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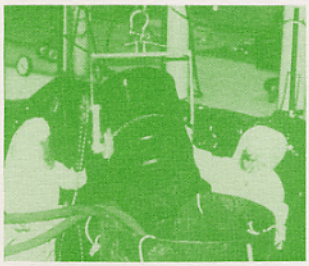

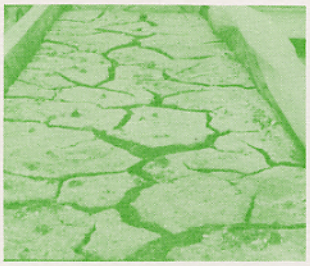

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NEW BEDFORD HARBOR SUPERFUND PROJECT, ACUSHNET RIVER ESTUARY ENGINEERING FEASIBILITY STUDY OF DREDGING AND DREDGED MATERIAL DISPOSAL ALTERNATIVES

Report 7

SETTLING AND CHEMICAL CLARIFICATION TESTS

by

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November 1988

Report 7 of a Series

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NEW BEDFORD HARBOR SUPERFUND PROJECT, ACUSHNET RIVER ESTUARY ENGINEERING FEASIBILITY STUDY OF DREDGING AND DREDGED MATERIAL DISPOSAL ALTERNATIVES

No. in Series	Report Title
1	Study Overview
2	Sediment and Contaminant Hydraulic Transport Investigations
3	Characterization and Elutriate Testing of Acushnet River Estuary Sediment
4	Surface Runoff Quality Evaluation for Confined Disposal
5	Evaluation of Leachate Quality
6	Laboratory Testing for Subaqueous Capping
7	Settling and Chemical Clarification Tests
8	Compatibility of Liner Systems with New Bedford Harbor Dredged Material Contaminants
9	Laboratory-Scale Application of Solidification/Stabilization Technology
10	Evaluation of Dredging and Dredging Control Technologies
11	Evaluation of Conceptual Dredging and Disposal Alternatives
12	Executive Summary

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One alternative for cleanup of the New Bedford Harbor Superfund site is dredging the contaminated sediments and placement into an upland or intertidal confined disposal facility (CDF). The conceptual design of either facility requires an evaluation of the settling properties of the dredged material to estimate storage requirements and effluent suspended solids concentrations. Suspended solids reduction beyond gravity settling may be achieved by chemical clarification.

Laboratory column tests were performed on three sediments: the composite, the hot spot, and the capping sediments. Their settling behavior was observed to be typical of other marine sediments if hydraulically dredged and placed in a CDF. The compression test data were used to develop the initial storage requirements. The zone settling velocity was found not to be a controlling factor in the storage design; therefore, zone tests were not

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performed on the hot spot and capping sediments. The flocculent test indicated that the suspended solids will settle by gravity. The chemical clarification test was conducted to further reduce those suspended solids left in the effluent.

PREFACE

This study was conducted as a part of the Acushnet River Estuary Engineering Feasibility Study (EFS) of Dredging and Dredged Material Disposal Alternatives. The US Army Corps of Engineers (USACE) performed the EFS for the US Environmental Protection Agency (USEPA), Region 1, as a component of the comprehensive USEPA Feasibility Study for the New Bedford Harbor Superfund Site, New Bedford, MA. This report, Report 7 of a series, was prepared by the US Army Engineer Waterways Experiment Station (WES) in cooperation with the New England Division (NED), USACE. Coordination and management support was provided by the Omaha District, USACE, and dredging program coordination was provided by the Dredging Division, USACE. The study was conducted between July 1986 and July 1987.

Project manager for the USEPA was Mr. Frank Ciavattieri. The NED project managers were Messrs. Mark J. Otis and Alan Randall. Omaha District project managers were Messrs. Kevin Mayberry and William Bonneau. Project managers for the WES were Messrs. Norman R. Francingues, Jr., and Daniel E. Averett.

The report was prepared by Mr. Roy Wade, Water Supply and Waste Treatment Group (WSWTG), Environmental Engineering Division (EED), Environmental Laboratory (EL), WES. Laboratory support was provided by Mr. Anthony Lewis and Mr. Chris Thomas, both of WSWTG. The report was edited by Ms. Jessica S. Ruff of the WES Information Technology Laboratory.

The study was conducted under the direct supervision of Mr. Norman R. Francingues, Jr., Chief, WSWTG, and under the general supervision of Dr. Raymond L. Montgomery, Chief, EED, and Dr. John Harrison, Chief, EL.

COL Dwayne G. Lee, EN, was the Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
acres	4,046.873	square metres
acre-feet	1,233.489	cubic metres
cubic feet	0.02831685	cubic metres
cubic feet per second per foot	0.093	cubic metres per second per metre
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
inches	2.54	centimetres
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use $K = (5/9)(F - 32) + 273.15$.

NEW BEDFORD HARBOR SUPERFUND PROJECT, ACUSHNET RIVER ESTUARY ENGINEERING FEASIBILITY STUDY OF DREDGING AND DREDGED MATERIAL DISPOSAL ALTERNATIVES

SETTLING AND CHEMICAL CLARIFICATION TESTS

PART I: INTRODUCTION

1. In August 1984, the US Environmental Protection Agency (USEPA) reported on the Feasibility Study of Remedial Action Alternatives for the Upper Acushnet River Estuary above the Coggeshall Street Bridge, New Bedford, MA (NUS Corporation 1984). The USEPA received extensive comments on the proposed remedial action alternatives from other Federal, state, and local officials, potentially responsible parties, and individuals. Responding to these comments, the USEPA chose to conduct additional studies to better define available cleanup methods. Because dredging was associated with all of the removal alternatives, the USEPA requested the Nation's dredging expert, the US Army Corps of Engineers (USACE), to conduct an Engineering Feasibility Study (EFS) of dredging and disposal alternatives. A major emphasis of the EFS was placed on evaluating the potential for contaminant releases from both dredging and disposal operations.

2. The technical phase of the EFS was completed in March 1988. However, as part of Task 8 of the EFS, the results of the study were compiled in a series of 12 reports, listed below.

a. Report 1, "Study Overview."

b. Report 2, "Sediment and Contaminant Hydraulic Transport Investigations."

c. Report 3, "Characterization and Elutriate Testing of Acushnet River Estuary Sediment."

d. Report 4, "Surface Runoff Quality Evaluation for Confined Disposal."

e. Report 5, "Evaluation of Leachate Quality."

f. Report 6, "Laboratory Testing for Subaqueous Capping."

g. Report 7, "Settling and Chemical Clarification Tests."

h. Report 8, "Compatibility of Liner Systems with New Bedford Harbor Dredged Material Contaminants."

i. Report 9, "Laboratory-Scale Application of Solidification/ Stabilization Technology."

j. Report 10, "Evaluation of Dredging and Dredging Control Technologies."

k. Report 11, "Evaluation of Conceptual Dredging and Disposal Alternatives."

l. Report 12, "Executive Summary."

This report is Report 7 of the series. The results of this study were obtained from conducting EFS Task 6, elements 7 and 8 (see Report 1). These study results are incorporated and used in the evaluation of conceptual dredging and dredged material disposal alternatives described in EFS Report 11.

Background

3. The technical approach to the EFS is described in Report 1 of this series. The study involved a series of innovative laboratory tests performed on a variety of sediment types (upper estuary composite, hot spot, and comparatively clean sediment for capping). The composited sediment sample that was tested extensively for the EFS represents the top 2 ft* of sediment in the upper Acushnet River Estuary and has a polychlorinated biphynel (PCB) concentration of approximately 2,000 mg/ℓ. The hot spot sample, which represents a much smaller portion of the site, is four to five times higher in PCB concentration than the upper estuary composite sample. The potential capping material sediment sample was collected from 3 ft below the upper estuary bottom along the eastern shore above the Coggeshall Street Bridge. Details on the sampling, compositing, and analytical procedures are given in Report 3. Sampling and characterization of the capping material are discussed in Report 6.

4. One remedial action alternative being considered for the New Bedford Superfund Site is hydraulic dredging with temporary or permanent dredged material disposal in either an upland or intertidal confined disposal facility (CDF). The conceptual design of either facility requires an evaluation of the settling behavior and properties of the dredged material to estimate the storage requirements for good solids separation. Efficient removal of

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

suspended solids benefits CDF effluent quality by reducing particulate-associated contaminants as well as suspended solids concentrations. Increased suspended solids removal and associated contaminant reductions beyond gravity settling may be achieved by the addition of chemicals to promote clarification of the discharged effluent. Both settling and chemical clarification test procedures have been developed to assist in CDF evaluations, and these were applied to the EFS sediment samples. Therefore, the primary purpose of this report is to document and present the results of the settling and chemical clarification tests performed as part of the EFS.

Testing Objectives

5. The objective of the settling tests was to develop data for predicting the settling behavior of New Bedford Harbor composite, hot spot, and capping sediments when hydraulically dredged and placed in a CDF (intertidal or upland). Objectives of the chemical clarification tests were to evaluate the effectiveness of polymers for the removal of suspended solids from CDF effluent and to develop a conceptual design for removing effluent suspended solids that will not settle by gravity in a dredged material confined disposal area.

Scope of Work

6. The scope of work included performing laboratory column settling tests on New Bedford Harbor sediments to estimate the volume requirements for the primary containment area. Jar tests were used to screen and select polymers to promote flocculation and settling of suspended solids in primary CDF effluent. The preliminary design of a mixing system to thoroughly mix the polymer and effluent from the primary containment area was also developed. Settling behavior was observed for three sediment types (upper estuary composite, hot spot, and potential capping sediments). The chemical clarification test was performed only on the upper estuary composite sediment sample, since it represented a majority of the contaminated material that may be removed by dredging.

PART II: EXPERIMENTAL PROCEDURES

Settling Tests

Background

7. The settling tests followed procedures found in Palermo, Montgomery, and Poindexter (1978) and Engineer Manual (EM) 1110-2-5027 (USACE 1987). The tests involve mixing sediment and site water to simulate a dredged material slurry, placing the material in a settling column, and observing each of several types of settling behavior. The general procedure is described below.

8. A bench test conducted in a 1-ℓ graduated cylinder is the method used to determine if a flocculent or a zone process will describe the initial settling. The bench test should be run at a slurry concentration of approximately 150 g/ℓ. If an interface forms within the first few hours of the test, the slurry mass is exhibiting zone settling, and the fall of the interface versus time should be recorded. The break in the curve will define the concentration at which compression settling begins. If no break in the curve is evident, the material has begun settling in the compression zone, and the bench test should be repeated at a lower slurry concentration. If no interface is observed in the bench test within the first few hours, the slurry mass is exhibiting flocculent settling. In this case, the bench test should be continued until an interface is observed between the turbid water above and the more concentrated settled solids below. The concentration of the settled solids (computed assuming zero concentration of solids above) is an indication of the concentration at which the material exhibits compression settling (EM 1110-2-5027).

9. The flocculent settling test consists of measuring the concentration of suspended solids at various depths and time intervals in a settling column. If an interface forms near the top of the settling column during the first day of the test, sedimentation of the material below the interface is described by zone settling, confirming the bench test. In that case, the flocculent test procedure should be continued only for that portion of the column above the interface. If an interface has not formed on the first day, flocculent settling is occurring in the entire slurry mass. One allows the slurry to settle, withdraws samples from each sampling port at regular time intervals, and determines the suspended solids concentrations. Substantial reductions of

suspended solids will occur during the early part of the test, but reductions will lessen at longer retention times (EM 1110-2-5027).

10. The zone settling test consists of placing a slurry in a sedimentation column and reading and recording the fall of the liquid-solids interface with time. These data are plotted as depth to interface versus time. The slope of the constant velocity settling zone of the curve is the zone settling velocity, which is a function of the initial test slurry concentration. A series of these tests is required if the material exhibits an interface within the first day. The range of initial slurry concentrations used in the series should vary from a low of approximately 50 g/ℓ to a high concentration above the transition concentration, at which the slurry begins to exhibit compression settling (determined by the bench settling test) (EM 1110-2-5027).

11. A compression settling test must be run to obtain data for estimating the volume required for initial storage of the dredged material. For slurries exhibiting zone settling, the compression settling data can be obtained from one of the series of zone settling tests with interface height versus time recorded. The only difference is that the test is continued for a period of 15 days, so that a relationship of log of concentration versus log of time in the compression settling range is obtained (EM 1110-2-5027).

Bench test

12. The initial solids concentration for the upper estuary composite material was reduced from 418 to 111 g/ℓ to run a pilot test. The bench test was performed in a 1-ℓ graduated cylinder to determine if flocculent or zone processes will govern initial settling. An interface was visible after only a few minutes of settling, indicating that zone settling processes would govern.

13. The bench test was not performed on the hot spot sample nor the potential capping sediment since these sediments are expected to have settling behavior similar to the upper estuary composite sediment. (This assumption was found to be valid, as will be discussed.)

Slurry preparation

14. The target slurry concentration to run the settling tests was 150 g/ℓ. The slurry was prepared by mixing the upper estuary composite sediment with site water also collected from the estuary. To achieve the target slurry concentration for the composite material, approximately 6 gal of sediment, which had a solids concentration of 418 g/ℓ, was mixed with 11 gal of site water. The slurry was pumped from a 55-gal drum with a positive

displacement pump into an 8-in.-diam, 6-ft column, with ports at 0.4-ft intervals beginning at the 5.4-ft depth (see Figure 1). Before the slurry was mixed, salinity of the site water was measured to be 26 ppt. After the slurry was thoroughly mixed and pumped into the column, six samples for total solids were extracted from ports at 5.4-, 5.0-, 4.0-, 3.0-, 2.0-, and 1.0-ft levels. The average total solids concentration for the slurry was determined to be 130 g/ℓ.

15. The hot spot sediment and potential capping sediment slurry concentrations were determined in the same manner. Sediment solids concentrations were 381 and 600 g/ℓ for each sample, respectively. The average total solids concentrations for these slurries when placed in the column were determined to be 134 and 109 g/ℓ, respectively.

Compression test

16. The depth to the interface was measured every 15 min for the first 13 hr. Thereafter, for 15 days, depth to the interface was measured at daily intervals.

Zone test

17. A series of zone settling tests were run on the upper estuary composite sediment at solids concentrations ranging from 50.0 to 181.3 g/ℓ. After loading the column, the depth to the interface was read every 15 min. The total solids concentration was determined from six samples extracted from ports at 5.4-, 5.0-, 4.0-, 3.0-, 2.0-, and 1.0-ft depths immediately after loading. Each zone test ran for approximately 5 or 6 hr. From the plots of the depth to interface (feet) versus time (hours), zone settling velocities were determined.

18. The zone test was not run on the hot spot or potential capping sediment samples. It was determined that the zone settling velocity of the upper estuary composite sediment was not the controlling design parameter for the CDF. This relationship was determined from the information that the initial storage area exceeded the minimum area needed for zone settling. Experience with other marine sediments also contributed to this decision.

Flocculent test

19. Flocculent settling tests were performed concurrently with the compression settling test on the same slurry. Therefore, the flocculent test slurry concentrations are the same as the compression test slurry concentrations. For the upper estuary composite sediment, samples of the supernatant

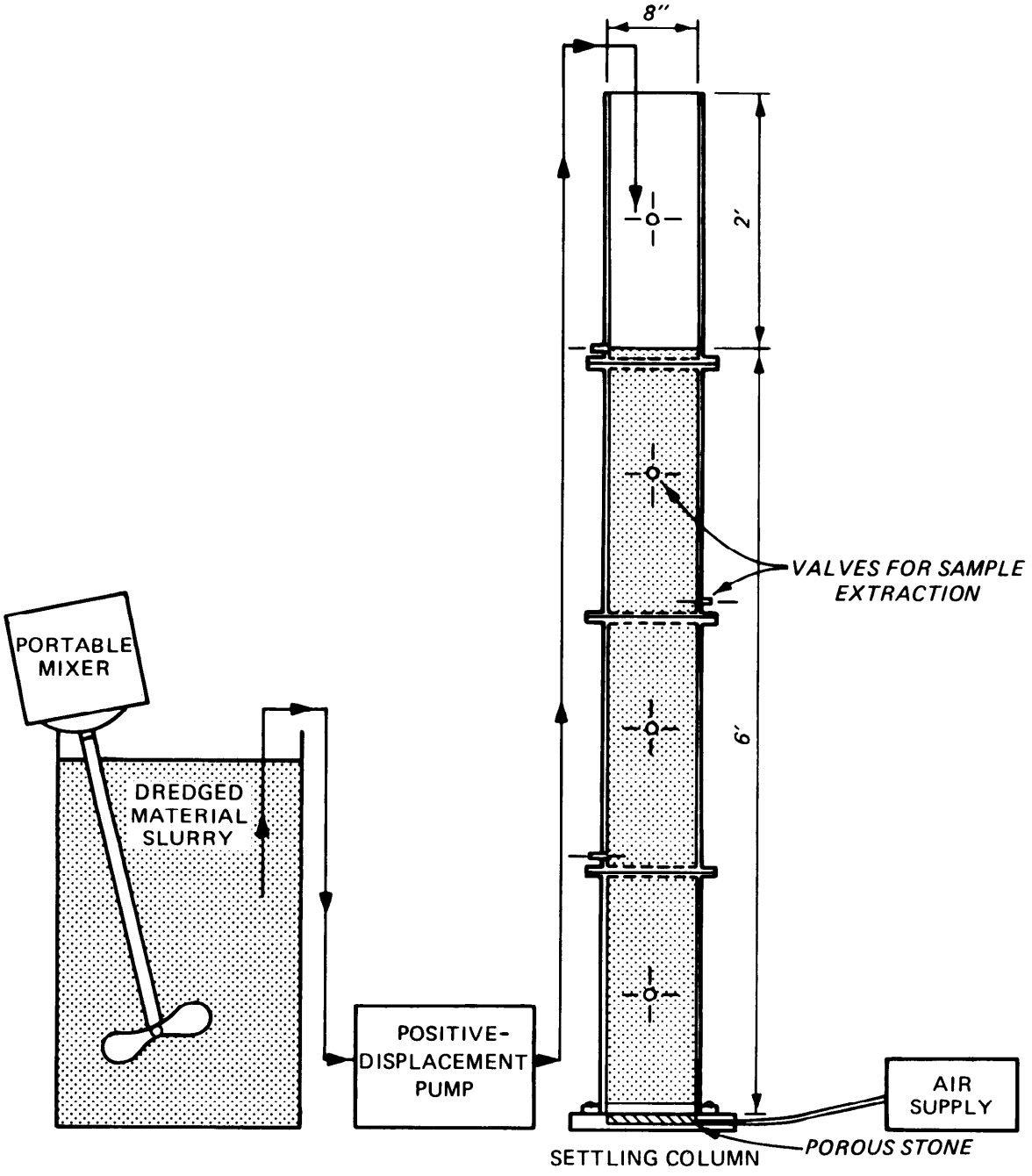


Figure 1. Schematic of the settling column

were extracted with a syringe at 5.0-, 4.7-, 4.4-, 4.0-, 3.8-, 3.5-, 3.0-, and 2.8-ft depths above the interface at different time intervals (1.5, 3.5, 6.0, 12.0, 24.0, 48.0, 97.0, and 192 hr). For the hot spot material, samples of the supernatant were extracted with a syringe at 5.4-, 5.0-, 4.4-, and 4.0-ft

depths above the interface at time intervals of 2.0, 4.0, 12.0, 24.0, 48.0, 96.0, 144.0, and 240.0 hr. Finally, for the potential capping sediment, samples of the supernatant were extracted with a syringe at 5.4-, 5.0-, 4.4-, 4.0-, 3.0-, and 2.8-ft depths above the interface at time intervals of 1.0, 2.0, 4.0, 8.0, 12.0, 24.0, 52.0, 120.0, and 144.0 hr. Suspended solids concentrations were then determined from the supernatants.

Chemical Clarification Tests

Apparatus and testing procedure

20. The clarification testing apparatus consists of a six-paddle Phipps and Bird stirrer. The test procedures involved placing six 1-ℓ beakers of effluent on the mixing stand. One mixture serves as a control with no polymer added; the rest are subjected to different dosages of the same polymer. The mixtures are subjected to a rapid mixing phase (flash mixing), a slow mixing phase (flocculation), and a settling phase. This procedure is outlined in Schroeder (1983).

Sample preparation

21. The composite dredged material slurry was prepared using upper estuary composite sediment sample (see Report 3). The total solids concentration of the sediment was 418 g/ℓ. The slurry was produced by the addition of site water obtained at the proposed dredging site. After thorough mixing, the slurry was allowed to settle 24 hr to simulate the settling that would occur in the primary basin of a CDF. This material was allowed to settle 24 hr because the flocculant test showed little settling improvement after a 24-hr period. The supernatant for testing was then collected and stored in a 55-gal drum for screening polymers. Supernatant samples for polymer optimization were stored in glass carboys for subsequent chemical analysis. The suspended solids concentration of the supernatant after 24 hr of settling was 228 mg/ℓ. Before being placed in 1,000-ml beakers, the supernatant in the carboy was thoroughly mixed.

Preparation and screening of polymers

22. Polymers were selected for testing based on the recommendations of technical sales representatives from the respective polymer manufacturers. Each sales representative made recommendations based on their experience. American Cyanamid and Allied Chemical representatives also recommended that

several of their products be screened in combinations if the individual polymers produced pin-sized flocs. The method for adding polymers in combination is to add the cationic polymer first, as usual, and then to add the anionic polymer at the end of the rapid mixing phase. The technical sales representatives also provided cost information for the polymers selected for optimization.

23. Three forms of polymers were evaluated: liquid, emulsion, and dry. Polymers were prepared for testing using the procedure outlined in Appendix A. The screening procedures are outlined in Wang and Chen (1977).

Optimization of polymer dosage

24. As a result of the initial screening process, 11 cationic and 2 anionic polymers were selected for further evaluation in accordance with the procedure detailed in Schroeder (1983). The test was similar to the screening process except that the polymers were tested over a range of concentrations where the optimum dosage was thought to occur. The suspended solids concentrations of the treated effluent were determined for each sample. Graphs of supernatant suspended solids versus polymer dosage were plotted for each polymer.

PART III: DATA ANALYSIS AND RESULTS

25. The behavior of New Bedford Harbor sediments at slurry concentrations equal to those expected for inflow to a confined site is governed by zone settling processes. As expected for saltwater conditions, the sediments exhibited a clear interface between settled material and clarified supernatant. The settling test data were analyzed using the Automated Dredging And Disposal Alternatives Management System (ADDAMS) (Hayes et al., in preparation). This system is a family of computer programs developed to assist in planning, designing, and operating dredging and dredged material disposal projects.

Compression Settling Tests

26. For the compression tests, the initial slurry concentration and and the height and depth to interface versus time were entered (Tables 1-3). The ADDAMS program uses the initial slurry concentration and height to determine the solids concentration at a given time. A plot is generated showing the relationship between solids concentration (grams per litre) and retention time (days). The ADDAMS also develops a regression equation for the resulting power curve relating solids concentration to time. Regression equations for the hot spot, upper estuary composite, and potential capping samples are as follows:

$$C_{HOT} = 178 \times T^{0.1097}$$

$$C_{COMP} = 221 \times T^{0.1054}$$

$$C_{CAP} = 239 \times T^{0.1185}$$

where

C = solids concentration, g/ℓ

T = time, days

27. Slopes of the solids concentration versus time curves for all three sediment samples were similar (Figure 2). However, the solids concentration

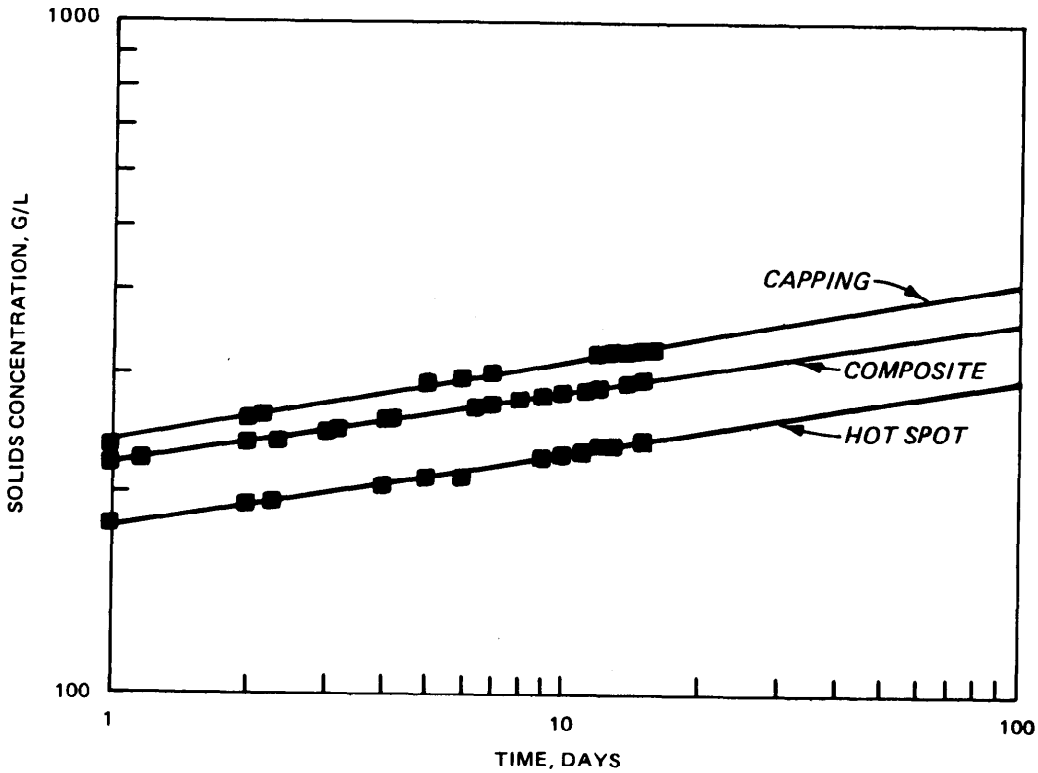


Figure 2. Comparison of compression test curves

after 1 day of settling was different for all tests because the zone settling velocities were different. The potential capping sediment sample settled faster the first few hours than the upper estuary composite and hot spot sediment samples, causing the capping sediment to exhibit compression settling at a greater solids concentration with time (Figure 3).

Zone Settling Tests

28. Zone settling velocities for the upper estuary composite sample were determined for each of the zone tests, i.e., for each solids concentration. Depth to interface and the corresponding time intervals were entered into a plotting routine used to determine the zone settling velocity (Tables 4-15). The zone settling velocities were recorded, along with the corresponding slurry concentrations. These data were then entered into ADDAMS, except the zone settling velocities with high slurry concentrations, i.e., 128.6, 148.6, 167.4, and 181.3 g/ℓ. The zone settling velocities were

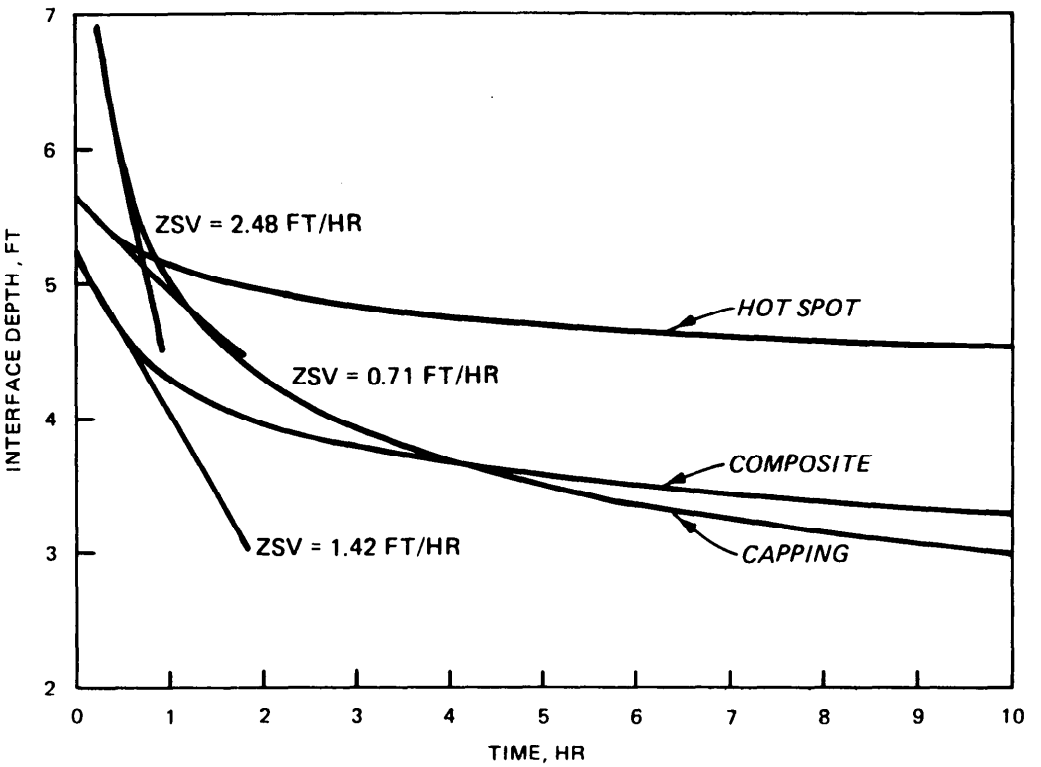


Figure 3. Comparison of the interface depth versus time

too high for those concentrations as a result of "bridging" against the column walls. The bridging of the particles at those concentrations is believed to result from using a small-diameter column. The settling of the solids interface increases because the water that is displaced by the subsidence of solids encounters less resistance flowing upward along the wall than the more difficult route between particles, as outlined in Montgomery (1978). The ADDAMS generated a plot showing a linear relationship between the logarithm of the zone velocities (feet per hour) and the slurry concentration (grams per litre) (Figure 4). An exponential equation was developed to determine the zone velocity at any given concentration.

29. The ADDAMS was also used to generate a solids loading curve using the zone settling curve to show the relationship between solids loading, S (pounds/hour-square foot) and solids concentration, C (pounds/cubic foot) (Figure 5).

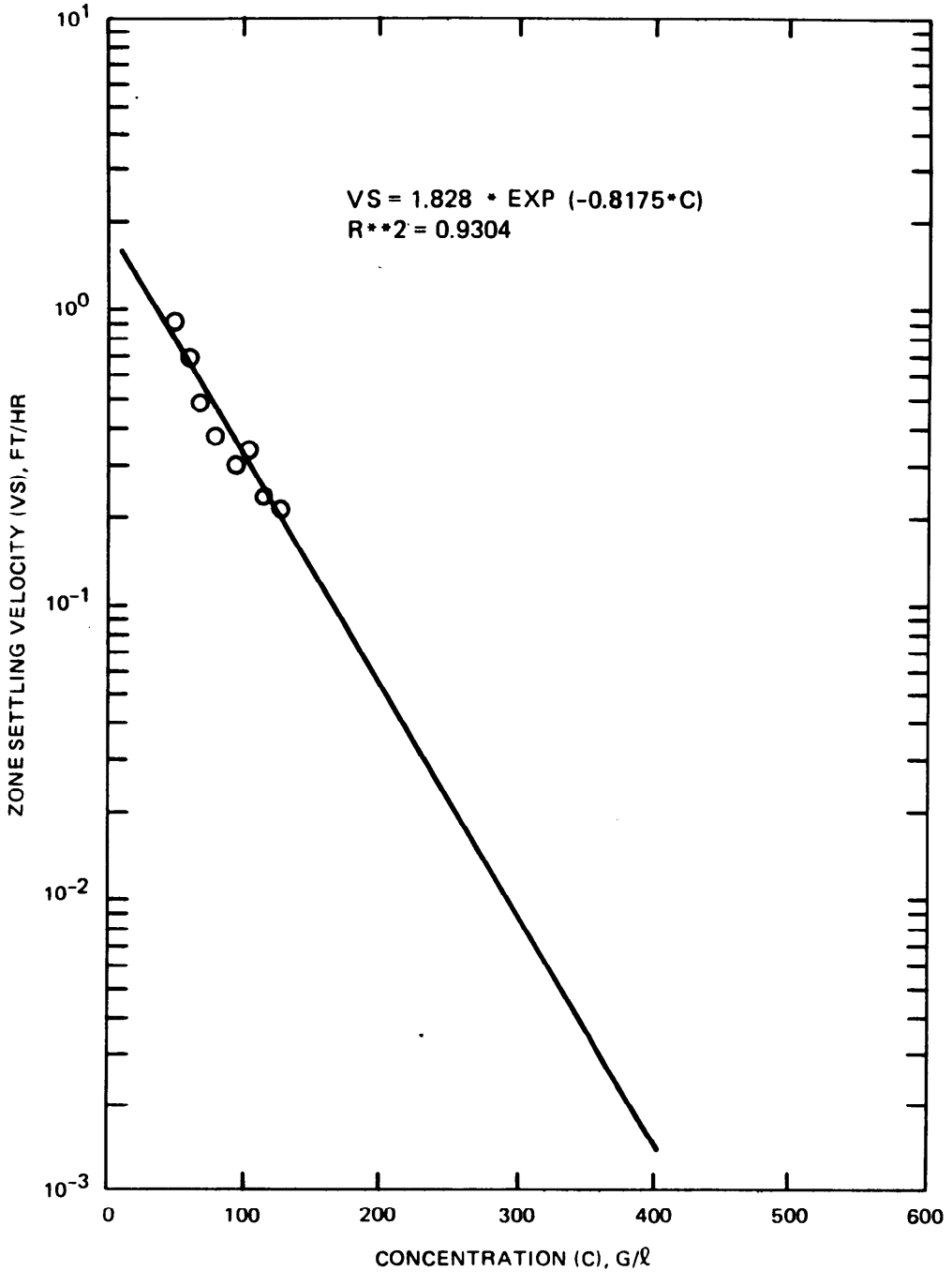


Figure 4. Zone settling curve

Flocculent Settling Tests

30. For the flocculent tests, the supernatant suspended solid concentrations at different depths and time intervals were used by ADDAMS to

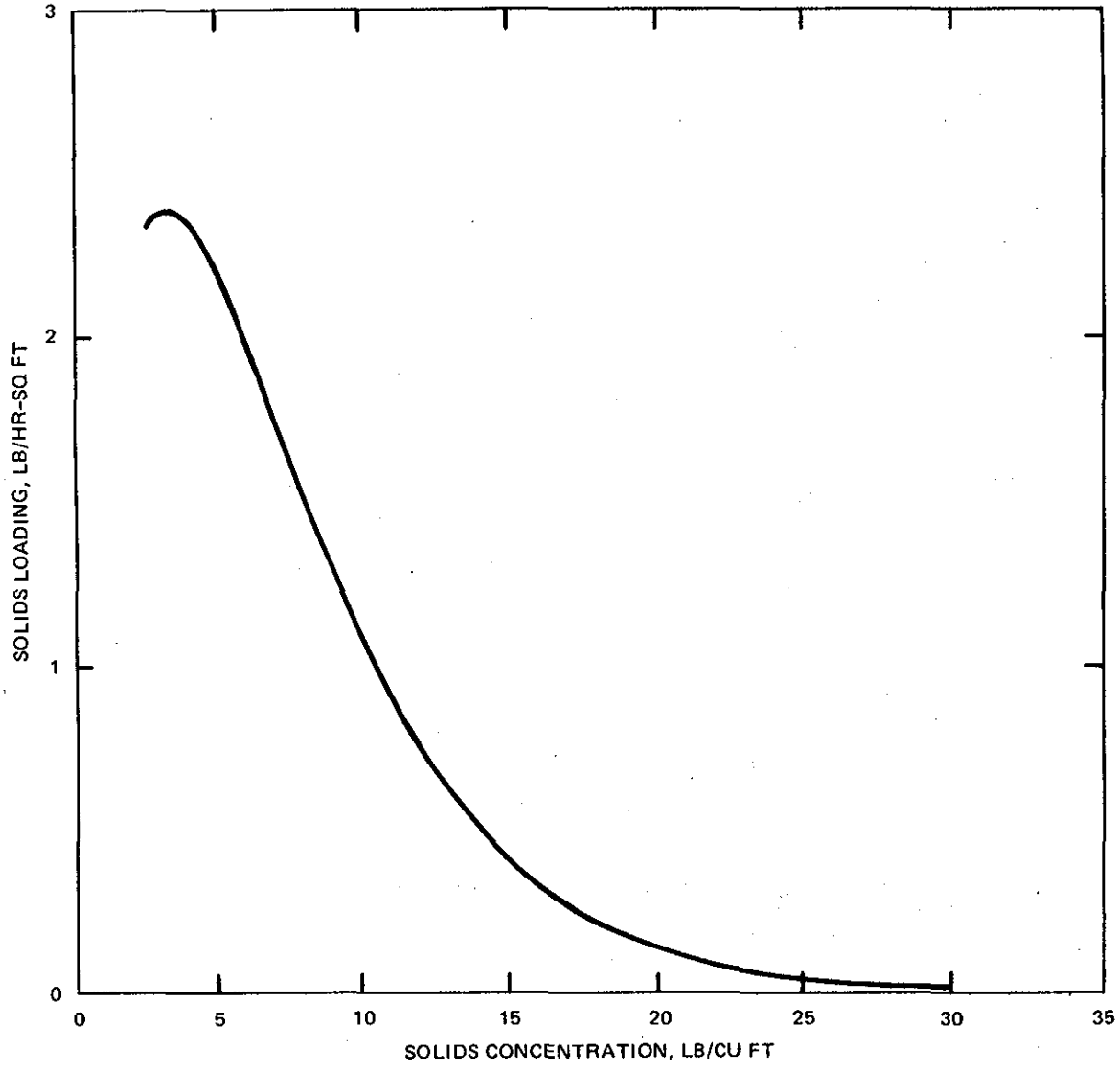


Figure 5. Solids loading curve

generate two curves (Tables 16-18), the concentration profile curve and the supernatant suspended solids curve (Figures 6-11). The 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 (1, 2, and 3 ft) at the weir. The supernatant suspended solids curves derived from the concentration profile curves compare the effect of retention time on supernatant suspended solids at 1-, 2-, and 3-ft ponding depths. This curve shows that increasing the

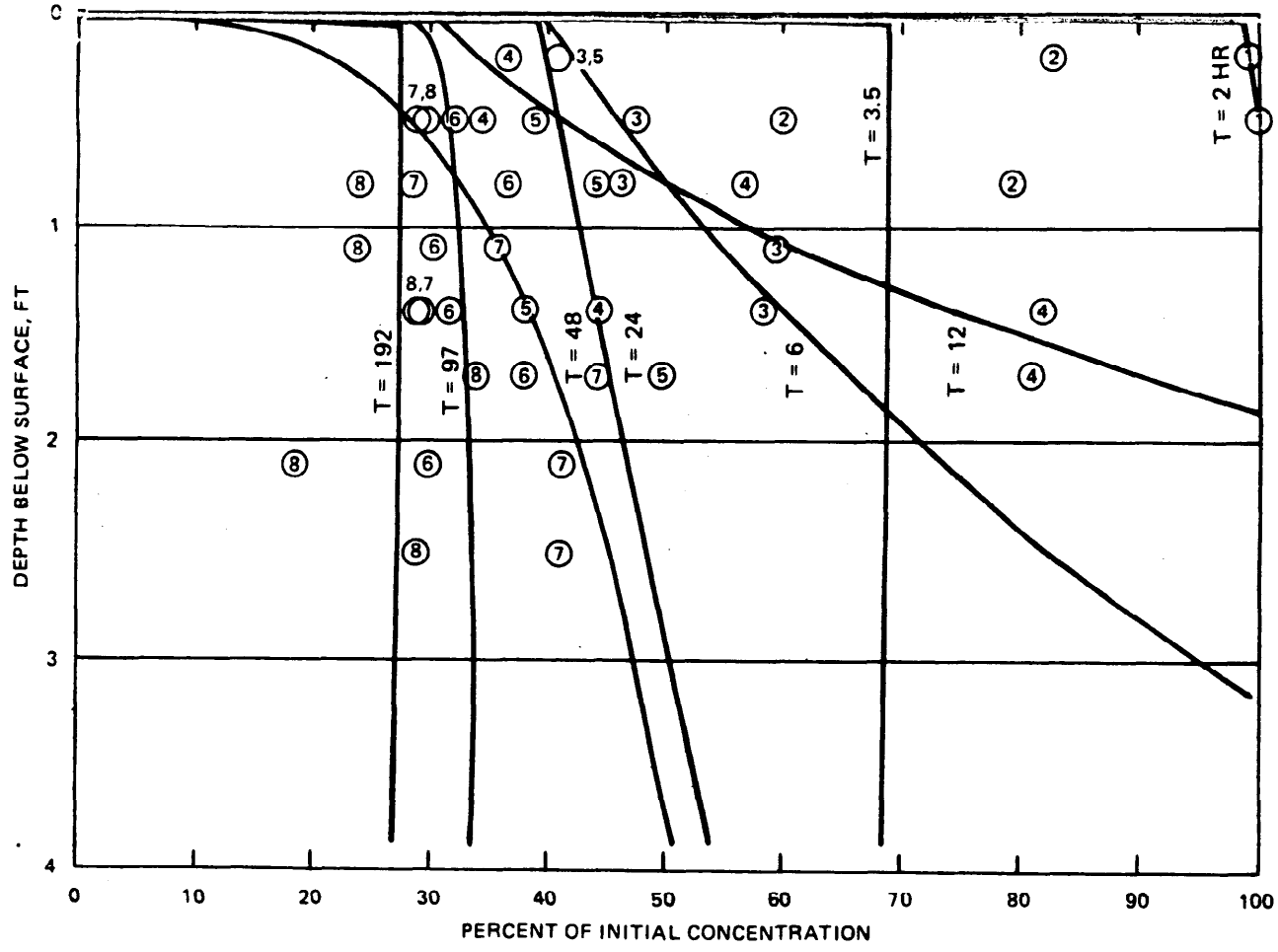


Figure 6. Composite solids concentration profile curve

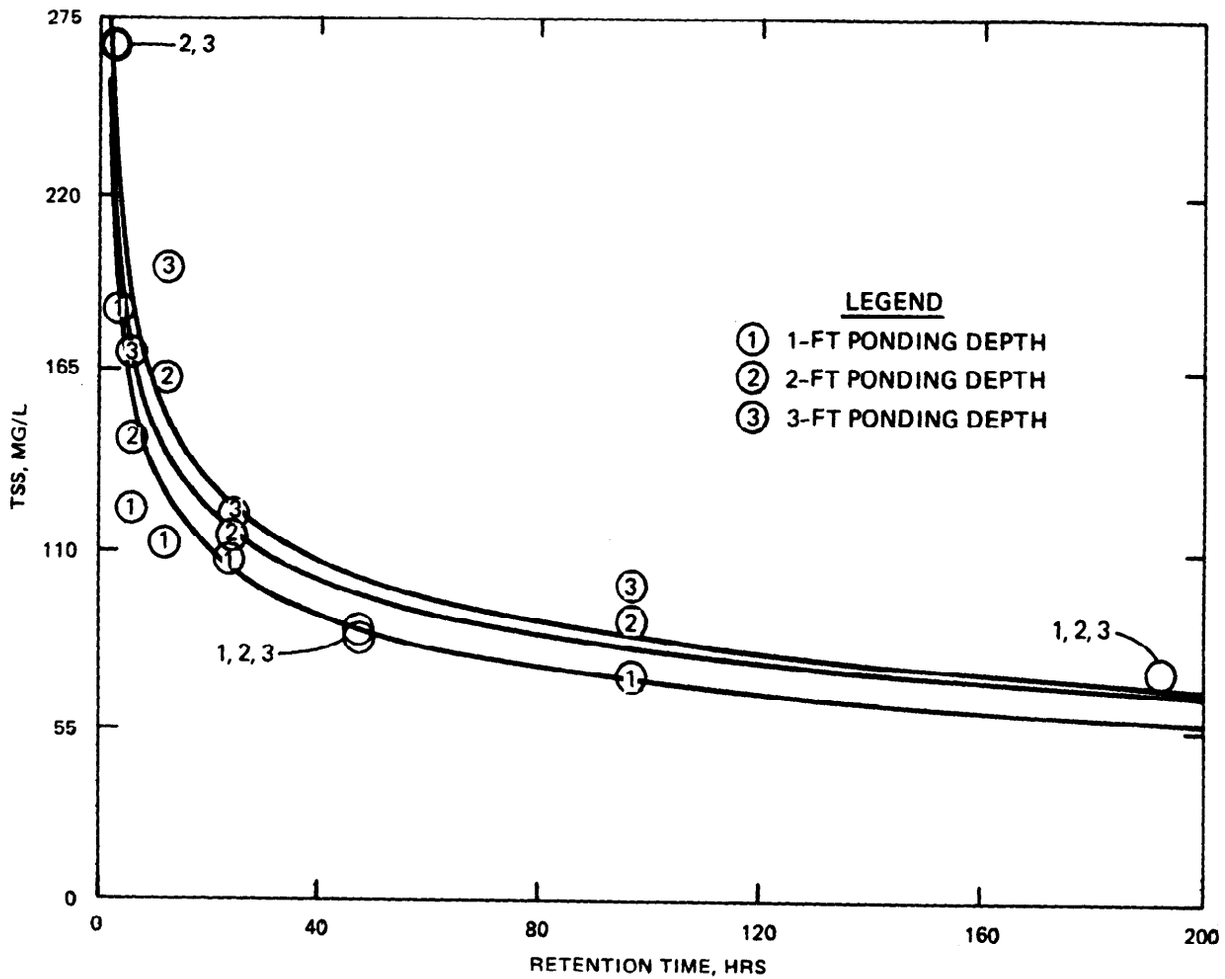


Figure 7. Composite supernatant suspended solids curve

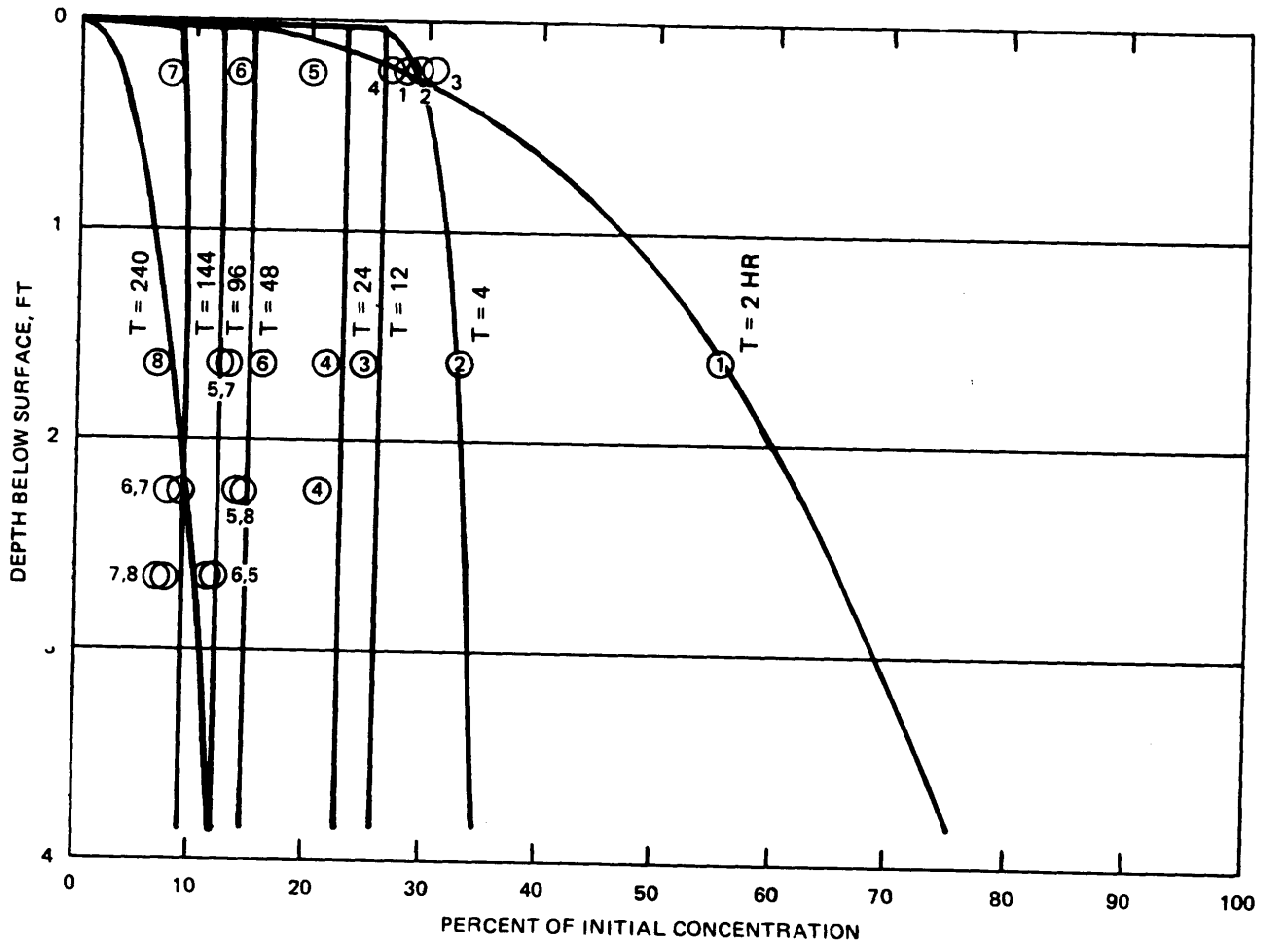


Figure 8. Hot spot solids concentration profile curve

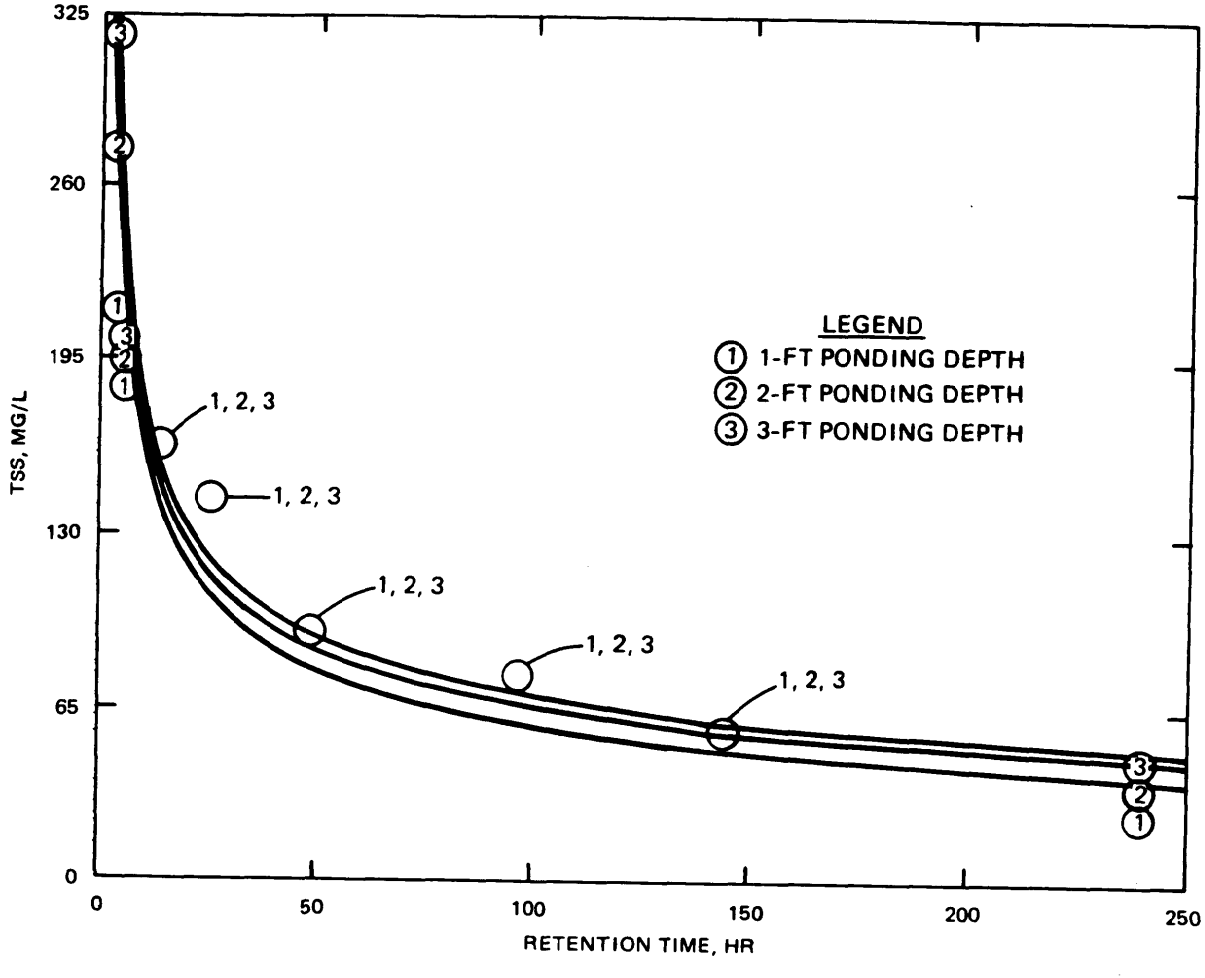


Figure 9. Hot spot supernatant suspended solids curve

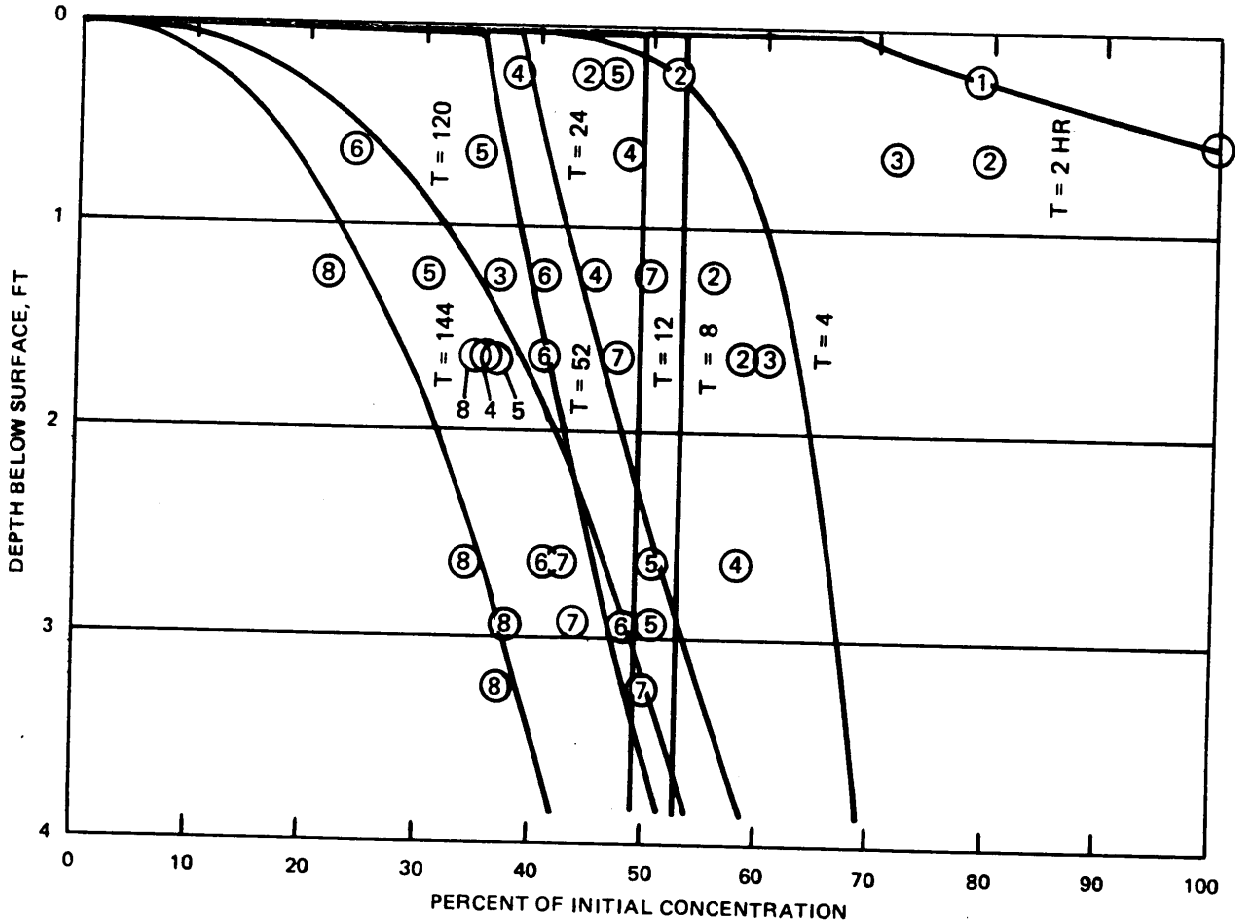


Figure 10. Capping material solids concentration profile curve

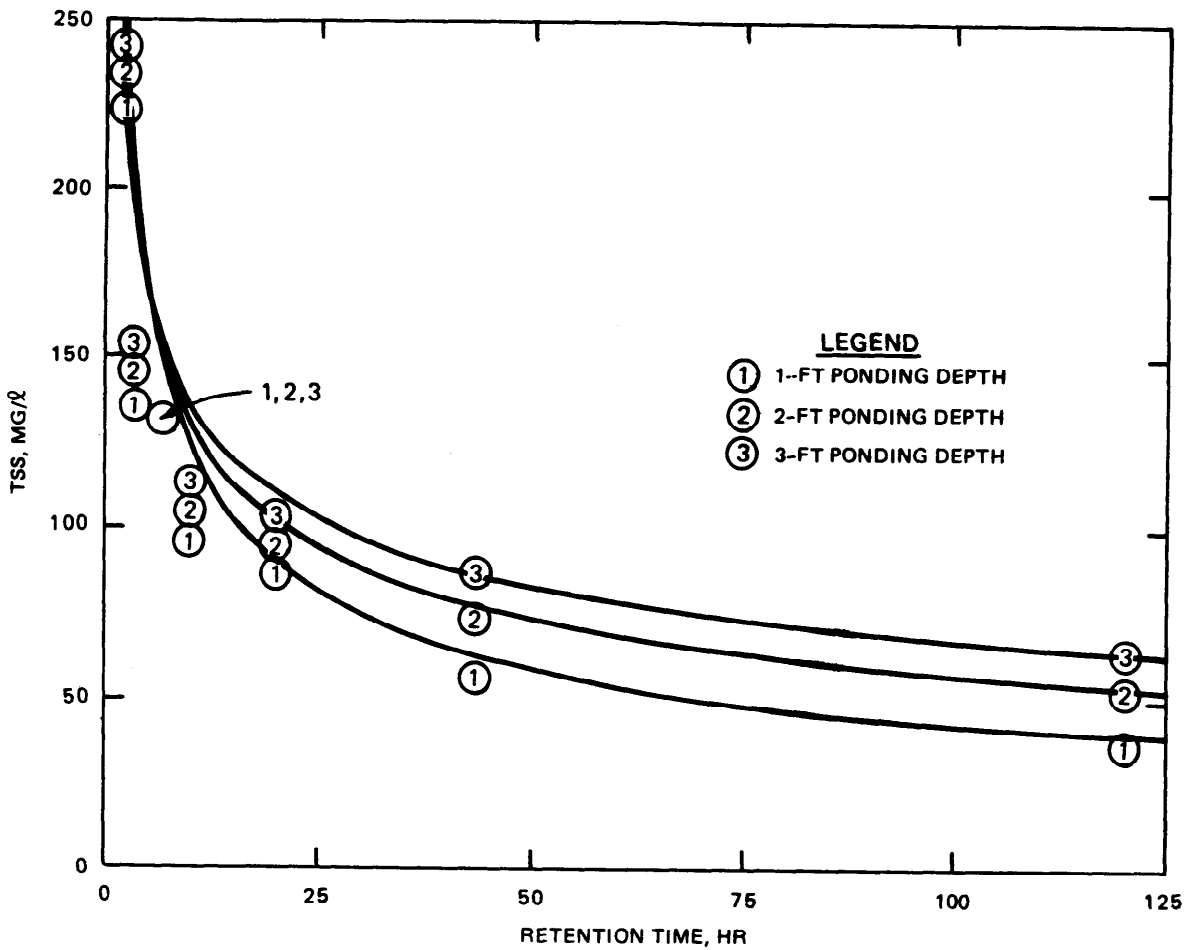


Figure 11. Capping material supernatant suspended solids curve

retention time beyond 40 hr provides little additional improvement in supernatant suspended solids concentration.

31. The hot spot material supernatant suspended solids at the 2-ft ponding depth settled more efficiently than the upper estuary composite and potential capping sediments, resulting in a slightly lower supernatant solids concentration (Figure 12). In other words, better suspended solids removal is possible with hot spot material as compared with upper estuary composite sediment at a given retention time. Actual field suspended solids will be greater because of resuspension by wind and wave action. The resuspension factor is approximately 1.5, depending on ponding depth and surface area (Palermo 1985).

Evaluation of Polymers for Chemical Clarification

32. Both qualitative and quantitative test observations were made during each test procedure. Qualitative observations included floc size and capture of fines. Quantitative observations included initial suspended solids,

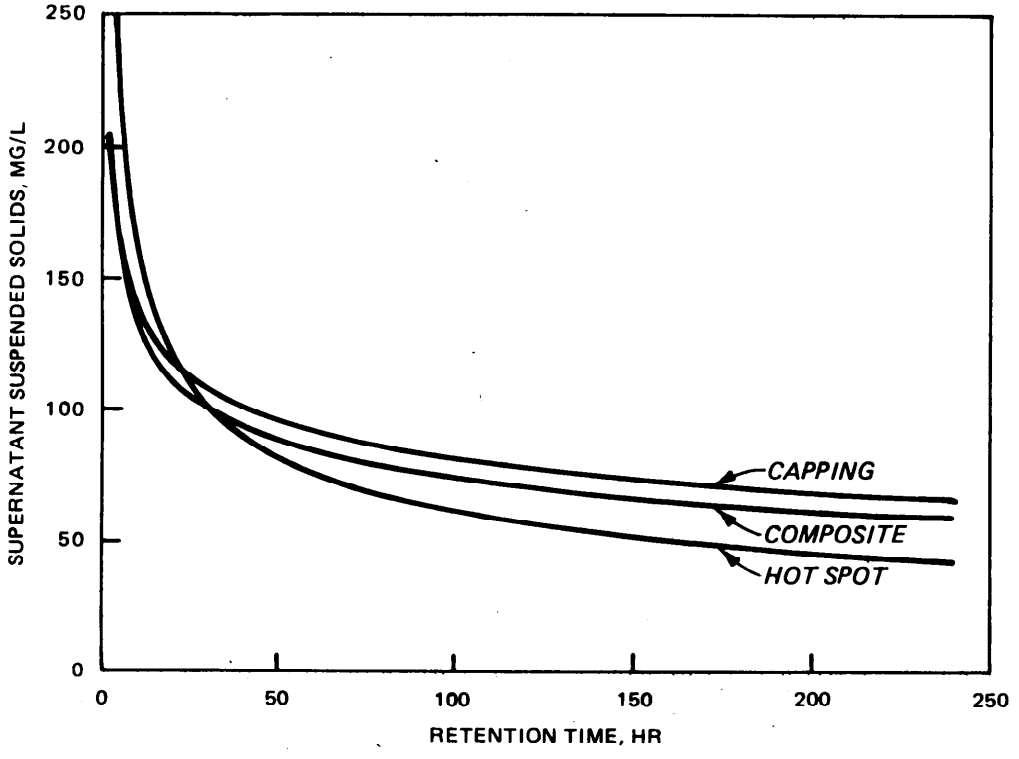


Figure 12. Supernatant suspended solids curve at 2-ft ponding depth

polymer dosage, and supernatant suspended solids following flocculation and settling.

Polymer screening

33. The polymers that were screened included 27 cationic, 8 anionic, and 1 nonionic polymer. Seven cationics and two anionics were evaluated in combination. Table 19 lists the polymers that were evaluated during this study. Polymer dosages ranged from 0.5 to 75 ppm for polymers used alone and from 5.5 to 58 ppm combined for polymers used in combination. Based on results of the initial screening process, most of the polymers were not effective for the upper estuary composite sediment. The polymers used in combination slightly improved performance, but the improvement was insufficient to justify the additional cost and the feeding and mixing requirement for two polymers.

Polymer optimization

34. Ten cationic and five anionic polymers were selected for optimization. Figure 13 illustrates the typical curve of suspended solids versus dosage for each polymer. The optimum dosage was determined as that resulting in the minimum value for supernatant suspended solids. For example, the optimum dosage for Magnifloc 1586C, illustrated in Figure 13, is 15 ppm, resulting in a supernatant suspended solids concentration of 37 mg/ℓ.

Polymer selection

35. Based on the results of the optimization testing, an appropriate polymer and chemical dosage concentration can be selected. The primary selection factors are suspended solids removal effectiveness and cost. The liquid polymers were found to be ineffective when applied to the New Bedford Harbor supernatant and were eliminated from further consideration.

36. Following the initial screening for suspended solids removal effectiveness, the remaining polymers were subjected to a preliminary cost comparison. This was accomplished by calculating the estimated cost per ton of solids removed for each polymer. The results of this analysis are summarized in Table 20.

37. The emulsion polymers and a dry polymer had the lowest optimum dosage and cost. However, because of the complexity of using dry polymers in the field, the emulsion polymers may be preferred. Magnifloc 1586C was selected as having the greatest potential for application to the New Bedford project in the EFS evaluation of dredging and dredged material disposal alternatives.

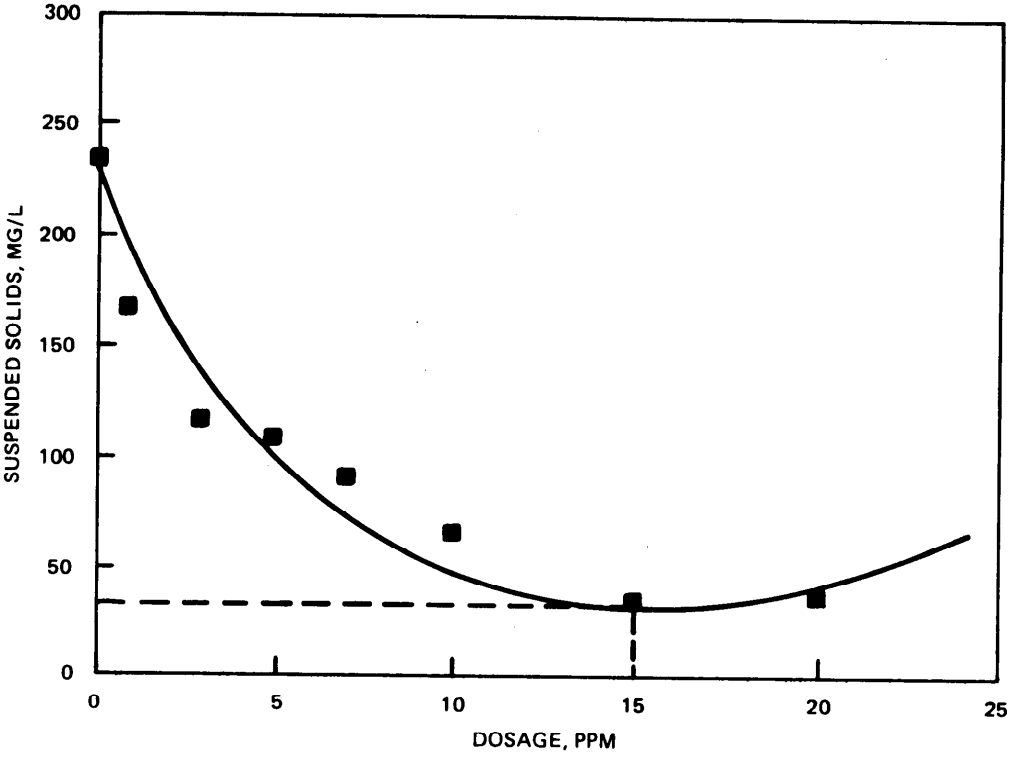


Figure 13. Polymer optimum dosage curve, Magnifloc 1586C

PART IV: APPLICATION OF RESULTS TO CONCEPTUAL DESIGN OF A TYPICAL CONFINED DISPOSAL FACILITY

Sediment Characteristics

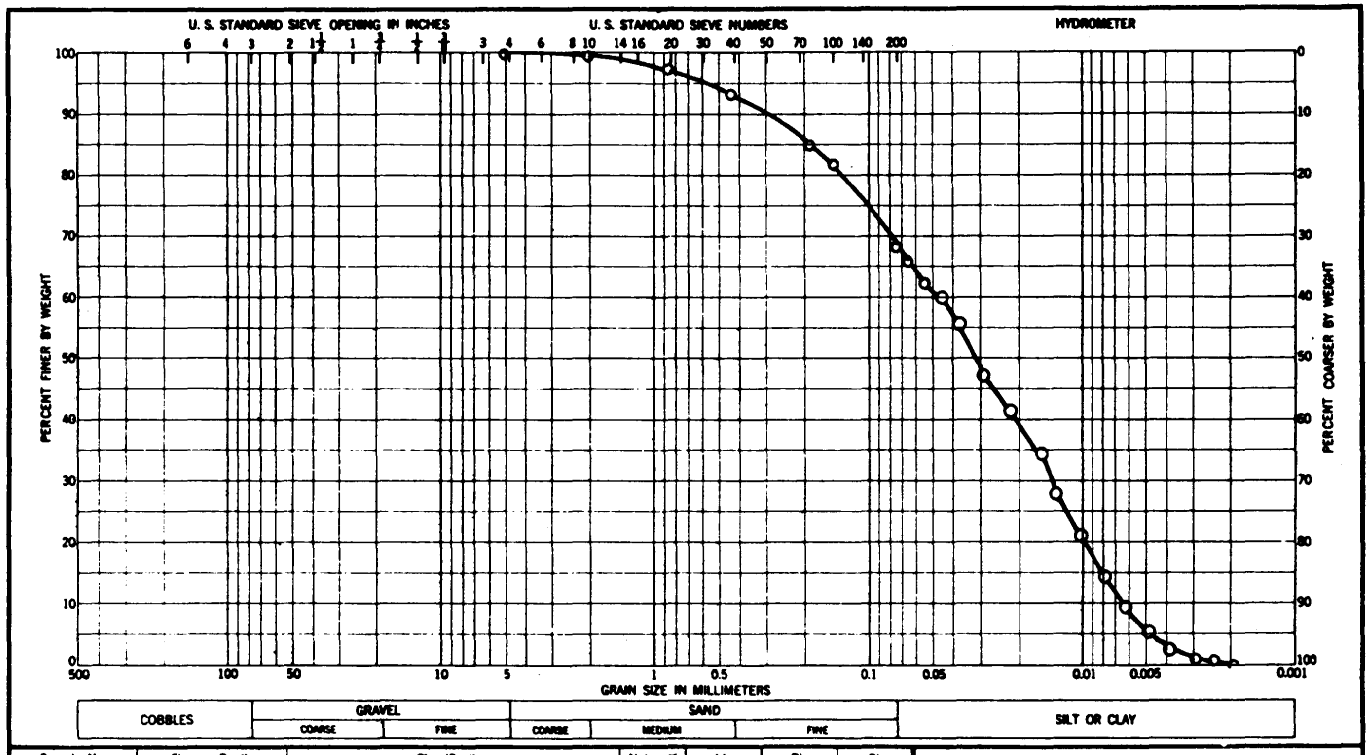
38. Sediment characteristics of the dredged material are important in the design of a CDF. A grain size distribution curve of the upper estuary composite sample is shown in Figure 14. The typical sediment characteristic values for the upper estuary are listed below.

Sediment Characteristic	Upper Estuary Composite
Initial water content	110
Specific gravity	2.5
Initial void ratio	2.8
Liquid limit	105
Percent sand	43

Predominant Unified Soil Classification System classifications are organic silts and clays (OH and OL) with silty sands (SM).

Typical Project Conditions

39. Preliminary design of a CDF also requires knowledge of specific project conditions. The dredge production rate, dredge flow rate, site capacity, dike height, sediment storage depth, ponding depth, and freeboard depth are needed. For the purpose of illustrating how to use the information developed in this study, the following project conditions are assumed: (a) the dredging equipment is expected to dredge at an effective production rate of 800 cu yd/day; (b) site capacities of 100,000 and 300,000 cu yd represent the available range; (c) the dredged material slurry flow rate is 3,200 cu yd/day for a slurry concentration of 125 g/ℓ; and (d) the dike, storage, ponding, and freeboard depths are 12, 8, 2, and 2 ft, respectively.



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI
27		DARK GRAY - SANDY ORGANIC SILT (OH)				

Project NEW BEDFORD, MA

Area COMPOSITE

Lab ser. no. 100-452-27

Date 29 JAN 87

GRADATION CURVES

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Figure 14. Grain size distribution curve

Design for Initial Storage

40. First, consider a site that will hold 100,000 cu yd of dredged material. Because this material has the tendency to bulk (increase in volume), the amount of material to be dredged will be less than 100,000 cu yd. The equations used are as follows:

$$BF = FC + \frac{(1 - FC)(1 + e_o)}{1 + e_i}$$

$$e_o = \frac{G_s \times 1{,}000}{C_d} - 1$$

where

BF = bulking factor

FC = percent coarse grain

e_o = dredged material final void ratio in CDF

e_i = initial void ratio, estuary sediment

G_s = specific gravity

C_d = design solids concentration

$= 221 \times T^{0.1054}$ (upper estuary composite)

A bulking factor of 1.59 was determined, yielding 64,000 cu yd of sediment to be dredged for this site. If an available site will hold 300,000 cu yd of material, 205,000 cu yd of sediment with a bulking factor of 1.46 can be dredged. The bulking factors differ because the dredging times were 80 days for a bulking factor of 1.59 and 256 days for a bulking factor of 1.46. The dredging time is then divided by 2 to obtain the average dredging time or T. This procedure is done by trial-and-error. The results are particularly sensitive to the initial voids ratio, which is calculated from the water content of the in situ sediment.

Predicted Effluent Suspended Solids Concentrations

41. After the dredged material has been dredged and placed in the containment area, solids that have not settled by gravity will remain suspended

in the water column. The solids that are suspended will flow over the weir structure. The concentration of the suspended solids is needed to determine the effectiveness of the containment area and to determine if any effluent regulations will be violated.

42. The effluent (supernatant) suspended solids concentration is determined as follows:

$$\begin{aligned}
\text{Total settling volume} &= 100{,}000 \text{ cu yd} \times 2 \text{ ft}/10 \text{ ft} \\
&= 20{,}000 \text{ cu yd (ponding depth represents only 20 percent of total depth)} \\
\text{Theoretical detention time} &= 20{,}000 \text{ cu yd}/3{,}200 \text{ cu yd/day} \\
&= 6.3 \text{ days} \\
\text{Hydraulic efficiency} &= 0.9\ [1 - \exp(-0.3L/W)] \\
&= 0.23 \text{ (assuming length-to-width ratio is 1)}
\end{aligned}$$

The hydraulic efficiency factor is applied due to containment area inefficiencies (Shields, Schroeder, and Thackston 1987).

$$\begin{aligned}
\text{Retention time} &= 6.3 \text{ days} \times 0.23 \\
&= 1.45 \text{ days}
\end{aligned}$$

43. The effluent suspended solids curve (Figure 7), a retention time of 1.45 days, and a 2-ft ponding depth yield a suspended solids concentration of 108 mg/ℓ in the column. A resuspension factor of 1.5 is recommended for a ponding depth of 2 ft or greater and a surface area less than 100 acres. The effluent suspended solids concentration estimated for the field conditions is 162 mg/ℓ. For the 300,000-cu yd site, a retention time of 18.8 days produces an effluent suspended solids concentration of 126 mg/ℓ including resuspension.

Design of Typical Chemical Clarification Components

44. Polymer-assisted clarification of a CDF effluent requires equipment to dilute and feed the polymer, to rapidly mix the polymer solution with the supernatant, to slowly mix the flocculent solids to encourage particle-to-particle contact and agglomeration, and to settle the flocculated suspension.

Optimum efficiency for these processes may be attained by designing a conventional water treatment plant. However, it may be possible to achieve adequate effluent treatment or pretreatment with a simpler system that has been demonstrated on other dredging projects. Components needed for a simple chemical clarification system for treating CDF effluent are weirs, corrugated metal pipe or culvert, 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 coagulated suspended solids. This section provides an example of the design approach for these auxiliary components of a CDF.

Weir

45. The purpose of the weir is to regulate the release of ponded water from the containment area. To design a weir to regulate the ponded water, several assumptions must be made. The dredged material slurry flow rate is assumed to be 400 cu yd per hour or 3,200 cu yd per day for an effective production time of 8 hr per day. The dredged material exhibits zone settling for the untreated material entering the primary containment area and flocculent settling for the treated material entering the secondary containment area. A rectangular weir will be designed to maintain 2 ft of ponding depth in each containment area.

46. Figure 15 illustrates the relationship between effective weir length and ponding depth necessary to discharge a given flow without entraining settled material (EM 1110-2-5027, USACE 1987). Using the assumptions mentioned earlier and Figure 15, construct a horizontal line at the design flow of 3 cfs (400 cu yd/hr) and the 2-ft ponding depth. A vertical line drawn at the point of intersection of the horizontal ponding depth line and the zone settling operation line yields a weir loading rate of 0.85 cfs/ft (see Figure 16). For 3 cfs, a weir length of 3.5 ft is required. Because of current uncertainties in the actual flow rates of the dredges to be selected and because in the final stages a ponding depth of less than 2 ft may occur, a safety factor of 2 will be applied to the design, yielding a weir length for the primary area of 7 ft.

47. A weir length of 8 ft is required for the secondary containment area. The procedure is the same as above except flocculent settling will occur instead of zone settling, and a deeper ponding depth (3 ft) could be made available in the secondary area (Figure 16).

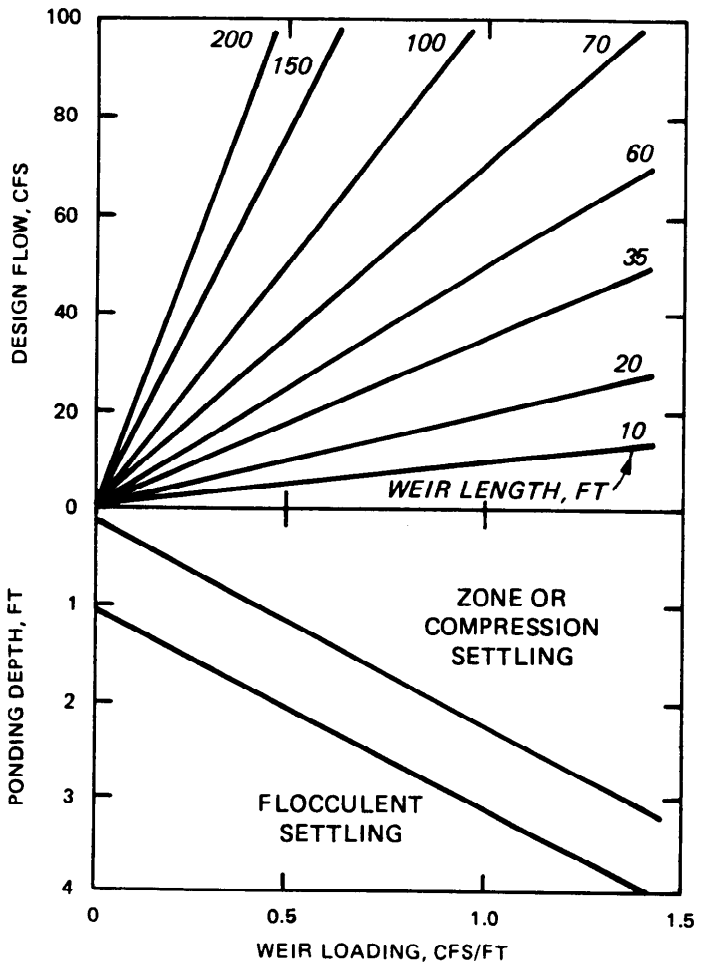


Figure 15. Weir design nomograph

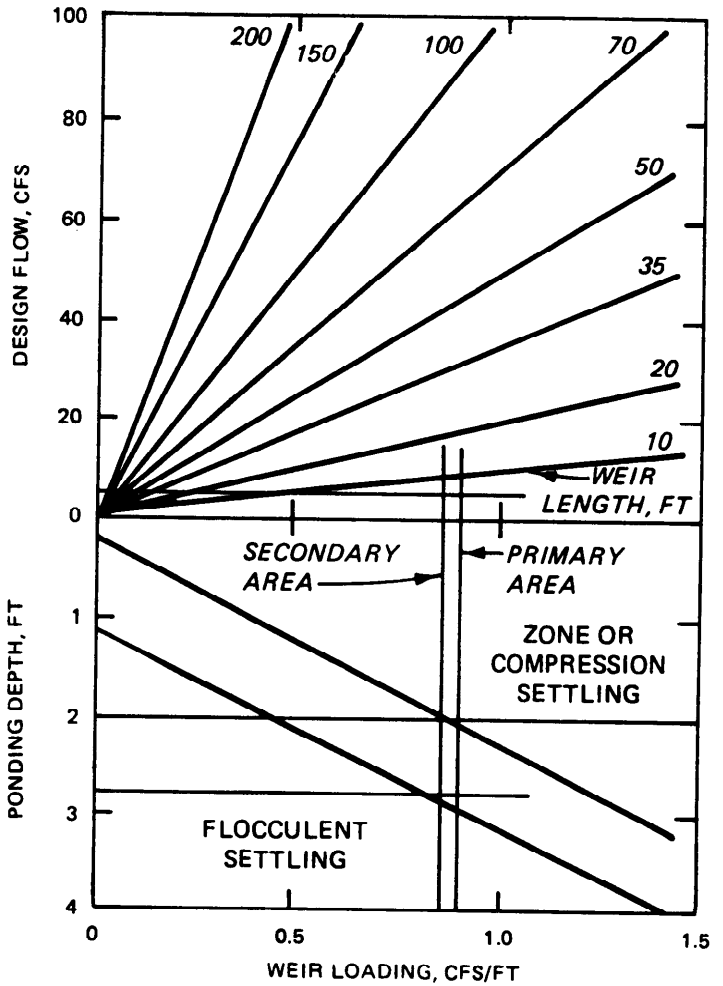


Figure 16. Example of a weir design

Polymer mixing and flocculation system

48. Weir box. The primary containment area should have a retention time greater than 24 hr at the 2-ft ponding depth. This will allow most of the settleable solids to settle by gravity, leaving the nonsettleable solids suspended in the effluent. The effluent from the primary containment area will drop over a weir into a weir box (see Figure 17). As the effluent drops into the weir box, a polymer will be injected uniformly over the entire weir length. The 0.8-ft drop into the weir box will provide adequate rapid mixing for the polymer and effluent. A weir box of the dimensions 9 (L) by 3 (W) by 5 ft (D) will provide adequate mixing and retention time. This will provide adequate mixing with a mean velocity gradient G of 178 per second, which is calculated using a flow rate of 3 cfs and a Gt of 8,000 (Schroeder 1983). Discharge from the weir box will be through a culvert.

49. Discharge culvert. The discharge culvert is designed to provide the required slow mixing. Design parameters include length, diameter, and number of culverts that will maximize slow mixing. A detailed procedure is outlined in Schroeder (1983). For an 800-cu yd per day production rate, a 15-in.-diam, 100-ft-long culvert is needed. The culvert will provide adequate mixing with a Gt value of approximately 8,000. The head difference between the primary and secondary containment area is 1.7 ft (see calculations in the next section). This head must be maintained so that the culvert will provide adequate mixing.

50. The design approach is to size the culvert for the maximum flow rate and the minimum available head and then to calculate the available mixing

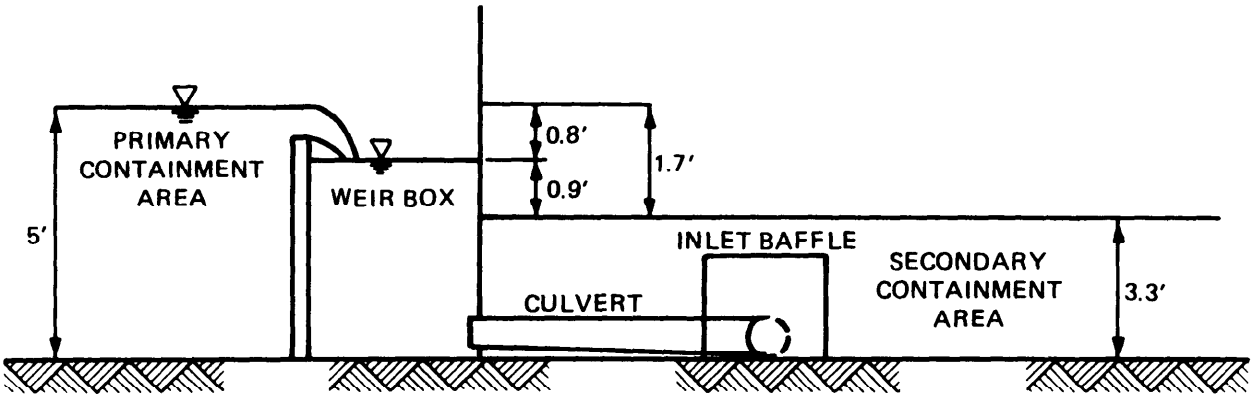


Figure 17. Weir mixing system

under average flow conditions. Assuming a 3-cfs flow rate, a head difference of 2 ft between the primary and secondary containment areas, a head loss through the culvert of 1.25 ft, and culvert lengths of 10, 50, and 100 ft based on the containment area design, the culvert design may proceed as follows:

a. If

D = culvert diameter, ft
Q = maximum flow rate, cfs
L = culvert length, ft
g = 32.2 ft/sec^2
H = maximum head loss through the culvert, ft
N = number of parallel culverts

then,

$$D = \left\{ \frac{8Q^2\left[1.5D^{4/3} + 185(0.025)^2 L\right]}{g\pi^2 H N^2} \right\}^{3/16}$$

$$H = \left[1.5 + \frac{185(0.025)^2 L}{D^{4/3}}\right] \left(\frac{8Q^2}{g\pi^2 N^2 D^4}\right)$$

$$L = \left(\frac{g\pi^2 H N^2 D^4}{8Q^2}\right) - 1.5\left[\frac{D^{4/3}}{185(0.025)^2}\right]$$

b. The calculated minimum diameters for the following numbers and lengths of culverts are

N	L, ft	D, ft	D, in.
1	10	0.85	10.2
1	50	1.06	12.7
1	100	1.18	14.2
2	10	0.64	7.6
2	50	0.80	9.7
2	100	0.90	10.8

c. The selected commercial sizes and calculated lengths are

N	D, in.	L, ft
1	12	35
1	15	139
2	8	14
2	10	62
2	12	178

d. The mean velocity (v) and friction factor (f) at average flow are

N	D, in.	v, fps	f
1	12	2.86	0.1156
1	15	1.83	0.1073
2	8	3.22	0.1324
2	10	2.06	0.1229
2	12	1.43	0.1156

Also,

$$Gt = \sqrt{\frac{\gamma_s f v L^2}{2 g \mu_s D}}$$

$$v = \frac{4\bar{Q}}{\pi D^2}$$

where

γ_s = specific weight, 62.4 lb/ft^3

f = friction factor

= $185n^2/D^{1/3}$ (n = Manning's coefficient, 0.025 for corrugated metal pipes)

v = mean velocity at average flow, fps

μ_s = absolute viscosity, 2.36×10^{-5} $lb\text{-}sec/ft^2$ at 60° F

$\bar{Q}$ = average flow rate, cfs

= Q × (production ratio, 0.75)

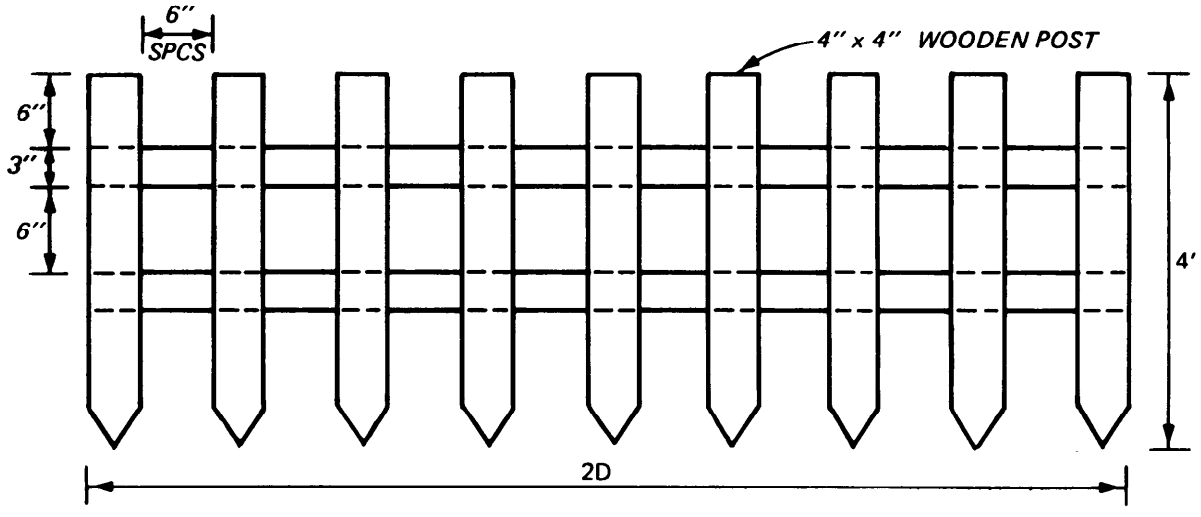
e. Mixing at average flow:

N	D, in.	L, ft	G, sec^{-1}	t, sec	Gt
1	12	35	334	12.1	4,043
1	15	139	147	76.2	11,195
2	8	14	519	4.5	2,333
2	10	62	230	30.1	6,924
2	12	178	118	124.4	14,656

f. Generally, a Gt of about 8,000 provides adequate mixing for flocculation. Either one 15-in.-diam, 139-ft-long culvert or two 12-in.-diam, 178-ft-long culverts could be used. However, one 15-in.-diam culvert would be the best design since it would provide shorter culvert length.

51. If a culvert length of 139 ft is too long for this secondary containment area, the next step is to design for a shorter culvert length with a 15-in.-diam culvert. Designing for a Gt value of 8,000, the culvert length is then reduced to 100 ft. The final step is to determine if the head loss will provide enough energy for adequate mixing through the culvert. Using the head loss equation and the new culvert diameter and length, the maximum head loss is 0.94 ft. The head difference between the primary and secondary containment areas is 1.7 ft.

52. Inlet baffle. An inlet baffle at the end of the culvert will reduce the effects of short-circuiting and turbulent flow and assist in distributing the flow laterally (Schroeder 1983). The inlet baffle should be placed 3 to 4 ft directly in front of the culvert discharge with a width of twice the distance from the baffle to the culvert discharge. The height should be approximately 2 ft above the bottom of the containment area. A slotted baffle may be made of 4- by 4-in. wooden posts spaced 6 in. apart (Figure 18).



D - DISTANCE FROM THE CULVERT TO THE BAFFLE

Figure 18. Slotted baffles

Secondary containment area

53. The secondary containment area has to be sized to provide adequate retention time for good settling and sufficient volume for storage of settled material. The total volume of the containment area is the sum of the ponded

volume and the storage volume. Ponded volume is based on the flow rate and the required retention time. Storage volume is based on the solids concentration entering the containment area, the depth of settled solids, the treated effluent volume, and the concentration of settled material.

54. To have good settling, a ponded depth of at least 2 ft and a mean retention time of at least 60 min are required. To account for hydraulic inefficiencies, a theoretical retention of 150 min for ponded volume is recommended. To reduce short-circuiting, a length-to-width ratio of at least 3:1 is required for the secondary containment area.

55. The settling properties of flocculated dredged material resulting from chemical clarifications are very fluid. The settled material is expected to accumulate near the culvert inlet. However, studies have shown that the kinetic energy of the inflow is capable of keeping the inlet clear of material. Studies also have shown that the average concentrations of settled material at the interface between the supernatant and settled layer are 50 g per litre, and the concentrations increase with increasing depth at a rate of 25 g/ℓ/ft. Therefore, deeper basins store more material in a given volume due to compaction (USACE 1987).

56. Using the following project information, an example secondary containment area size may be designed:

a. Project information.

Volume of sediment to be dredged	64,000 cu yd
Primary effluent solids concentration	162 mg/ℓ
Secondary effluent solids concentration	81 mg/ℓ
Volume to be treated	1.47×10^8 ℓ
Depth available for storage and ponding	4 ft
Average flow rate	3 cfs

b. Volume of settled treated material (assuming a storage depth of 1 ft).

$$\text{Mass of settled material} = (0.162 - 0.081)\ \text{g/ℓ} \times 1.47 \times 10^8\ \text{ℓ}$$
$$= 1.19 \times 10^7\ \text{g}$$

Average concentration of settled material

$$= [(2 \times 50\ \text{g/ℓ}) + (25\ \text{g/ℓ/ft} \times 1\ \text{ft})]/2$$
$$= 62.5\ \text{g/ℓ}$$

This estimate of the average concentration of settled material is based on a sediment concentration at the interface between the supernatant and settled layer of 50 g/ℓ. The concentration increases with increasing depth at a rate of 25 g/ℓ/ft.

Volume of settled material

$= 1.19 \times 10^7$ g/62.5 g/ℓ

= 190,212 ℓ

= 6,718 ft^3 or 0.15 acre-ft

c. Required area based on storage.

Area = 0.15 acre-ft/1 ft

= 0.15 acre

d. Volume of ponding based on retention time.

Ponded volume = 3 cfs × (150 min)(60 sec/min)

= 27,000 ft^3 or 0.62 acre-ft

e. Required area based on ponding.

Area = 0.62 acre-ft/3 ft

= 0.21 acre

Since the surface area is the larger of the two areas required, the surface area is then 0.21 acre. A detailed procedure is outlined in Schroeder (1983).

Polymer feed system

57. The polymer feed system should be designed to handle a liquid polymer of low viscosity. This type of polymer will minimize handling, pumping, and any dilution problems that occur. A more detailed discussion of this is given in EM 1110-2-5027.

58. Storage. For a 100,000-cu yd site containing 64,000 cu yd of sediment, 685 gal of polymer would be required to be stored onsite in thirteen 55-gal drums (see calculations below). The polymer will be pumped directly from the drums to an in-line static mixer by a polymer pump. These drums will have to be protected against freezing.

59. The volume of polymer required is based on the assumption that 192,000 cu yd of effluent from the primary CDF will be treated. The optimum polymer dosage is 15 mg/ℓ. The specific weight of the polymer is 8.5 lb/gal. Thus,

Volume of polymer required, gal

$$= \frac{192{,}000 \text{ cu yd} \times 764.4 \ \ell/\text{cu yd} \times 15 \text{ mg}/\ell}{8.5 \text{ lb/gal} \times 454{,}000 \text{ mg/lb}}$$

= 685 gal (with a 1.2 safety factor)

60. Concentrated polymer pumping. The concentrated polymer should be dispensed using a positive displacement pump. The pump should be capable of discharging between the range of 0.002 to 0.08 gpm to handle the possible range of required polymer dosages and flow rates of water to be treated. The average polymer feed rate is based on the average flow rate, the polymer optimum dosage, and the specific weight of polymer (see calculations below).

Average feed rate, gpm

$$= \frac{3 \text{ cfs} \times 15 \text{ mg}/\ell \times 28.31 \ \ell/\text{ft}^3 \times 60 \text{ sec/min}}{8.5 \text{ lb/gal} \times 454{,}000 \text{ mg/lb}}$$

= 0.02 gpm

The polymer pump flow capabilities should range between 0.1 and 4 times the average feed rate. The pump range is 0.002 to 0.08 gpm.

61. Polymer dilution. The polymer must be diluted with water to reach a polymer concentration of 0.5 percent. Therefore, the water pump must be able to discharge at a rate of 8.1 gpm (see calculations below). The polymer and dilution water will be mixed using an in-line static mixer.

62. The polymer dilution pump rate is based on the specific weight of the polymer, the average polymer feed rate, and the final polymer concentration of 0.5 percent (or 5 g/ℓ). The dilution factor must be 204. At the average polymer flow rate, the required dilution water flow rate would be 4.1 gpm. The dilution water pump capacity should be twice this rate to dilute higher polymer flows adequately. Therefore, the dilution water flow rate should be

Polymer dilution rate, gpm

$$= \frac{8.5 \text{ lb/gal} \times 2 \times 0.02 \text{ gpm}}{5 \text{ g}/\ell \times 1 \text{ lb}/454 \text{ g} \times 3.785 \ \ell/\text{gal}}$$

= 8.1 gpm

63. Water may be obtained from the treated supernatant from the secondary containment area, a tanker truck located onsite, or a branch off a nearby water distribution system. The dilution water must be clean and free of any debris that may cause mechanical pump problems and hender the effectiveness of the polymer on the dredged material effluent.

64. Injector and feed line. The injection system should distribute the polymer uniformly throughout the water as it flows over the weir. The system will distribute the polymer solution from a 1-in.-diam polyvinyl chloride (PVC) pipe at the leading edge of the weir. The PVC pipe must have 1/8-in.-diam holes that will dispense the polymer along the entire weir length at a uniform rate. The feed lines may be constructed of rubber hoses or PVC pipe. However, a PVC pipe must be used for the polymer injection system.

Static mixer

65. The static mixer is an in-line mixer that will mix the polymer and dilution water to the final desired concentration. These devices are commercially available.

PART V: CONCLUSIONS

66. Based on the results of the settling and chemical clarification tests, it is concluded that:

a. Settling tests for the upper estuary composite, hot spot, and potential capping sediment samples exhibited zone settling behavior typical of other saline sediments tested.

b. The hot spot sediment is not expected to densify to as great a solids concentration in a confined disposal facility as the upper estuary composite or potential capping sediments.

c. Effluent total suspended solids concentrations after 24 hr of settling under laboratory conditions were 140, 151, and 150 mg/ℓ for the upper estuary composite, hot spot, and potential capping sediment samples, respectively.

d. Chemical clarification using polymer addition is a potentially effective treatment process for removing suspended solids from CDF effluents generated by disposal of New Bedford Superfund Site dredged material. Additional suspended solids removal by the addition of Magnifloc 1586C was 82 percent in laboratory jar tests.

e. Low-viscosity, highly cationic emulsion polymers were found to be the most effective, economical, and simplest to use for a simulated New Bedford Harbor site effluent developed by using the upper estuary composite sediment sample and estuary site water.

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Table 1

Composite Sediment Compression Test Data

Date	Time hr	Time Interval hr	Time Interval days	Interface Depth ft
21 Jul	1120	0.00		--
	1137	0.28		5.03
	1153	0.55		4.73
	1205	0.75		4.51
	1222	1.03		4.22
	1237	1.28		4.08
	1253	1.55		3.96
	1305	1.75		3.93
	1320	2.00		FI
	1335	2.25		FI
	1350	2.50		FI
	1405	2.75		FI
	1420	3.00		FI
	1435	3.25		FI
	1456	3.60		3.66
	1520	4.00		3.65
	1553	4.55		3.59
	1605	4.75		3.57
	1720	6.00		3.50
	1820	7.00		3.44
	1920	8.00		3.39
	2120	10.00		3.32
	2220	11.00		3.29
	2320	12.00		3.26
	0120	14.00		3.21
22 Jul	1120	24.00	1.00	3.05
23 Jul	1120	48.00	2.00	2.85
24 Jul	1120	72.00	3.00	2.74
25 Jul	1220	97.00	4.04	2.64
27 Jul	2035	153.25	6.39	2.52
28 Jul	1120	168.00	7.00	2.49
29 Jul	1120	192.00	8.00	2.45
30 Jul	1120	216.00	9.00	2.43
31 Jul	1120	240.00	10.00	2.40
1 Aug	1120	264.00	11.00	2.39
2 Aug	1120	288.00	12.00	2.36
4 Aug	1120	336.00	14.00	2.32
5 Aug	1120	360.00	15.00	2.30

Note: The initial slurry solids concentration and initial interface depth were 130.2 g/ℓ and 5.20 ft, respectively.

* Interface was at the column's flange; therefore, no reading.

Table 2

Hot Spot Sediment Compression Test Data

Date	Time hr	Time Interval hr	Time Interval days	Interface Depth ft
13 Jun	0930	0.00		--
	0947	0.28		5.48
	1000	0.50		5.32
	1015	0.75		5.20
	1030	1.00		5.12
	1045	1.25		5.05
	1100	1.50		5.02
	1115	1.75		4.98
	1130	2.00		4.94
	1145	2.25		4.91
	1200	2.50		4.88
	1215	2.75		4.85
	1230	3.00		4.83
	1245	3.25		4.81
	1300	3.50		4.79
	1315	3.75		4.77
	1330	4.00		4.75
	1345	4.25		4.74
	1420	4.83		4.70
	1450	5.33		4.67
	1530	6.00		4.64
	1600	6.50		4.61
	1630	7.00		4.60
	1700	7.50		4.59
	1810	8.17		4.53
	2130	12.00		4.44
14 Jun	0930	24.00	1.00	4.21
15 Jun	0945	48.25	2.01	3.94
17 Jun	0930	96.00	4.00	3.67
18 Jun	0930	120.00	5.00	3.58
19 Jun	0945	144.25	6.01	3.56
22 Jun	0900	215.50	8.98	3.34
23 Jun	0930	240.00	10.00	3.30
24 Jun	0930	264.00	11.00	3.26
25 Jun	0930	288.00	12.00	3.22
26 Jun	0930	312.00	13.00	3.20
28 Jun	0930	360.00	15.00	3.14

Note: The initial slurry solids concentration and initial interface depth were 133.8 g/ℓ and 5.65 ft, respectively.

Table 3

Capping Sediment Compression Test Data

Date	Time hr	Time Interval hr	Time Interval days	Interface Depth ft
29 Jul	1055	0.00		--
	1110	0.25		5.50
	1130	0.58		5.35
	1140	0.75		5.25
	1155	1.00		5.15
	1210	1.25		5.03
	1225	1.50		4.91
	1240	1.75		4.79
	1255	2.00		4.68
	1310	2.25		4.59
	1325	2.50		4.48
	1340	2.75		4.36
	1357	3.03		4.24
	1410	3.25		4.14
	1425	3.50		4.04
	1440	3.75		3.94
	1450	3.92		3.87
	1525	4.50		3.63
	1540	4.75		3.51
	1555	5.00		3.39
	1610	5.25		3.29
	1625	5.50		3.23
	1640	5.75		3.21
	1655	6.00		3.17
	1710	6.25		3.14
	1725	6.50		3.12
	1740	6.75		3.10
	1755	7.00		3.08
	1855	8.00		3.02
	1925	8.50		2.99
	1955	9.00		2.97
	2040	9.75		2.94
	2055	10.00		2.93
	2125	10.50		2.91
	2155	11.00		2.89
	2225	11.25		2.88
	2255	12.00		2.86
	2325	12.50		2.84
	0025	13.50		2.82
30 Jul	1055	24.00	1.00	2.60
31 Jul	1055	48.25	2.00	2.36
3 Aug	1055	96.00	5.00	2.10
4 Aug	1055	120.00	6.00	2.06
5 Aug	1055	144.25	7.00	2.02
10 Aug	1115	215.50	12.01	1.90
11 Aug	1237	240.00	13.03	1.89
12 Aug	1055	264.00	14.00	1.89
13 Aug	1023	288.00	14.98	1.88
14 Aug	1025	383.50	15.98	1.87

Note: The initial slurry solids concentration and initial interface depth were 108.6 g/ℓ and 5.64 ft, respectively.

Table 4

Composite Sediment Zone Test Data

Slurry Concentration, 181.3 g/ℓ

18 Aug Time, hr	Time Interval hr	Interface Depth ft
0908	0.00	--
0930	0.37	5.44
0945	0.62	5.33
1000	0.87	5.27
1015	1.12	5.21
1030	1.37	5.19
1045	1.62	5.15
1100	1.87	5.12
1115	2.12	5.10
1130	2.37	5.08
1145	2.62	5.05
1200	2.87	5.03
1209	3.02	5.01
1223	3.25	4.99
1238	3.50	4.98
1253	3.75	4.96
1323	4.25	4.93
1338	4.50	4.92
1355	4.75	4.90
1408	5.00	4.89
1423	5.25	4.88
1438	5.50	4.86
1453	5.75	4.85
1508	6.00	4.84
1523	6.25	4.83

Note: The initial interface depth was 5.55 ft.

Table 5

Composite Sediment Zone Test Data

Slurry Concentration, 167.4 g/ℓ

19 Aug Time, hr	Time Interval hr	Interface Depth ft
0923	0.00	--
0933	0.17	5.53
0938	0.25	5.48
0943	0.33	5.42
0948	0.42	5.33
0953	0.50	5.23
0958	0.58	5.14
1003	0.67	5.07
1013	0.83	4.93
1018	0.92	4.88
1038	1.25	4.73
1043	1.33	4.71
1053	1.50	4.67
1108	1.75	4.61
1123	2.00	4.57
1138	2.25	4.53
1153	2.50	4.49
1208	2.75	4.46
1238	3.25	4.41
1253	3.50	4.39
1308	3.75	4.36
1323	4.00	4.34
1338	4.25	4.32
1353	4.50	4.30
1408	4.75	4.29
1423	5.00	4.27
1453	5.50	4.24
1508	5.75	4.23

Note: The initial interface depth was 5.56 ft.

Table 6

Composite Sediment Zone Test Data

Slurry Concentration, 148.6 g/ℓ

20 Aug Time, hr	Time Interval hr	Interface Depth ft
1015	0.00	--
1030	0.25	5.54
1045	0.50	5.42
1107	0.87	5.30
1115	1.00	5.29
1130	1.25	5.15
1145	1.50	5.00
1200	1.75	4.95
1215	2.00	4.83
1231	2.27	4.71
1245	2.50	4.57
1300	2.75	4.46
1315	3.00	4.35
1331	3.27	4.29
1345	3.50	4.24
1400	3.75	4.20
1415	4.00	4.16
1435	4.33	4.10
1445	4.50	4.09
1506	4.85	4.04
1518	5.05	4.03
1530	5.25	4.01

Note: The initial interface depth was 5.60 ft.

Table 7

Composite Sediment Zone Test Data

Slurry Concentration, 128.6 g/ℓ

21 Aug Time, hr	Time Interval hr	Interface Depth ft
0852	0.00	--
0907	0.25	5.50
0922	0.50	5.40
0937	0.75	5.30
0945	0.88	5.25
0950	0.97	5.22
0955	1.05	5.20
1000	1.13	5.17
1005	1.22	5.14
1010	1.30	5.12
1015	1.38	5.10
1020	1.47	5.07
1025	1.55	5.05
1030	1.63	5.03
1035	1.72	5.01
1040	1.80	4.99
1045	1.88	4.97
1050	1.97	4.95
1055	2.05	4.93
1105	2.22	4.88
1110	2.30	4.85
1115	2.38	4.83
1120	2.47	4.81
1125	2.55	4.79
1130	2.63	4.77
1135	2.72	4.75
1152	3.00	4.69
1222	3.50	4.59
1239	3.78	4.52
1252	4.00	4.47
1307	4.25	4.41
1322	4.50	4.34
1337	4.75	4.28
1352	5.00	4.22
1407	5.25	4.15
1422	5.50	4.08
1437	5.75	4.01
1452	6.00	3.93

Note: The interface depth was 5.58 ft.

Table 8

Composite Sediment Zone Test Data

Slurry Concentration, 114.2 g/ℓ

22 Aug Time, hr	Time Interval hr	Interface Depth ft
0830	0.00	--
0845	0.25	5.51
0900	0.50	5.42
0915	0.75	5.35
0930	1.00	5.29
0945	1.25	5.21
1000	1.50	5.15
1015	1.75	5.08
1030	2.00	5.01
1100	2.50	4.91
1115	2.75	4.86
1130	3.00	4.81
1145	3.25	4.75
1200	3.50	4.70
1215	3.75	4.64
1230	4.00	4.59
1245	4.25	4.54
1303	4.55	4.45
1315	4.75	4.41
1332	5.03	4.34
1347	5.28	4.29
1400	5.50	4.24
1415	5.75	4.17
1430	6.00	4.10
1445	6.25	4.02
1500	6.50	3.95

Note: The initial interface depth was 5.60 ft.

Table 9

Composite Sediment Zone Test Data

Slurry Concentration, 116.8 g/ℓ

7 Aug Time, hr	Time Interval hr	Interface Depth ft
1000	0.00	--
1015	0.25	5.40
1030	0.50	5.35
1045	0.75	5.30
1100	1.00	5.25
1115	1.25	5.20
1132	1.53	5.12
1145	1.75	5.05
1200	2.00	5.00
1215	2.25	4.93
1230	2.50	4.89
1245	2.75	4.82
1300	3.00	4.78
1315	3.25	4.71
1330	3.50	4.65
1345	3.75	4.59
1402	4.03	4.52
1430	4.50	4.41
1445	4.75	4.36
1500	5.00	4.29
1530	5.50	4.12
1545	5.75	4.03
1600	6.00	3.92
1615	6.25	3.88

Note: The initial interface depth was 5.45 ft.

Table 10

Composite Sediment Zone Test Data

Slurry Concentration, 104.1 g/ℓ

8 Aug Time, hr	Time Interval hr	Interface Depth ft
1043	0.00	--
1055	0.20	5.29
1112	0.48	5.15
1125	0.70	5.06
1140	0.95	4.96
1156	1.22	4.88
1214	1.52	4.80
1225	1.70	4.74
1242	1.98	4.65
1300	2.28	4.58
1312	2.48	4.52
1325	2.70	4.46
1413	3.50	4.17
1425	3.70	4.09
1440	3.95	3.99
1455	4.20	3.89
1530	4.78	3.70
1555	5.20	3.66
1610	5.45	3.63

Note: The initial interface depth was 5.35 ft.

Table 11

Composite Sediment Zone Test Data

Slurry Concentration, 95.2 g/ℓ

11 Aug Time, hr	Time Interval hr	Interface Depth ft
1118	0.00	--
1148	0.50	5.40
1203	0.75	5.33
1220	1.03	5.24
1237	1.32	5.16
1248	1.50	5.10
1303	1.75	5.05
1318	2.00	4.96
1333	2.25	4.88
1348	2.50	4.80
1403	2.75	4.73
1418	3.00	4.66
1433	3.25	4.59
1448	3.50	4.51
1503	3.75	4.42
1518	4.00	4.34
1533	4.25	4.29
1548	4.50	4.17
1603	4.75	4.09
1618	5.00	4.01
1633	5.25	3.92

Note: The initial interface depth was 5.51 ft.

Table 12

Composite Sediment Zone Test Data

Slurry Concentration, 80.5 g/ℓ

12 Aug Time, hr	Time Interval hr	Interface Depth ft
0845	0.00	--
0915	0.50	5.47
0930	0.75	5.36
0945	1.00	5.26
1000	1.25	5.16
1015	1.50	5.06
1030	1.75	5.96
1045	2.00	4.86
1100	2.25	4.78
1115	2.50	4.69
1130	2.75	4.60
1145	3.00	4.52
1208	3.42	4.40
1216	3.52	4.36
1230	3.75	4.27
1245	4.00	4.19
1300	4.25	4.11
1315	4.50	4.02
1330	4.75	3.94
1425	5.50	3.63
1450	5.75	3.52
1475	6.00	3.41

Note: The initial interface depth was 5.60 ft.

Table 13

Composite Sediment Zone Test Data

Slurry Concentration, 68.4 g/ℓ

13 Aug Time, hr	Time Interval hr	Interface Depth ft
0845	0.00	--
0900	0.25	5.39
0915	0.50	5.26
0930	0.75	5.13
0945	1.00	5.00
1000	1.25	4.87
1015	1.50	4.75
1030	1.75	4.61
1045	2.00	4.49
1100	2.25	4.38
1115	2.50	4.26
1130	2.75	4.14
1145	3.00	4.01
1200	3.25	3.92
1233	3.80	3.69
1245	4.00	3.60
1300	4.25	3.47
1315	4.50	3.36
1330	4.75	3.25
1345	5.00	3.14
1402	5.25	3.03

Note: The initial interface depth was 5.50 ft.

Table 14

Composite Sediment Zone Test Data

Slurry Concentration, 61.4 g/ℓ

14 Aug Time, hr	Time Interval hr	Interface Depth ft
0815	0.00	--
0830	0.25	5.40
0845	0.50	5.22
0900	0.75	5.04
0915	1.00	4.85
0930	1.25	4.67
0945	1.50	4.50
1000	1.75	4.32
1015	2.00	4.14
1030	2.25	3.97
1115	3.00	3.54
1130	3.25	3.39
1145	3.50	3.25
1200	3.75	3.14
1215	4.00	3.01
1245	4.50	2.80
1300	4.75	2.74

Note: The initial interface depth was 5.53 ft.

Table 15

Composite Sediment Zone Test Data

Slurry Concentration, 50.0 g/ℓ

15 Aug Time, hr	Time Interval hr	Interface Depth ft
0815	0.00	--
0830	0.25	5.25
0835	0.33	5.17
0845	0.50	5.00
0900	0.75	4.75
0915	1.00	4.50
0930	1.25	4.25
0945	1.50	4.04
1015	2.00	3.64
1030	2.25	3.44
1045	2.50	3.25
1100	2.75	3.09
1115	3.00	2.92
1130	3.25	2.80
1149	3.47	2.64
1200	3.75	2.55
1215	4.00	2.48

Note: The initial interface depth was 5.50 ft.

Table 16

Composite Sediment Flocculent Settling Test, Suspended Solids Concentration, mg/ℓ

Time hr	Depth from Top of Settling Column, ft							
	0.20	0.50	0.80	1.20	1.40	1.70	2.20	2.40
0.0	268.8*	268.8	268.8	BI**	BI	BI	BI	BI
3.5	221.6	160.4	212.8	367.4	BI	BI	BI	BI
6.0	240.4	127.1	122.9	159.1	156.5	BI	BI	BI
12.0	97.7	91.1	152.1	115.6	220.0	217.5	BI	BI
24.0	108.7	104.3	119.5	82.6	102.2	133.3	BI	BI
48.0	--	79.2	97.9	80.9	85.1	102.1	80.4	BI
97.0	--	77.8	76.2	95.5	118.6	117.8	111.1	110.6
192.0	--	85.1	64.4	63.8	77.8	90.5	50.0	77.8

Note: The slurry concentration was 130.2 g/ℓ.

* Concentration at highest port used as initial supernatant concentration.

** Port is below interface, and no sample was collected at this time interval.

Table 17

Hot Spot Sediment Flocculent Settling Test, Suspended Solids Concentration, mg/ℓ

Time hr	Depth from Top of Settling Column, ft			
	0.25	0.65	1.25	1.65
0.0	628.6*	628.6	BI**	BI
2.0	176.0	348.5	BI	BI
4.0	181.5	206.3	BI	BI
12.0	189.3	154.6	BI	BI
24.0	168.6	134.4	130.9	BI
48.0	124.5	80.1	88.5	71.0
96.0	86.6	95.3	53.8	70.0
144.0	52.7	81.4	56.2	45.6
240.0	--	44.7	85.7	49.7

Note: The slurry concentration was 133.8 g/ℓ.

* Concentration at highest port used as initial supernatant concentration.

** Port is below interface, and no sample was collected at this time interval.

Table 18

Capping Sediment Flocculent Settling Test, Suspended Solids Concentration, mg/ℓ

Time hr	Depth from Top of Settling Column, ft					
	0.24	0.64	1.24	1.64	2.64	2.84
0.0	298.6*	298.6	BI**	BI	BI	BI
2.0	235.2	315.7	BI	BI	BI	BI
4.0	134.4	222.8	165.9	174.6	BI	BI
8.0	156.0	198.1	105.6	180.0	BI	BI
12.0	113.8	143.4	133.7	105.3	173.5	BI
24.0	138.4	104.5	91.2	108.5	151.1	151.4
52.0	--	71.9	120.7	122.2	123.6	145.3
120.0	--	--	148.4	141.5	126.3	130.7
144.0	--	--	65.2	103.9	102.7	112.6

Note: The slurry concentration was 108.6 g/ℓ.
* Concentration at highest port used as initial supernatant concentration.
** Port is below interface, and no sample was collected at this time interval.

Table 19

List of Polymers Used for Screening

Manufacturer	Product Code	Product Form	Type	Selection*
Allied Corp.**	Clarifloc A-210	Emulsion	Anionic	
Allied Corp.**	Clarifloc C-1020	Liquid	Cationic	
Allied Corp.**	Clarifloc C-2020	Liquid	Cationic	
Allied Corp.**	Clarifloc C-1005	Liquid	Cationic	
Allied Corp.	Clarifloc C-2005	Liquid	Cationic	
Allied Corp.	Clarifloc C-4450	Emulsion	Cationic	
Betz	1192	Liquid	Cationic	
Betz	1160	Dry	Cationic	
Calgon	WT-2392	Liquid	Cationic	
Calgon	WT-2372	Liquid	Anionic	
Calgon	POL-EZ-7736	Emulsion	Cationic	X
Cyanamide	Magnifloc 1820A	Emulsion	Anionic	
Cyanamide	Magnifloc 581C	Liquid	Cationic	
Cyanamide	Magnifloc 1586C	Emulsion	Cationic	X
Cyanamide	Magnifloc 507C	Liquid	Cationic	
Cyanamide	Magnifloc 572C	Liquid	Cationic	
Cyanamide	Magnifloc 834A	Dry	Anionic	
Nalco	7135	Liquid	Cationic	
Nalco	7109	Liquid	Cationic	
Nalco	8105	Liquid	Cationic	
Nalco	7767	Liquid	Anionic	
Nalco	7133	Emulsion	Cationic	
Nalco	7139	Emulsion	Cationic	
Nalco	8108	Liquid	Cationic	
Nalco	7768	Liquid	Anionic	
Nalco	7763	Liquid	Anionic	
Nalco	7126	Emulsion	Cationic	X
Nalco	7129	Emulsion	Cationic	
Nalco	7134	Liquid	Cationic	
Nalco	7769	Liquid	Anionic	
Nalco	7181	Emulsion	Nonionic	
Nalco	86WP-019	Liquid	Cationic	
Nalco	85WP-258	Liquid	Cationic	

* Polymer selected for optimization.
** Polymer used in combination.

Table 20

Comparison of Polymers Selected for New Bedford Site

Product	Optimum Dosage ppm	Observed Floc Size*	Observed Capture of Fines	Suspended Solids mg/ℓ	Percent Removal	Pounds Polymer/ DT Solids Removed	$/DT/ Removal
Betz 1167L	3	S	Very poor	177.5	4.0	810.8	429.13
Pol-Ez-7736 (Calgon)	3	P+	Very poor	207.5	15.0	163.3	88.20
Magnifloc 1586C	15	L+	Very good	42.5	82.0	155.7	84.10
Nalco 7126	5	M+	Good	145.0	41.0	98.5	91.64

Note: P = pin floc.
S = small floc.
M+ = slightly larger than a medium floc.
L+ = slightly larger than a large (L) floc.
DT = dry ton.

APPENDIX A: POLYMER MAKEDOWN PROCEDURES

0.1-Percent Solution of Drys

1. Measure 100 mg of dry polymer.
2. Add slowly to 40 ml of tap water being agitated on magnetic stirrer.
3. Mix 30 min minimum to dissolve.
4. Add 60 ml of tap water to make total volume of 100 ml.
5. Mix 5 min and observe to ensure solution is completely mixed.

0.5-Percent Solution of Liquids

1. Measure 99.5 ml of tap water.
2. Add 0.5 ml of polymer with a syringe.
3. Mix 5 min on a magnetic stirrer.

0.1-Percent Solution of Emulsions

1. Measure 0.5 ml of emulsion polymer with a syringe.
2. Add to 99.5 ml of tap water being agitated on a magnetic stirrer.
3. Mix for 5 min at high speed. Result is 0.5-percent solution.
4. Take 20 ml of the 0.5-percent polymer solution, place in a 150-ml jar, and mix 30 min minimum.
5. Add 80 ml of tap water and mix an additional 5 min on a magnetic stirrer.