ERDC/EL TR-09-17

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Evaluation of Dredged Material Disposal and Management for Upper James River Federal Navigation Channel, Richmond, Virginia

Modeling and Testing of Contaminant Release for Expansion of Richmond Deepwater Terminal

Roy Wade and Paul Schroeder

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US Army Engineer Research and Development Center
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Final report

Prepared for U.S. Army Corps of Engineers, Norfolk District

Abstract: The Federal Navigation Channel in the Upper James River requires frequent maintenance dredging to ensure safe navigation. One of the shoals is the Federal Channel at Richmond Deepwater Terminal (RDWT). The U.S. Army Corps of Engineers, Norfolk District has proposed expansion of the river basin at RDWT, such that ships arriving at the terminal can turn around and return downriver. Previous investigations determined that RDWT sediments were contaminated with diesel range petroleum hydrocarbons. Dredging and disposal of these sediments into a CDF may result in an adverse impact to water quality from effluent water returned to the James River.

Since previous results of a settling test performed on localized material in December 2003 and June 2007, the settling test results were different and no data were collected on zone settling and compression settling. Therefore, ERDC performed an abbreviated settling test (February 2008) on the new work sediment sample to collect compression settling data for predicting storage needs and to verify the sediment settling behavior. Results of this study show the effluent total suspended solids (TSS) concentration to be very dependent on the sediment being disposed. A wide range of TSS concentrations were examined in jar tests to evaluate the effectiveness of chemical clarification.

Based on the ERDC column settling test (February 2008), RDWT Expansion sediment underwent zone settling at a rate of 7.2 ft/hr. The areas of both cells are sufficient to allow the dredged material slurry to settle. Screening results showed that only Betz PC 1195 and Nalco 8131 were effective. These two polymers reduced the effluent suspended solids concentration by at least 98%. However, PC 1195 outperformed Nalco 8131. Even though the unit cost of Nalco 8131 is less than PC 1195, the required large dosage rate of Nalco offset that cost. The runoff contaminant pathway showed a potential exceedance of the discharge permit water quality, particularly for the period before the dredged material desiccates, forms a crust, or becomes vegetated. Operational controls are required to allow the TSS in the runoff to settle to a concentration below 2.9 g/L before discharging the runoff. The leachate and volatilization contaminant pathway shows no potential for concern.

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Preface

This report describes the settling behavior and laboratory testing of dredged material from the expansion of the James River Deepwater Terminal for evaluating the suitability of the dredged material for upland disposal. The Environmental Laboratory (EL) of the U.S. Army Engineer Research and Development Center (ERDC) performed this work. Background support is available in an ERDC technical report by Wade et al. (2002). The project manager is Gregory Steele of U.S. Army Engineer District, Norfolk.

Roy Wade and Dr. Paul Schroeder of the Environmental Engineering Branch (EP-E), Environmental Processes and Engineering Division (EPED), EL wrote this report.

This study was conducted under the direct supervision of William A. Martin, Chief of EP-E, and under the general supervision of Dr. Richard E. Price, Chief of EPED, Dr. Beth Fleming, Director of EL, Dr. James R. Houston, Director of ERDC, and COL Gary E. Johnston, Commander and Executive Director of ERDC.

The authors would like to acknowledge Richard Hudson for laboratory support.

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412 E-03	cubic meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms

1 Introduction

Background

The Federal Navigation Channel in the Upper James River extends from Richmond to Hopewell, Virginia and has six shoals that require frequent maintenance dredging to ensure safe navigation. One occurs in the Federal Channel at Richmond Deepwater Terminal (RDWT). The shoal requires maintenance dredging almost yearly to maintain the project depth of -25 ft mean lower low water (MLLW). The U.S. Army Corps of Engineers, Norfolk District proposed expansion of the river basin at RDWT such that ships arriving at the terminal can safely turn around and return downriver. Figures 1 and 2 show the vicinity and area of interest for the proposed expansion project, respectively. Through the Virginia Water Protection Permit (VWPP) program, the Norfolk District as recently as January 2007 was granted permission to expand the size of the turning basin.

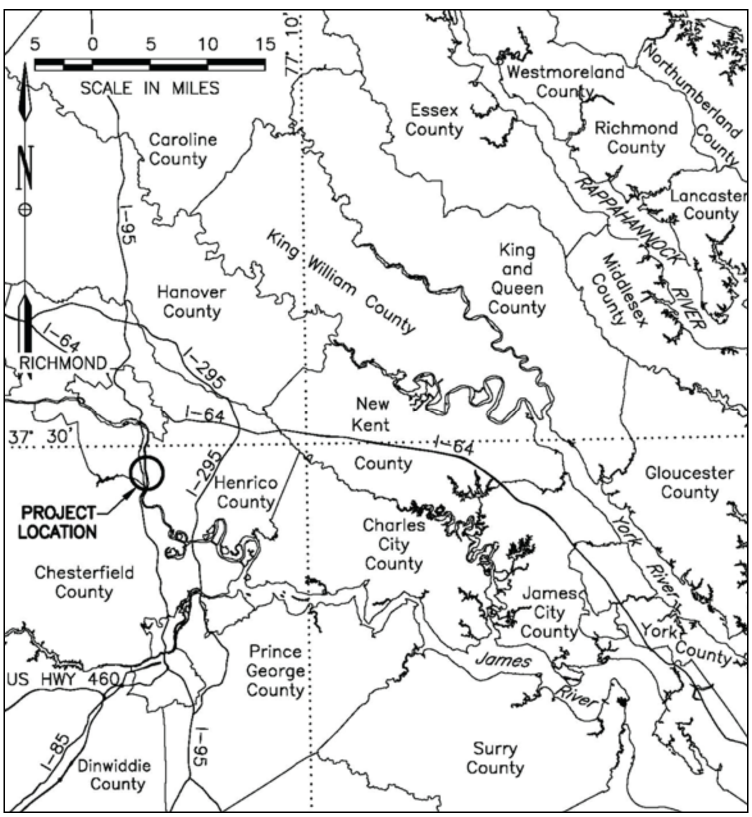

Figure 1. Vicinity map (Norfolk District – July 2005).

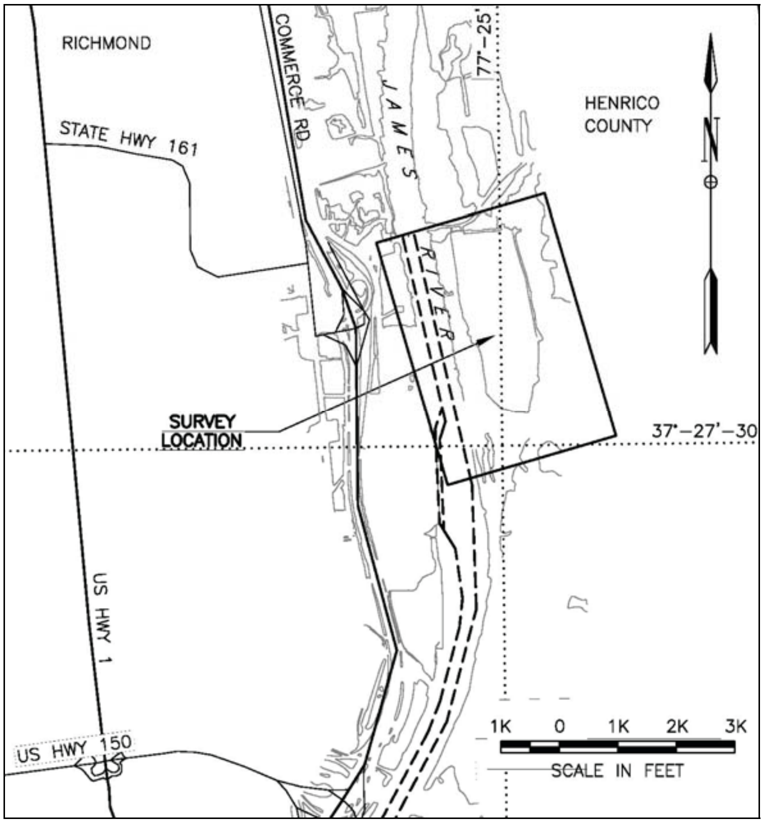

Figure 2. Location map (Norfolk District – July 2005).

The turning basin expands to no more than 825 ft long on its eastern side and 1,179 ft on its western side, no more than 165 ft wide at the subaqueous bottom, no more than 255 ft wide at the top of the channel side-slope, and no more than –28 ft deep MLLW. The Norfolk District proposes to dispose of the new dredged material along with the maintenance dredged material at an existing maintenance dredging confined disposal facility (CDF). An early chemical investigation in April 2002 determined that RDWT soils were contaminated with diesel range petroleum hydrocarbons (Wade et al. 2002). In December 2003, the Norfolk District conducted another chemical investigation of the sediment and site water at the RDWT shoal because of permit conditions imposed by the Virginia Department of Environmental Quality (VDEQ) through the state's VWPP program. Results from that investigation determined that no detectable levels of benzene, toluene, ethylbenzene, and xylenes (BTEX); organotin compounds; or total petroleum hydrocarbon (TPH) were present in the surface water. However, naphthalene and low levels of various metals were detected in the surface water. The bulk sediment chemistry indicated that various metals might be of some concern. This raised concerns by VDEQ that sediments at RDWT may contain contaminants that, when dredged and disposed of in a CDF, can result in an adverse impact to water quality from effluent water returned to the James River.

Additional sediment samples for the new work dredging were collected in May 2007 for physical and chemical evaluation. The bulk sediment chemistry indicated PAH contaminants were present. The new work sediment was determined to be mostly fine-grained, while the previous maintenance dredging material was characterized as predominantly coarse-grained sediment material.

Objective

The overall objective is to support the Norfolk District in managing disposal of contaminated dredged material at the RDWT upland site. Specific objectives are to utilize existing dredging operations plans, CDF information, geotechnical, settling behavior, elutriate, water column and bulk sediment chemistry data to evaluate the CDF for containment, to evaluate contaminant release from the disposed dredged material via the CDF air and water pathways, to evaluate engineering controls for the effluent discharge to meet VDEQ water quality standards, and to evaluate oil sheen characteristics and controls.

2 Richmond Deepwater Terminal Sediment Evaluation

Task 1: Effluent quality

In Task 1 the existing modified elutriate data collected in May 2007 were used to compute the total organic contaminant concentrations in the effluent from a CDF. The modified elutriate data also determine the maximum allowable total suspended solids (TSS) concentration in the effluent to meet the permissible discharge water quality thresholds that were derived from Virginia Water Quality Standards (VWQS) by considering dilution in a mixing zone. Dissolved and total contaminant concentrations are shown in Tables 1 and 2. The discharge criteria for the end of pipe for the organic constituents are listed in the Final Virginia Water Protection Permit for the Deepwater Terminal Turning Basin Expansion. Organic contaminant concentrations associated with the suspended solids in the modified elutriate tests are given in Table 3. Table 4 presents the maximum TSS concentrations that can exist in the effluent and still meet the water quality criteria established in the permit, given the dissolved contaminant concentrations in the modified elutriate tests. The required TSS concentrations at the return flow discharge point were greater than the maximum allowable 1,560 mg/L. Sedimentation alone cannot always meet the target effluent quality of 1,560 mg/L, especially when dredging new work clays in a freshwater environment. Therefore, chemical clarification may be needed to reduce the effluent TSS concentration to ensure that the effluent quality is acceptable. Chemical clarification is generally able to achieve an effluent TSS concentration of less than 250 mg/L in a CDF without special treatment/mixing facilities or controls.

Task 2: Settling analysis

Task 2 used existing settling data to determine the anticipated TSS concentration at several points of interest in the CDF: a) the discharge weir of the secondary cell, b) the discharge point of the primary cell, and c) the location of a potential divider dike in the secondary cell for a tertiary cell for polishing the effluent. These TSS concentrations, when compared with the maximum allowable TSS concentration determined in Task 1, were used to determine the need for effluent controls and the required treatment efficiency.

Table 1. Dissolved Organic Contaminant Concentrations from Modified Elutriate Test.

Constituent	Dissolved Concentration, µg/l								
	07-JR-DWTX-1-EL-3-9	07-JR-DWTX-1-EL-9-15	07-JR-DWTX-1-EL-15-21	07-JR-DWTX-1-EL-FD	07-JR-DWTX-1-EL-21-27	07-JR-DWTX-2-EL-3-9	07-JR-DWTX-2-EL-9-15	07-JR-DWTX-2-EL-15-21	07-JR-DWTX-2-EL-21-27
Acenaphthene	0.56	3.9	14.1	42.8	1.9	<2.6	6.8	43.0	7.8
Anthracene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Benzo(a)anthracene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Benzo(a)pyrene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Benzo(b)fluoranthene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Chrysene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Fluoranthene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4
Fluorene	<2.2	1.0	1.9	9.1	<2.2	<2.6	0.87	10.7	1.7
Naphthalene	<2.2	<2.2	0.49	0.83	<2.2	<2.6	<2.8	0.69	<2.4
Pyrene	<2.2	<2.2	<2.3	<2.2	<2.2	<2.6	<2.8	<2.3	<2.4

Note: 07-JR-DWTX-1-EL-FD is a duplicate of 07-JR-DWTX-1-EL-15-21.

Table 2. Total Organic Contaminant Concentrations from Modified Elutriate Test.

Constituent	Total Concentration, µg/l unless noted								
	07-JR-DWTX-1-EL-3-9	07-JR-DWTX-1-EL-9-15	07-JR-DWTX-1-EL-15-21	07-JR-DWTX-1-EL-FD	07-JR-DWTX-1-EL-21-27	07-JR-DWTX-2-EL-3-9	07-JR-DWTX-2-EL-9-15	07-JR-DWTX-2-EL-15-21	07-JR-DWTX-2-EL-21-27
Acenaphthene	0.96	44.8	202	427	26.5	0.54	46.7	57.4	13.7
Anthracene	<2.2	7.4	61.5	136	11.9	<2.2	8.0	13.4	5.5
Benzo(a)anthracene	<2.2	6.2	25.9	73.1	4.9	<2.2	5.5	5.1	3.1
Benzo(a)pyrene	<2.2	4.2	18.4	54.8	2.9	<2.2	3.9	3.8	2.1
Benzo(b)fluoranthene	<2.2	1.9	8.7	20.7	1.4	<2.2	1.8	1.8	1.0
Chrysene	<2.2	5.2	20.8	81.3	4.2	<2.2	4.5	4.2	2.6
Fluoranthene	0.57	21.0	76.9	236	15.0	<2.2	17.2	16.0	8.1
Fluorene	<2.2	18.3	80	201	15.2	<2.2	18.6	22.8	7.3
Naphthalene	<2.2	<2.2	1.9	<2.2	0.54	<2.2	0.53	0.57	<2.2
Pyrene	1.0	36.5	126	378	23.3	0.72	30.1	25.0	12.6
TSS, mg/l	3,650	9,250	14,000	17,800	17,500	1,800	7,680	860	3,880

Table 3. Particulate Associated Organic Contaminant Concentrations from Modified Elutriate Test.

Constituent	Contaminant Fraction of Solids Mass (FSS, ug/kg)								
	07-JR-DWTX-1-EL-3-9	07-JR-DWTX-1-EL-9-15	07-JR-DWTX-1-EL-15-21	07-JR-DWTX-1-EL-FD	07-JR-DWTX-1-EL-21-27	07-JR-DWTX-2-EL-3-9	07-JR-DWTX-2-EL-9-15	07-JR-DWTX-2-EL-15-21	07-JR-DWTX-2-EL-21-27
Acenaphthene	110	4,420	13,400	21,600	1,410	300	5,200	16,700	1,520
Anthracene	—	800	4,390	7,640	680	—	1,040	15,600	1,420
Benzo(a)anthracene	—	670	1,850	4,110	280	—	716	5,930	799
Benzo(a)pyrene	—	454	1,310	3,080	166	—	508	4,420	541
Benzo(b)fluoranthene	—	205	621	1,160	80	—	234	2,090	258
Chrysene		562	1,490	4,570	240	—	586	4,880	670
Fluoranthene	156	2,270	5,490	13,300	857	—	2,240	18,600	2,090
Fluorene	—	1,870	5,580	10,800	869	—	2,310	14,100	1,440
Naphthalene	—	—	101	—	31	—	69	—	—
Pyrene	274	3,950	9,000	21,200	1,330	400	3,920	29,100	3,250

Table 4. Maximum Allowable TSS Concentrations from Modified Elutriate Test to Satisfy Screening Criteria.

Constituent	Screening Criteria (ug/L)	Maximum Allowable TSS to Satisfy Screening Criteria (g/L)								
		07-JR-DWTX - 1-EL-3-9	07-JR-DWTX -1-EL-9-15	07-JR-DWTX -1-EL-15-21	07-JR-DWTX -1-EL-FD	07-JR-DWTX -1-EL-21-27	07-JR-DWTX -2-EL-3-9	07-JR-DWTX - 2-EL-9-15	07-JR-DWTX -2-EL-15-21	07-JR-DWTX -2-EL-21-27
Acenaphthene	51,300	468,107	11,601	3,821	2,375	36,493	171,000	9,873	3,061	33,731
Anthracene	2,090,000	—	2,612,500	475,772	273,544	3,073,529	—	2,006,400	134,134	1,474,400
Benzo(a)anthracene	9.31	—	14	5.0	2.27	33	—	13	1.57	12
Benzo(a)pyrene	9.31	—	21	7.1	3.02	56	—	18	2.11	17
Benzo(b)fluoranthene	9.31	—	45	15.0	8.01	116	—	40	4.45	36
Chrysene	9.31	—	17	6.3	2.04	39	—	16	1.91	14
Fluoranthene	7,030	45,017	3,097	1,280	530	8,202	—	3,139	378	3,367
Fluorene	266,000	—	142,225	47,682	24,672	306,250	—	115,221	18,905	184,299
Naphthalene	62	—	—	611	—	2,009	—	898	—	—
Pyrene	209,000	762,850	52,966	23,222	9,842	156,974	522,500	53,326	7,190	64,359

Note:

1) Maximum allowable TSS (g/L) = $[(C_{criteria} - C_{diss}) \times 10^3]/FSS$ where $C_{criteria}$ and C_{diss} are in ug/L and FSS is in ug/kg.

2) — denotes sample concentration below detection and not needing reduction.

In addition to predicting effluent TSS concentrations, the settling analysis was used to examine the adequacy of the CDF for storing the dredged material. A column settling test was conducted to collect settling data, in particular compression settling data, and to verify the settling behavior exhibited by the new work sediment sample in the June 2007 settling test. Zone and compression settling data were not collected in the June 2007 settling test, requiring a new settling test to perform the storage evaluation. The settling analysis was conducted for two dredging operations: disposal by a 12-in. hydraulic dredge and a 16-in. hydraulic dredge.

Updated Settling Test. ERDC conducted a column test on the new work sediment sent from Norfolk District as described below. Settling test data are summarized in Appendix A.

Slurry preparation

The target slurry concentration selected for the settling tests was dependent on the grain size distribution of the sample to simulate the solids concentration anticipated during production by a hydraulic dredge. Typically, 4 or 5 parts of water are added to 1 part of sediment by volume. However, the available volume of sediment was too small to prepare a slurry at this ratio, so a ratio of 7.5:1 was used to create enough slurry to fill the column. The target slurry was prepared by mixing the appropriate amount of sediment at its initial solids concentration and site water into a 130-L plastic barrel. Since no site water was available, tap water was used. The average solids content for the sediment sample prior to mixing was 1,066 g/L. Approximately 20 kg of sediment were mixed with 90 L of tap water, achieving a slurry concentration of about 125 g/L. The mixture of sediment and site water was thoroughly blended using a Lightning mixer for 30 minutes. After completely mixing the slurry, the mixing intensity was decreased to allow the majority of the coarse-grained material to settle in the plastic barrel while keeping the fine-grained material in suspension. While slowly mixing, the fine-grained slurry was transferred from the 130-L plastic barrel to an 8-in.-diam, 7-ft-tall column with ports at 0.5-ft intervals starting at the 6.5-ft height. Immediately after loading the column with the fine-grained slurry, samples were extracted from the sampling ports at 1.0-ft intervals throughout the depth of the slurry in the column to analyze for total solids concentration of the slurry as placed in the column. The average suspended solids concentration was determined to be 55 g/L. The difference between the target total solids concentration and the solids concentration of slurry as placed is due to the sedimentation of the coarse fraction provided in the 130-L plastic barrel. .

Zone settling test

The zone settling test was performed concurrently with the compression settling test on the same slurry in the same column. The height of the interface was read at approximately 5-min intervals for 1 hr and then 15-30 min thereafter. From the plot of the height of the interface (ft) versus time (hr), the zone settling velocity was determined from the slope of the straight-line portion of the curve. Figure 3 is a photo of the settling test.

Figure 3. New work column test.

Compression settling test

Following the zone-settling test, the height of the interface was measured twice a day for 15 days. The height of the interface, the initial height of the slurry, and the initial solids concentration of the slurry in the column are used to estimate the concentration of settled solids below the interface as a function of time as required in the compression settling analysis.

Settling test results

The new work sediment underwent zone settling. This material settled rapidly even after the removal of the coarser material. Apparently, a separation of the silt and clay fractions occurred. This conflicts with the December 2003 settling data and possibly the June 2007 settling data (the supernatant may have been too cloudy to delineate the interface for zone and compression settling). However, the zone settling velocity (ZSV) for the new work sediment was determined using the zone settling test results in the ADDAMS SETTLE program. The height of the interface and the corresponding elapsed time from the start of the test when the heights were entered and plotted in the SETTLE program was used to determine the ZSV of 7.16 ft/hr (Figure 4). The ZSV is the slope of the straight-line portion of the settling curve prior to transition settling. When the zone settling curve departs from the linear relationship, compression settling begins. The transition from zone to compression settling occurred between 0.5 and 12 hr. The ZSV of this test is considerably higher than that commonly observed in tests on other sediments. The high settling velocity is primarily a function of the sediment properties and not the testing conditions. The sediment, being new work sediment, is quite different from maintenance sediments and apparently has poor hydrating characteristics, permitting more rapid, dense settling.

For the compression tests, the initial slurry concentration and height, and height of the interface versus time were entered into the ADDAMS SETTLE program to determine the settled solids concentration as a function of time. A plot was generated showing the relationship between solids concentration (g/L) and retention time (days) (Figure 5). SETTLE also generated a regression equation for the resulting power curve relating solids concentration to time.

Flocculent settling analysis

The ADDAMS SETTLE model was used for the settling analysis. Two sets of existing settling data (December 2003 and June 2007) were used to determine the anticipated TSS concentration in the CDF. The December 2003 sample was very different from the June 2007 and February 2008 samples. The December 2003 sample was maintenance sediment that was more than 98% coarse-grained. The settling test on this sediment had an initial concentration of less than 1 g/L and the sediment settled rapidly in the test. This O&M sediment sample would not require chemical clarification to satisfy the effluent quality criteria. The June 2007 and February 2008 samples were new work sediments and predominantly fine-grained as shown in Figure 6. In the June 2007 test, the slurry had an initial solids concentration of about 100 g/L and settled slowly by flocculent settling. The initial concentration in the February 2008 test was about 55 g/L. The slurry underwent zone settling but formed a supernatant having very high concentrations of TSS, greater than 15 g/L. The ADDAMS SETTLE model was used for the settling analysis to determine the need for effluent controls and the required treatment efficiency.

SETTLE model input data were obtained from previous reports and settling data dated December 2003 and June 2007 (Tables 5 and 6). Data from the February 2008 test were not used because this flocculent settling test was conducted for confirmatory purposes. The concentration used in the test was lower than desired for the flocculent settling analysis; an initial TSS concentration of 80 to 100 g/L would have been preferable. Consequently, the TSS concentrations in the supernatant were lower than expected to occur in the CDF. Based on an effluent TSS target of 1,560 mg/L, chemical clarification or other TSS controls are required to meet the VWQS for the June 2007 sediment sample.

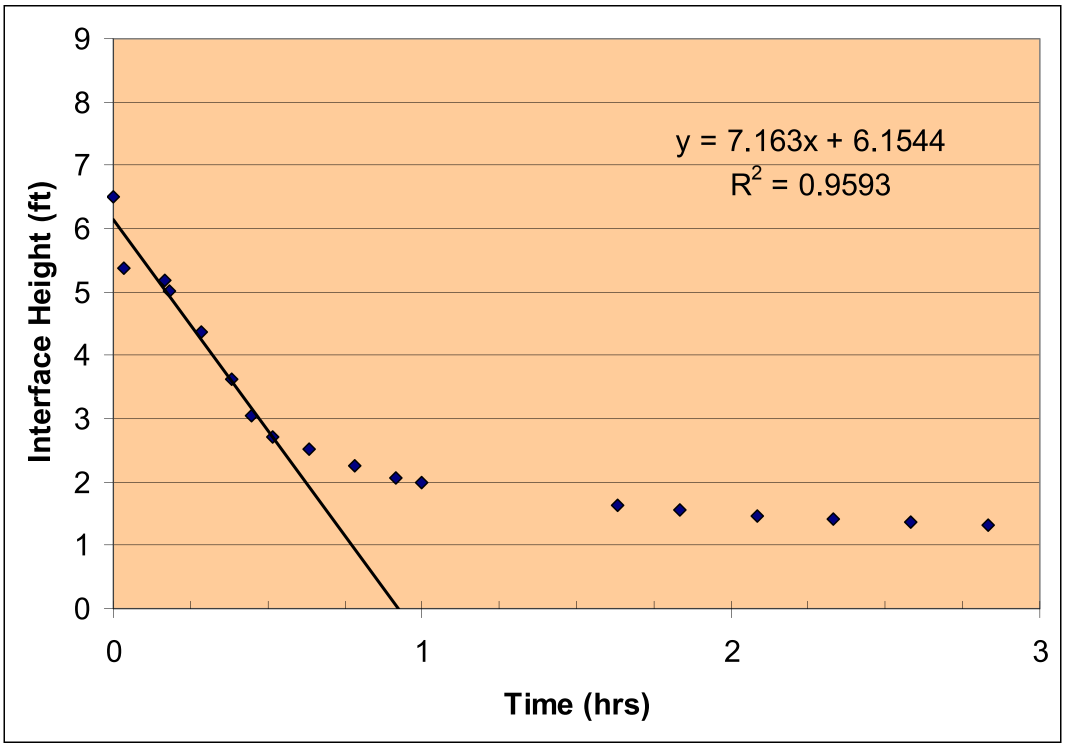

Figure 4. Zone settling test results.

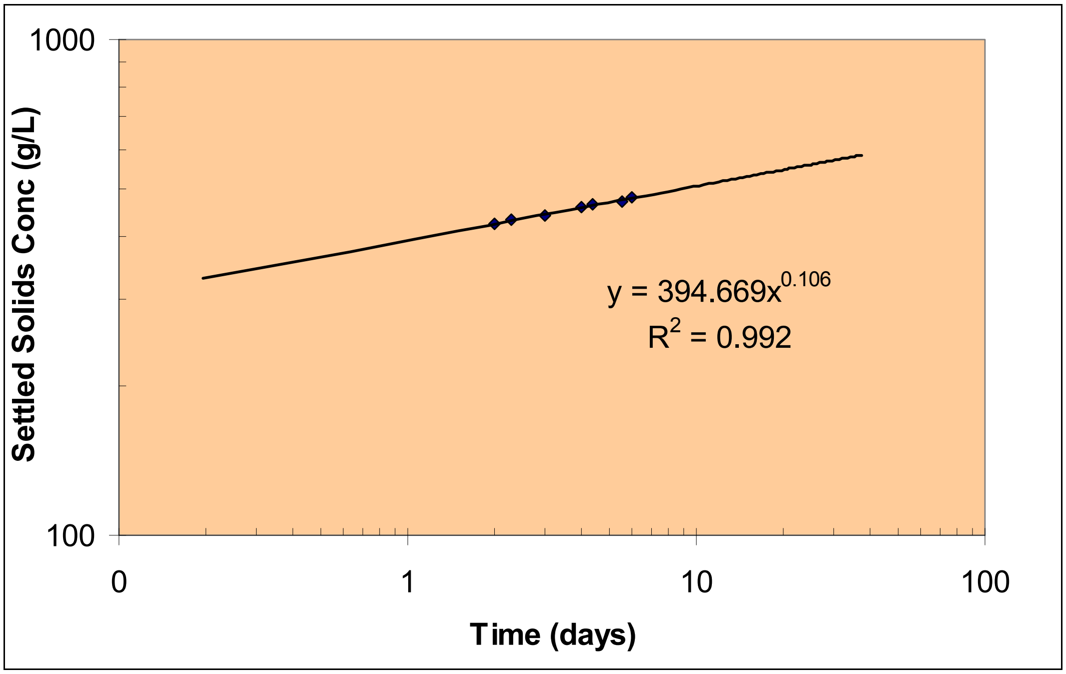

Figure 5. Compression settling test results.

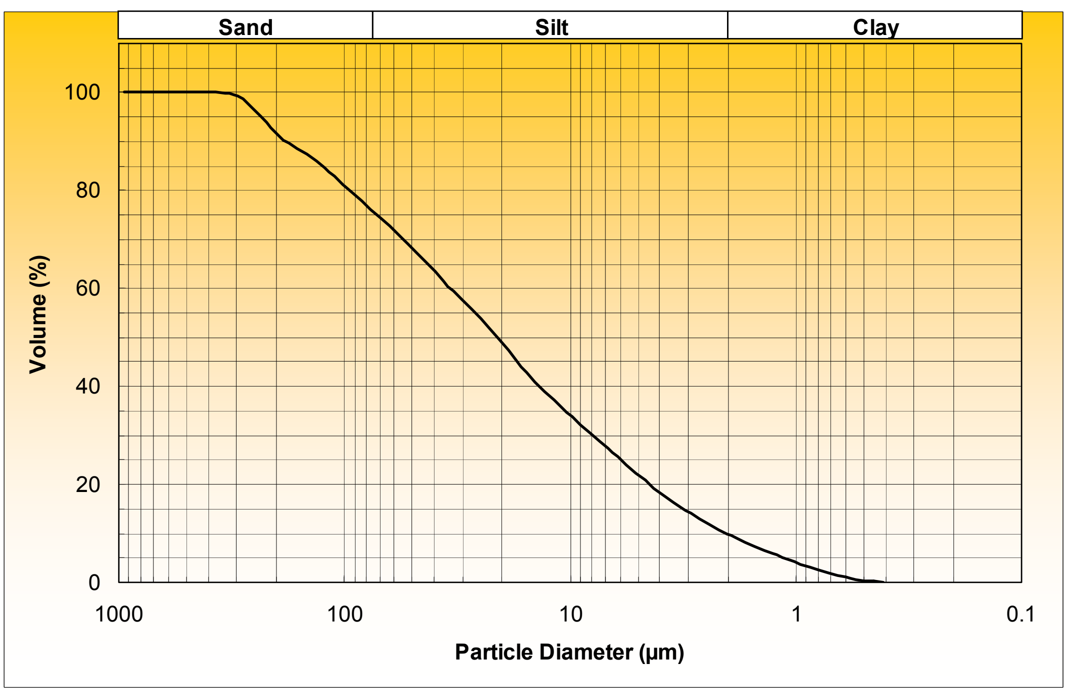

Figure 6. Particle size distribution for June 2007 sediment sample.

Table 5. Flocculent Settling Test Data (December 26, 2003).

Time (hr)	Depth from Top of Settling Column, ft											
	0.36	0.86	1.36	1.86	2.36	2.86	3.36	3.86	4.36	4.86	5.36	5.86
0.0	457	—	466	—	1340	—	474	—	620	—	580	—
1.0	166	—	230	—	258	—	239	—	227	—	246	—
2.0	152	—	143	—	156	—	157	—	157	—	174	—
4.0	—	304	127	—	142	—	128	—	120	—	133	—
7.0	—	73.9	—	455	—	295	—	824	—	288	—	394
12.0	—	63.4	—	223	—	90	—	117	—	80.4	—	92.3
22.8	—	59.4	—	60.1	—	52.8	—	58.1	—	58.5	—	62.7
47.5	—	26.5	—	41.8	—	32.3	—	46	—	48.7	—	42.7
72.0	—	18.2	—	—	—	—	—	7	—	6.1	—	—
96.00	—	—	13.5	—	—	—	—	0.2	—	—	—	—
168.0	—	—	—	—	23.8	—	10	—	24.5	—	24.8	—
264.0	—	—	29.3	35.5	—	30.1	—	26.5		31.6		30.1
360.0	—	—	26	—	40.6	—	37.1	—	45.5	—	49.4	—

The initial slurry height was 6.36 ft.

Table 6. Flocculent Settling Test Data (June 26, 2007).[1]

Time (hr)	Height (ft)[2]	Depth from Top of Settling Column, ft							
		0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.5
0	6.50	91,400	—	—	—	—	—	—	—
1	6.48	19,400	22,300	11,400	—	21,500	—	44,600	32,300
2	6.36	27,700	37,600	33,100	—	40,800	—	44,400	47,100
4	6.24	12,900	30,300	16,000	34,400	38,100	—	40,700	17,600
7	6.10	21,300	13,300	10,700	19,000	42,200	—	14,000	19,200
12	6.00	9,090	23,800	11,400	22,300	31,500	18,700	32,500	—
24	5.81	—	40,500	11,700	12,500	25,700	28,000	26,400	—
32	5.69	—	15,600	19,200	23,000	22,300	—	26,100	30,200
48	5.59	—	—	14,100	17,700	18,500	—	22,400	25,800
72	5.49	—	—	12,100	15,900	13,600	17,600	20,600	—

[1]Initial slurry concentration and height were 268 g/L and 6.5 ft, respectively.

[2]Height was calculated based on initial height and amount of sample collected per event.

Based on 2003 and 2007 data, the RDWT sediment underwent flocculent settling. The initial concentration and the supernatant suspended solids concentrations at different depths and time intervals were used by ADDAMS SETTLE to generate the concentration profile curve. Figure 7 shows the solids concentration profile graph for June 2007 settling data. The solids concentration profile curve, which plots the depth below the surface (feet) versus percent of initial concentration, shows that the suspended solids concentrations decrease with time and increase at deeper ponding depths at the weir.

The SETTLE model was used to calculate the effluent suspended solids. The model calculated the effluent suspended solids concentration at the end of the disposal operation to be 640 and 74,000 mg/L at the discharge point of the primary cell for the December 2003 and June 2007 tests, respectively. Similarly, SETTLE calculated the effluent suspended solids concentration at the end of the disposal operation using a 16-in. dredge to be 250 and 21,000 mg/L at the discharge point of the secondary cell for December 2003 and June 2007 tests, respectively. Effluent suspended solids concentrations at the end of the disposal operation using a 12-in. dredge were predicted to be 200 and 6,900 mg/L at the discharge point of

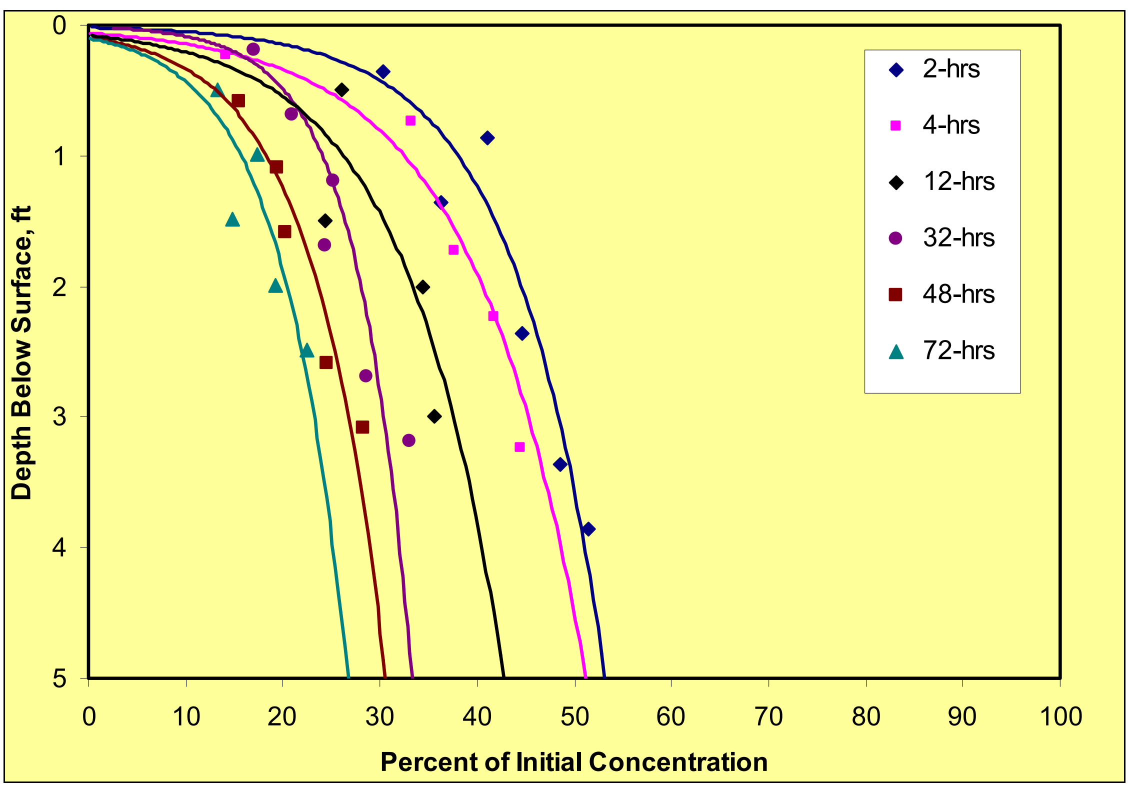

Figure 7. Solids concentration profile curves for June 2007 data.

the secondary cell for the December 2003 and June 2007 tests, respectively. Therefore, engineering controls are deemed necessary to achieve water quality standards for the June 2007 sediment, but not for the December 2003 sediment.

Results of the settling test on the new work sediment sample were deemed more representative of the turning basin expansion project. The concentration of suspended solids in the discharges from the two cells will increase throughout the disposal project as the retention time of the cells decreases due to the retention of the dredged material solids in the cells. The TSS concentrations were predicted throughout the project to determine the mass of suspended solids that would require flocculation by polymer addition. The effluent TSS predictions for the two cells and a subdivided second cell are shown in Table 7 for the 16-in. dredge discharge and in Table 8 for the 12-in. dredge discharge. These two tables also contain the changes in the input data throughout the project duration required to perform the analysis.

Evaluation of existing CDF for storage

Using the ADDAMS Model, two dredged material placement operations were evaluated to determine whether the cells were large enough to contain all of the settled dredged material and chemically flocculated dredged material. The dredge sizes evaluated were 12- and 16-in. discharge pipe. Another option evaluated was whether or not and where to construct an interior cell in the north cell (Cell 2) for chemical clarification (Figures 8 and 9).

The south cell is designed to function as the primary storage cell for the dredged material and the north cell is designed to provide additional suspended solids removal or polish the effluent. Volumes of the cells as a function of elevation are shown in Table 9. For this analysis, dike height of the south cell was set at 63 ft and dike height of the north cell was set at 43 ft.

Table 7. Predicted Effluent TSS for 16-in. Dredge as a Function of Project.

South Cell – 28.5 acres – 2-ft freeboard – 9.5-ft dike						
Percent Dredged	Volume Disposed yd³	Percent Ponded	Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Effluent TSS Conc. g/L
0	0	100.0	51.5	7.5	84.8	14.4
20	44,000	97.5	50.6	5.8	62.8	21.2
40	88,000	95.0	49.8	4.4	45.7	28.5
60	132,000	92.5	49.0	3.2	31.9	37.2
80	176,000	90.0	48.2	2.2	15.7	54.3
100	220,000	87.5	47.4	1.4	9.6	74.1
Average						38.3
Note: Net storage of 264,392 yd³ in South Cell						
North Cell – 20.8 acres – 2-ft freeboard – 11.2-ft dike – 100% ponded – 46.7% hyd. eff.						
Percent Dredged	Volume Disposed yd³	Apparent Cell 2 Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Combined Retention Time hours	Effluent TSS Conc. g/L
0	0	104.2	9.2	68.9	153.7	3.9
20	44,000	92.2	8.6	64.4	127.2	6.5
40	88,000	81.9	8.1	60.6	106.3	9.6
60	132,000	72.4	7.8	58.0	89.9	13.1
80	176,000	59.9	7.4	55.4	71.1	18.6
100	220,000	55.1	7.2	53.5	63.1	21.1
Average						12.13
Note: Net storage of 79,295 yd³ in North Cell						
Middle Cell (50%) – 10.4 acres – 2-ft freeboard – 11.2-ft dike – 100% ponded –27.6% hyd. eff.						
Percent Dredged	Volume Dredged yd³	Apparent Cell 2 Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Combined Retention Time hours	Effluent TSS Conc. g/L
0	0	181.0	9.2	15.3	100.1	5.7
20	44,000	157.0	8.1	13.4	76.2	10.4
40	88,000	131.0	7.35	12.2	57.9	16.7
60	132,000	105.5	6.8	11.3	43.2	23.2
80	176,000	66.9	6.65	11.0	26.7	34.4
100	220,000	51.6	6.65	11.0	20.6	41.5
Average						21.98

Note:

1) Net storage of 49,427 yd³ of fines in Divided North Cell #1

2) Net storage of 125,365 yd³ of chemically flocculated dredged material in Divided North Cell #2

Table 8. Predicted Effluent TSS for 12-in. Dredge as a Function of Project.

South Cell – 28.5 acres – 2-ft freeboard – 9.5-ft dike						
Percent Dredged	Volume Disposed yd³	Percent Ponded	Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Effluent TSS Conc. g/L
0	0	100.0	51.5	7.5	150.8	3.0
20	44,000	97.5	50.6	5.7	109.8	7.1
40	88,000	95.0	49.8	4.3	79.4	13.4
60	132,000	92.5	49.0	3.0	52.2	22.5
80	176,000	90.0	48.2	1.9	32.2	45.5
100	220,000	87.5	47.4	1.2	14.0	73.0
Average						27.4
Note: Net storage of 282,064 yd³ in South Cell						
North Cell – 20.8 acres – 2-ft freeboard – 11.2-ft dike – 100% ponded – 46.7% hyd. eff.						
Percent Dredged	Volume Disposed yd³	Apparent Cell 2 Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Combined Retention Time hours	Effluent TSS Conc. g/L
0	0	104.2	9.2	122.4	273.2	0.2
20	44,000	90.5	8.8	117.1	226.9	0.6
40	88,000	80.1	8.4	111.1	190.5	1.3
60	132,000	69.7	8.0	105.8	158.0	2.6
80	176,000	61.6	7.6	101.1	133.3	4.3
100	220,000	53.4	7.3	97.1	111.1	6.9
Average						2.65
Note: Net storage of 70,648 yd³ in North Cell						
Middle Cell (50%) – 10.4 acres – 2-ft freeboard – 11.2-ft dike – 100% ponded –27.6% hyd. eff.						
Percent Dredged	Volume Dredged yd³	Apparent Cell 2 Hydraulic Efficiency %	Ponded Depth ft	Retention Time hours	Combined Retention Time hours	Effluent TSS Conc. g/L
0	0	107.4	9.2	102.3	253.1	0.3
20	44,000	92.7	8.7	96.7	206.5	1.0
40	88,000	81.0	8.3	91.7	171.1	1.9
60	132,000	69.4	7.9	87.3	139.5	3.8
80	176,000	60.2	7.5	83.4	115.6	6.3
100	220,000	51.0	7.2	80.0	94.0	9.9
Average						3.87

Note:

1) Net storage of 67,178 yd³ of fines in Divided North Cell #1

2) Net storage of 21,239 yd³ of chemically flocculated dredged material in Divided North Cell #2

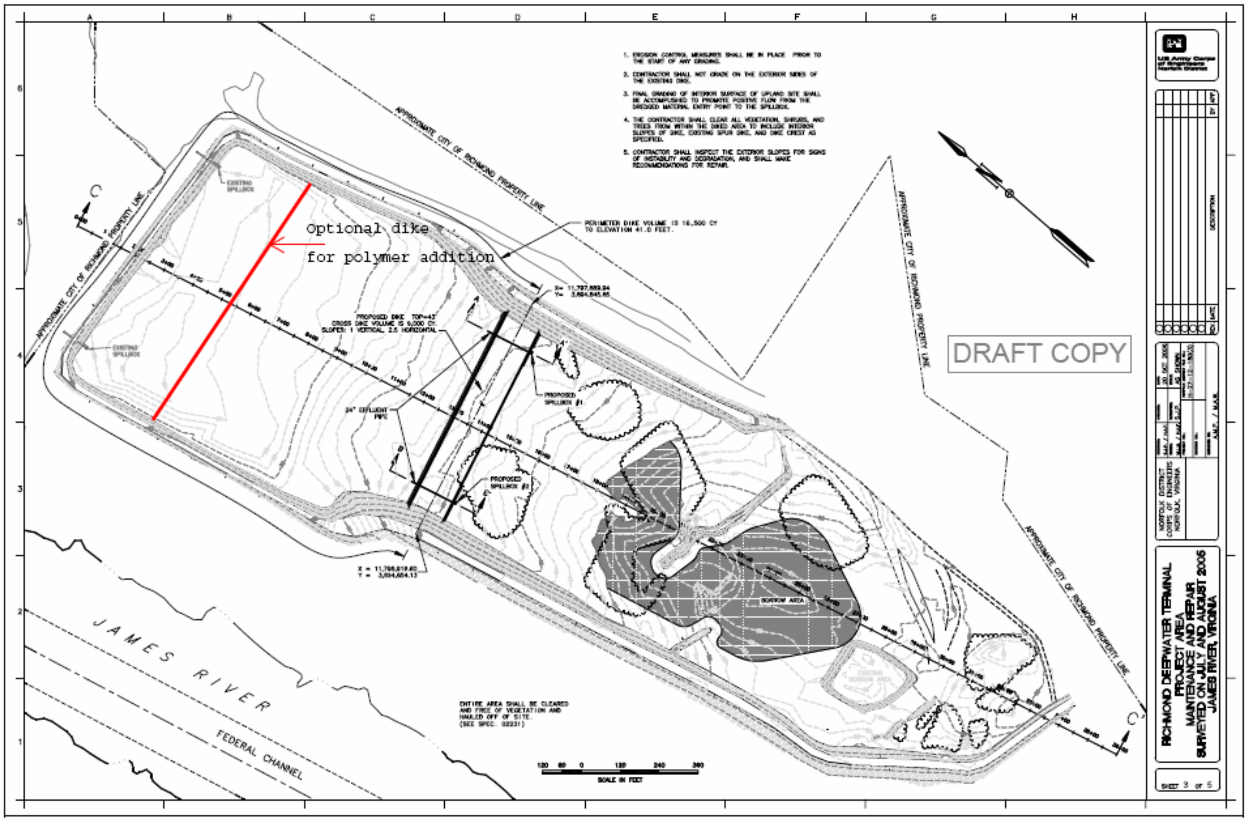

Figure 8. Existing CDF with optional dike location (Norfolk 2006).

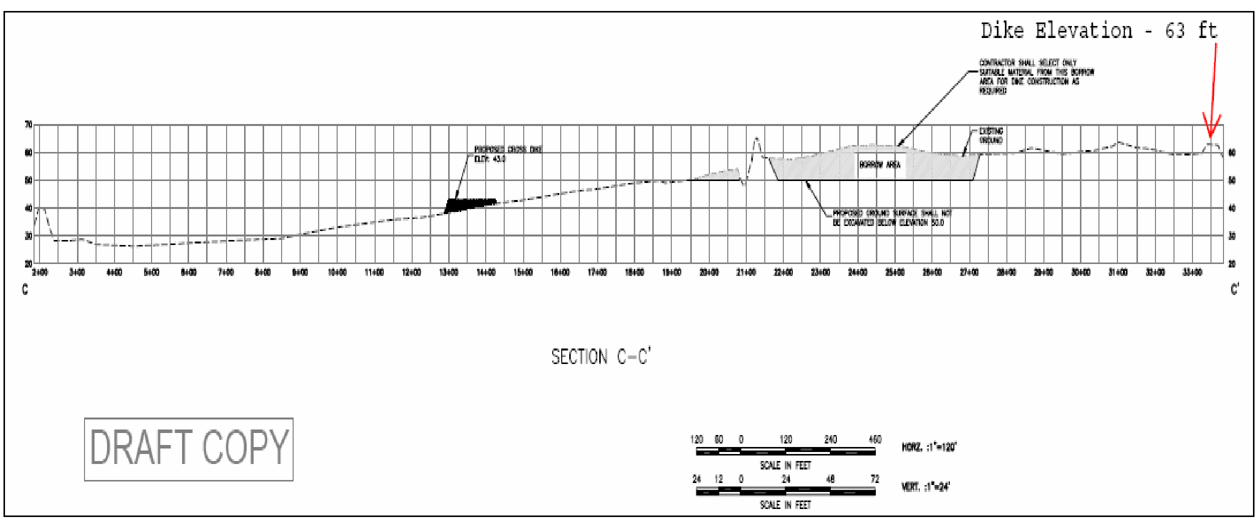

Figure 9. Cross-section view of the existing CDF (Norfolk 2008).

Table 9. Fill Volumes for Richmond Deepwater Terminal Confined Upland.

Placement Site						
Surface	Elevation	Units	Cut	Units	Fill	Units
NORTH CELL	40	FT	14	Cubic Yards	275,511	Cubic Yards
NORTH CELL	39	FT	2	Cubic Yards	241,680	Cubic Yards
NORTH CELL	38	FT	2	Cubic Yards	208,726	Cubic Yards
NORTH CELL	37	FT	0	Cubic Yards	177,117	Cubic Yards
SOUTH CELL	60	FT	1,232	Cubic Yards	297,581	Cubic Yards
SOUTH CELL	59	FT	331	Cubic Yards	215,454	Cubic Yards
SOUTH CELL	58	FT	552	Cubic Yards	191,582	Cubic Yards
SOUTH CELL	57	FT	29	Cubic Yards	171,760	Cubic Yards

NOTES:
Volume of cells calculated under the assumption that a Cross Dike will be built segregating the North Cell from the South Cell. Cross Dike will be constructed at 3:1 slopes to an elevation of 60 ft with a 20-ft berm width. Material needed to construct cross dike will be borrowed from the South Cell. Volume to construct the Cross Dike is 22,750 yds^3, which would add approximately that same additional volume capacity to the South Cell.

The storage areas of the south and north cells were measured to be 28.5 acres and 20.8 acres, respectively. Based on the fill volumes and the storage areas, the average dike heights above the base of the south and north cells were calculated to be 9.5 ft and 11.2 ft, respectively.

The results of the compression settling analysis for cell configurations are shown in Table 10. For the 16-in. dredge operation, results show that the storage available in the South Cell will contain the settled material at a height of about 5.6 ft or an elevation of about 59.6 ft. This would allow 2 ft of freeboard and about 1.9 ft of ponding at the end of the disposal operation. For the 12-in. dredge operation, the results show that the storage available in the South Cell will contain the settled material at a height of about 6.0 ft or an elevation of about 59.9 ft. This would allow 2 ft of freeboard and about 1.5 ft of ponding at the end of the disposal operation. Therefore, the South Cell should be large enough if the dikes are constructed to an elevation of 63 ft.

Table 10. Storage and Ponding Predictions at End of Disposal Operation.

Parameter	South Cell	North Cell Without Polymer Addition	North Cell With Polymer Addition	Divided North Cell #1 Without Polymer Addition	Divided North Cell #2 With Polymer Addition
16-in. Dredge					
Depth of Storage, ft	5.59	2.36	6.72	2.95	7.47
Depth of Ponding, ft	1.91	6.84	2.48	6.25	1.73
12-in. Dredge					
Depth of Storage, ft	6.03	2.11	4.71	2.11	7.03
Depth of Ponding, ft	1.47	7.09	4.49	7.09	2.17

The compression settling analysis of the North Cell considers three options: additional sedimentation of the South Cell effluent with and without polymer addition at the South Cell weir structures, and division of the North Cell into a polishing pond for the South Cell effluent and a settling cell for chemically flocculated effluent from the North Cell polishing pond. (Note: The effluent from the North Cell without polymer addition would not meet the effluent water quality criteria.) For the 16-in. dredge operation without polymer addition, results show that the storage available in the North Cell will contain the settled material at a height of about 2.4 ft or an elevation of about 34.3 ft. This would allow 2 ft of free-board and about 6.8 ft of ponding at the end of the disposal operation. For the 12-in. dredge operation without polymer addition, the results show that the storage available in the North Cell will contain the settled material at a height of about 2.1 ft or an elevation of about 34 ft. This would allow 2 ft of freeboard and about 7.1 ft of ponding at the end of the disposal operation. This cell is much larger than needed if the dikes are constructed to an elevation of 43 ft. Inflow could be diverted from the South Cell to the North Cell if needed due to limitations in the South Cell dike elevation.

The compression settling analysis of the North Cell with polymer addition at the South Cell weir structures is given below. For the 16-in. dredge operation with polymer addition, results show that the storage available in the North Cell will contain the settled material at a height of about 6.7 ft or an elevation of about 38.5 ft. This would allow 2 ft of freeboard and about 2.5 ft of ponding at the end of the disposal operation. For the 12-in. dredge operation with polymer addition, results show that the storage available in the North Cell will contain the settled material at a height of about 4.7 ft or an elevation of about 36.5 ft. This would allow 2 ft of freeboard and about 4.5 ft of ponding at the end of the disposal operation.

The compression settling analysis of the divided North Cell with polymer addition at the divided cell weir structures is given below. For the 16-in. dredge operation, results show that the storage available in the Divided North Cell #1 without polymer addition will contain the settled material at a height of about 3.0 ft or an elevation of about 34.9 ft. This would allow 2 ft of freeboard and about 6.3 ft of ponding at the end of the disposal operation. The storage available in the Divided North Cell #2 with polymer addition will contain the settled material at a height of about 7.5 ft or an elevation of about 39.3 ft. This would allow 2 ft of freeboard and about 1.7 ft of ponding at the end of the disposal operation. For the 12-in. dredge operation, results show that the storage available in the Divided North Cell #1 without polymer addition will contain the settled material at a height of about 2.1 ft or an elevation of about 34.0 ft. This would allow 2 ft of freeboard and about 7.1 ft of ponding at the end of the disposal operation. Storage available in the Divided North Cell #2 with polymer addition will contain the settled material at a height of about 7.0 ft or an elevation of about 38.8 ft. This would allow 2 ft of freeboard and about 2.2 ft of ponding at the end of the disposal operation. The cell is large enough to permit lower dike elevation or diversion of inflow from the South Cell to North Cell if needed due to limitations in the South Cell dike elevation.

Task 3: Jar tests

Sedimentation is the most commonly practiced process to separate the solid and liquid phases of a dredged material slurry discharged to a CDF. When sedimentation alone is insufficient to achieve TSS targets, chemical clarification is the most commonly employed process to supplement sedimentation. Chemical clarification can be applied to either the influent dredged slurry or to the discharge from the primary sedimentation cell of the CDF. Chemical clarification is more typically applied to provide additional removal of solids from CDF effluent and potentially solids-associated and dissolved contaminants because it requires much lower polymer dosages to achieve good clarification. However, chemical clarification has been applied in very few dredging projects, perhaps less than a dozen projects. Based on the results of Task 1, the target effluent TSS was 1,500 mg/L.

Since the sediment is characterized as fine-grained material with potential PAH and petroleum hydrocarbon contamination, chemical clarification using polymeric flocculants was evaluated for several TSS concentrations to determine the degree and range of effectiveness, dosage requirements, mixing requirements, environmental suitability, and ease of use for clarification of dredged material supernatants.

Methods and materials

A Phipps and Bird jar test mixer was used in the jar testing to screen potential flocculants, evaluate the dosage rate of flocculants as a function of suspension concentration, examine mixing impacts, and determine potential removal efficiency for TSS using the procedure described in Technical Report D-83-2 (Schroeder 1983). Based on the ADDAMS SETTLE model results, the jar testing suspensions were 0.3, 1.0, 2.0, 16, 32, and 36 g/L TSS. Table 11 lists the test conditions.

The selected polymer underwent compression settling testing to determine its settling behavior and storage requirement. This test was conducted in a 4-L cylinder. The optimum dosage was used for this evaluation.

Table 11. Jar Test Conditions for Polymer Screening.

Simulated injection location	Primary settling basin
TSS concentration	2.0 g/L
Rapid mix speed	100 rpm
Rapid mix duration	1 minute
Rapid mix Gt[1]	~12,000
Slow mix speed	20 rpm
Slow mix duration	5 minutes
Slow mix Gt[1]	~6,000
Settling time	10 minutes

[1] Gt is the net missing, the product of the mean velocity gradient or mixing intensity, (second^{-1}) and duration (second) (USACE 1987)

Jar test results

Total solids concentrations of the sediment samples after homogenization were run in triplicate, resulting in an average solids concentration of 1,060 g/L. Using the existing settling data, CDF design data, and typical

CDF assumptions, ADDAMS calculated the expected effluent solids concentration at 640 mg/L and 32,527 mg/L for December 2003 and June 2007 data, respectively. Therefore, the solids concentration was reduced multiple times from 1,060 g/L to 0.293, 0.867, 2.0, 16, 32.8, and 36 g/L. During jar test preparation, no oil sheen was visible during sediment homogenization or during polymer screening. Therefore, an extra sample was not collected for oil sheen analysis.

Several polymers were obtained and screened for the most effective polymer for additional testing. Nine polymers from GE Betz, Inc. and Oneida-Nalco were screened for their ability to remove solids. Initially the Betz polymers were the only polymers tested because of availability. Later, Nalco responded to the request for polymers and provided four polymers to test. Because of Oneida-Nalco's late response, extra time was needed to evaluate additional polymers. Table 12 lists the evaluated polymers and their reported properties. Polymers were diluted with distilled, deionized water to concentrations of approximately 0.1% (Betz) and 1% (Nalco) for test application based upon company recommendations. Each polymer was handled with ease.

Table 12. Polymer Characteristics and Screening Results.

Manufacturer/ Trade Name	Form	Type	Turbidity NTU	Floc Size
GE Betz Inc.				
Betz PC 2710	Emulsion	Anionic, medium charge	785	Very Fine
Betz PC 1195	Liquid	Cationic, high charge	211	Medium
Betz PC 1192	Liquid	Cationic, high charge	1,327	None
Betz AS 1002	Emulsion	Anionic, high charge	1,245	None
Betz AE 1125	Emulsion	Anionic, high charge	1,244	None
Oneida-Nalco				
Nalco 7880	Emulsion	Anionic, low molecular weight	95	Fine
Nalco 7888	Emulsion	Anionic, low molecular weight	801	Very Fine
Nalco 8130	Liquid	Cationic	127	Medium
Nalco 8131	Liquid	Cationic	44	Medium

For initial screening, a suspension of approximately 2 g/L was prepared by diluting the RDWT sediment of 1,060 g/L with tap water in lieu of site water. A typical polymer dosage of 2.5 milligrams (mg) of polymer per gram (g) of solution was utilized for screening. The jar tests were conducted according to procedures listed in Appendix E ("Jar Test Procedures for Chemical Clarification") of Engineer Manual 1110-2-5027 titled "Confined Disposal of Dredged Material" (U.S. Army Corps of Engineers (USACE) 1987). Jar tests are generally based on site-specific samples and conditions, which would typically yield estimates of suspension concentration, mixing conditions, settling time, and effluent requirements. Because site-specific information was limited, guidance from USACE (1987) suggests a TSS concentration of approximately 2 g/L (which is a typical effluent concentration from a well-designed containment area with freshwater sediments containing clays). Other USACE guidance is that the percent coarse material (as defined by the percentage of material retained by the No. 200 sieve) be less than 10 percent on a dry weight basis. In lieu of site-specific conditions for mixing, mixing intensities of 100 rpm for 1 minute, followed by 20 rpm for 5 minutes, and settling for 10 minutes were utilized. This is the mixing intensity specified by the American Society for Testing and Materials (ASTM) for jar tests (ASTM 1999). These TSS concentrations and mixing conditions are more representative of conditions encountered as the CDF fluid passes from a primary to a secondary basin as opposed to injection of the flocculant into the dredging pipeline.

The test apparatus included a Phipps & Bird six-paddle programmable jar tester with B-KER2 square containers (Figure 10). To screen the polymers, they were diluted according to company recommendation. The Betz polymer solutions were diluted to 1 mg of polymer/ml of water while Nalco polymers were diluted to 10 mg of polymer/ml of water. The Phipps & Bird beakers were filled with 1 L of suspension and mixed at 100 rpm. Polymer solutions were added to the suspensions during rapid mixing, then rapid mixed for 1 minute. The suspensions were then mixed at 20 rpm for 5 minutes and settled for 10 minutes. The jar test suspensions were observed for floc development, floc size, turbidity, and TSS concentrations. Upon completion of settling, samples were withdrawn from the 700-ml level B-KER2 ports, wasting the first few milliliters to flush the port of trapped flocs. The turbidity of each sample was measured using a Hach 2100N turbidimeter. Suspended solids concentration was measured using the filtration method described in Technical Report D-83-2 (Schroeder 1983).

Figure 10. Jar test apparatus.

Screening results are shown in Table 12. Results for the Betz polymers showed high turbidity with development of no floc for each polymer except for PC 1195. Screening results for the Nalco polymers showed higher turbidity with development of very fine flocs except for Nalco 8131, which had good floc size. PC 1195 and Nalco 8131 polymers were selected for further testing for dosage requirements. As mentioned, ADDAMS calculated an effluent suspended solids concentration ranging from 200 to 640 mg/L for the December 2003 sediment. Therefore, additional jar tests were conducted at TSS concentrations of 0.293, 0.867, and 2.0 g/L. Using the 2007 settling data, additional sets of jar tests were conducted at 1, 16, 32.8, and 36 g/L; tests on the 1 g/L suspension were run to ensure continuity with the first set of testing.

The dosage ranges, TSS concentrations, and corresponding turbidity for PC 1195 and Nalco 8131 are shown in Table 13. Figures 11 and 12 show the resulting TSS concentrations as a function of polymer dosage for the high range of TSS concentrations predicted for the June 2007 sediment. The results show that Betz PC 1195 required much lower dosages of polymer than Nalco 8131; however, Nalco 8131 had a broader range of dosages yielding very good removals, providing more flexibility. Nevertheless, both polymers were able to achieve the target TSS concentration of 1,500 mg/L over a wide range of dosages.

Table 13. Jar Test Results.

Polymer Name	Dosage, mg/g	TSS, mg/L	Turbidity, NTU	Fraction Remaining
PC 1195 at 0.1%	0.00	285	422	1.000
TSS of 0.3 g/L	1.71	300	420	1.053
	3.41	110	239	0.386
	6.83	180	147	0.632
	10.24	107	85	0.374
	34.13	86	107	0.302
	68.26	255	381	0.895
	102.39	290	427	1.018
PC 1195 at 0.1%	0.00	867	1,254	1.000
TSS of 1 g/L	1.15	727	956	0.838
	2.31	590	774	0.680
	3.46	500	654	0.577
	4.61	360	460	0.415
	8.07	147	126	0.169
	11.53	177	191	0.204
	13.84	84	127	0.097
	23.07	143	218	0.165
	28.84	108	148	0.125
	115.34	673	946	0.776
PC 1195 at 0.1%	0.00	1,910	3,105	1.000
TSS of 2 g/L	3.00	940	1,513	0.492
	6.00	447	608	0.234
	10.00	710	1,078	0.372
	15.00	215	303	0.113
	45.00	255	493	0.134
PC 1195 at 1.0%	0.00	4,930	7,884	1.000
TSS at 16 g/L	2.45	188	110	0.038
	4.91	32.31	34.2	0.007
	8.59	350	365	0.071
	12.27	356.67	471	0.072
	24.54	860	1,582	0.174
PC 1195 at 0.1%	0.00	6,370	7,573	1.000
TSS at 33 g/L	0.30	140	145	0.022
PC 1195 at 0.1%	0.61	415	520	0.065
TSS at 33 g/L	1.22	1,090	1,700	0.171
	3.05	1,810	3,520	0.284
	4.88	2,000	3,928	0.314

Polymer Name	Dosage, mg/g	TSS, mg/L	Turbidity, NTU	Fraction Remaining
PC 1195 at 1.0%	0.00	9,560	15,688	1.000
TSS at 36 g/L	1.12	2,430	3,782	0.254
	2.79	188	83.1	0.020
	5.59	332	268	0.035
	11.17	440	476	0.046
	16.76	560	798	0.059
	22.35	930	1,230	0.097
	27.93	940	1,395	0.098
	39.11	1,070	1,743	0.112
Nalco 8131 at 1%	0.00	753	944	1.000
TSS at 1 g/L	9.09	693	903	0.920
	18.18	673	877	0.894
	22.73	560	699	0.743
	27.27	427	436	0.566
	36.36	287	317	0.381
	54.55	145	211	0.192
	90.91	52.5	64.7	0.070
	109.09	23.1	36.1	0.031
	181.82	4.41	9.1	0.006
	363.64	15.4	6.7	0.020
Nalco 8131 at 1%	0.00	4,930	7,884	1.000
TSS at 16 g/L	1.23	3,180	5,100	0.645
	2.45	2,690	3,978	0.546
	4.91	1,640	2,029	0.333
	8.59	1,170	1,931	0.237
	12.27	1,650	2,661	0.335
	24.54	152.5	83	0.031
	49.08	124	115	0.025
	61.35	236	181	0.048
	73.62	56	49.2	0.011
Nalco 8131 at 1%	0.00	6,370	7,573	1.000
TSS at 33 g/L	3.05	4,100	7,218	0.644
	6.10	2,950	5,064	0.463
	12.20	733	1,009	0.115
	24.39	104	103	0.016
	25.40	42	44	0.007
	30.49	64	56	0.010
	48.78	150	127	0.024

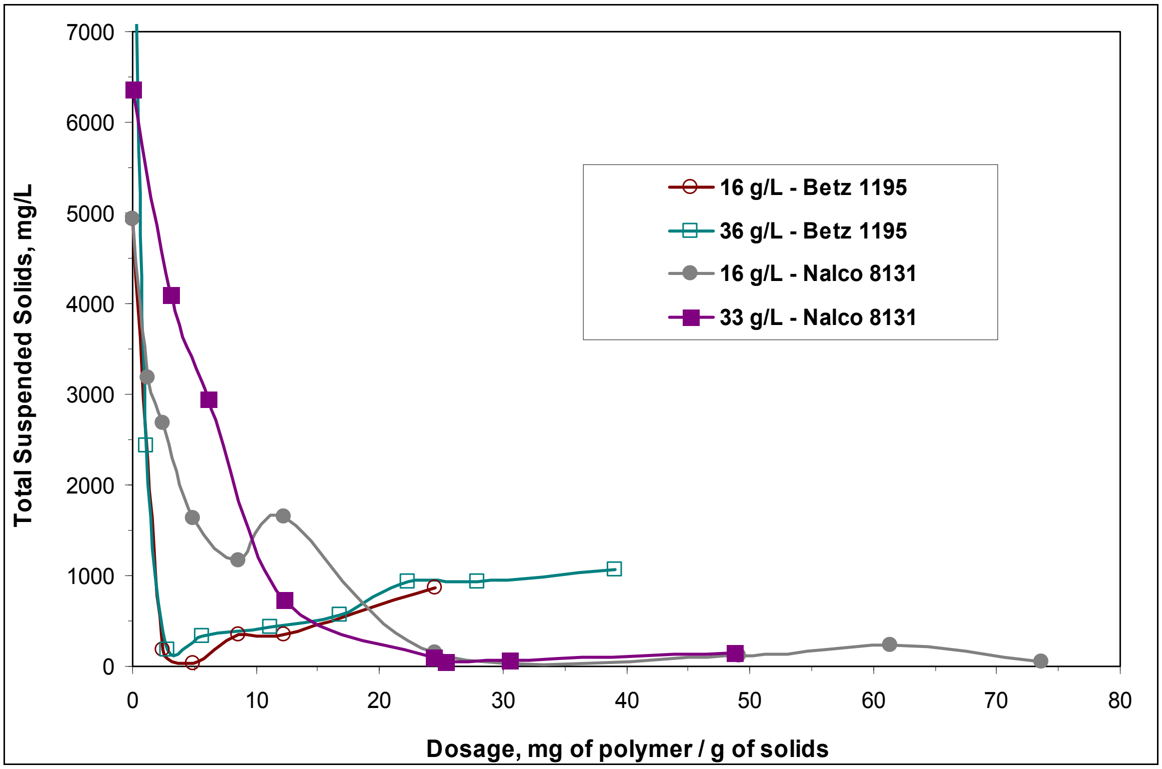

Figure 11. Jar test results comparing polymers at high TSS concentrations.

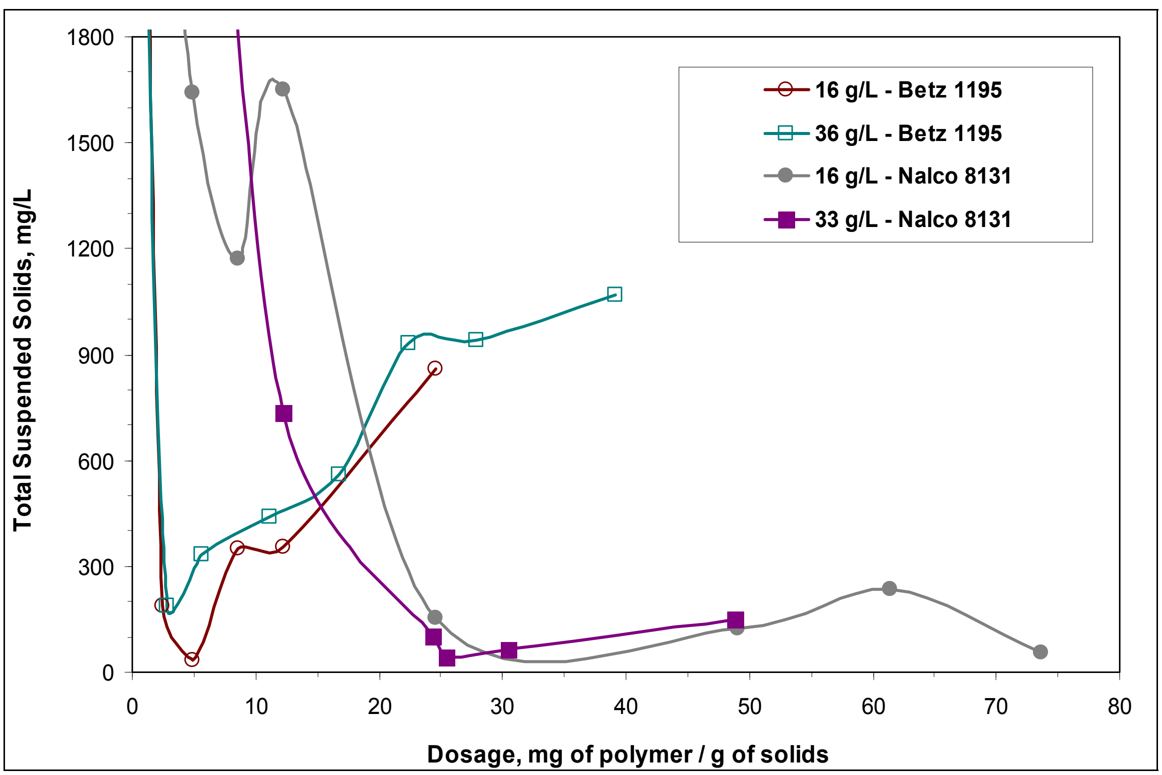

Figure 12. Detailed jar test results at high TSS concentrations.

Betz PC 1195 underwent more testing than Nalco 8131 because at the time it was the only polymer available for testing. Data from these jar tests for a very wide range of TSS suspensions were also plotted as the fraction of solids remaining (C/C_O) vs. polymer concentration application (mg of polymer per gram of solids). C represents the TSS concentration resulting from the polymer addition and C_O represents the resulting TSS concentration with no polymer addition (Table 13 and Figure 13 for Betz PC 1195 and Figure 14 for Nalco 8131). The Betz PC 1195 underwent testing at TSS concentrations of 0.293, 0.867, and 2.0 g/L, which are similar to the range of effluent suspended solids concentration (0.2 g/L to 0.64 g/L) from the December 2003 settling test. The Betz PC 1195 was also tested using TSS concentrations of 16 g/L and 36 g/L, similar to the June 2007 ADDAMS effluent suspended solids concentration of 12 g/L to 32 g/L. The optimum dosage for Betz PC 1195 is about 4 mg/g at high TSS concentrations and about 8 mg/g at low TSS suspension concentrations. These dosages are typical of dosages applied at other dredged material disposal operations (Schroeder 1983; Wade 1988, 2001; Wang and Chen 1977).

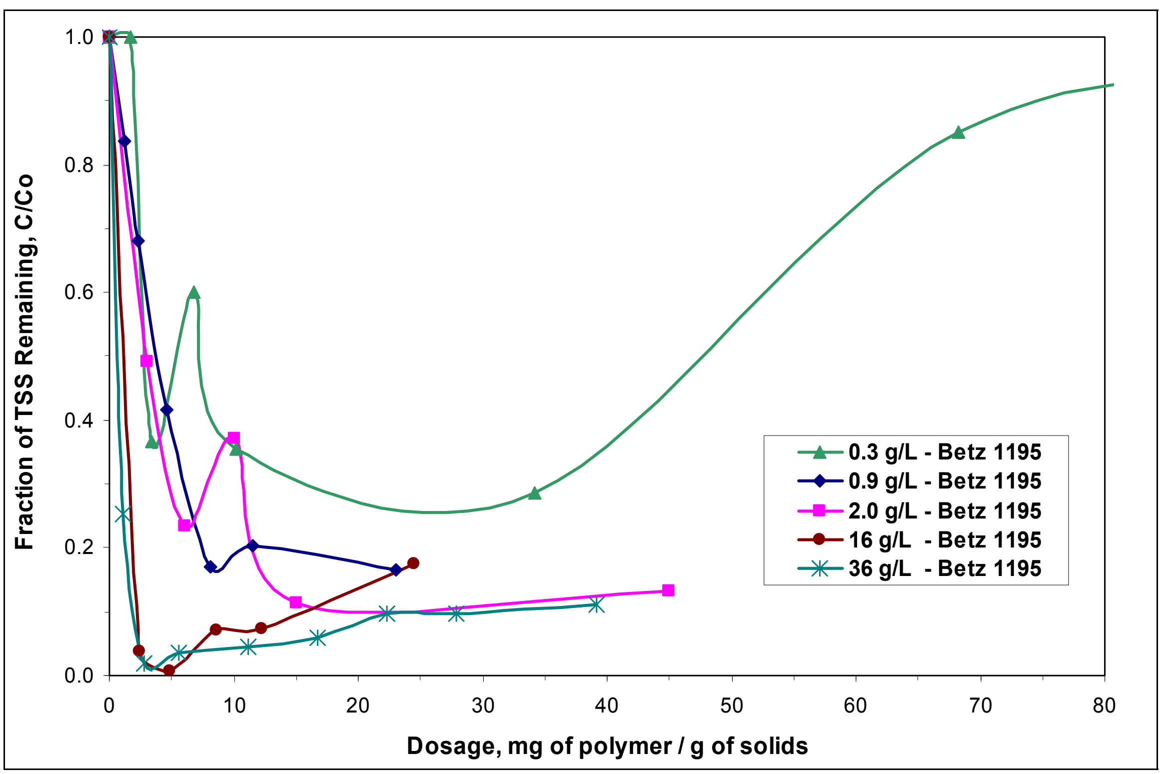

Figure 13. Jar test results for Betz 1195.

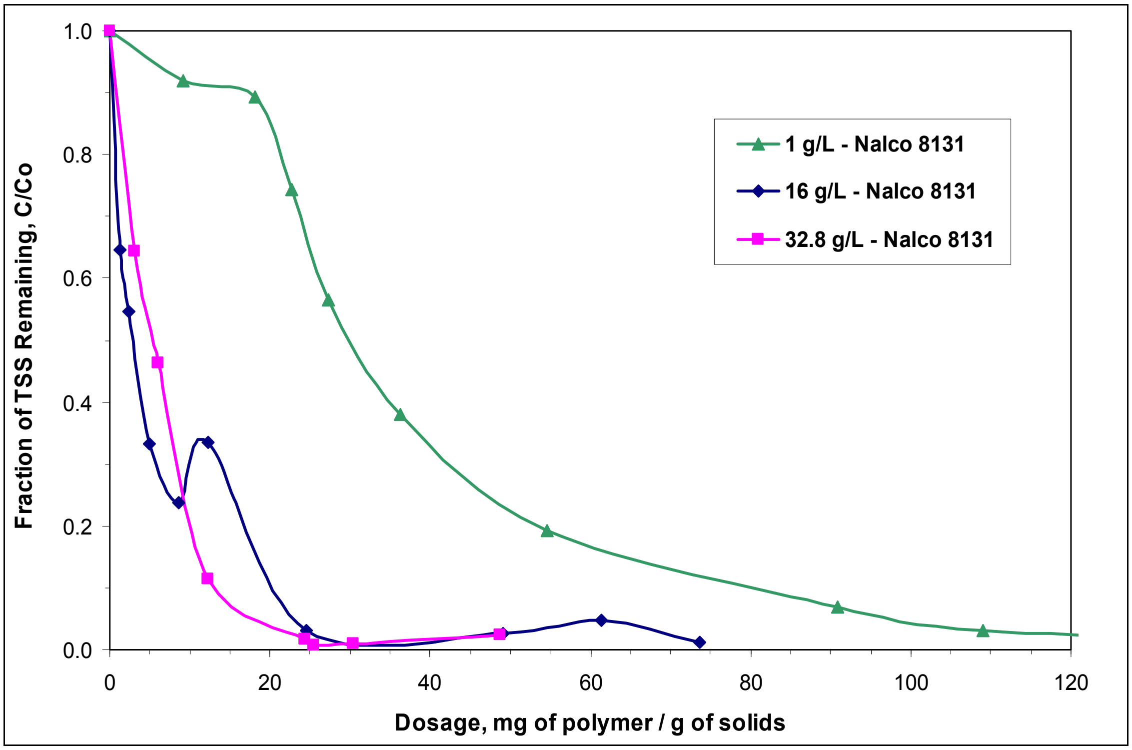

Figure 14. Jar test results for Nalco 8131.

Nalco 8131 was also tested using TSS concentrations of 1, 16, and 32.8 g/L, which is similar to the range of predicted effluent suspended solids concentrations by the ADDAMS SETTLE program using the June 2007 settling data. The results are shown in Figure 14. The optimum dosage is about 25 mg/g at high TSS concentrations and about 100 mg/g at low TSS concentrations. These dosages are very high and untypical of polymer applications.

The effect of mixing on polymer performance was examined on a 0.9-g/L TSS suspension using the Betz PC 1195 polymer. The results are plotted in Figure 15, showing the effects of mixing are very small. Additional mixing improved the effluent quality somewhat at higher dosages but did not change the optimum dosage.

The required dosages for Nalco 8131 are much greater than the dosages required on other sediments that were tested. In addition, the removals are lower than obtained with other sediments, which were typically greater than 97% at TSS concentrations of 1 g/L. However, the dosage rate for PC 1195 is a typical dosage rate (4 mg/g). Screening and testing of additional polymers may yield a polymer that would achieve better removals, stronger flocs, and lower dosage requirements. Examining more polymers

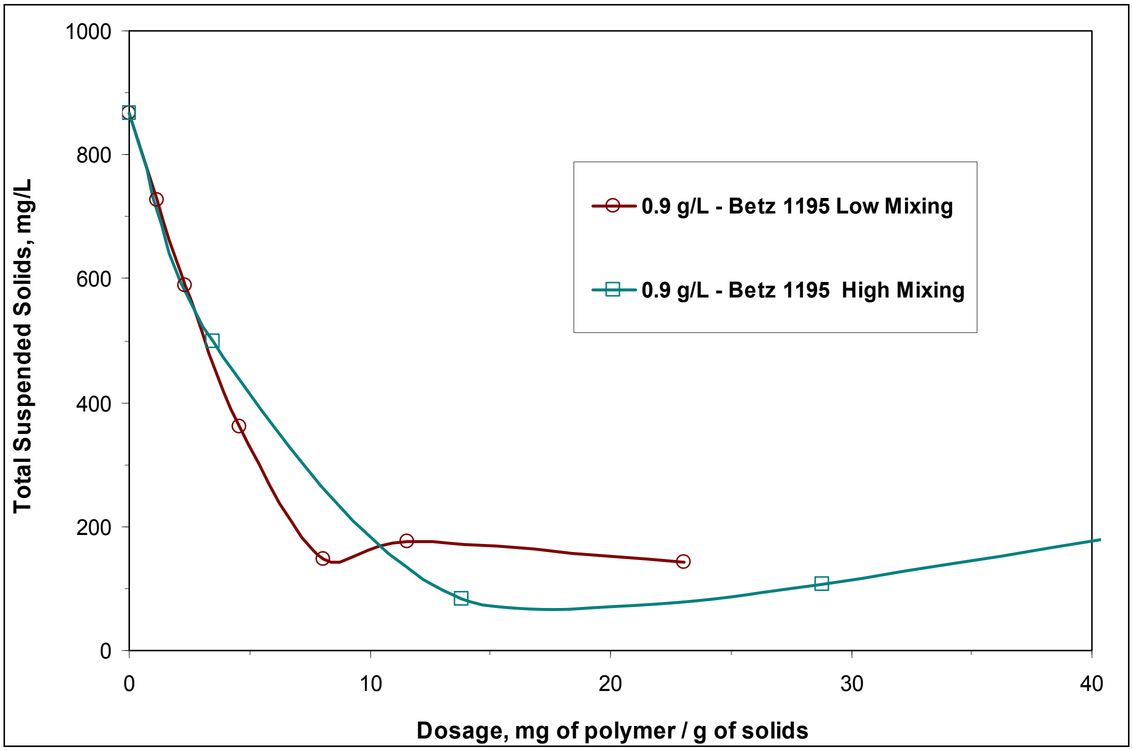

Figure 15. Jar test results as a function of mixing.

was not an option due to the limited amount of sediment on hand. Even though testing is limited, PC 1195 is expected to meet the effluent suspended solids concentration with the available mixing.

Jar test compression settling results

A short duration compression test was performed using Betz PC 1195 polymer at the anticipated solids concentration. This settling test was conducted in a 4-L cylinder and evaluated using ADDAMS SETTLE. The selected 1% polymer concentration was injected at the previously determined dosage rate of 5 mg/g. The initial solids concentration was 36 g/L excluding sand and coarse silt fractions. The flocculated slurry was created using the screening procedure and the Phipps and Bird jar apparatus. After the flocs settled overnight, the supernatant was extracted, homogenized, and determined to have an average effluent suspended solids concentration of 3.75 mg/l. The settled flocculated slurry was homogenized and placed into a 4-L cylinder. The solids concentration of the settled slurry was determined to be 122 g/L. The height of the slurry was recorded as a function of time (Appendix A). Figure 16 shows the settling behavior of the flocculated slurry after 10 minutes and 6 days of settling in a 4-L cylinder. Figure 17 shows the settling rate of 0.49 ft/hr and the corresponding equation. The transition from zone to compression settling occurred between 0.5 and 20 hr.

For the compression settling test, the initial slurry concentration and height, and height of the interface versus time, were entered into the SETTLE program. The ADDAMS SETTLE program computes the relationship between the settled solids concentration and time. Figure 18 shows the relationship predicted between the chemically flocculated settled solids concentration and time. The treated material settled to a concentration of about 225 g/L and did not change appreciably with time after the first 3 days. The density of the treated sludge may be greater if a greater thickness of sludge were produced but additional testing would be required to define this relationship.

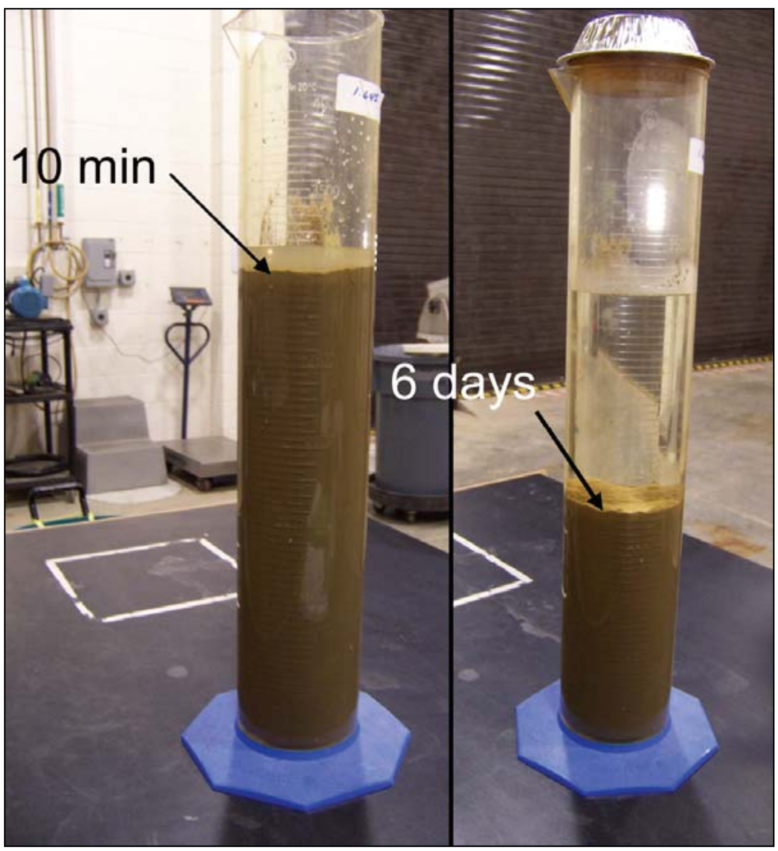

Figure 16. Polymer settling test.

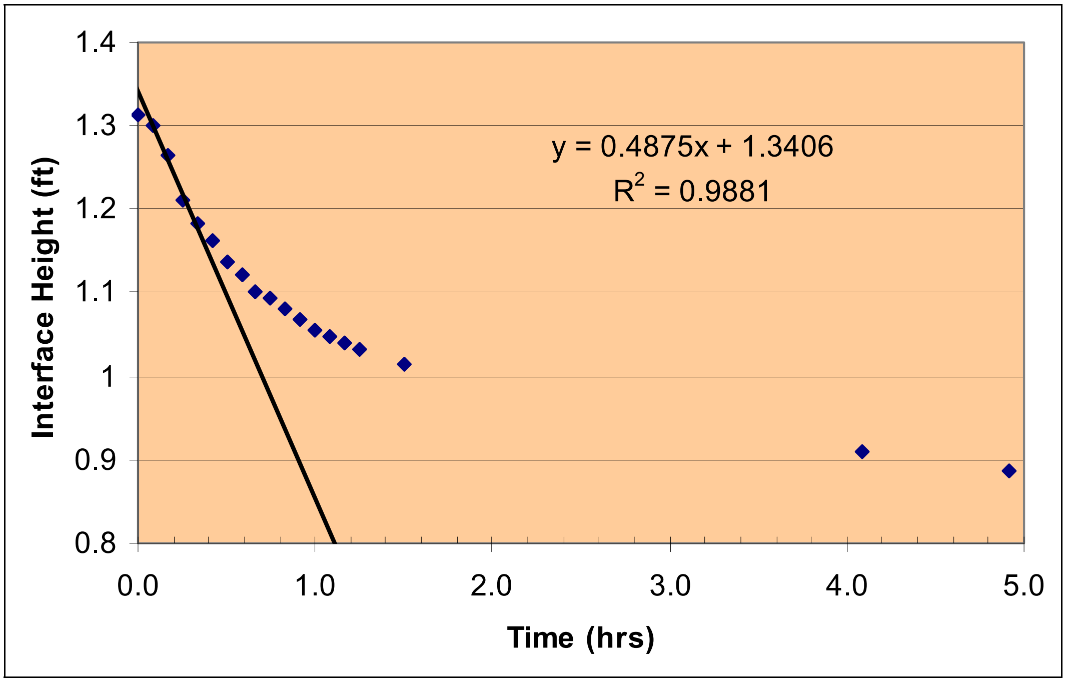

Figure 17. Zone settling test of chemically flocculated sediment.

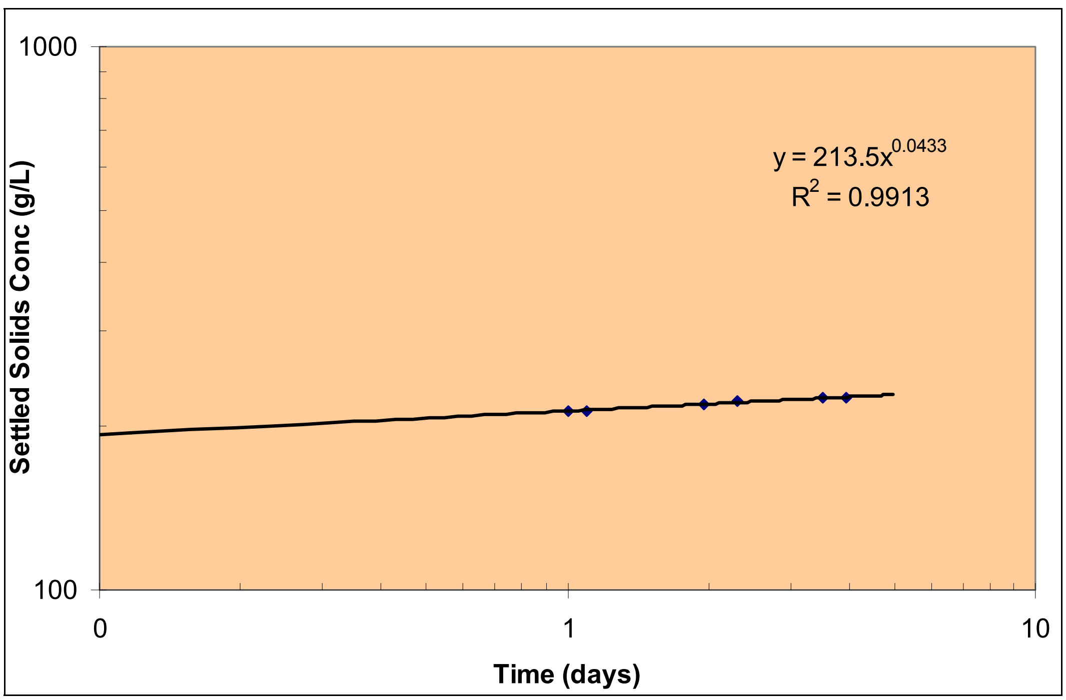

Figure 18. Polymer compression test.

Cost comparison

The cost of Betz PC 1195 for this application is calculated as follows. The discharge volume is estimated to be five times the volume to be dredged (220,000 yd^3) or 1,100,000 yd^3. The optimum dosage is 4 mg/g and the sediment concentration is 38.3 g/L for the 16-in. dredge operation with polymer addition at the South Cell weirs. The volume of polymer required for this site is estimated at 128,800 kg. The bulk cost is \$3.19/kg delivered. The cost of the PC 1195 polymer is \$411,000. Costs for a 12-in. dredged operation would be about \$294,000 or 28% less due to lower sediment concentration in the South Cell effluent. The polymer cost for treating the effluent from a divided North Cell would be about \$236,000 for a 16-in. dredge operation and \$42,000 for a 12-in. dredge operation.

Cost of Nalco 8131 is calculated as follows. The dredged volume is estimated as 1,100,000 yd^3. The optimum dosage is 25 mg/g. The sediment concentration is calculated to be 38.3 g/L for the 16-in. dredge operation with polymer addition at the South Cell weirs. The volume of polymer required for this site is estimated at 805,300 kg. The bulk cost is \$1.10/kg delivered. The cost for using Nalco 8131 polymer at the CDF is estimated at \$886,000. The polymer cost of the Nalco polymer would be more than double the cost of the Betz polymer. The use of either polymer would incur O&M costs such as labor, power equipment rental, etc. There may be additional costs if additional mixing and pumping are required due to the lack of sufficient head elevation to promote flow and mixing. Since the density of PC 1195 is lower than the Nalco 8131, additional handling effort may be warranted.

The required dosages for Nalco 8131 are much greater than the dosages required on other sediments that were tested. In addition, the removals are lower than those obtained with other sediments; typically, removals greater than 97% have been achieved. However, the dosage rate for PC 1195 is a typical dosage rate (4 mg/g). Screening and testing of additional polymers may yield a polymer that would achieve better removals, stronger flocs, and lower dosage requirements. Examining more polymers was not an option due to the limited amount of sediment on hand. Even though testing is limited, PC 1195 is expected to meet the effluent suspended solids concentration with the available mixing.

Design of chemical clarification system

At least two methods can be employed to conduct chemical clarification at a CDF site. These methods are pipeline injection from the dredge and injection over a weir structure. This discussion is limited to injecting polymer at the weir structure. Chemical clarification of a CDF effluent requires equipment to dilute and feed the polymer solution, to rapidly mix the polymer solution with the supernatant, to slowly mix the flocculated solids in the discharge culvert or entrance zone in the secondary settling cell to encourage particle-to-particle contact and agglomeration, and to settle the flocculated suspension. Components needed for a simple chemical clarification system to treat CDF effluent are weirs, pipe, polymer pumps, and equipment to inject the polymer into the effluent from the primary containment area. A secondary containment area provides the capacity for gravity settling of the flocculated suspended solids.

Polymer feed system.

The polymer feed system should be designed to handle a liquid polymer of low viscosity and minimize handling, pumping, and any dilution problems that occur. Engineer Manual 1110-2-5027 (USACE 1987) provides more details of a polymer feed system.

Project Information:

In situ sediment volume	220,000 yd^3
Dredge discharge pipe sizes	12 or 16 in.
16-in. dredge discharge rate	21 cfs
12-in. dredge discharge rate	12 cfs
Polymer concentration	1% or 10 g/L
Polymer specific weight	9.6 lb/gallon
Polymer pump flow range	0.1 to 4 times
Polymer dilution capacity	4 times
Effluent TSS for 16-in. dredge	38.3 g/L
Effluent TSS for 12-in. dredge	27.4 g/L
Betz PC 1195 optimum dosage	4 mg/g

The amount of polymer required to treat the effluent from the primary cell of a CDF is based on the assumption that the volume of effluent is five times the volume of sediment dredged (220,000 yd^3). Therefore, 1,100,000 yd^3 of effluent with a TSS of 38.3 g/L (for a 16-in. dredge) and 27.4 g/L (for a 12-in. dredge) operation will be treated at the South Cell weirs. The optimum dosage for PC 1195 is 4 mg/g. The specific weight of the polymer is 9.6 lb/gallon.

Volume of polymer required, gal

$$= \frac{1{,}100{,}000 \text{ yd}^3 \times 764.4 \text{ L/yd}^3 \times \text{Effluent TSS, g/L} \times 4 \text{ mg/g}}{9.6 \text{ lb/gallon} \times 454{,}000 \text{ mg/lb}}$$

= 30,700 gallon of polymers for a 16-in. dredge

= 22,000 gallon of polymers for a 12-in. dredge

Concentrated polymer feed pump. The concentrated polymer should be dispensed using a positive displacement pump. The pump should be capable of discharging between the range of 0.13 gpm (0.50 L/m) to 5 gpm (19 L/m) to handle the range of required polymer dosages and flow rates of water to be treated from a 16-in. dredge. The pump should be capable of discharging between the range of 0.05 g/m (0.20 L/m) to 2 g/m (8 L/m) to handle the range of required polymer dosages and flow rates of water to be treated from a 12-in. dredge. The average polymer feed rate was based on the average flow rate, the polymer optimum dosage, and the specific weight of the polymer. Polymer pump flow capacities should range between 0.1 and 4 times the average feed rate (EM 1110-2-5027, USACE 1987).

Average feed rate, gpm

$$= \frac{\text{Flow rate, cfs} \times 4 \text{ mg/g} \times \text{Effluent TSS, g/L} \times 28.31 \text{ liter/ft}^3 \times 60 \text{ sec/min}}{9.6 \text{ lb/gal} \times 454{,}000 \text{ mg/lb}}$$

Average feed rate$_{16\text{-in}}$ = 1.25 g/m (4.8 L/min)

Average feed rate$_{12\text{-in}}$ = 0.51 g/m (2.0 L/min)

Pump range$_{16\text{-in}}$ = 0.13 g/m (0.50 L/min) to 5 g/m (19 L/min)

Pump range$_{12\text{-in}}$ = 0.05 g/m (0.20 L/min) to 2.0 g/m (8 L/min)

Polymer dilution. Prior to treating the effluent from the primary CDF cell, the polymer must be diluted with water to reach a polymer concentration of 1 percent or 10 g/L for polymers with low viscosity as selected in this study. Lower polymer concentrations such as 0.1% or 1 g/L may be needed for polymers with higher viscosity. The dilution factor must be 115 for low polymer viscosity [(100% x 9.6 lb/gal) / (1% x 8.31 lb/gal)]. Using the average polymer feed rate and a dilution factor of 115, the required dilution water flow rate would be 146 g/m for a 16-in. dredge and 60 g/m for a 12-in. dredge. The dilution water pump capacity should be four times this rate to dilute higher polymer flows adequately. Therefore, the dilution water flow rate is calculated as follows.

Polymer dilution rate, g/m, for a dilution factor of 115

= 115 x 4 x Average Polymer Feed Rate, gpm
= 580 g/m for a 16-in. dredge
= 235 g/m for a 12-in. dredge

Injector and feed line

The injection system must distribute the polymer throughout the water to be treated as uniformly as practically possible. Nozzles or a perforated diffuser pipe running along the weir crest may be used. The system should be as maintenance-free as possible. Fine spray nozzles should be avoided because suspended material from the dilution water may clog them. The feed lines may be constructed of rubber hoses or PVC pipes. The PVC pipe size must be designed to carry the design flows of the viscous polymer solution at low temperature. Provisions may be required to prevent freezing in cold climates when the system is not operational. The source for the dilution water must be clean and free from any debris that may cause mechanical pump problems and hinder the effectiveness of the polymer on the dredged material effluent.

Task 4: Sheen analysis

Since the sediment is characterized as fine-grained material with potential petroleum hydrocarbon contamination, oil sheen was expected and deemed for analysis. If an organic-based sheen was created during preparation of the suspension for jar testing, a sample was to be collected for chemical analysis to characterize potential volatilization constituents and needs for controls.

Result. No oil sheen was observed on sediment sent to EL during storage, jar test preparation, or testing. Therefore, no oil sheen sample was collected and analyzed. Nevertheless, the sediment was tested for petroleum hydrocarbons.

Sediment Physical and Chemical Properties. The sediment sample was sent to ERDC-EL from the Norfolk District. The sediment sample was homogenized and aliquots were collected for particle size distribution and contaminants of concern analyses. The initial sediment particle size distribution was determined to be 75% fine-grained material (Figure 6). The initial average petroleum hydrocarbon concentrations expressed as Gas

Range Organic (GRO) and Diesel Range Organic (DRO) were determined to be 1.10 and 234 mg/kg, respectively (Table 14). BTEX, MTBE, and Oil Range Organic (ORO) concentrations were not detected.

Table 14. Petroleum Hydrocarbon Results.

Analyte	Sample Concentrations, mg/kg			
	Replicate 1	Replicate 2	Replicate 3	Average
Benzene	ND	ND	ND	ND
Toluene	ND	ND	ND	ND
Ethylbenzene	ND	ND	ND	ND
Total Xylene	ND	ND	ND	ND
MTBE	ND	ND	ND	ND
Oil Range Organic	ND	ND	ND	ND
Gas Range Organic	1.06	1.22	1.01	1.10
Diesel Range Organic	207	245	251	234

ND denotes not detected

Task 5: Contaminant fate evaluation

The contaminant fate of the organic contaminants of concern (COCs) discussed below were evaluated using the equilibrium partitioning screening model published in the Upland Testing Manual (USACE 2003). The screening model was used to perform the contaminant pathway evaluations for runoff, leachate, and volatilization utilizing established screening criteria and bulk chemistry, site, and physical sediment data. Input data are summarized in Appendix B.

Results. An analysis of the modified elutriate results given in Tables 3 and 4 showed that sample 07-JR-DWTX-2-EL-15-21 was the worst-case sample in the dataset and would yield the highest or very near the highest losses for each contaminant and pathway. Therefore, the sediment chemical and physical characteristics, along with conservative CDF and chemical properties, were used to evaluate the runoff, leachate, and volatilization pathways for potential adverse impacts and the need for additional testing. Table 15 summarizes the findings.

The runoff pathway evaluated using the same effluent discharge criteria as the effluent pathway is shown in Table 4. The concentrations of organic COCs associated with the TSS in the runoff were assumed equal to the bulk sediment concentration when adjusted for the silt and clay fraction. Results of the analysis show that the TSS concentration in the runoff might need to be controlled before discharging site surface water to the river. For fresh unoxidized dredged material as would be present in the secondary settling cell, the TSS concentration can be as high as 20 g/L and is often higher than 5 g/L. Screening analysis results in Table 16 show that the maximum allowable TSS in the runoff is 2.89 g/L. Therefore, provisions should be established to allow the runoff to settle in a small ponded area in front of the secondary weir prior to discharge of site surface water.

The leachate pathway was evaluated using screening criteria for drinking water, when available, or dissolved freshwater chronic toxicity. The evaluation was conducted for a period of 100,000 years without degradation for a receptor at a distance of 100 m from the edge of the CDF. The evaluation showed that the pore water concentrations for eight of the ten COCs exceeded the screening criteria; the contaminants not exceeding the criteria yielded a result of No-1 in Table 15. Three of the remaining eight contaminants would have sufficient attenuation in the vadose zone such that the contaminant concentration would never exceed the screening criteria in the groundwater; these three contaminants yielded a result of No-2 in Table 15. None of the remaining five COCs were predicted to exceed the screening criteria in the groundwater during 100,000 years of screening; these five contaminants yielded a result of No-3 in Table 15. As shown in Table 17, the peak concentration at the receptor was predicted to be less than 3% of the screening criteria. Therefore, the leachate pathway does not pose any potential for concern.

The volatilization pathway was evaluated using conservative long-term inhalation reference doses for the screening criteria. The evaluation was conducted for long-term exposures by on-site workers at the CDF and off-site children residing 1,000 ft from the CDF. The results show no potential concern for workers or nearby residents. As shown in Table 17, the predicted peak exposure dosage was less than 14% of the screening criteria for a conservative evaluation. Therefore, the volatilization pathway does not pose any potential for concern.

Table 15. Summary of Contaminant Pathway Screening Evaluation.

Organic COC	Runoff		Leachate	Volatilization			
				Ponded Conditions		Drying Conditions	
	TSS Controls Required? *Unoxidized*	TSS Controls Required? *Oxidized*	Testing Required?	Testing Required? *Off site*	Testing Required? *On site*	Testing Required? *Off site*	Testing Required? *On site*
PAH's							
Acenaphthene	No	No	No-2	No	No	No	No
Anthracene	No	No	No-3	No	No	No	No
Benzo(a)anthracene	Needed	No	No-3	No	No	No	No
Benzo(b)fluoranthene	Needed	No	No-3	No	No	No	No
Benzo(a)pyrene	Needed	No	No-3	No	No	No	No
Chrysene	Needed	No	No-3	No	No	No	No
Fluoranthene	No	No	No-1	No	No	No	No
Fluorene	No	No	No-2	No	No	No	No
Naphthalene	No	No	No-1	No	No	No	No
Pyrene	No	No	No-2	No	No	No	No

No-1 denotes contaminants that would not exceed the screening criteria in the pore water.

No-2 denotes contaminants that would attenuate sufficiently in the vadose zone that they would never exceed the screening criteria.

No-3 denotes contaminants that are retarded sufficiently during the period of interest to not exceed the screening criteria during the period of interest.

Table 16. Runoff Screening Results.

Organic COC	Maximum Predicted Total Concentration		Maximum Allowable TSS in Runoff	
	Unoxidized ug/L	*Oxidized* ug/L	*Unoxidized* g/L	*Oxidized* g/L
PAH's				
Acenaphthene	262.46	46.24	5,347	5,350
Anthracene	109.15	17.87	436,213	436,214
Benzo(a)anthracene	49.50	6.58	2.99	3.15
Benzo(b)fluoranthene	35.99	4.70	4.53	4.67
Benzo(a)pyrene	51.63	6.77	2.89	3.03
Chrysene	43.56	5.82	3.60	3.67
Fluoranthene	145.20	20.24	1,026	1,026
Fluorene	125.20	21.84	52,164	52,166
Naphthalene	11.70	1.74	183	198
Pyrene	248.48	35.31	17,941	17,941

Table 17. Comparisons of Screening Predictions to Criteria.

Organic COC	Ratio of Pathway Exposure Prediction to Screening Criteria						
	Runoff		Leachate	Volatilization			
				Ponded Conditions		Drying Conditions	
	Predicted Total Conc. to Runoff Criteria *Unoxidized*	Predicted Total Conc. to Runoff Criteria *Oxidized*	Predicted Water Conc. at Receptor to Leachate Criteria	Inhalation Dose to Volatilization Criteria *Off Site*	Inhalation Dose to Volatilization Criteria *On Site*	Inhalation Dose to Volatilization Criteria *Off Site*	Inhalation Dose to Volatilization Criteria *On Site*
PAH's							
Acenaphthene	0.0051	0.0009	0.0189	0.0308	0.0485	0.1006	0.0233
Anthracene	0.0001	0.00001	0.0196	0.0009	0.0015	0.0025	0.0006
Benzo(a)anthracene	5.3166	0.7072	0.0164	0.0251	0.0395	0.0526	0.0143
Benzo(b)fluoranthene	3.8659	0.5050	0.0094	0.0249	0.0393	0.0976	0.0234
Benzo(a)pyrene	5.5452	0.7271	0.0273	0.0642	0.1012	0.1345	0.0452
Chrysene	4.6787	0.6249	0.0145	0.0181	0.0285	0.1027	0.0242
Fluoranthene	0.0207	0.0029	0.0004	0.0034	0.0053	0.0066	0.0016
Fluorene	0.0005	0.0001	0.0148	0.0134	0.0211	0.0317	0.0074
Naphthalene	0.1887	0.0280	0.0262	0.0054	0.0085	0.0151	0.0035
Pyrene	0.0012	0.0002	0.0013	0.0072	0.0113	0.0103	0.0026

3 Summary

The RDWT Expansion sediment and existing settling column data were used to evaluate the need for engineering controls to meet VDEQ requirements if placed in an upland CDF. The results of that evaluation are as follows:

1. The sediment particle size distribution in the June 2007 sample used for testing was approximately 77% fines (which was different from the December 2003 RDWT maintenance sediment samples of 2% fines). The 2007 sample was characteristic of the material for the new work construction dredging. The settling results for the June 2007 new work sediment sample were used for the settling analyses.

2. Based on existing column settling tests, RDWT Expansion sediment underwent flocculent settling. The expected effluent suspended solids concentration from the South Cell for the June 2007 data ranges from 3 to 74 g/L over the course and range of the disposal operations. The expected effluent suspended solids concentration from the North Cell for the June 2007 data ranges from 4 to 21 g/L over the course of the 16-in. dredge operation and from 0.2 to 6.9 g/L over the course of the 12-in. dredge operation. The allowable TSS concentration based on the results of the modified elutriate test and the permit discharge criteria would limit the allowable TSS concentration in the effluent to 1,560 mg/L. Therefore, the effluent would fail the VWQS established in the permit without treatment.

3. Based on the new column settling test (February 2008), RDWT Expansion sediment underwent zone settling at a rate of 7.2 ft/hr. The areas of both cells are sufficient to allow the dredged material slurry to settle.

4. The compression settling analysis showed that the South Cell was large enough to store the dredged material solids if it were constructed to an elevation of 63 ft. The North Cell had sufficient volume to store additional dredged material solids, which could be diverted from the South Cell.

5. Based on the settling test for the PC 1195 polymer, the zone settling velocity of the chemically flocculated slurry at 122 g/L was 0.49 ft/hr. The maximum solids concentration of the chemically flocculated slurry for a

16-in. dredge was predicted to be 38.3 g/L. At this concentration, the zone settling velocity would be much greater and sufficient to settle in a 2-acre polishing cell.

6. The North Cell or a divided North Cell is sufficient in size to store all of the chemically flocculated dredged material effluent from the South Cell. Depending on the dredging operation, the polishing cell in the North Cell would need to range from 2 to 10 acres.

7. The average GRO and DRO concentrations were 1.10 and 234 mg/kg, respectively.

8. Of the nine polymers tested, Betz PC 1195 and Nalco 8131 passed the screening criterion.

9. The fractions of solids remaining after chemical clarification varied with dosage and initial TSS concentration, but both Betz PC 1195 and Nalco 8131 were able to achieve the target TSS concentration of 1,500 mg/L for a wide range of dosages.

10. The optimum concentration of Betz PC 1195 polymer ranged from 4 to 8 mg/g: 4 mg/g for TSS concentrations of 16 to 36 g/L and 8 mg/g for TSS concentrations of 0.3 to 2 g/L. The range of TSS concentrations to be treated is 2 to 70 g/L. The dosage range for Betz PC 1195 was typical or slightly greater than typical of other chemical clarification applications for dredged material. The optimum concentration of Nalco 8131 polymer ranged from 24 mg/g to about 100 mg/g -- 25 mg/g for TSS concentrations of 16 to 33 g/L and 100 mg/g for a TSS concentration of 1 g/L. The dosage range for Nalco 8131 was much greater than typical of other chemical clarification applications for dredged material.

11. None of the flocs that were formed by either Betz PC 1195 or Nalco 8131 was especially dense or large. The flocs could be readily resuspended by wind-driven currents or scour at the weir. As such, the polymer selection is less than optimal and additional screening should be considered. Nevertheless, the results show that chemical clarification can successfully treat the dredged material effluent to meet the TSS criteria.

12. The costs of polymers in the proposed application would be as much as $411,000 for Betz PC 1195 and $886,000 for Nalco 8131 for the highest

required dosage (16-in. dredge operation with polymer addition at the South Cell weirs). The costs of polymers would be as little as $42,000 for Betz PC 1195 and $90,000 for Nalco 8131 for the lowest required dosage (12-in. dredge operation with polymer addition at the dividing dike in a divided North Cell).

13. No oil sheen was observed during slurry preparation for the jar testing.

14. Evaluation of the runoff contaminant pathway showed a potential exceedance of the discharge permit water quality, particularly for the period before the dredged material desiccates, forms a crust, or becomes vegetated. Operational controls are required to allow the TSS in the runoff to settle to a concentration below 2.9 g/L before discharging the runoff.

15. Evaluation of the leachate and volatilization contaminant pathways shows no potential for concern. The conservative screening predictions were well below the protective screening criteria.

References

American Society for Testing and Materials (ASTM). 1999. Standard practice for coagulation-flocculation jar test of water. *In Annual Book of ASTM Standards*. Vol. 11.01. West Conshohocken, PA.

Schroeder, P. R. 1983. *Chemical clarification methods for confined dredged material disposal*. Technical Report D-83-2. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station. http://el.erdc.usace.army.mil/e2d2/pdfs/trd83-2.pdf

U.S. Army Corps of Engineers (USACE). 1987. *Confined disposal of dredged material*. Engineer Manual 1110-2-5027. Washington, DC: Office, Chief of Engineers.

U.S. Army Corps of Engineers (USACE). 2003. *Evaluation of dredged material proposed for disposal at island, nearshore, or upland confined disposal facilities - testing manual*. Technical Report ERDC/EL TR-03-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/dots/pdfs/trel03-1.pdf.

Wade, R. 1988. *New Bedford Harbor Superfund Project, Acushnet River Estuary Engineering Feasibility Study of dredging and dredged materials disposal alternatives; Report 7: Settling and chemical clarification tests*. Technical Report EL-88-15. Prepared for U.S. Environmental Protection Agency. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station. http://el.erdc.usace.army.mil/e2d2/pdfs/trel88-15-7.pdf

Wade, R. 2001. *Little Sunflower River dredged material sedimentation and chemical clarification studies, Rolling Fork, Mississippi, Final Report*. Prepared for U.S. Army Corps of Engineers, Vicksburg District. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Wade, R., R. A. Price, J. W. Simmers, C. Price, M. R. Palermo, and A. B. Gibson. 2002. *Evaluation of dredged material disposal and management for Appomattox River Federal Navigation Channel, Petersburg, Virginia, Phases I and II – Environmental and Engineering Studies*. Technical Report ERDC/EL TR-02-36. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://el.erdc.usace.army.mil/elpubs/pdf/trel02-36.pdf

Wang, C. C., and K. Y. Chen. 1977. *Laboratory study of chemical coagulation as a means of treatment for dredged material*. Technical Report D-77-39. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station. http://el.erdc.usace.army.mil/e2d2/pdfs/trd77-39.pdf

Appendix A: Settling Test Results - February 2008

Table A-1. Initial Total Solids Concentration for Column Settling Test on Richmond Deep Water Terminal New Work Sediment.

Port Height, ft	Total Solids Concentration, g/L
5.8	54.0
5.3	57.7
4.3	53.6
3.3	55.2
2.3	52.7
1.3	56.6
Average	55.0

Table A-2. Zone Settling Test Data for Column Settling Test on Richmond Deep Water Terminal New Work Sediment at 55 g/L.

Elapsed Time, hrs	Interface Height, ft	Elapsed Time, hrs	Interface Height, ft
0.00	6.50	1.63	1.62
0.03	5.38	1.83	1.55
0.17	5.18	2.08	1.47
0.18	5.01	2.33	1.41
0.28	4.36	2.58	1.37
0.38	3.62	2.83	1.33
0.45	3.04	3.15	1.30
0.52	2.72	4.05	1.24
0.63	2.51	7.20	1.14
0.78	2.27	12.00	1.05
0.92	2.06	24.00	0.95
1.00	1.98		

Table A-3. Flocculent Settling Data for Column
Settling Test on Richmond Deep Water Terminal New Work Sediment at 55 g/L.

Time hr	Port Ht ft	TSS g/L	Time hr	Port Ht ft	TSS g/L
1	5.8	15.6	72	5.8	4.4
	5.3	13.5		5.3	5.3
	4.3	15.9		4.3	6.8
	3.3	13.1		3.3	6.5
	2.3	12.7		2.3	7.5
4	5.8	9.1		1.3	7.7
	5.3	8.0	96	5.8	3.8
	4.3	12.7		5.3	5.2
	3.3	9.4		4.3	7.2
	2.3	9.4		3.3	6.6
	1.3	10.8		2.3	8.3
12	5.8	8.2	144	5.8	2.0
	5.3	7.2		5.3	14.1
	4.3	9.1		4.3	7.2
	3.3	8.4		3.3	4.5
	2.3	8.9		2.3	4.6
	1.3	9.2		1.3	11.6
24	5.8	8.5	168	5.8	0.9
	5.3	7.6		5.3	3.5
	4.3	6.9		4.3	3.8
	3.3	8.7		3.3	4.1
	2.3	7.4		2.3	4.3
	1.3	6.9		1.3	4.5
48	5.8	5.4			
	5.3	5.9			
	4.3	7.5			
	3.3	6.2			
	2.3	6.6			
	1.3	6.4			

Table A-4. Compression Settling Test Data for Column Settling Test on Richmond Deep Water Terminal New Work Sediment at 55 g/L.

Elapsed Time, days	Interface Height, ft	Settled Solids Concentration, g/L
1.00	0.949	376.7
2.00	0.843	424.1
2.28	0.828	431.8
3.00	0.810	441.4
4.00	0.780	458.3
4.35	0.769	464.9
5.56	0.758	471.6
6.00	0.752	475.4
6.50	0.749	477.3
7.00	0.748	477.9
7.54	0.747	478.6
8.00	0.745	479.9

Initial height was 6.5 ft.

Table A-5. Compression Settling Test Data for Chemically Flocculated Richmond Deep Water Terminal New Work Sediment at 122.5 g/L.

Elapsed Time, days	Volume of Settled Solids, mL	Solids Concentration, g/L
1.00	1,852	213.6
1.10	1,850	213.9
1.96	1,800	219.8
2.31	1,780	222.3
3.52	1,755	225.5
3.95	1,750	226.1
4.47	1,749	226.2
4.97	1,749	226.2
5.50	1,749	226.2
5.97	1,749	226.2

Initial volume was 3,230 mL (height of 1.312 ft). The test was run in a 4-Liter graduated cylinder.

Appendix B: Upland Testing Manual (UTM) – Screening Model Input Data

Table B-1.

UTM Screening Model Input Data					
In Situ Sediment Properties	Units	Value	Plant and Animal Uptake Parameters	Units	Value
Total Organic Carbon	%	4.92	Silt & Clay Fraction for Reference Soil	%	75
Silt & Clay Fraction	%	91	Total Organic Carbon of Reference Soil	%	9.5
Clay Fraction	%	39	Leachate Parameters		
Enrichment Factor	-	2.26	Distance from Edge of CDF to Receptor	m	100
Specific Gravity	-	2.68	Length of CDF Cell	m	750
Dissolved Organic Carbon	mg/L	20	Width of CDF Cell	m	275
Water Content	%	61	Area of CDF Cell	m^2	206,250
Hydraulic Dredging Operational Parameters			Time Period of Interest	years	100,000
Influent Slurry Solids Concentration	g/L	150	Foundation Soil Total Organic Carbon	%	2
Influent Slurry Porosity	-	0.94	Foundation Soil Silt & Clay Fraction	%	65
Effluent Parameters			Specific Gravity of Foundation Soil	-	2.68
Dilution within Mixing Zone	-	0	Thickness of Dredged Material in the CDF	m	2
Background Exceedance	%	10	Thickness of the Foundation Soil (Vadose)	m	5
Runoff Parameters			Thickness of the Saturated Zone	m	5
Dilution within Mixing Zone	-	0	Effective Porosity of Foundation (Vadose)	-	0.3
Background Exceedance	%	10	Effective Porosity of Foundation (Aquifer)	-	0.5
Unoxidized Runoff Solids Conc.	g/L	20	Hydraulic Conductivity	m/year	30,000
Oxidized Runoff Solids Conc.	g/L	2	Slope of the Water Table	-	0.001
Volatilization Exposure Parameters			Net Recharge Percolating into Plume	m/year	0.4
Average Weight of Off-site Child	kg	19	Percolation Rate from Facility (CDF)	m/year	0.03
Off-Site Exposure Period	min/day	1440	Vertical Dispersivity	m	0.15
Respiration Rate of Off-site Child	L/min	12	Transverse Dispersivity	m	1.5
Breathing Rate of Off-site Child	m^3/day/kg	0.91	Max Depth of Mixing at Edge of Facility	m	16.30
Average Weight of On-site Adult	kg	72.57	Thickness of the Plume at the Receptor	m	18.80
Respiration Rate of On-site Adult	L/min	28.6	Aquifer Dilution Factor	-	2.76
On-Site Ponded Exposure Period	min/day	600			
On-Site Drying Exposure Period	min/day	480			
Ponded Breathing Rate of On-site Adult	m^3/day/kg	0.24			
Drying Breathing Rate of On-site Adult	m^3/day/kg	0.19			
Wind Speed	m/s	2.5			
Temperature of Ponded Water	°K	298			
Water Depth	m	0.7			
Length of CDF Cell	m	750			
Width of CDF Cell	m	275			
Unit Air Conc. Factor	$(mg/m^3)/(g/s)$	0.08			

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
November 2009

2. REPORT TYPE
Final report

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Evaluation of Dredged Material Disposal and Management for Upper James River Federal Navigation Channel, Richmond, Virginia

Modeling and Testing of Contaminant Release for Expansion of Richmond Deepwater Terminal

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Roy Wade and Paul Schroeder

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/EL TR-09-17

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The Federal Navigation Channel in the Upper James River requires frequent maintenance dredging to ensure safe navigation. One of the shoals is the Federal Channel at Richmond Deepwater Terminal (RDWT). The U.S. Army Corps of Engineers, Norfolk District has proposed expansion of the river basin at RDWT, such that ships arriving at the terminal can turn around and return downriver. Previous investigations determined that RDWT sediments were contaminated with diesel range petroleum hydrocarbons. Dredging and disposal of these sediments into a CDF may result in an adverse impact to water quality from effluent water returned to the James River.

Since previous results of a settling test performed on localized material in December 2003 and June 2007, the settling test results were different and no data were collected on zone settling and compression settling. Therefore, ERDC performed an abbreviated settling test (February 2008) on the new work sediment sample to collect compression settling data for predicting storage needs and to verify the sediment settling behavior. Results of this study show the effluent total suspended solids (TSS) concentration to be very dependent on the sediment being disposed. A wide range of TSS concentrations were examined in jar tests to evaluate the effectiveness of chemical clarification.

(Continued)

15. SUBJECT TERMS
Confined disposal facility (CDF)
Dredging
Navigation
Richmond Deepwater Terminal (RDWT)
Upper James River

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED		60	

Abstract continued:

Based on the ERDC column settling test (February 2008), RDWT Expansion sediment underwent zone settling at a rate of 7.2 ft/hr. The areas of both cells are sufficient to allow the dredged material slurry to settle. Screening results showed that only Betz PC 1195 and Nalco 8131 were effective. These two polymers reduced the effluent suspended solids concentration by at least 98%. However, PC 1195 outperformed Nalco 8131. Even though the unit cost of Nalco 8131 is less than PC 1195, the required large dosage rate of Nalco offset that cost. The runoff contaminant pathway showed a potential exceedance of the discharge permit water quality, particularly for the period before the dredged material desiccates, forms a crust or becomes vegetated. Operational controls are required to allow the TSS in the runoff to settle to a concentration below 2.9 g/L before discharging the runoff. The leachate and volatilization contaminant pathway shows no potential for concern.