, percolation, evapotranspiration, soil moisture storage, lateral drainage to leachate collection systems, and percolation through synthetic liners, soil liners, and composite liners. Local climatology is one of the important components of hydrologic modeling that the HELP model simulates on a daily basis. The HELP model has been used in previous studies to estimate leachate generation in CDFs (Averett et al. 1989; Environmental Laboratory 1987; Lee et al. 1992, "Evaluation of Upland Disposal of Richmond Harbor, California, Sediment from Santa Fe Channel" (In Preparation), "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel-Sediment" (In Preparation).

Leachate flow from the CIDMMA was estimated using the HELP model in two simulations—vertical percolation and lateral drainage. These simulations were conducted to estimate leachate flow for two pore pressure conditions in the foundation soils beneath the CIDMMA. As discussed in Chapter 2, excess pore pressures in the foundation soils exceed the elevation of the confining dikes; percolation of leachate from the CIDMMA into foundation soils, even when filled to maximum capacity, is not possible unless excess pore pressures in the foundation soils are first relieved. Chapter 2 proposes to relieve the excess pore pressures in the foundation soils beneath the CIDMMA to improve consolidation and increase storage capacity.

The vertical percolation simulation provides estimates of long-term, steady-state leachate flow for a free-draining condition; that is, excess pore pressures have been dissipated. In this simulation, leachate generation is controlled by precipitation and the ability of the dredged material surface to accept and transmit water. Because there is no resistance to leachate generation by excess pore pressures in the foundation soils or in the dredged material, the vertical percolation simulation represents the overall Worst Case scenario for leachate generation in the CIDMMA.

Vertical percolation was calculated for a 1-ft crust and a 4-ft layer of unsaturated dredged material. The material beneath the 4-ft layer of unsaturated dredged material was assumed to be free draining, that is, no resistance to flow. Initially, there may be some storage of water that infiltrates into the crust and underlying unsaturated zone. However, in the long term, infiltration, soil moisture storage, and percolation will tend toward a steady-state condition in which water storage and leachate generation is nearly constant from year to year. The general simulation parameters for the vertical percolation simulation are listed in Table 3-4. Table 3-5 lists average annual totals for a 10-year vertical percolation simulation period. The HELP model's synthetic weather generator was used to develop the climatic database for the simulation. The precipitation total listed in Table 3-5 equates to 44.1 in./year. The percolation from layer 2 (approximately 14.3 million cu ft) is the amount of water moving into and out of the CIDMMA under free-draining conditions. Although this estimate was made using a vertical percolation simulation, leachate released from layer 2 could move in all directions, including laterally through the perimeter dikes. Because this simulation neglects resistance to flow by foundation soils and saturated dredged material, the leachate flow estimate is unrealistic for existing conditions.

Table 3-4
Simulation Parameters for Vertical Percolation

Facility Design Parameters
■ Layer 1 - 1 ft, crust, vertical percolation layer
■ Layer 2 - 4 ft, unsaturated dredged material, vertical percolation layer
Soil and Dredged Material Properties
■ Porosity
Layer 1 = 0.4300
Layer 2 = 0.3777
■ Field capacity
Layer 1 = 0.321
Layer 2 = 0.296
■ Initial water content
Layer 1 = 0.3019
Layer 2 = 0.3232
■ Saturated hydraulic conductivity
Layer 1 = 3.30 E-06 cm/sec
Layer 2 = 1.65 E-07 cm/sec
Other
■ Evaporative zone depth = 12 in.
■ SCS Curve Runoff No. = 95.28
■ No vegetative cover

Table 3-5
Average Annual Totals for 10-Year Vertical Percolation Simulation

Hydrologic Process	Million, cu ft	Percent
Precipitation	350	100.0
Runoff	118	33.7
Evapotranspiration	218	62.3
Percolation from Layer 2	14.3	4.08
Change in water storage	0.03	0.01

The lateral drainage simulation provides a more realistic estimate of leachate drainage from the CIDMMA. In the lateral drainage simulation, the excess pore pressure condition in the foundation soils was simulated as a no-flow boundary. As indicated in Table 3-6, the simulated CIDMMA consisted of four layers and was assumed to be filled to +30 ft MLW. The first two layers were the 1-ft crust and 4-ft layer of unsaturated dredged material as in the vertical percolation simulation. Layers 1 and 2 were treated as vertical percolation layers, which in the HELP model means that lateral drainage is not allowed. The third layer was a 40-ft layer of saturated dredged material that was treated as a lateral drainage layer. In the HELP model, water in a lateral drainage layer can move both vertically and horizontally. The final layer was a 90-ft layer of clay representing the foundation soils. This layer was treated as a barrier soil so that the liner option in the HELP model could be used to simulate the resistance to flow provided by the excess pore pressures in the foundation soils at the CIDMMA. The lateral drainage length for layer 3 was 200 ft. Because of the way the HELP model calculates a lateral flow-through area, the surface area used in the simulation was adjusted to provide proper similitude for the CIDMMA surface area and perimeter dike lengths.

Figure 3-2 shows annual lateral drainage volumes for a 20-year simulation. The average annual lateral drainage is 31,454 cu ft. Although this amount is significantly less than the amount estimated in the vertical percolation simulation, it is a Worst Case estimate for existing conditions because the lateral drainage layer included the dredged material profile from -10 to +25 ft MLW.

Leachate quality

Two types of predictive techniques for leachate quality are discussed in this section, the first involving laboratory leach tests, and the second being an a priori technique. Both techniques are based on equilibrium partitioning theory. Application of this theory to dredged material leaching is described by Hill, Myers, and Brannon (1988) and Myers, Brannon, and Price (1992).

Equilibrium partitioning as used in this report is a simplified description of the processes that govern contaminant interphase transfer from dredged material solids to pore water. Interphase contaminant transfer is a complicated interaction of many elementary processes and factors affecting these processes (Myers, Brannon, and Price 1992). A complete description of all processes, their interactions, and factors affecting these processes is not presently possible. Instead, a lumped parameter, the equilibrium distribution coefficient, is used to describe the distribution of contaminant between aqueous and solid phases.

At equilibrium, the net transfer of contaminant across the solids-water interface is zero, and the mass of contaminant in each phase is constant, but not necessarily equal. Thus, only the relative distribution of contaminant between solid and aqueous phases is needed to predict leachate quality. This

Table 3-6
Simulation Parameters for Lateral Drainage

Facility Design Parameters
■ Layer 1 - 1 ft, crust
■ Layer 2 - 4 ft, unsaturated dredged material, vertical percolation
■ Layer 3 - 35 ft, saturated dredged material, lateral drainage
■ Layer 4 - 90 ft, clay foundation
Soil and Dredged Material Properties
■ Porosity
Layer 1 = 0.4300
Layer 2 = 0.3777
Layer 3 = 0.3777
Layer 4 = 0.4224
■ Field capacity
Layer 1 = 0.3210
Layer 2 = 0.2960
Layer 3 = 0.2960
Layer 4 = 0.3495
■ Initial water content
Layer 1 = 0.3019
Layer 2 = 0.3232
Layer 3 = 0.3777
Layer 4 = 0.4224
■ Saturated hydraulic conductivity
Layer 1 = 3.30 E-06 cm/sec
Layer 2 = 1.65 E-07 cm/sec
Layer 3 = 1.65 E-07 cm/sec
Layer 4 = 1.00 E-07 cm/sec
Other
■ Evaporative zone depth = 12 in.
■ Type of vegetative cover - None
■ SCS Curve Runoff No. = 95.28

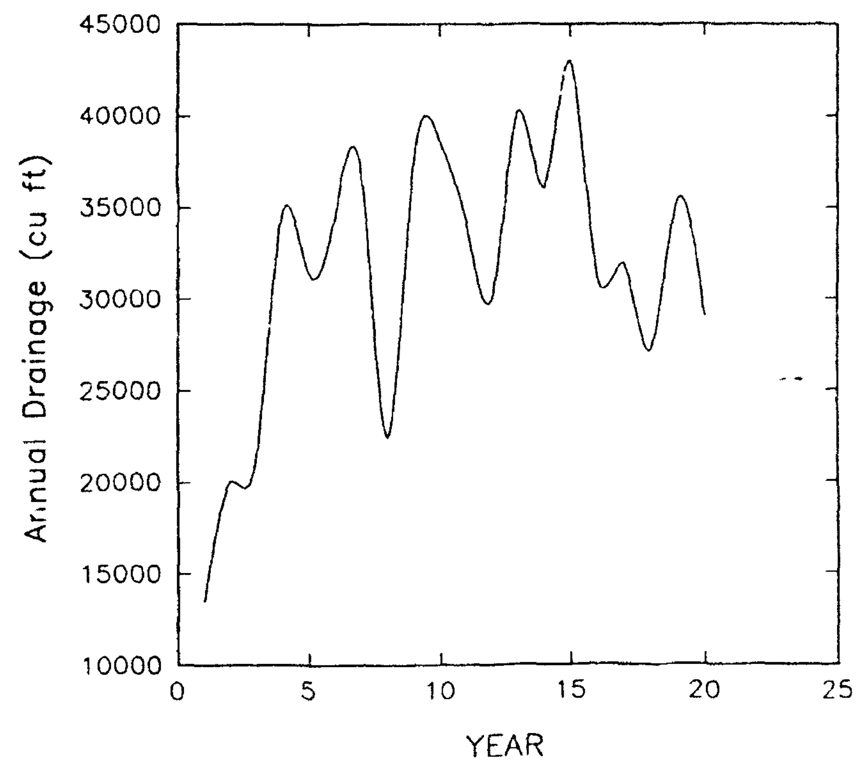

Figure 3-2. HELP model estimates of annual lateral drainage volumes

distribution of contaminant mass between solid and aqueous phases is represented by the equilibrium distribution coefficient defined as follows:

$$K_d = \frac{\left(\frac{M_{cs}}{M_s}\right)}{\left(\frac{M_{cw}}{M_w}\right)} \qquad (3\text{-}6)$$

where

K_d = equilibrium distribution coefficient, dimensionless

M_{cs} = mass of contaminant in the solid phase, kg

M_s = mass of solids, kg

M_{cw} = mass of contaminant in the aqueous phase, kg

M_w = mass of water, kg

The mass fractions in Equation 3-6 can be replaced with phase contaminant concentrations without any loss of generality so that Equation 3-6 becomes

$$K_d = \frac{C_s}{C_w} \qquad (3\text{-}7)$$

where

K_d = equilibrium distribution coefficient, ℓ/kg

C_s = contaminant concentration in the solid phase at equilibrium, mg/kg

C_w = contaminant concentration in the aqueous phase at equilibrium, mg/ℓ

Equations 3-6 and 3-7 describe the equilibrium distribution of a single contaminant in dredged material; that is, equilibrium distribution coefficients are contaminant and dredged material specific. In addition, the distribution of contaminant mass is affected by various factors, such as pH, ionic strength, redox potential, and sediment organic carbon. Varying these factors during leaching can shift the equilibrium position of the system and change the K_d value.

The equilibrium assumption is valid when the seepage velocity is slow relative to the rate at which contaminants desorb from dredged material solids. This is a realistic assumption for the fine-grained dredged material in the CIDMMA because seepage velocities are usually very low because of the low hydraulic conductivity of fine-grained dredged material.

Laboratory tests. Currently, laboratory sequential batch and column leach tests are being developed and evaluated at WES for determining distribution coefficients and predicting leachate quality in CDFs (Myers and Brannon 1991; Myers, Brannon, and Price 1992). In sequential batch leach tests (SBLTs), sediment solids are leached with successive aliquots of distilled-deionized water in an agitated system. After the aqueous and solid phases have reached steady state, the phases are separated by centrifugation and filtration; then the leachate is analyzed for contaminants of concern. The solid phase is then releached with fresh distilled-deionized water, and the process of phase separation and leachate analysis is repeated. As shown in Figure 3-3, SBLTs require several cycles, each cycle involving an equilibration step, a phase separation step, and a leachate analysis step. A table of solid phase and aqueous phase concentrations is developed from chemical analysis of the leachates, and these data are plotted to produce desorption isotherms. From the desorption isotherms, contaminant-specific equilibrium distribution coefficients are obtained. SBLTs have been used in seven major dredged material disposal alternative evaluations (Brannon, Myers, and Price 1992; Environmental Laboratory 1987; Lee et al. 1992, "Evaluation of Upland Disposal of

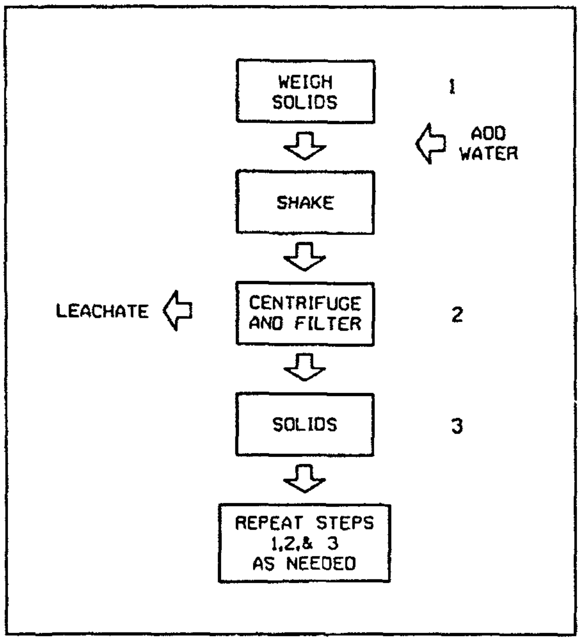

Figure 3-3. Schematic of WES sequential batch leach test

Richmond Harbor, California, Sediment from Santa Fe Channel" (In Preparation), "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation); Myers and Brannon 1988; Palermo et al. 1989) to determine the relations between solid phase contaminant concentrations C_s and aqueous phase contaminant concentrations C_w during leaching.

SBLTs, useful for determining distribution coefficients and long-term leaching characteristics, cannot simulate the advective-dispersive and other mass transfer effects occurring during leachate generation. Column leach tests are used at WES to provide a laboratory-scale physical model of leaching in a CDF and to confirm application of SBLT data to estimation of leachate quality in the field. Figure 3-4 shows the column leaching apparatus currently in use at the WES. If column elution histories predicted using an advection-dispersion model and distribution coefficients from SBLTs agree with observed column elution histories, then the processes governing interphase transfer of contaminants is sufficiently understood to reliably predict the time dependency of field leachate quality.

A priori techniques. Since sequential batch and column leach data are not available for materials that may be included in the Restricted Use Program, estimation of leachate quality using a priori techniques is necessary. Rearrangement of Equation 3-7 yields Equation 3-8 is the a priori predictive equation for organic chemical concentrations in dredged material leachate. To use Equation 3-8 and the bulk sediment contaminant concentrations listed in Table 3-1 to predict leachate contaminant concentrations, contaminant-specific distribution coefficients $K_d s$ are needed. Empirical equations that relate

$$C_w = \frac{C_s}{K_d} \qquad (3\text{-}8)$$

distribution coefficients to sediment organic carbon and octanol-water partitioning coefficients are available for this purpose (Karickhoff 1981; Lyman, Reehl, and Rosenblatt 1990). These relations were developed mainly through batch adsorption tests using soils, sediments, and aquifer materials. The generality of these relationships for desorption of contaminants from dredged material is uncertain, but the basic technique is widely accepted.

The following empirical relation developed by Karickhoff (1981) was used to estimate distribution coefficients for the PAHs in Table 3-1.

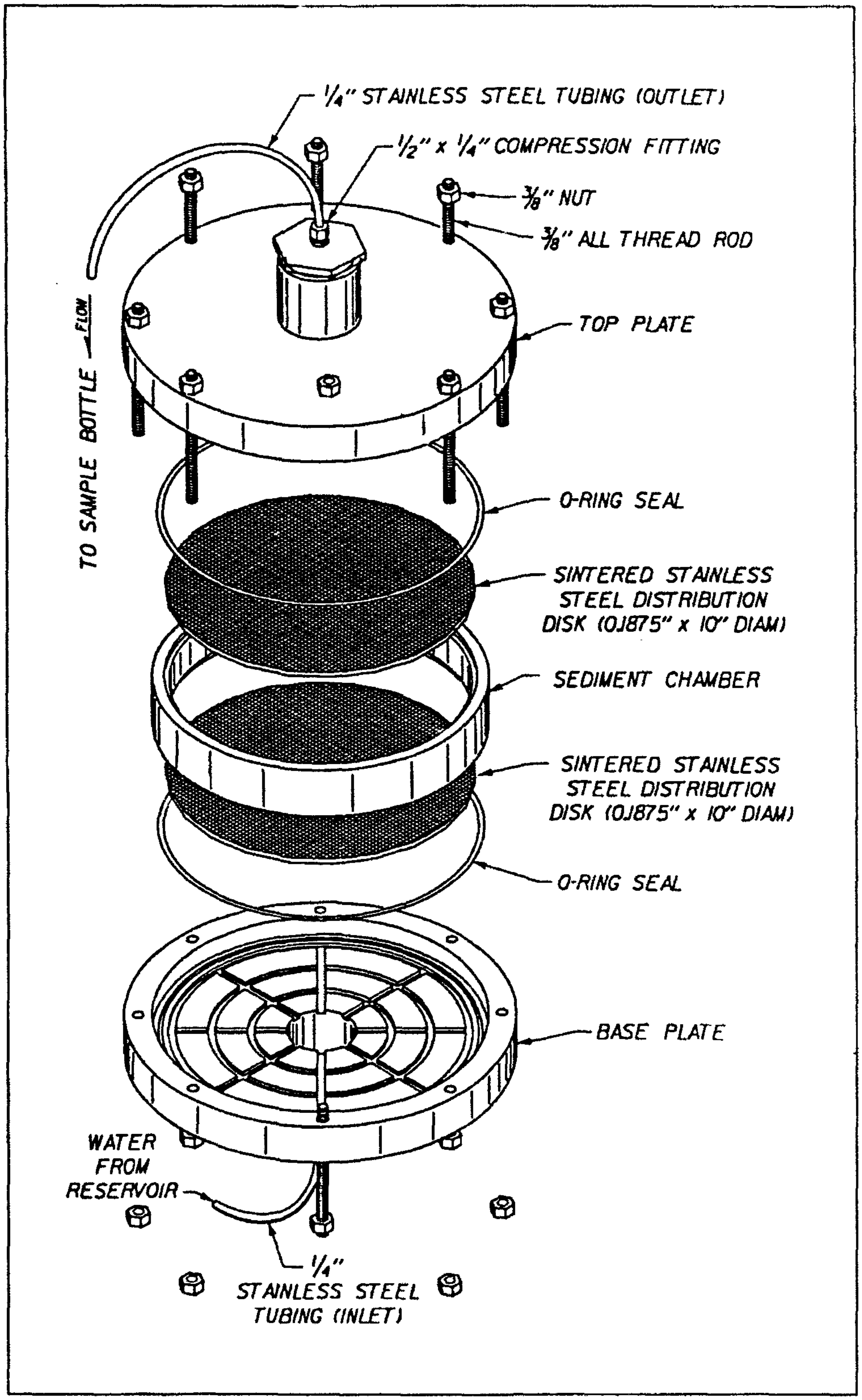

Figure 3-4. Schematic of column leaching apparatus for sediments and dredged material

$$K_d = 0.411\, f_{oc}\, K_{ow}$$

where

f_{oc} = fraction organic carbon

K_{ow} = octanol-water partitioning coefficient

Distribution coefficients for chrysene, fluoranthene, phenanthrene, and pyrene were estimated using octanol-water partitioning coefficients reported by Miller and Wasik (1985). The octanol-water partitioning coefficient for benzofluoranthene was estimated using activity-structure relationships described by Lyman, Rheel, and Rosenblatt (1990). A priori predictions for distribution coefficients and dissolved leachate PAH concentration for dredged material from the sampling areas listed in Table 3-1 are listed in Table 3-7. The fraction organic carbon used to calculate the K_d estimates in Table 3-7 was 0.038, the value reported by Palermo (1988) for sediment in the Norfolk area. The predicted values are very low—subpart-per-billion to part-per-billion range. The sum of the leachate PAH concentrations for dredged material from each sediment area is below the marine water acute and chronic toxicity criteria.

Table 3-7
Predicted PAH Concentrations (µg/ℓ) in Leachate

PAH	Sediment Area						
	CI	NH	PN	TP	EB	WB	NN
Benzofluoranthene	0.017	0.052	0.19	0.069	0.21	0.024	0.021
Chrysene	0.045	1.66	0.67	0.15	0.84	0.093	0.073
Fluoranthene	0.27	4.67	6.91	0.55	10.5	0.33	0.82
Phenanthrene	0.50	21.2	34.6	1.22	24.6	0.50	0.74
Pyrene	0.30	3.33	5.20	0.90	7.57	0.42	0.85

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port of Norfolk, TP = Town Point, EB = Elizabeth River, East Branch, WB = Elizabeth River, West Branch, NN = Newport News.

Equilibrium partitioning theory with some modification can also be used to develop a priori predictions of metal concentrations in dredged material leachate. The theoretical and experimental basis for a priori estimation of metal pore water concentrations is not as well established as that for organic contaminants. The basic approach for metals is the same as the approach for organic contaminants except that Equation 3-8 as stated is not applicable because the bulk metals concentrations in the dredged material solids are in geochemical phases that are not leached by water (Brannon et al. 1976; Environmental

Laboratory 1987; Myers, Brannon, and Price 1992; Steneker, Van der Sloot, and Das 1988).

Modification of Equation 3-8 for the leachable metal concentration provides a method for estimating pore water metal concentrations. For the modified equilibrium approach, metal pore water concentration is given by

$$C_w = \frac{C_{sL}}{K_d} \tag{3-9}$$

where C_{sL} = the leachable metal concentration in the dredged material solids (mg/kg).

Empirical relationships for estimating C_{sL} and K_d for metals are not available. These parameters are sediment specific, as well as metal specific. For these reasons, K_d and C_{sL} are difficult to estimate a priori. To provide a priori predictions of metals concentrations in leachate for a Restricted Use Program for the CIDMMA, SBLT data for one east coast and six west coast sediments were used to develop estimates of C_{sL} and K_d.

Data from Myers and Brannon (1988), Palermo et al. (1989), and Lee et al. (1992, "Evaluation of Upland Disposal of Richmond Harbor, California, Sediment from Santa Fe Channel" (In Preparation), "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation)) on leachable metal fractions in estuarine sediments are presented in Table 3-8. As indicated in Table 3-8, between about 0.04 to 1.2 percent of the chromium, 1 to 10 percent of the copper, 0.2 to 6.2 percent of the lead, and 1 to 3 percent of the zinc in the sediments investigated in these studies were leachable. Distribution coefficients in these studies ranged from 3 to 90 ℓ/kg, depending on the metal and the sediment.

Predicted metals concentrations in leachate from dredged materials from the sediment sites listed in Table 3-1 are provided in Tables 3-9 through 3-12. Predicted concentrations are presented as functions of percent leachable and distribution coefficients. Three values for percent leachable metal concentration were used. The arithmetic mean listed in Table 3-8 was used as the minimum percent leachable. The arithmetic mean plus two sample standard deviations was used as the maximum percent leachable, and the arithmetic mean plus one standard deviation was used as an intermediate value. Distribution coefficients used in the predictions ranged from 3 to 10 ℓ/kg. Because conservative estimates are obtained when high values of K_d are avoided, the lower end of the range in expected K_d values was used.

Predicted copper (Table 3-9), lead (Table 3-11), and zinc (Table 3-12) concentrations in leachate exceed marine water acute and chronic toxicity criteria for all sites and all C_{sL} and K_d values. Depending on the percent leachable and the distribution coefficient, predicted chromium concentrations in

Table 3-8
Leachable Metal Concentrations in Selected Sediments, Percent

	Sediment								
Metal	**EB**	**NBH**	**IOH**	**OOH**	**RH**	**PS**	**WR**	**x**	**s**
Arsenic	7.33	1.73	6.23	9.28	13.02	4.07	5.10	6.68	3.68
Cadmium	3.33	0.68	4.05	5.58	9.68	8.09	3.70	5.02	3.05
Chromium	1.11	0.69	0.04	0.14	0.72	0.38	0.19	0.47	0.39
Copper	2.32	1.31	3.38	6.02	9.00	9.31	2.82	4.88	3.26
Nickel	3.74	0.98	0.92	0.87	1.55	1.37	0.89	1.47	1.03
Lead	2.50	0.25	8.13	3.59	6.19	5.04	1.93	3.95	2.70
Zinc	2.02	0.97	3.11	2.00	4.02	3.02	1.40	2.36	1.07

Note: EB = Everett Bay, Everett, WA, from Palermo et al. (1989);
NBH = New Bedford Harbor, MA, from Myers and Brannon (1988);
IOH = Inner Oakland Harbor, CA, from Lee et al. (1992);
OOH = Outer Oakland Harbor, CA, from Lee et al. (1992);
RH = Richmond Harbor, CA, from Lee et al. "Evaluation of Upland Disposal of Richmond Harbor, California, Sediment from Santa Fe Channel Sediment" (In Preparation);
PS = Pinole Shoal area, J. F. Baldwin Channel, CA, from Lee et al. "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation);
WR= West Richmond area, J. F. Baldwin Channel, CA, from Lee et al. "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation);
x = Arithmetic mean;
s = Sample standard deviation.

leachate (Table 3-10) in some cases exceeds marine water acute and chronic toxicity criteria for hexavalent chromium (criteria listed in Table 3-3).

Tables 3-10 and 3-11 also indicate a potential for exceeding drinking water standards for chromium (0.05 mg/ℓ) and lead (0.05 mg/ℓ), depending on the distribution coefficient and percent leachable. There are no copper and zinc drinking water standards for comparison.

Leachate summary

Leachate seepage through the confining dikes is probably more significant than vertical percolation into foundation soils. The HELP model simulations indicated an estimated 31,454 cu ft/year of leachate could seep through the dikes. This estimate does not take into account the potential for water to move from foundation soils into the CIDMMA because of excess pore pressures in the foundation soils. Additional simulations of seepage through the dikes using a two-dimensional model, such as the SEEPU model available from Virginia Polytechnic Institute and State University, are recommended.

Table 3-9
Predicted Copper Concentration (mg/ℓ) in Leachate for Selected Distribution Coefficients and Percents Leachable

Sampling Area	Cs mg/kg	%L	Kd, ℓ/kg 3	4	5	6	7	8	9	10
CL	70	4.88	1.139	0.854	0.683	0.569	0.488	0.427	0.380	0.342
		8.14	1.899	1.425	1.140	0.950	0.814	0.712	0.633	0.570
		11.40	2.660	1.995	1.596	1.330	1.140	0.998	0.887	0.798
NH	110	4.88	1.789	1.342	1.074	0.895	0.767	0.671	0.596	0.537
		8.14	2.985	2.239	1.791	1.492	1.279	1.119	0.995	0.895
		11.40	4.180	3.135	2.508	2.090	1.791	1.568	1.393	1.254
PN	70	4.88	1.139	0.854	0.683	0.569	0.488	0.427	0.380	0.342
		8.14	1.899	1.425	1.140	0.950	0.814	0.712	0.633	0.570
		11.40	2.660	1.995	1.596	1.330	1.140	9.998	0.887	0.798
EB	180	4.88	2.928	2.196	1.757	1.464	1.255	1.098	0.976	0.878
		8.14	4.884	3.663	2.930	2.442	2.093	1.832	1.628	1.465
		11.40	6.840	5.130	4.104	3.420	2.931	2.565	2.280	2.052
WB	70	4.88	1.139	0.854	0.683	0.569	0.488	0.427	0.380	0.342
		8.14	1.899	1.425	1.140	0.950	0.814	0.712	0.633	0.570
		11.40	2.660	1.995	1.596	1.330	1.140	0.998	0.887	0.798
NN	60	4.88	0.976	0.732	0.586	0.488	0.418	0.366	0.325	0.293
		8.14	1.628	1.221	0.977	0.814	0.698	0.611	0.543	0.488
		11.40	2.280	1.710	1.368	1.140	0.977	0.855	0.760	0.684

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port Norfork,
EB = Elizabeth River-East Bank, WB = Elizabeth River-West Bank, NN = Newport News,
%L = percent leachable.

A priori predictions of leachate quality indicated a potential for leachate quality to exceed marine water acute and/or chronic toxicity criteria for metals. Predictions with less uncertainty than a priori predictions can be made if process descriptors such as distribution coefficients are determined experimentally. The WES sequential batch leach tests are recommended for determining distribution coefficients and refining leachate quality predictions. Such testing would probably show increasing contaminant concentrations in leachate as salt is washed out. A salt washout effect has been observed in several studies of estuarine dredged material (Myers and Brannon 1988; Palermo et al. 1989; Lee et al. 1992, "Evaluation of Upland Disposal of Richmond Harbor, California, Sediment from Santa Fe Channel" (In Preparation), "Evaluation of

Table 3-10
Predicted Chromium Concentration (mg/ℓ) in Leachate for Selected Distribution Coefficients and Percents Leachable

Sampling Area	Cs mg/kg	%L	Kd, ℓ/kg							
			3	4	5	6	7	8	9	10
CI	55	0.47	0.086	0.065	0.052	0.043	0.037	0.032	0.029	0.026
		0.86	0.158	0.118	0.095	0.079	0.068	0.059	0.053	0.047
		1.25	0.229	0.172	0.38	0.115	0.098	0.086	0.076	0.069
NH	44	0.47	0.069	0.052	0.041	0.034	0.030	0.026	0.023	0.021
		0.86	0.126	0.095	0.076	0.063	0.054	0.047	0.042	0.038
		1.25	0.183	0.138	0.110	0.092	0.079	0.069	0.061	0.055
PN	52	0.47	0.081	0.061	0.049	0.041	0.035	0.031	0.027	0.024
		0.86	0.149	0.112	0.089	0.075	0.064	0.056	0.050	0.045
		1.25	0.217	0.163	0.130	0.108	0.093	0.081	0.072	0.065
EB	67	0.47	0.105	0.079	0.063	0.052	0.045	0.039	0.035	0.031
		0.86	0.192	0.144	0.115	0.096	0.082	0.072	0.064	0.058
		1.25	0.279	0.209	0.168	0.140	0.120	0.105	0.093	0.084
WB	55	0.47	0.086	0.065	0.052	0.043	0.037	0.032	0.029	0.026
		0.86	0.158	0.118	0.095	0.079	0.068	0.059	0.053	0.047
		1.25	0.229	0.172	0.138	0.115	0.098	0.086	0.076	0.069
NN	33	0.47	0.052	0.039	0.031	0.026	0.022	0.019	0.017	0.016
		0.86	0.095	0.071	0.057	0.047	0.041	0.035	0.032	0.028
		1.25	0.138	0.103	0.083	0.069	0.059	0.052	0.046	0.041

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port Norfork, EB = Elizabeth River-East Bank, WB = Elizabeth River-West Bank, NN = Newport News, %L = percent leachable.

Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation)). The salt washout effect was not included in the leachate analysis presented in this report because sediment-specific data are needed to analyze the effect.

Volatile Emission Losses

When contaminated dredged material is placed in a CDF, the potential exists for organic chemicals associated with the dredged material solids to be released to the air during and after disposal. The release process is termed

Table 3-11
Predicted Lead Concentration (mg/ℓ) in Leachate for Selected Distribution Coefficients and Percents Leachable

Sampling Area	Cs mg/kg	%L	Kd, ℓ/kg							
			3	4	5	6	7	8	9	10
CI	80	3.95	1.053	0.790	0.632	0.527	0.451	0.395	0.351	0.316
		6.65	1.773	1.330	1.064	0.887	0.760	0.665	0.591	0.532
		9.35	2.493	1.870	1.496	1.247	1.069	0.935	0.831	0.748
NH	42	3.95	0.553	0.415	0.332	0.277	0.237	0.207	0.184	0.166
		6.65	0.931	0.698	0.559	0.466	0.399	0.349	0.310	0.279
		9.35	1.309	0.982	0.785	0.655	0.561	0.491	0.436	0.393
PN	180	3.95	2.370	1.778	1.422	1.185	1.016	0.889	0.790	0.711
		6.65	3.990	2.993	2.394	1.995	1.710	1.496	1.330	1.197
		9.35	5.610	4.208	3.366	2.805	2.404	2.104	1.870	1.683
EB	290	3.95	3.818	2.864	2.291	1.909	1.636	1.432	1.273	1.146
		6.65	6.428	4.821	3.857	3.214	2.755	2.411	2.143	1.929
		9.35	9.038	6.779	5.423	4.519	3.874	3.389	3.013	2.712
WB	130	3.95	1.712	1.284	1.027	0.856	0.734	0.642	0.571	0.514
		6.65	2.882	2.161	1.729	1.441	1.235	1.081	0.961	0.865
		9.35	4.052	3.039	2.431	2.026	1.736	1.519	1.351	1.216
NN	70	3.95	0.922	0.691	0.553	0.461	0.395	0.346	0.307	0.277
		6.65	1.552	1.164	0.931	0.776	0.665	0.582	0.517	0.466
		9.35	2.182	1.636	1.309	1.091	0.935	0.818	0.727	0.655

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port Norfork,
EB = Elizabeth River-East Bank, WB = Elizabeth River-West Bank, NN = Newport News,
%L = percent leachable.

volatilization and under certain conditions may involve organic chemicals that are not usually thought of as volatile organic chemicals (VOCs). Organic chemical emission rates from dredged material are presently unknown, and there are no laboratory tests available for predicting emission rates from dredged material. It is therefore necessary to estimate volatile emission losses using theoretical models.

Theoretical chemodynamic models for volatile emission rates from dredged material were described by Thibodeaux (1989). The theoretical models proposed by Thibodeaux (1989) for volatilization from ponded water in CDFs, exposed dredged material, and capped dredged material in CDFs were used to

Table 3-12
Predicted Zinc Concentration (mg/ℓ) in Leachate for Selected Distribution Coefficients and Percents Leachable

Sampling Area	Cs mg/kg	%L	Kd, ℓ/kg 3	4	5	6	7	8	9	10
CI	220	2.36	1.731	1.298	1.038	0.865	0.742	0.649	0.577	0.519
		3.43	2.515	1.887	1.509	1.258	1.078	0.943	0.838	0.755
		4.50	3.300	2.475	1.980	1.650	1.414	1.238	1.100	0.990
NH	245	2.36	1.927	1.446	1.156	0.964	0.826	0.723	0.642	0.578
		3.43	2.801	2.101	1.681	1.401	1.201	1.050	0.934	0.840
		4.50	3.675	2.756	2.205	1.838	1.575	1.378	1.225	1.103
PN	780	2.36	6.136	4.602	3.682	3.068	2.630	2.301	2.045	1.841
		3.43	8.918	6.689	5.351	4.459	3.822	3.344	2.973	2.675
		4.50	11.700	8.775	7.020	5.850	5.014	4.388	3.900	3.510
EB	490	2.36	3.855	2.891	2.313	1.927	1.652	1.446	1.285	1.156
		3.43	5.602	4.202	3.361	2.801	2.401	2.101	1.867	1.681
		4.50	7.350	5.513	4.410	3.675	3.150	2.756	2.450	2.205
WB	645	2.36	5.074	3.806	3.044	2.537	2.175	1.903	1.691	1.522
		3.43	7.375	5.531	4.425	3.687	3.161	2.765	2.458	2.212
		4.50	9.675	7.256	5.805	4.838	4.146	3.628	3.225	2.903
NN	220	2.36	1.731	1.298	1.038	0.865	0.742	0.649	0.577	0.519
		3.43	2.515	1.887	1.509	1.258	1.078	0.943	0.838	0.755
		4.50	3.300	2.475	1.980	1.650	1.414	1.238	1.100	0.990

Note: CI = Craney Island, NH = Norfolk Harbor, PN = Port Norfork,
EB = Elizabeth River-East Bank, WB = Elizabeth River-West Bank, NN = Newport News,
%L = percent leachable.

estimate volatile emission losses from the CIDMMA. The model equations and results are described in the following sections.

Ponded water

The volatilization pathway in this case involves desorption from suspended solids followed by transport through the air-water interface. The model equation for volatilization from the ponded water locale is given below (Thibodeaux 1989).

$$n_p = K_{OL} \left(C_w - C_w^* \right) \qquad (3\text{-}10)$$

where

n_p = ponded water volatile flux, $g/cm^2/sec$

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

C_w = dissolved contaminant concentration, g/cm^3

C_w^* = hypothetical dissolved chemical concentration in equilibrium with background air, g/cm^3

The dissolved contaminant concentration C_w can be estimated using Equation 3-8, or data on dissolved contaminant concentrations from the modified elutriate test can be used. Equation 3-10 is applicable when the dissolved contaminant concentration is constant. Since volatilization continuously removes chemical mass from the dissolved phase, there is an implicit assumption for application of Equation 3-10 that either volatilization is so small that it does not affect dissolved chemical concentrations, or there is a source(s) of chemical that replenishes the dissolved chemical mass as fast as it volatilizes. Two sources can replenish chemical mass lost through volatilization. First, chemical is being continuously added in dissolved form by disposal operations. Second, there is a continuous solids flux through the water column during disposal operations that through partitioning processes tends to maintain constant dissolved chemical concentrations. For these reasons, the assumption of a constant dissolved chemical concentration is probably a good approximation of the field condition. This assumption is conservative because the gradient driving the volatilization process is not allowed to decrease.

Probably the largest source of error in Equation 3-10 is estimation of the overall liquid phase mass transfer coefficient. Thomas (1990) describes techniques for estimating the overall liquid phase mass transfer coefficient that are based on two-resistance theory as follows (Thibodeaux 1979):

$$\frac{1}{K_{OL}} = \frac{1}{K_L} + \left(\frac{1}{H\,K_G} \right) \qquad (3\text{-}11)$$

where

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

H = Henry's constant, dimensionless

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

Although Equation 3-11 is a theoretical equation, estimation of K_G and K_L is highly empirical. Thomas (1990) suggested using Southworth's correlations for volatilization of PAHs to estimate K_G as follows:

$$K_G = 0.32\ (V_x + V_{curr}) \sqrt{\frac{18}{M_A}} \qquad (3\text{-}12)$$

where

V_x = wind speed, m/sec

V_{curr} = water velocity, m/sec

Thomas (1990) also discusses using rule-of-thumb values for K_L and K_G when making the type of a priori estimates discussed in this report. These rule-of-thumb values are presented in Table 3-13 and can be used when contaminants other than PAHs are of interest.

Table 3-13
Rule-of-Thumb Values for Liquid-Side and Gas-Side Mass Transfer Coefficients, cm/hr

	K_L[1]	K_G[2]
V_x < 3 m/sec	3	--
3 m/sec < V_x < 10 m/sec	5-30	--
V_x > 10 m/sec	<70	--
Sea Surface Conditions		$K_G = 3000(18/M_A)^{1/4}$

[1] Source: Cohen, Cocchio, and Mackay (1978), as cited by Thomas (1990).
[2] Source: Thomas (1990).

Predicted fluxes (mass transfer per unit area per time) of benzofluoranthene, chrysene, fluoranthene, phenanthrene, and pyrene from ponded water are presented in Table 3-14. The Henry's constants for benzofluoranthene, fluoranthene, phenanthrene, and pyrene were obtained from Montgomery and Wilkeem (1990). The Henry's constant for chrysene was estimated using procedures described in Lyman, Rheel, and Rosenblatt (1990). Two fluxes for dredged material from the sediment areas in Table 3-1 were estimated. One flux is for a wind speed of 3 m/sec (6.6 mph), and the second flux is for a wind speed of 10 m/sec (22 mph). The overall liquid phase mass transfer coefficient K_{OL} was estimated using K_L = 3 cm/hr for a wind speed of 3 m/sec and K_L = 10 cm/hr for a wind speed of 10 m/sec. The gas-side mass transfer coefficient was estimated using Equation 3-12 with water velocity equal to

Table 3-14
Predicted Volatile Fluxes (mg/m^2 · day) from Ponded Water

Sediment Area	Wind Speed m/sec	Chemical				
		BEN	CHR	FLU	PHE	PYR
Craney Island	3 10	0.012 0.041	0.00042 0.0014	0.197 0.658	0.358 1.19	0.219 0.706
Norfolk Harbor	3 10	0.037 0.125	0.015 0.052	3.36 11.2	15.2 50.5	2.34 7.81
Port of Norfolk	3 10	0.136 0.456	0.0062 0.021	5.00 16.6	24.8 82.6	3.66 12.3
Town Point	3 10	0.049 0.166	0.0014 0.0046	0.397 1.32	0.873 2.92	0.638 2.13
Elizabeth River East Branch	3 10	0.151 0.505	0.0079 0.026	7.59 25.1	17.6 58.8	5.33 17.8
Elizabeth River West Branch	3 10	0.017 0.058	0.00083 0.0028	0.238 0.797	0.358 1.192	0.298 0.994
Newport News	3 10	0.015 0.059	0.00069 0.0023	0.594 1.99	0.530 1.77	0.596 1.99

Note: BEN = Benzofluoranthene, CHY = Chrysene, FLU = Fluoranthene,
PHE = Phenanthrene, PYR = Pyrene.

zero. The estimated PAH fluxes from ponded water in the CIDMMA during disposal of dredged material from the sediment areas listed in Table 3-1 are very small and probably do not represent a significant loss pathway. There are, however, no area volatile emission criteria with which to compare these numbers.

Exposed dredged material

This volatilization locale is characterized by dredged material that is exposed directly to air. There is no ponded water covering the material, and the surface is void of vegetative or other cover. Exposed dredged material is probably the most significant source of volatile emissions from CDFs (Thibodeaux 1989).

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

Dredged material begins evaporative drying and volatile chemical emission as soon as it is exposed to air. Initially, the chemical emission rate is governed by air-side resistance. As the top microlayer becomes depleted of volatile chemicals (and water), continuing losses of volatile chemicals come from the pore spaces within the dredged material. At this point, the emission process is transient and changes from being air-side resistance controlled to dredged material-side vapor diffusion controlled. The overall model equation is given below (Thibodeaux 1989).

$$n_e = \frac{C_w H - C_a}{\sqrt{\dfrac{\pi t}{D_{A3}\left[\varepsilon_1 + \dfrac{K_d \rho_b}{H}\right]}} + \dfrac{1}{K_G}} \qquad (3\text{-}13)$$

where

n_e = instantaneous flux exposed dredged material interface at time t, $g/cm^2/sec$

C_w = dissolved concentration, g/cm^3

H = Henry's constant, dimensionless

C_a = background concentration of chemical A in air at the dredged material-air interface, g/cm^3, usually assumed to be zero

π = 3.14159

t = time since initial exposure, sec

D_{A3} = effective diffusivity of chemical A in the dredged material pores, cm^2/sec

ε_1 = air filled porosity, dimensionless

K_d = distribution coefficient, ℓ/kg

ρ_b = bulk density of the dredged material, kg/ℓ

The instantaneous flux predicted by Equation 3-13 decreases with time as shown in Figures 3-5 and 3-6. The horizontal axis in Figures 3-5 and 3-6 is log base 10 of time in days. The horizontal axis tic marks are the exponents

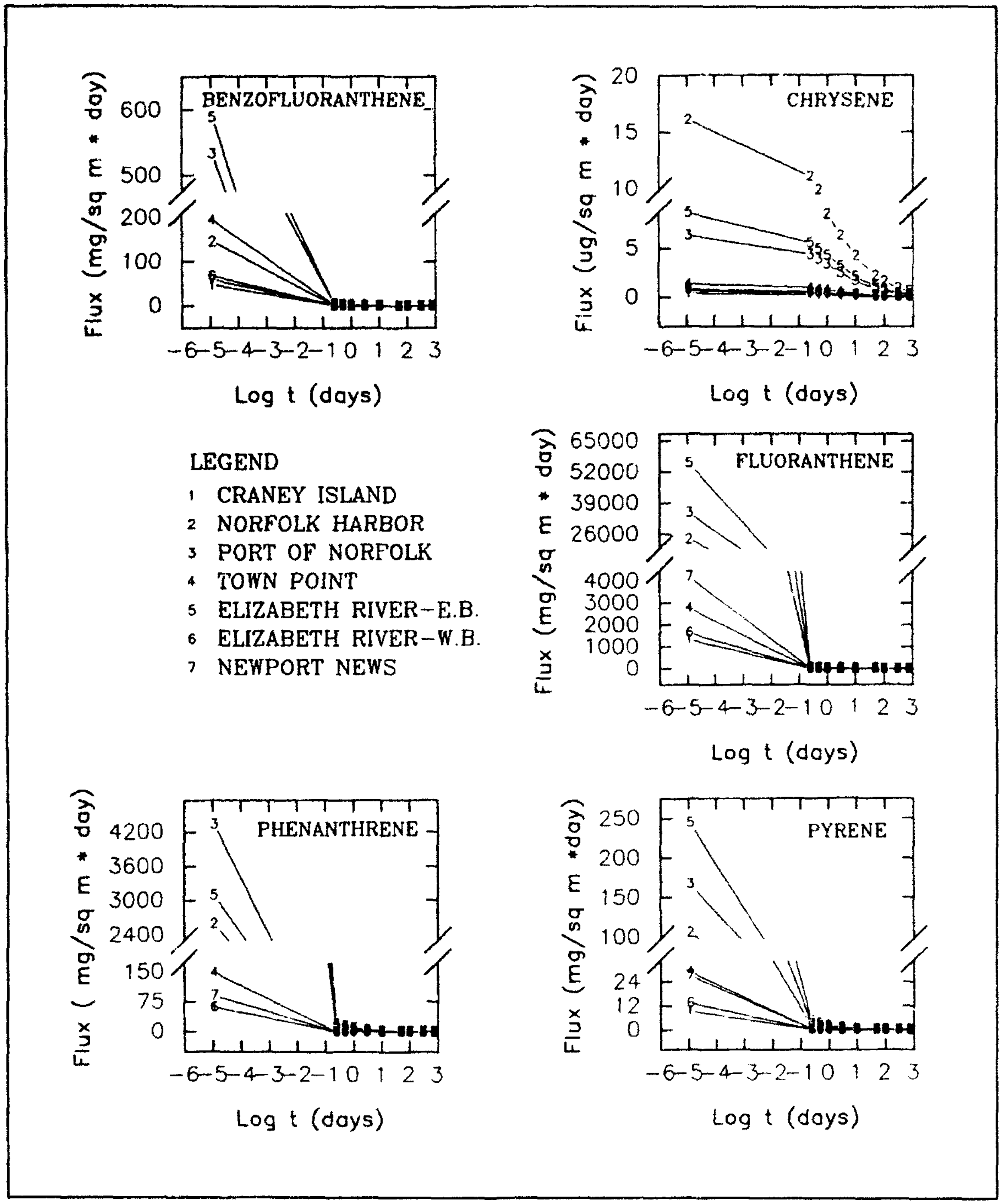

Figure 3-5. Volatile fluxes from exposed dredged material for wind speed of 3 m/second

associated with time in days. For example, the tic mark "-5" is 0.00001 day (approximately 1 sec), the tic mark "0" is 1 day, and the tic mark "2" is 100 days. The initial flux will persist as long as fresh dredged material is exposed. For disposal operations that continuously renew exposed dredged material surfaces with fresh dredged material, volatile flux at the initial value

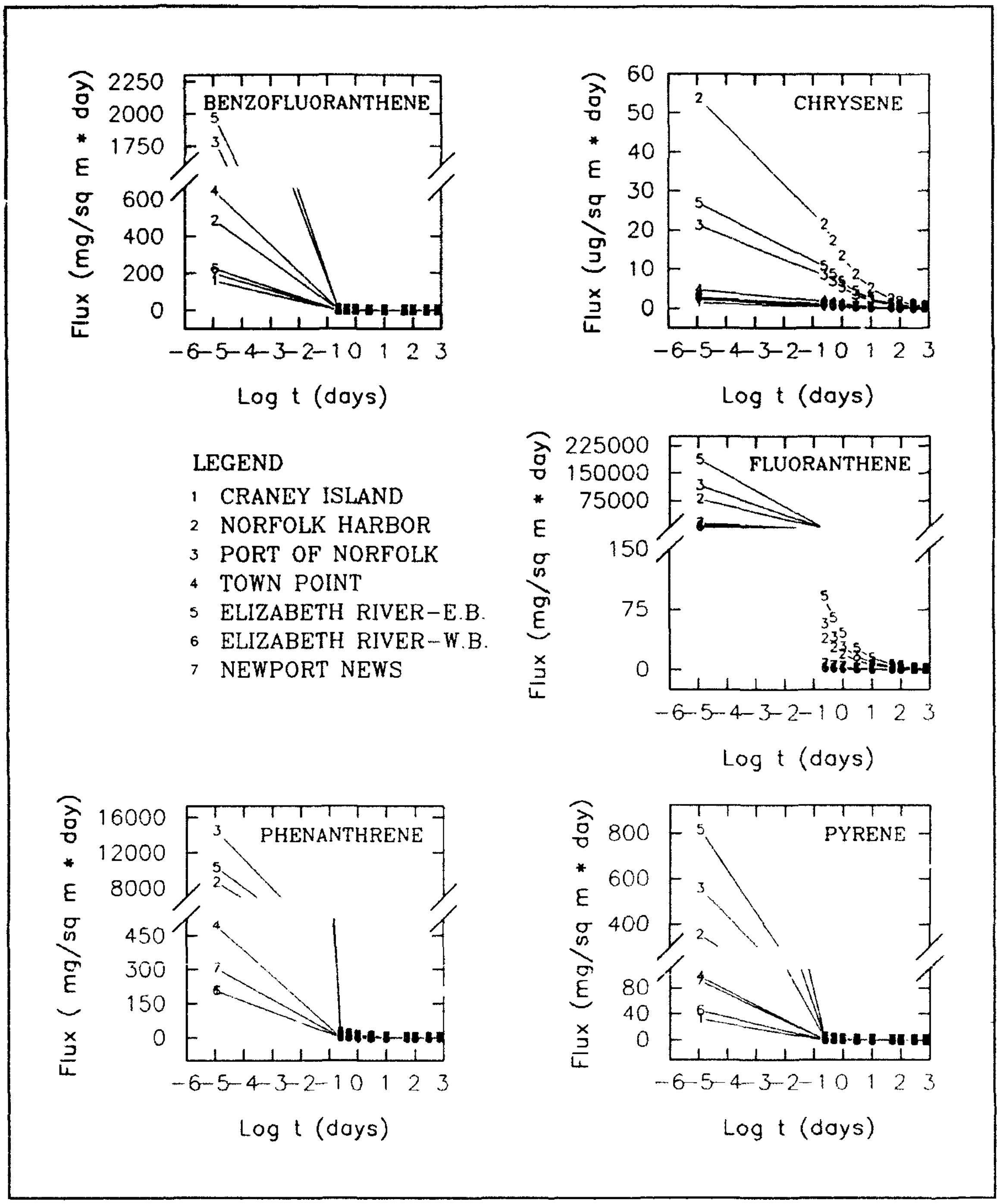

Figure 3-6. Volatile fluxes from exposed dredged material for wind speed of 10 m/second

will persist. For this reason, the initial flux can last much longer than indicated in Figures 3-5 and 3-6. Once the continuous renewal of exposed dredged material ceases, PAHs on the solids at the dredged material-air interface are quickly depleted, and the volatile fluxes decrease significantly.

Capped dredged material

Volatile emissions from exposed dredged material can be reduced by placing clean material over the contaminated material, that is, capping. The model equation for volatile flux from a cap covering contaminated material is given below (Thibodeaux 1989).

$$n_c = D_{A3} \frac{[C_w H - C_a]}{h} \tag{3-14}$$

where

n_c = flux through cap-air interface, g/cm^2/sec

h = cap thickness, cm

Figure 3-7 shows volatile fluxes versus cap thickness for benzofluoranthene, chrysene, fluoranthene, phenanthrene, and pyrene for the sediment areas listed in Table 3-1.

Volatile emission summary

The preceding calculations provide state-of-the-art estimates of volatile fluxes for disposal of PAH-contaminated dredged material. The relative volatile fluxes are 50,000:500:1 for exposed dredged material, ponded water, and capped dredged material, respectively. These are relative ratios, with the 1-m cap as the base case. The estimates may error significantly from actual losses in the field, but the relative magnitudes of losses from exposed dredged material, ponded water, and capped dredged material should be correct. Because the theoretical models available do not account for water evaporation and desiccation cracking, there is some uncertainty about how accurate these models are. Additional research is needed to determine if coevaporation ano cracking enhance volatilization.

The volatile flux predictions suggest operation and management strategies for minimizing volatile emissions. For example, capping with clean material will be an effective control methodology, and little advantage is gained by increasing cap thickness beyond 1 m.

Runoff Losses

Estimation of runoff losses involves estimation of runoff flow and quality. Runoff flow predictions were obtained in previously discussed HELP model simulations. The HELP model runoff estimate listed in Table 3-5 indicates

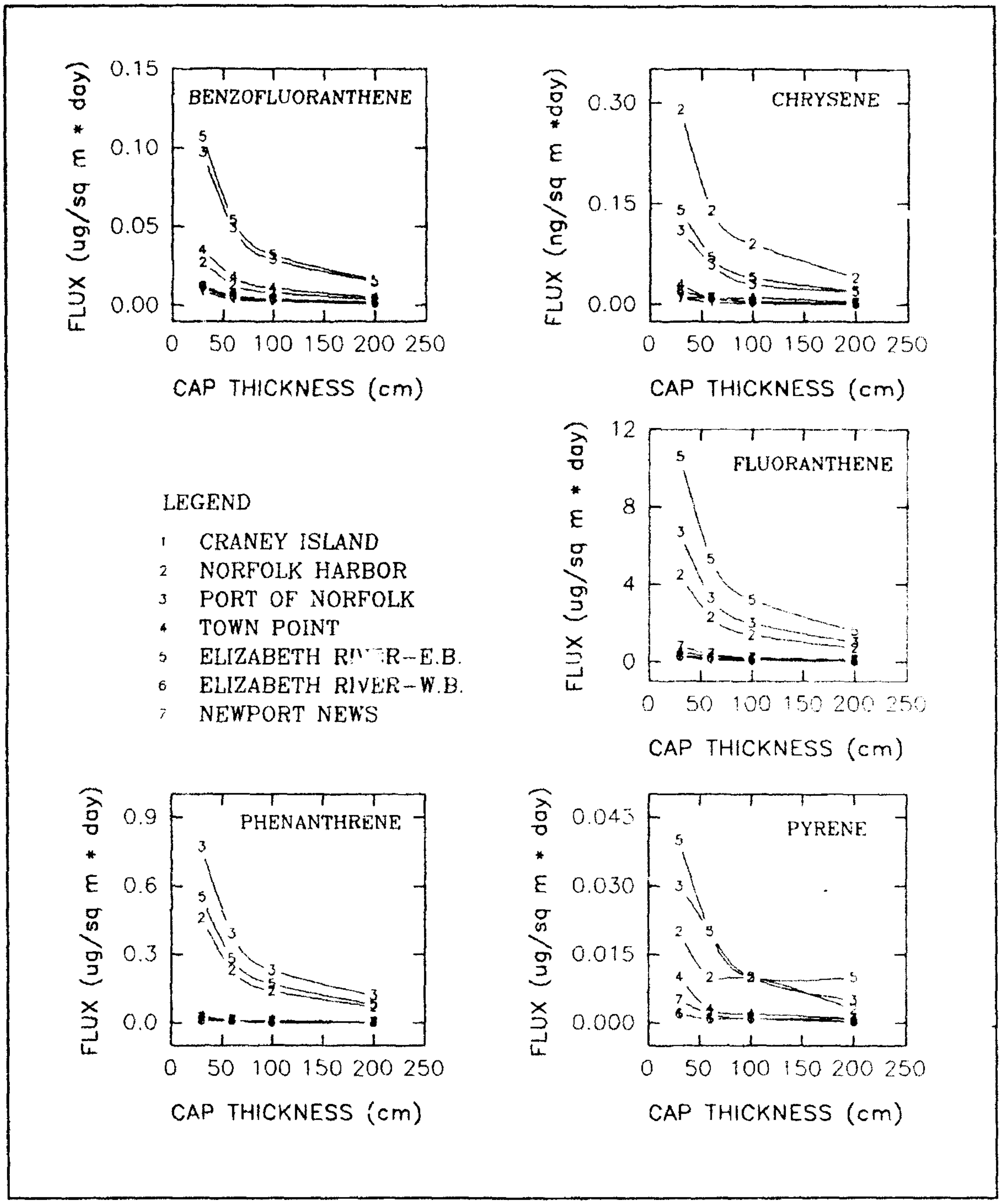

Figure 3-7. Volatile fluxes from capped dredged material

that runoff accounts for about one-third of the annual water budget. In terms of flow, runoff is a potentially significant contaminant loss pathway. A priori estimation of runoff losses and comparison of runoff losses with losses from other pathways, however, is not possible because a priori techniques for predicting runoff quality are not available.

The WES Rainfall Simulator-Lysimeter System (RSLS) (Figure 3-8) has been used in several studies to develop preproject estimates of runoff quality (Environmental Laboratory 1987; Lee et al. 1992, "Evaluation of Upland Disposal of Richmond Harbor, California, Sediment from Santa Fe Channel" (In Preparation), "Evaluation of Upland Disposal of J. F. Baldwin Ship Channel Sediment" (In Preparation); Palermo et al. 1989; Skogerboe, Price, and Brandon 1988). The RSLS is a rotating disk-type rainfall simulator modified from a design of Morin, Goldberg, and Seginer (1967). It incorporates the latest methods to accurately duplicate drop size and terminal velocities of natural rainfall (Westerdahl and Skogerboe 1982). Extensive field verification studies have been conducted with the RSLS that showed that the RSLS can accurately simulate surface runoff from natural storm events under a variety of conditions (Lee and Skogerboe 1984; Skogerboe et al. 1987; Westerdahl and Skogerboe 1982).

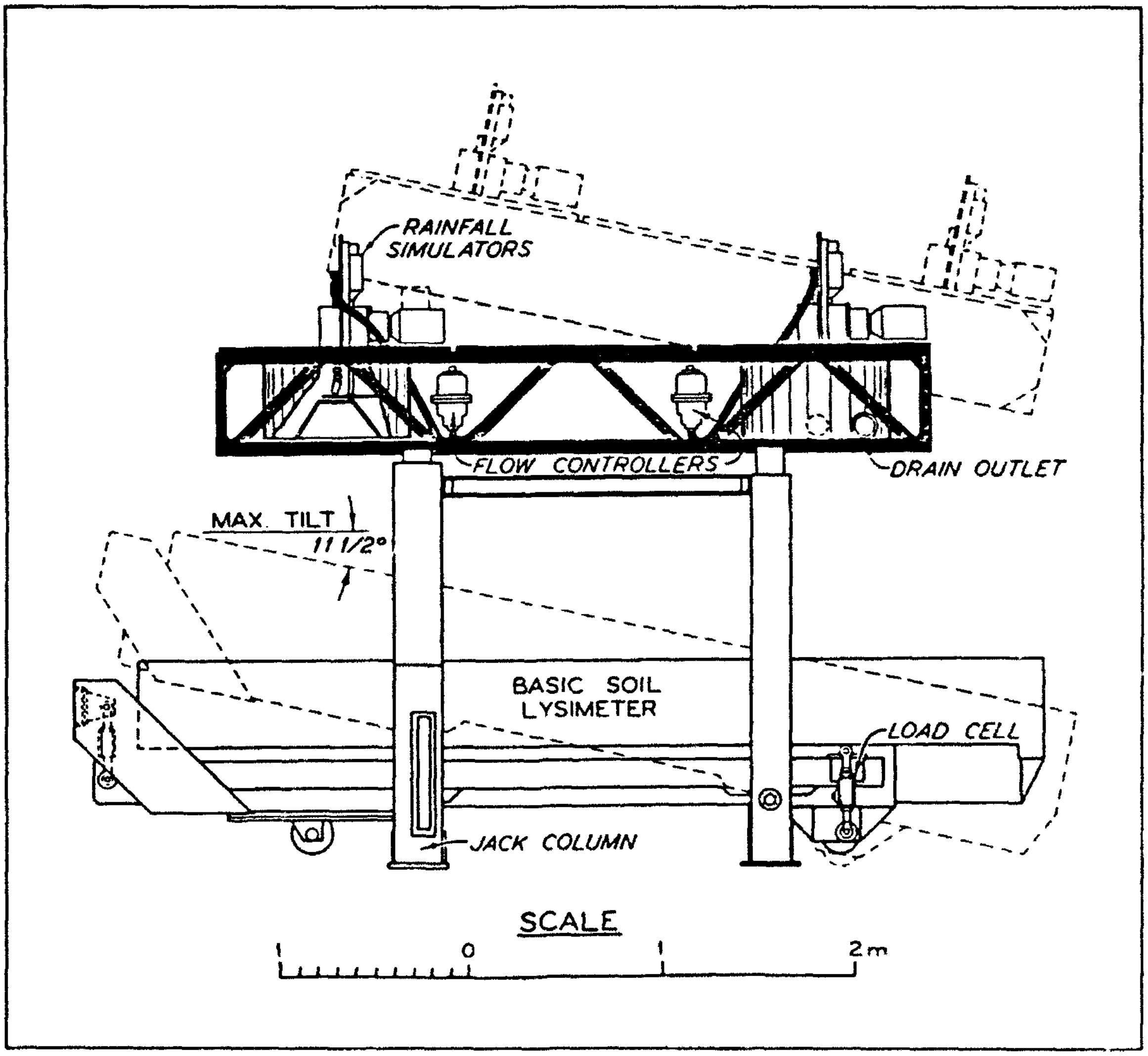

Figure 3-8. Schematic of WES Rainfall Simulator-Lysimeter System

These studies have shown that when dredged material is placed in CDFs, physicochemical changes associated with evaporative drying affect contaminant mobility, including surface runoff quality. Newly dredged sediment is generally anaerobic, near neutral pH, and high water content. During the wet, anaerobic stage, the transport of contaminants in runoff is mainly through the transport of suspended solids. As the material dries and oxidizes, the pH can decrease significantly and result in mobilization of soluble metals.

Potential surface runoff water quality problems during the wet, unoxidized period can be controlled by managing CDFs to remove particulates. Runoff losses can also be controlled by ponding water and allowing it to evaporate. Soluble metal runoff losses from dry, oxidized dredged material may require consideration of a mixing zone beyond the discharge weir or controls involving treatment, capping, or amendment of the dredged material.

Because the runoff potential accounts for as much as one-third of the water budget in the CIDMMA, runoff tests are needed to fully evaluate the significance of this contaminant loss pathway. These tests should be conducted to provide information on changes in runoff quality as dredged materials that may be included in the Restricted Use Program undergo evaporative drying.

Migration Losses by Plant and Animal Uptake

Biological uptake is a potential contaminant loss pathway for CDFs that in terms of total mass loss is probably insignificant compared with pathways involving movement of large amounts of water. Biological uptake, however, can mobilize contaminants in ways that conveyance by water cannot. Biological uptake introduces contaminants into the food chain where bioaccumulation can adversely impact ecological health, especially in environmentally sensitive areas. Since the Restricted Use Program is anticipated to include contaminated dredged material, this pathway should be considered in the development of a revised CIMP for restricted use. Evaluation of this pathway is needed to fully evaluate capping requirements and the suitability of candidate cap materials.

Predictive techniques

Experimental methods for conducting plant and animal uptake studies have been developed for estuarine dredged material (Folsom and Lee 1985; Simmers, Rhett, and Lee 1986, 1988) that are applicable to the CIDMMA. Figure 3-9 shows the experimental unit used in plant uptake studies. Cordgrass (*Spartina alterniflora*) is the index plant used in studies involving estuarine sediments and dredged materials. Figure 3-10 shows the experimental unit used in animal uptake studies. The earthworm (*Eisenia foetida*) is the

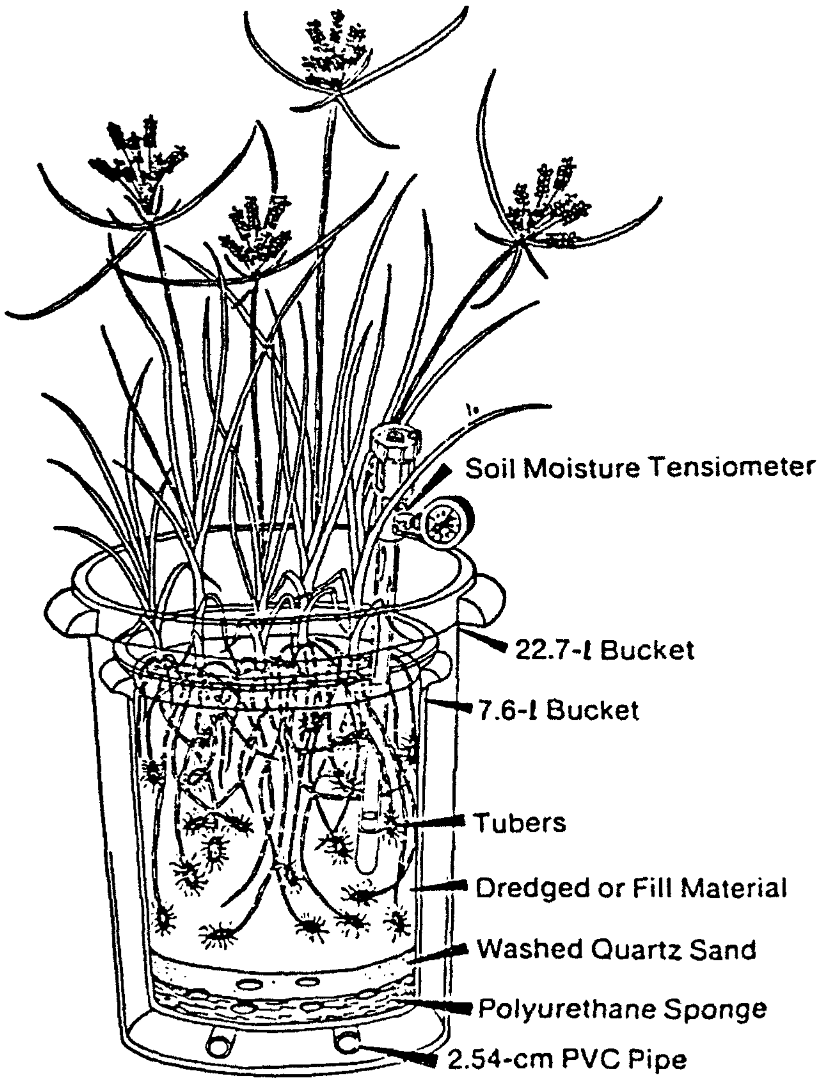

Figure 3-9. Schematic of experimental unit used in plant uptake studies

index animal used in studies involving sediments and dredged material. In the earthworm tests, the salinity of estuarine sediments must be removed prior to testing because high salt concentrations are toxic to earthworms. The earthworm then serves as a surrogate indicator species (Simmers, Rhett, and Lee 1988).

A priori techniques for estimating biouptake are not available. Techniques based on diethylenetriaminepentaacetic acid (DTPA) extractable metals show promise as implied procedures for both plant and animal uptake (Folsom and

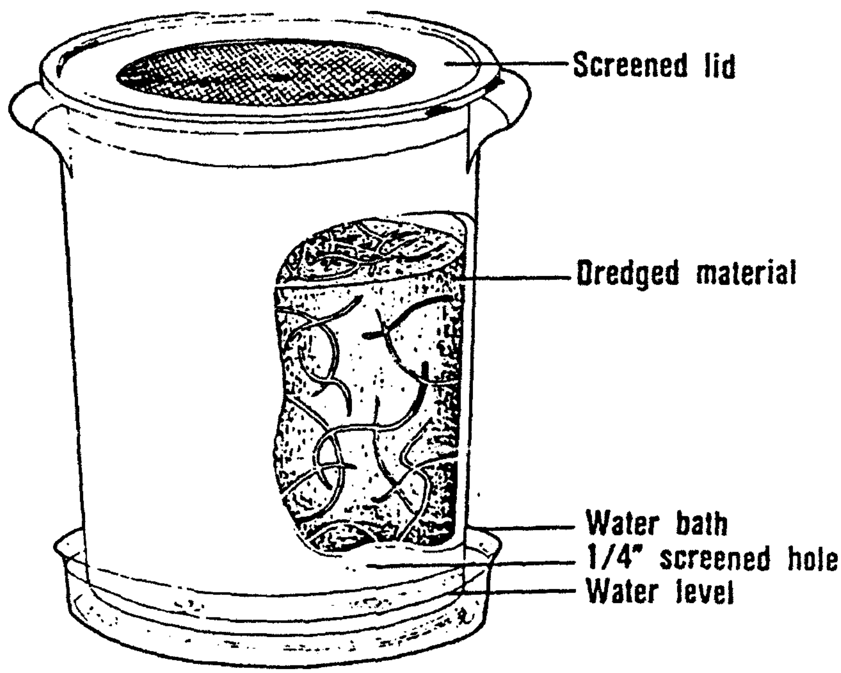

Figure 3-10. Schematic of experimental unit used in animal uptake studies

Houck 1990; Simmers, Rhett, and Lee 1986), but the procedures have not been fully worked out for estuarine sediments.

Previous studies

Simmers et al. (1981) found heavy metals concentrations were similar in marsh plants from natural stands, dredged material disposal sites, and greenhouse plants grown on contaminated sediments as long as the dredged material or sediment was flooded (reducing conditions). Allowing cadmium-contaminated sediments to dry and oxidize resulted in increased cadmium uptake. Folsom, Lee, and Bates (1981) found that plant uptake of heavy metals, especially cadmium and zinc, for dry, oxidized sediments was greater than that from flooded sediments. These studies indicate that plant uptake of metals in the CIDMMA can be minimized by maintaining flooded conditions in the CIDMMA. Flooded conditions, however, conflict with other objectives such as maximizing storage capacity.

Plant and animal uptake summary

As the CIDMMA is filled, vegetation will be periodically buried. Each succeeding stand of volunteer vegetation will begin anew the uptake process.

Historically, vegetative cover has been sparse at the CIDMMA. For these reasons, biouptake is probably not a major contaminant loss pathway during the period it takes to fill the CIDMMA.

Once the CIDMMA is filled, vegetation will eventually establish, and the site will slowly take on the characteristics of a natural area. Biouptake and introduction of contaminants into the food chain could become a concern once plants and animals are established at the site. Closing the site with a cap of clean material is one way to eliminate such concerns. However, placement of clean material in the site may not be fully compatible with the Restricted Use Program. Another alternative is to cap the site with dredged materials that have been tested and accepted for capping purposes. This alternative would involve conducting plant and animal uptake tests on candidate materials. Such studies should be conducted close to the time of closure and, therefore, are not a priority for testing at the present.

Mass Loss Calculations

In this section, site-specific conditions and time frames are applied to the loss equations previously described for effluent, leachate, and volatile migration pathways. Estimated losses are presented as mass lost over selected time frames.

Site-specific conditions

Two dredging scenarios were considered in the chapter on storage evaluations, Baseline and Worst Case Scenarios. Worst Case is defined in Chapter 2 in relation to storage volume, not contaminant release. From Tables 2-7 through 2-12, the estimated total in situ volumes of material to be dredged and placed in the CDF are 72,800,000 cu yd (55,660,000 cu m) and 52,100,000 cu yd (39,400,000 cu m) for the Baseline and Worst Case Scenarios, respectively. Worst Case volume is less than the baseline volume because within the context of a storage volume evaluation, the Worst Case results in less storage volume available and therefore less dredged material placed in the CDF. The operating periods for the Baseline and Worst Case Scenarios are estimated to be 140 and 90 years, respectively. Thus, in the context of maximizing storage, the Worst Case Scenario also results in shorter usable life than the Baseline Scenario.

Average contaminant levels in the materials for Baseline and Worst Case Scenarios for storage evaluations are not known. To estimate the total contaminant masses to be placed in the CIDMMA under Baseline and Worst Case Scenarios, averages from Table 3-1 were used. The contaminant levels in the sampling sites listed in Table 3-1 were averaged and assumed to describe materials placed in the CDF under both Baseline and Worst Case Scenarios for storage. Estimates of total contaminant masses placed in the CIDMMA are provided in Table 3-15. As indicated in Table 3-15, total contaminant masses for the Baseline Scenario are higher than for the Worst Case Scenario. This difference in total contaminant masses placed will be reflected in the emission estimates described later in this section.

Table 3-15
Estimated Average[1] Contaminant Levels and Total Contaminant Masses (kg) Placed in the CIDMMA Under Baseline and Worst Case Scenarios

Contaminant	Average Concentration[2]	Total Mass (kg) Placed in CIDDMA	
		Baseline	Worst Case
Copper	93.3	3,730,000	2,640,000
Chromium	51.0	2,040,000	1,445,000
Lead	132	5,280,000	3,740,000
Zinc	433	17,300,000	12,300,000
Benzofluoranthene	3,429	137,000	97,100
Chrysene	4,857	194,000	138,000
Fluoranthene	8,891	350,000	252,000
Phenanthrene	6,917	277,000	196,000
Pyrene	6,272	251,000	178,000

[1] Average for sampling sites listed in Table 3-1.
[2] Metals in mg/kg and PAHs in μg/kg.

The total masses placed were calculated as follows:

$$M = V_i \rho_{b,i} C_s \qquad (3\text{-}15)$$

where

M = total contaminant mass placed, kg_c

V_i = in situ volume of sediment, cu m

$\rho_{b,i}$ = in situ bulk density, kg_s/cu m

C_s = sediment in situ contaminant concentration, kg_c/kg_s

Average values listed in Table 3-15 were used for sediment in situ contaminant concentration. The bulk density was estimated from in situ sediment water content and specific gravity data provided by the Norfolk District. The average bulk density was 719 kg_s/cu m.

Effluent

Effluent emission losses are given by

$$M_E = (1 - CEF)M \tag{3-16}$$

where M_E is the mass loss (kg) over discharge weirs during hydraulic filling, and the other terms are as previously described. Estimated emissions associated with the effluent pathway are listed for the Baseline and Worst Case Scenarios in Table 3-16. The CEF value used in these calculations was 0.98.

Table 3-16
Estimated Effluent Losses (kg) for the CIDMMA Under Baseline and Worst Case Scenarios

	Emission, kg		Average Annual Emission Rate, kg/year	
Contaminant	**Baseline**	**Worst Case**	**Baseline**	**Worst Case**
Copper	74,600	52,800	533	593
Chromium	40,800	28,900	291	325
Lead	105,600	74,800	754	840
Zinc	346,000	246,000	2,470	2,760
Benzofluoranthene	2,740	1,940	19.6	21.8
Chrysene	3,880	2,760	27.7	31.0
Fluoranthene	7,120	5,040	50.9	56.7
Phenanthrene	5,540	3,920	39.6	44.0
Pyrene	5,020	3,560	35.9	40.0

The average annual emission rates presented in Table 3-16 reflect the differences in disposal volumes and disposal periods required under Baseline and Worst Case Scenarios for storage. Average annual emission rates for the effluent pathway are higher for the Worst Case Scenario, while the total emission is lower.

Leachate

Emission loss because of leaching is given by

$$M_L = Q_L \, C_W \, \Delta t \tag{3-17}$$

where

M_L = mass loss because of leaching, kg_c

Q_L = volumetric flow of leachate, cu ft/year

C_w = leachate contaminant concentration, kg_c/cu m

Δt = period of time for analysis of leaching losses, year

HELP model simulations, as previously discussed, were conducted for two site conditions at the CIDMMA. First, leachate flow for a dewatered condition was estimated to be 14,300,000 cu ft/year (404,980 cu m/year). Second, leachate flow for existing foundation conditions with excess pore pressure was estimated to be 31,454 cu ft/year (890 cu m/year). Thus, the dewatered condition represents a Worst Case for leachate generation because leachate generation is higher.

Two types of leachate emission estimates were developed based on these flows. The two types of leachate emission estimates are not analogous to the two effluent emission estimates based on Baseline and Worst Case Dredging Scenarios because leachate generation was modeled as independent of dredging scenario. The two flow estimates were prepared to contrast leachate emissions if the site is dewatered as suggested in the section on storage evaluations with leachate emissions for existing site conditions.

The appropriate time period for analysis of leaching losses is difficult to ascertain because there are no guidelines available for CDFs. Clearly, the time period of analysis should cover at least the time required to fill the CDF. If the time required for filling is the minimum period of time for analysis of leaching losses, then the minimum Δt in Equation 3-17 is 140 and 90 years for the Baseline and Worst Case scenarios, respectively. Leaching, however, continues for some time after the CDF is filled and closed. Analysis of batch and/or column leaching data can provide an indication of the time required for leaching losses to become negligible. Because such data are not available, the appropriate Δt must be estimated. A 500-year leaching period was selected for use in the analysis prepared for this report. Selection of this period of time should not be construed to imply that a generally applicable procedure for selecting Δt has been developed. A time period of 500 years is entirely arbitrary.

For leachate contaminant concentrations C_w in Equation 3-17, the estimates previously discussed and presented in Tables 3-7 and 3-9 through 3-12 were averaged over sampling sites. The data in Table 3-7 were averaged over the seven sampling sites for each PAH to estimate leachate PAH concentrations for use in Equation 3-17. For metals, maximum values for each sampling site in Tables 3-9 through 3-12 were averaged over the six sampling sites to provide estimates of maximum metals concentrations in leachate. Similarly, minimum values in Tables 3-9 through 3-12 were averaged to provide estimates of minimum metals concentrations in leachate.

The approach used to determine the leachate quality estimates provided in Table 3-7 and 3-9 through 3-12 does not account for the salt washout effect previously discussed. The salt washout effect was not included in this analysis because the time required to elute the approximately five to six pore volumes for the effect to occur may not be reached. For the volume of material to be disposed in the Baseline Scenario, estimated times required for elution of one pore volume are 100 and 46,000 years for leachate flows under dewatered and existing conditions, respectively. For the volume of material to be disposed in the Worst Case Scenario, estimated times required for elution of one pore volume are 71 and 32,000 years for leachate flows under dewatered and existing conditions, respectively. Thus, within the 500-year period of analysis, the salt washout effect will not be important unless the CIDMMA is dewatered and the Worst Case Scenario is followed. Even then, a salt washout effect is not likely until after 350 years have passed.

Estimated PAH losses for leaching are listed in Table 3-17. Leachate PAH losses for the dewatered condition are higher than those for existing conditions. The estimated PAH losses for the existing condition are 0.22 percent of the estimated PAH losses for the dewatered condition. If leachate generated during dewatering were treated, PAH losses could be reduced. Treatability studies would be needed to determine if leachate treatment could reduce the losses for the dewatering condition to the same loss level as for existing conditions.

Estimated metals losses for leaching are listed in Table 3-18. As indicated in Table 3-18, four estimates were developed for each metal. Loss estimates based on estimated average maximum and minimum metals concentrations in leachate were developed for each site condition simulated (existing and dewatered conditions). The estimates for metals losses vary significantly with site conditions and leachate metals concentrations. For example, copper emission estimates range from 200 to 750,000 kg. The range in estimated losses for chromium, lead, and zinc are similar. The lowest estimates (minimum concentration and flow under dewatered conditions) lower than the highest estimates (maximum concentration and flow under existing conditions) by a factor of about 1/3,500.

Table 3-17
Estimated Average Leachate PAH Concentrations and 500-Year Leachate PAH Losses for the CIDMMA

PAH	Average[1] Leachate Concentration kg/m^3	Site Condition[2]	Loss kg
Benzofluoranthene	8.3 E-08	DW[b] EC[c]	16.8 0.04
Chrysene	5.0 E-07	DW EC	100 0.22
Fluoranthene	3.4 E-06	DW EC	600 1.5
Phenanthrene	1.2 E-05	DW	2,400 5.3
Pyrene	2.6 E-06	DW EC	537 1.2

[1] From Table 3-7, average over sampling sites.
[2] DW = dewatered condition; EC = existing condition with excess pore pressures.

Table 3-18
Estimated Probable Maximum/Minimum Leachate Metals Concentrations and 500-Year Leachate Metals Losses for the CIDMMA

Metal	Maximum[1] Leachate Concentration kg/m^3	Minimum[2] Leachate Concentration kg/m^3	Site Condition[3]	Loss, kg	
				Max	Min
Copper	0.0036	0.00046	DW EC	750,000 1,600	93,000 200
Chromium	0.00021	0.000024	DW EC	43,000 93	4,000 11
Lead	0.0041	0.00052	DW EC	830,000 1,800	105,000 231
Zinc	0.0065	0.0010	DW EC	1,300,000 2,900	200,000 445

[1] Average maximum values from Tables 3-9, 3-10, 3-11, and 3-12 averaged across sampling sites.
[2] Average minimum values from Tables 3-9, 3-10, 3-11, and 3-12 averaged across sampling sites.
[3] DW = dewatered condition; EC = existing condition with excess pore pressures.

Volatile losses

During disposal operations. Volatile losses during disposal are given by

$$M_v = n_p A_p \Delta t_p + n_e A_e \Delta t_e \tag{3-18}$$

where

M_v = mass loss because of volatilization, kg

n_p = ponded water volatile flux, kg/sq m· sec

A_p = effective ponded water surface area, cu m

Δt_p = time period for volatile emission from ponded water, sec

n_e = exposed dredged material volatile flux, kg/sq m· sec

A_e = effective exposed dredged material surface area, sq m

Δt_e = time period for volatile emission from exposed dredged material, sec

As indicated in Equation 3-18, time and area terms are needed to calculate volatile losses. *Time and area terms are site-specific and depend on site operation and management.* For volatile emissions during disposal operations, the following assumptions were used to obtain time terms:

- Two hundred thousand cubic yards of in situ sediment can be disposed in 30 days, a disposal rate of 6,667 cu yd/day.

- For the Baseline Scenario, 140 years are required for disposal of 72,800,000 cu yd. For the second assumed disposal rate, 10,920 days of active disposal operations will be required over the 140-year period.

- For the Worst Case Scenario, 90 years are required for disposal of 52,100,000 cu yd. For the second assumed disposal rate, 7,815 days of active disposal operations will be required over the 90-year period.

For volatile losses during disposal operations, the following assumptions were used to obtain area terms:

- Surface areas for the three compartments can be averaged.

- During disposal operations, ponded water covers 20 percent of the available surface area for ponding.

- During disposal operations, the surface area covered with fresh dredged material solids is negligible.

Under the Baseline and Worst Case Dredging Scenarios for storage, disposal is rotated among the three compartments in the CIDMMA. The active disposal times, therefore, do not apply to the total surface area of the CIDMMA. Since disposal is rotated among three compartments, the total active disposal time is applicable to the average compartment surface area. The average surface area for the three compartments is 730 acres. As discussed below, this average compartment surface area is not the effective surface areas for volatilization referred to in Equation 3-18.

The ponded water surface at the CIDMMA is anticipated to cover 10 to 40 percent of the surface of a compartment during disposal. In most cases, 20 percent or more will be covered by water. Coverages of more than 40 percent are anticipated to be relatively infrequent. Another factor considered in selecting an effective surface area for volatilization from water is consistency with the assumption set for application of the basic flux equation (Equation 3-10). In the development of Equation 3-10, equilibrium partitioning between suspended solids and water was assumed. This is a good assumption so long as there is a continuous flux of solids through the water column during disposal operations. (Note: Continuous solids flux provides the source needed to maintain a steady dissolved concentration as loss occurs by volatilization.) Solids flux is not likely to be spacially uniform, and some ponded water areas will not have a continuous solids flux during disposal operations. It is also likely that equilibrium is only approximated and never fully reached. For these reasons, the effective area for volatilization from ponded water is probably less than the ponded water surface area. The volatile loss calculations for ponded water use 20 percent of the average compartment area. For the reasons discussed above, this may be an overestimate of the effective surface area.

During disposal, the effective area for volatilization from fresh, exposed dredged material is expected to be significantly lower than the effective surface area for volatilization from ponded water. The buildup of deltas of exposed dredged material during disposal operations is small compared with the subaqueous deposition occurring in the ponded water zone. Most of the buildup of exposed dredged material occurs in the immediate vicinity of the discharge pipe and consists of coarse-grained material. The size of the exposed delta beneath a dredged material discharge pipe is primarily a function of discharge (dredged material flow) and is usually very small compared with the surface area of the disposal site. For these reasons, volatile losses from exposed dredged material during disposal operations is probably negligible compared with volatile emissions from ponded water.

Estimated ponded water volatile losses are shown in Table 3-19 for Baseline and Worst Case Dredging Scenarios. Fluxes shown in Table 3-19 are averages for each PAH from Table 3-14. Ponded water PAH losses are significant. Estimated phenanthrene volatile loss from ponded water is about 10 times the estimated effluent loss (Table 3-16). Estimated ponded water volatile losses for fluoranthene and pyrene are about twice estimated effluent

Table 3-19
Estimated PAH Volatile Losses from Ponded Water During Disposal Operations for Baseline and Worst Case Scenarios

PAH	Flux[2] $mg/m^2 \cdot day$	Total Loss[1] Baseline kg	Worst Case kg
Benzofluoranthene	0.06	384	275
Chrysene	0.0046	30	21
Fluoranthene	2.48	16,000	11,500
Phenanthrene	8.53	55,000	39,400
Pyrene	1.87	12,100	8,625

[1] Baseline and Worst Case Scenarios for storage; total emission for each scenario.
[2] Average from Table 3-14 for wind speed of 3 m/sec.

losses. Estimated benzofluoranthene volatile ponded water volatile loss is about one-tenth the effluent losses.

Between disposal operations. Equation 3-18 is also used to estimate volatile losses during intervals between disposal operations. The area and time terms for volatile losses during intervals between disposal operations are more complicated than the previously discussed area and time terms for volatile losses during disposal operations. Area and time terms for volatile losses during intervals between disposal operations are complicated because of the time dependency of volatile flux from exposed dredged material and the rotational filling schedules anticipated for Baseline and Worst Case Dredging Scenarios.

For volatile losses during intervals between disposal operations, the major assumptions are listed below. Additional assumptions are introduced and described in the discussions that follow.

- During the interval between disposal operations, the effective surface area for volatilization from ponded water is negligible.

- During the interval between disposal operations, the effective surface area for volatilization from exposed dredged material is 50 percent of the ponded water surface area during disposal operations.

- The rotational impacts of the Baseline and Worst Case Dredging Scenarios on volatile losses from exposed dredged material can be approximated without explicitly simulating each disposal activity.

During the interval between disposal operations, the ponded water surface area is anticipated to be significantly reduced compared with the ponded water surface area during disposal operations. The ponded water surface is probably less than 1 percent of the total surface area of a compartment during the interval between disposal operations. In addition, without a dredged material discharge, continuous solids flux through the water column is not as likely, although resuspension could introduce a solids flux through the water column on windy days. As previously discussed, a continuous solids flux through the water column is one of the conditions needed for application of Equation 3-10. Because the ponded water surface area is small and one of the conditions needed for application of the ponded water volatile flux equation (Equation 3-10) is questionable, volatile loss from ponded water during the interval between disposal operations is probably insignificant relative to the losses from exposed dredged material.

The effective surface area for volatile loss from exposed dredged material during the interval between disposal operations is dependent on the ponded water surface area during disposal operations. Sedimentation in the ponded water during disposal results in a thickened layer of dredged material solids overlain by clarified water. When the ponded water is removed, a fresh layer of dredged material solids is exposed. Because deposition may not occur over the entire ponded water surface area, the surface area of fresh dredged material solids is probably less than the ponded water surface area, depending on deposition patterns during disposal. The volatile loss calculations for exposed dredged material during intervals between disposal operations use 50 percent of the effective ponded water surface area. As previously discussed, effective ponded water surface area was estimated to be 20 percent of the surface area of a compartment in the CIDMMA. The volatile loss calculations for exposed dredged material during the interval between disposal operations use 10 percent of the average compartment surface area as the effective area for volatile losses from exposed dredged material.

The fluxes needed for application of Equation 3-18 to exposed dredged material are not as straightforward as the fluxes used for application of Equation 3-18 to ponded water during disposal operations. As shown in Figure 3-5, volatile flux from exposed dredged material is time dependent. For this reason, the flux and time terms in Equation 3-18 cannot be separated. In order to calculate the mass loss because of volatilization from exposed dredged material, the flux equation (Equation 3-13) must be integrated over the time period of interest.

In the early stages, volatile flux from exposed dredged material transitions from being air-side resistance controlled to diffusion from dredged material controlled. The two resistances are combined in Equation 3-13, and their combined effect on volatile flux is shown in Figure 3-5. A piecewise integration of Equation 3-13 over time was conducted to separate the rapid decay in volatile flux from the less transient portion of the flux curves. For the initial portion of the flux curves, a simple Riemann sum approach was used. For the less transient portion of the curves, an analytical solution for a simplified form of Equation 3-13 was used. Separation into initial (highly time dependent) and extended (less transient) parts of the flux curve was based on information provided in Figure 3-5. The Riemann sum approach was implemented over the time period of 0 to 1 day for benzofluoranthene, fluoranthene, phenanthrene, and pyrene and over the time period of 0 to 150 days for chrysene.

After the microlayer on the surface is depleted, the volatilization process is controlled by diffusion from beneath the surface. Once the process is diffusion controlled, Equation 3-13 can be simplified by dropping the term accounting for the air-side resistance ($1/K_G$). The integrated form of the simplified equation was used for the extended part of the flux curve. The extended part of the flux curve began at 1 day for benzofluoranthene, fluoranthene, phenanthrene, and pyrene and at 150 days for chrysene. For each PAH, the piecewise integration was performed for each sampling site curve shown in Figure 3-5. The integrated results for each sampling site were then averaged to obtain mass loss per unit area. Selected results are presented in Table 3-20. The integration times listed in Table 3-20 are used later to estimate PAH volatile losses from exposed dredged material.

Table 3-20
Estimated PAH Losses for Selected Time Intervals[1] as Mass per Unit Area

Time Interval years	Estimated PAH Losses, kg/sq m				
	BEN	CHY	FLU	PEN	PYR
0 - 0.25	4.90 E-05	1.03 E-07	2.52 E-03	2.56 E-04	2.69 E-05
0 - 0.58	5.93 E-05	1.77 E-07	2.67 E-03	2.93 E-04	3.53 E-05
0 - 1.25	7.28 E-05	3.42 E-07	2.87 E-03	3.41 E-04	4.63 E-05
0 - 2.25	8.75 E-05	4.20 E-07	3.07 E-03	3.92 E-04	5.83 E-05
0 - 2.50	9.06 E-05	4.37 E-07	3.12 E-03	4.04 E-04	6.08 E-05
0 - 3.33	9.99 E-05	4.87 E-07	3.21 E-03	4.47 E-04	6.84 E-05

[1] Numerical integration from 0 to 1 day for BEN, FLU, PHE, and PYR and 0 - 150 days for CHY followed by analytical integration of simplified flux equation.
Note: BEN = benzofluoranthene, CHY = chrysene, FLU = fluoranthene, PEN = phenanthrene, PYR = pyrene.

The results presented in Table 3-20 were applied to approximations of the filling schedules described previously for Baseline and Worst Case Dredging Scenarios. For the Baseline Dredging Scenario, the rotational schedule (Tables 2-7 through 2-12) involves sometimes two, sometimes three disposal operations per year in one compartment. There are always at least two disposal operations per year. Generally, disposal is not scheduled for the same compartment in consecutive years, but there are exceptions. Thus, the number of disposal operations per year and the recurrence interval for disposal in a compartment varies under the baseline storage scenario. Under the Worst Case Dredging Scenario, the disposal schedule is more regular. Conversion of the disposal schedules into repeating exposure times for efficient calculation of volatile losses from exposed dredged material is discussed below.

The exposure time for the first disposal operation in a compartment is usually about 0.25 year (4 months between the first and second disposal, minus 1 month for disposal). Tables 2-7 through 2-9 show that there are 143 episodes under the Baseline Dredging Scenario for which there is a 0.25-year exposure time. When there are two disposal operations in a compartment followed by disposal in the same compartment the next year, the exposure time between the second disposal one year and the first disposal the next year is about 0.58 years. Tables 2-7 through 2-9 show that there are 80 episodes for which there is a 0.58-year exposure time. The remaining disposal operations under the Baseline Dredging Scenario are too variable to efficiently classify according to exposure time. Those disposal operations not yielding 0.25- or 0.58-year exposure times were lumped into one average exposure time of 3.33 years. This average represents 68 exposure episodes with a range in exposure times of 0.92 to 5.25 years.

For the Worst Case Dredging Scenario, the rotational schedule involves approximately three disposal operations per year in one of the three compartments. As with the Baseline Scenario, one compartment is in use while two compartments are inactive each year. The recurrence interval for disposal in a compartment under the Worst Case Dredging Scenario is approximately once every 2 years. As was the case for the Baseline Scenario, the exposure time for the first disposal operation in a compartment is about 0.25 year (4 months minus 1 month for disposal operations). The exposure time for the second disposal operation is also approximately 0.25 year, and the exposure time for the third disposal operation is about 1.25 years. There are some variations from this schedule. Tables 2-10 through 2-12 show that there are 180 episodes for which there is a 0.25-year exposure time, 47 episodes for which there is a 1.25-year exposure time, 36 episodes for which there is a 2.25-year exposure time, and 1 episode for which there is a 2.5-year exposure time under the Worst Case Dredging Scenario.

The average compartment area concept, previously discussed for volatile losses during disposal operations, was used to convert the rotational aspects of filling three compartments of different sizes into filling one equivalent average compartment. Total PAH losses from exposed dredged material (Table 3-21) were estimated using the average compartment area concept, the exposure times previously discussed, and the time integrated unit area losses in Table 3-21. Example calculations are given below.

Baseline Dredging Scenario - benzofluoranthene. The mass loss for an exposure time is the mass loss per square meter for that exposure time (Table 3-20) times the number of times that exposure time occurs times the effective surface area.

Table 3-21
Estimated Total PAH Volatile Losses (kg) for Baseline and Worst Case Dredging Scenarios During Intervals Between Disposal Operations

PAH	Scenario	
	Baseline	Worst Case
Benzofluoranthene	5,500	4,500
Chrysene	18.2	14.8
Fluoranthene	233,600	207,000
Phenanthrene	26,700	22,600
Pyrene	3,300	2,700

$$0.25\text{-}year\ losses = \left(4.90E\text{-}05 \frac{kg}{sq\ m}\right)(143)\ (0.1)\left(\frac{2189\ acres}{3}\right)\left(4041\ \frac{sq\ m}{acres}\right)$$

$$0.58\text{-}year\ losses = \left(5.93E\text{-}05 \frac{kg}{sq\ m}\right)(80)\ (0.1)\left(\frac{2189\ acres}{3}\right)\left(4041 \frac{sq\ m}{acres}\right)$$

$$3.33\text{-}year\ losses = \left(9.99E\text{-}05\ \frac{kg}{sq\ m}\right)(68)\ (0.1)\left(\frac{2189\ acres}{3}\right)\left(4041 \frac{sq\ m}{acres}\right) \quad (3\text{-}21)$$

$$Total = 0.25\text{-}year\ losses + 0.58\text{-}year\ losses + 3.33\text{-}year\ losses$$

The estimated volatile losses for exposed dredged material (Table 3-21) are significant except for chrysene. Estimated benzofluoranthene volatile loss from exposed dredged material is about 40 times the estimate for benzofluoranthene volatilization from ponded water. Estimated volatile loss of fluoranthene from exposed dredged material is about 20 times the estimated ponded water volatile loss for fluoranthene. In addition, the estimated fluoranthene violates conservation of mass; that is, the mass loss estimate for fluoranthene exceeds the estimate for the mass of fluoranthene placed in the CIDMMA (Table 3-15). Estimated volatile losses of chrysene, phenanthrene, and pyrene are about one-half the estimated ponded water volatile losses.

Limitations of volatile loss calculations. There are three major potential sources of error in the volatile loss estimates: errors in Henry constants and mass transfer coefficients, inappropriate area and time terms, and problems with application of the flux equations. Probably the single most important parameter in the calculations is the Henry constant. The Henry constant is a chemical property that should be essentially invariant, with the exception of temperature effects, in most situations of environmental interest. The published values of the Henry constant for most PAHs, however, vary significantly. The variation in published values indicates uncertainty in the chemical property database and subsequent potential for errors in calculations. Mass transfer coefficients vary depending on environmental conditions; however, for a given set of conditions, the estimates do not vary significantly. Area and time terms were based on engineering judgement and are, therefore, subject to error. Henry constants, mass transfer coefficients, and area and time terms could be revised, but whether or not objective revisions would tend to increase or decrease the volatile loss estimates is not clear. However, the flux equations and the way the flux equations were implemented can be objectively analyzed to indicate the direction of errors.

The volatile flux equations (Equations 3-10 and 3-13) are derived from a mass balance in the vertical direction. Each equation includes in the numerator a term to account for the background air contaminant concentration. The higher the background air contaminant concentration, the lower the volatile flux. For large areas, such as the CIDMMA, the equations represent well volatile flux on the upwind edge of an area of exposed dredged material. The background air contaminant concentration may be zero or some value greater than zero. On the downwind side, volatile flux from the exposed dredged material on upwind side increases the background air contaminant concentration crossing the downwind side. Prediction of this increase is not included in the simple model equations presented in this report. To be conservative, the volatile loss calculations assumed zero PAH concentration in the background air. Thus, the calculations yield overestimates of volatile losses. Although the magnitude of the overestimation is not known, laboratory data suggest that the losses calculated are possible. Open-air aging of sediment from Indiana Harbor, IN, showed that 80 percent of the PAHs could be lost in 6 months (Environmental Laboratory 1987).

To account for the impacts of upwind areas on downwind areas, plume modeling with an area source term would be required, and the modeling effort could require an iterative scheme because the plume and the source are not independent. The effective surface area could be reduced or the background air contaminant concentration increased in an attempt to account for upwind/downwind area effects. Adjustment of either effective surface area or background air contaminant concentrations, however, would be arbitrary, and there are no field data from confined dredged material disposal areas on which to judge the appropriate adjustments.

Because the volatile loss estimates for PAHs are high relative to effluent and leachate losses and there is significant uncertainty in the volatile loss estimates, field studies of PAH volatilization is recommended. The development of a priori theoretical volatile emission models for dredged material is limited by the availability of reliable field data. Although revision and improvement in a priori estimation techniques for volatile emissions from CDFs is technically feasible and a needed effort, without field data against which to compare predictions, significant uncertainty will remain.

Mass loss summary

Figure 3-11 shows estimated effluent and leachate losses for metals (copper, lead, chromium, and zinc) identified in the Virginia State Water Control Board Toxics Database Report for the Hampton Roads Harbor area. Copper, chromium, lead, and zinc are assumed to be nonvolatile, and no loss estimates via volatilization were made for these metals.

Effluent losses for the Baseline and Worst Case Dredging Scenarios are shown. Because the Worst Case Scenario for dredging results in less dredged material disposal in the CIDMMA and, hence, less effluent, effluent losses for the Worst Case Dredging Scenario are less than the effluent losses for the Baseline Dredging Scenario. The error bars for the effluent losses represent retention efficiencies ranging from 96 to 98 percent. Palermo (1988) reported retention efficiencies of 99.0, 99.4, 94.7, and 99.9 percent at the CIDMMA for copper, chromium, lead, and zinc, respectively. Thus, the effluent loss estimates for copper, chromium, and zinc are conservative (overestimate losses). The estimates of lead effluent losses may be slightly low and could be one and one-half times that indicated by the errors bars.

Leachate loss estimates are shown for existing and dewatered site conditions. The leachate metals losses for the existing conditions are so small that they are buried in the axes of the graphs shown in Figure 3-11. The leachate metals losses for the dewatered condition are significant and with the exception of chromium are larger than the effluent losses. The leachate metals losses shown in Figure 3-11 represent the midpoint between maximum and minimum losses listed in Table 3-18. The error bars show the maximum value in Table 3-18.

The leachate loss estimates for the dewatered condition represent the potential losses associated with a free-draining condition in which rainfall infiltrates, percolates, and flows offsite with no resistance from the foundation soils or dredged material beneath the upper crust. As previously discussed, estimates for the dewatered condition were prepared to provide information on potential leachate impacts if the CIDMMA could be dewatered to a free-draining condition. The metals loss estimates for leachate reflect the differences in percolation estimates from the HELP model for the two conditions. Although it is not likely that the dewatered condition simulated could be achieved, the loss estimates for the dewatered condition help bound the magnitude of potential losses or leachate treatment effort needed to control losses.

Figure 3-12 shows effluent, leachate, and volatile loss estimates for PAHs. With the exceptions of chrysene and pyrene, the relative order of pathway significance for PAHs is volatilization > effluent > leachate-dewatered conditions > leachate-existing conditions. For chrysene, the relative order of pathway significance is effluent > leachate-dewatered conditions > volatilization > leachate-existing conditions.

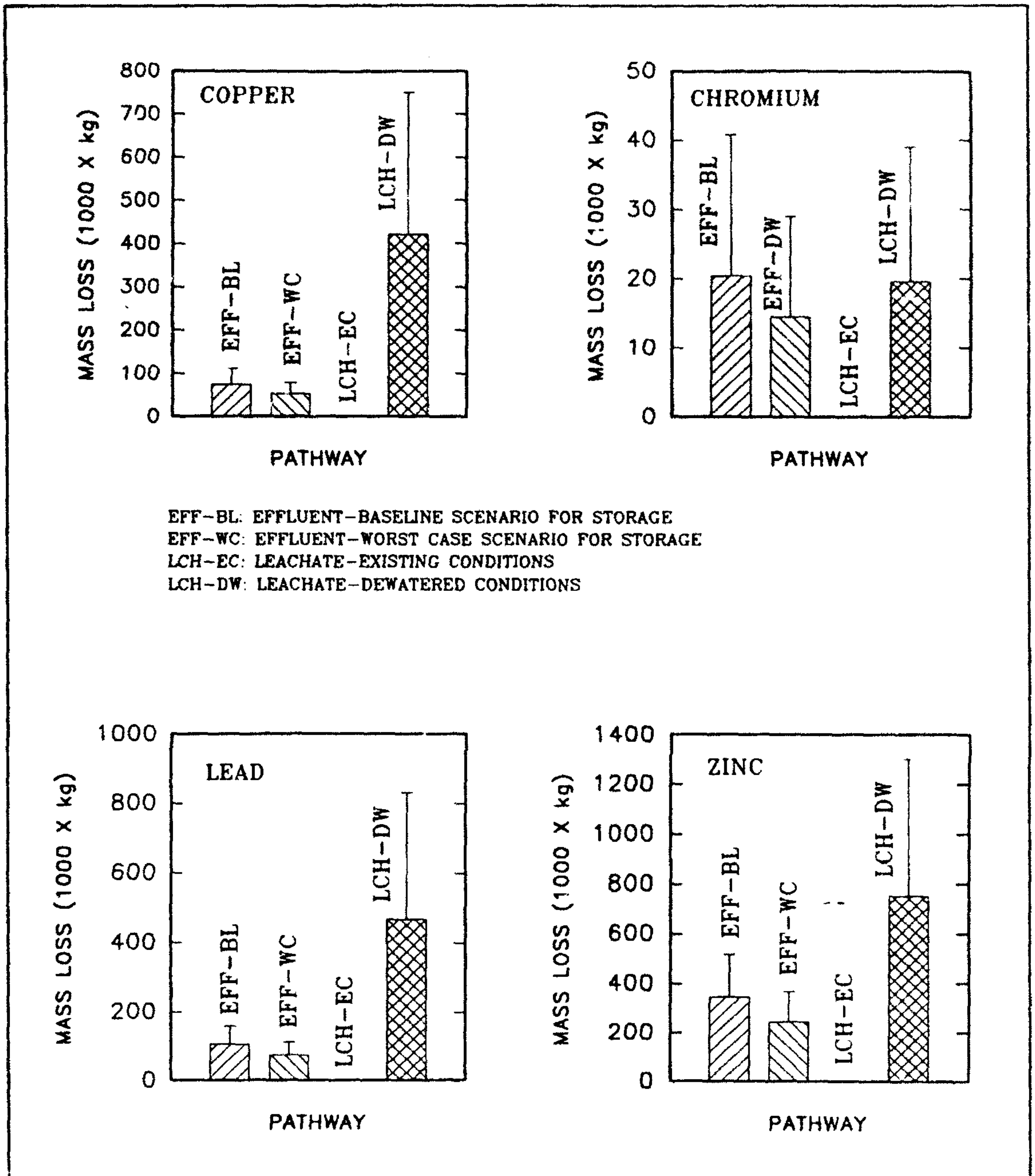

Figure 3-11. Estimated metals losses for the CIDMMA

The overall analysis shows that leaching is a relatively insignificant migration pathway for metals and PAHs at the CIDMMA. The thick layer of marine clay and excess pore pressures in this layer of material beneath the CIDMMA prohibit downward percolation of leachate. If the resistance to downward percolation is removed, then leaching becomes a significant pathway for metals losses, but not PAHs.

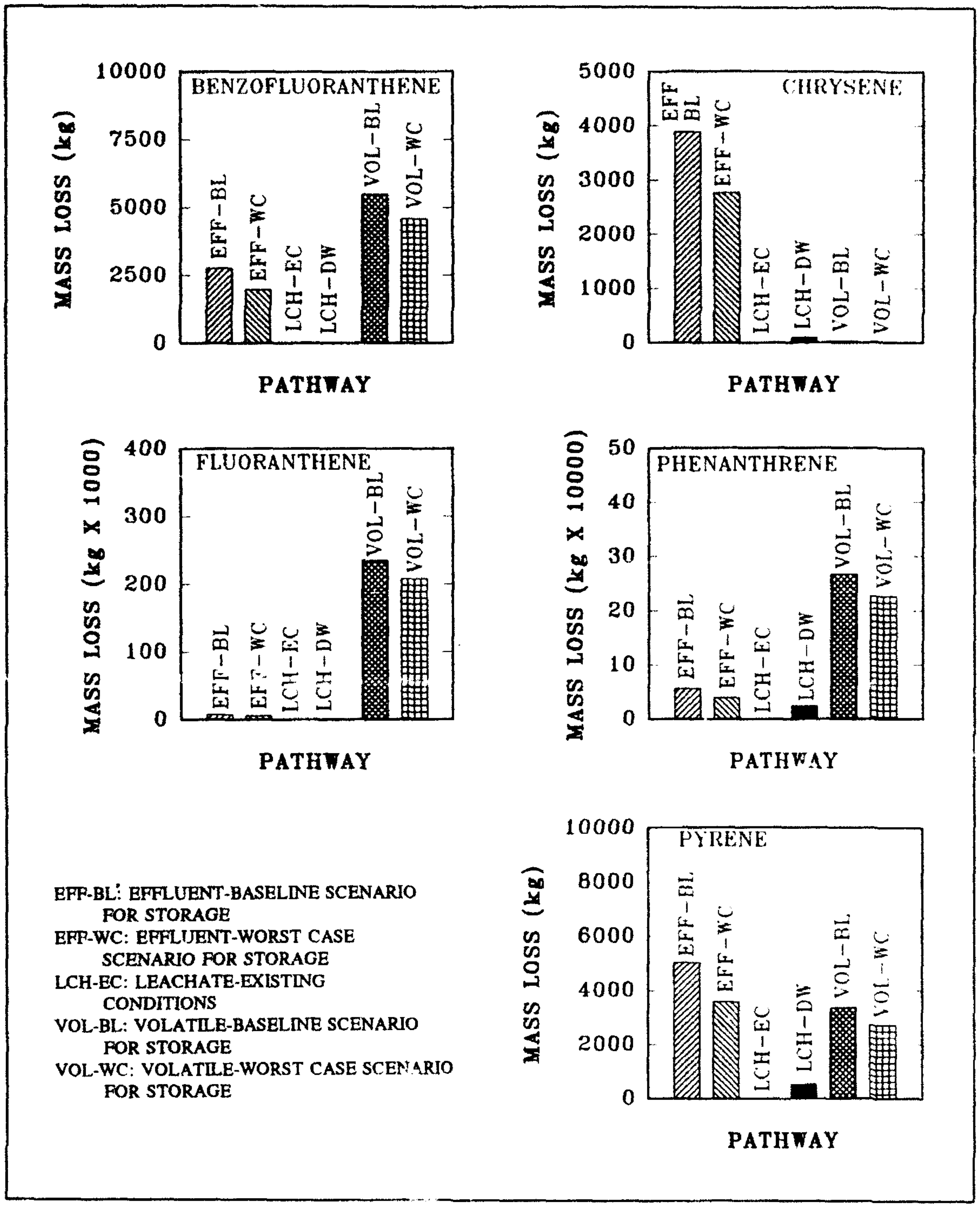

Figure 3-12. Estimated PAH losses for the CIDMMA

The effluent pathway is important for metals and PAHs and is the dominant pathway for metals losses unless the site is dewatered. Operation and management of CDFs affect effluent losses, and it is through careful selection of operation and management strategies that these losses can be minimized.

Volatilization is the dominant migration pathway for several PAHs. The estimated losses suggest that a layer of water will reduce but not eliminate volatile emissions. If water is managed at the CIDMMA to optimize evaporative loss of water, volatile emissions will be maximized and most PAH concentrations in the surface crust will decrease significantly.

4 Conclusions and Recommendations

Conclusions

The service life of the CIDMMA was evaluated by comparing simulations of past filling rates with field monitoring data and projections of future filling rates with the ultimate surface elevation of +30 ft MLW. The filling rates were estimated using a mathematical model that considers both consolidation and desiccation of the dredged material. Mathematical model simulations of the past filling history between 1956 and 1984 (prior to closure of cross dikes) and 1984 to 1992 (after closure) show excellent agreement with field data. These simulations served to calibrate the model for future projections of fill rates under the proposed Restricted Use Program.

Based on projections of fill rates under the Restricted Use Program, the service of the CIDMMA will be significantly extended by reducing the quantity of dredged material entering this facility. In particular, the CIDMMA will reach capacity in approximately 140 years under the Baseline Maintenance Dredging Scenario and in about 90 years under the Worst Case Dredging Scenario. Clearly, these service life estimates are for planning level purposes and should only be used to determine if the proposed Restricted Use Program deserves further consideration. The service life of the CIDMMA can be extended by installing vertical strip drains to consolidate the dredged fill and foundation clay. Results from the installation of a strip drain test section show that the dredged fill and foundation clay are undergoing substantial consolidation settlement (2 to 2.5 ft in 3 months). This consolidation will result in increased storage capacity and an increase in undrained shear strength of the dredged fill and foundation clay. An increase in undrained shear strength should allow the perimeter dikes to be constructed to higher elevations without setbacks or stability berms.

Comprehensive analysis of contaminant migration pathways was conducted using a priori estimation techniques. Estimates of contaminant losses along three major contaminant migration pathways (effluent, leachate, and volatile) were developed for dredged materials with contaminant levels described in the Virginia State Water Control Board (VSWCB) Toxics Database Report. The

VSWCB Toxics Database Report includes PAH data for seven sampling sites and metals data for six sampling sites in the Hampton Roads area. The reliability of the estimates is highly pathway dependent. The relative order of reliability from highest to lowest is effluent > leachate > volatile. A priori estimation techniques were not available for losses by runoff and plant and animal uptake; and losses along these pathways could not, therefore, be estimated.

Two types of loss estimates were developed for the CIDMMA. First, effluent and leachate contaminant concentrations were predicted. Second, contaminant mass losses for effluent, leachate, and volatile emission pathways were estimated.

Effluent quality predictions indicated that concentrations in effluent will be below marine acute water quality criteria for dredged materials from six of the seven sampling sites in the VSWCB Toxics Database Report. Total PAHs in effluent during disposal of dredged material from the East Branch of the Elizabeth River may exceed marine acute water quality criteria. (Marine chronic water quality criteria are not available for PAHs.) Predicted effluent copper and zinc concentrations exceeded marine acute and chronic water quality criteria for the seven sampling sites in the VSWCB Toxics Database Report. Predicted effluent chromium concentrations did not exceed marine acute water quality criteria, but predicted effluent chromium concentrations exceeded marine chronic water quality criteria for six of the seven sampling sites in the VSWCB Toxics Database Report. Predicted effluent lead concentrations exceeded marine acute water quality criteria for dredged material from five of six sampling sites in the VSWCB Toxics Database Report.

Predicted metals concentrations in leachate did not exceed drinking water standards except for lead and chromium. Predicted lead concentrations exceeded drinking water standards by factors of 4 to 180. Predicted chromium concentrations in leachate did not always exceed drinking water standards and ranged from less than the drinking water standard to about six times the drinking water standard. Predicted copper, lead, and zinc concentrations in leachate exceeded marine acute and chronic toxicity criteria in all cases. In some cases, predicted chromium concentrations in leachate exceeded marine acute and chronic water quality criteria for hexavalent chromium.

Comprehensive analysis of migration pathways showed slightly higher losses for the Baseline Dredging Scenario than for the Worst Case Dredging Scenario. Losses were higher for the Baseline Dredging Scenario because more dredged material will be placed in the CIDMMA under the Baseline Dredging Scenario than under the Worst Case Dredging Scenario. The increase in losses for the Baseline Dredging Scenario relative to the Worst Case Dredging Scenario were proportional to the volumes of material disposed for effluent losses but were not proportional to the volumes of material disposed for leachate or volatile losses.

Effluent was the most significant pathway for metals losses. There is a potential for exceeding water quality standards for some metals, depending on sediment quality and site operation and management. Leachate metal losses were insignificant because of the low hydraulic conductivities of the dredged material and foundation soils and excess pore pressures in the foundation soils. Operation and management strategies for controlling metals losses should focus on the effluent pathway.

Volatilization was a most significant pathway for PAH losses. The volatile emission estimates for some PAHs suggest that the site may be self-cleaning. Theoretical chemodynamic analysis of the volatilization process indicated the usefulness of certain strategies for controlling volatile emissions. For example, a 1-ft layer of clean material is an effective barrier for volatile emissions. Operation and management strategies for controlling PAH losses should focus on the volatile pathway.

Leachate losses for existing conditions in the foundation soils and for a fully dewatered condition were estimated. The analysis showed that if a fully dewatered condition could be established and maintained, significant leaching of contaminants relative to existing conditions in the CIDMMA would result. Leachate losses for a fully dewatered condition could exceed effluent losses for some metals. PAH leachate losses for a fully dewatered condition would not exceed effluent losses. Contaminant levels in the pore water removed during dewatering may exceed water quality standards, depending on contaminant levels in the dredged materials disposed.

Recommendations

Vertical strip drains can be installed to consolidate the dredged fill and foundation clay and thus extend the life of the CIDMMA as proposed in the current disposal plan. The proposed consolidation will result in substantial settlement and increase in undrained shear strength of the dredged material, which will permit construction of a new disposal area on top of the existing area. Some of the material projected for the north compartment should be distributed to the center and south compartments to reduce the possibility of the north compartment reaching capacity sooner than the center and south compartments.

Testing is needed to refine contaminant loss estimates and provide information for evaluating restricted use/consolidation programs proposed for the CIDMMA. Specific testing recommendations are as follows:

a. Develop and implement a sediment sampling plan for providing a composite(s) sample representative of materials likely to be disposed under a Restricted Use Program.

b. The composite sample(s) should be physically and chemically characterized. Physical characterization should include grain-size distribution, specific gravity, water content, and plastic and liquid limits. Chemical characterization should include analyses of arsenic, cadmium, chromium, copper, lead, mercury, selenium, benzofluoranthene, chrysene, fluoranthene, phenanthrene, pyrene, and total organic carbon concentrations.

c. Modified elutriate and column settling tests should be conducted to provide information needed for improved prediction of particulate and dissolved contaminant concentration in effluent.

d. Surface runoff tests should be conducted to provide a basis for predicting runoff quality and potential need for controls.

e. Leachate tests should be conducted to provide a basis for predicting the quality of leachate removed by vertical strip drains and potential need for controls.

f. Volatilization tests should be conducted to confirm the potential for significant self-cleaning predicted by theoretical chemodynamic models and potential need for controls.

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13. ABSTRACT *(Maximum 200 words)*

The Craney Island Management Plan was developed to extend the life of the Craney Island Dredged Material Management Area (CIDMMA). The CIDMMA is used to dispose maintenance and new work dredged material from the project area. With current practice, the CIDMMA would reach ultimate capacity by the year 2000. If, however, suitable material is barged to the sea and only contaminated material is placed in the facility (Restricted Use Program), then the life of the facility can be extended. Two tasks were addressed in this study: (a) determine service life under Restricted Use and (b) determine contaminant losses and conduct a Comprehensive Analysis of Migration Pathways (CAMP) expected to occur under Restricted Use. The results showed that the service life of the CIDMMA could be extended under Restrictive Use for approximately 140 years under baseline conditions or 90 years under Worst Case conditions. The CAMP analysis was conducted along three major contaminant migration pathways (effluent, leachate, and volatile). Effluent was the most significant pathway for metal losses and volatilization and for polynuclear aromatic hydrocarbon (PAH) losses. Leachate losses under a fully dewatered condition would not exceed effluent losses for some metals. PAH losses for a fully dewatered condition would not exceed effluent losses.

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