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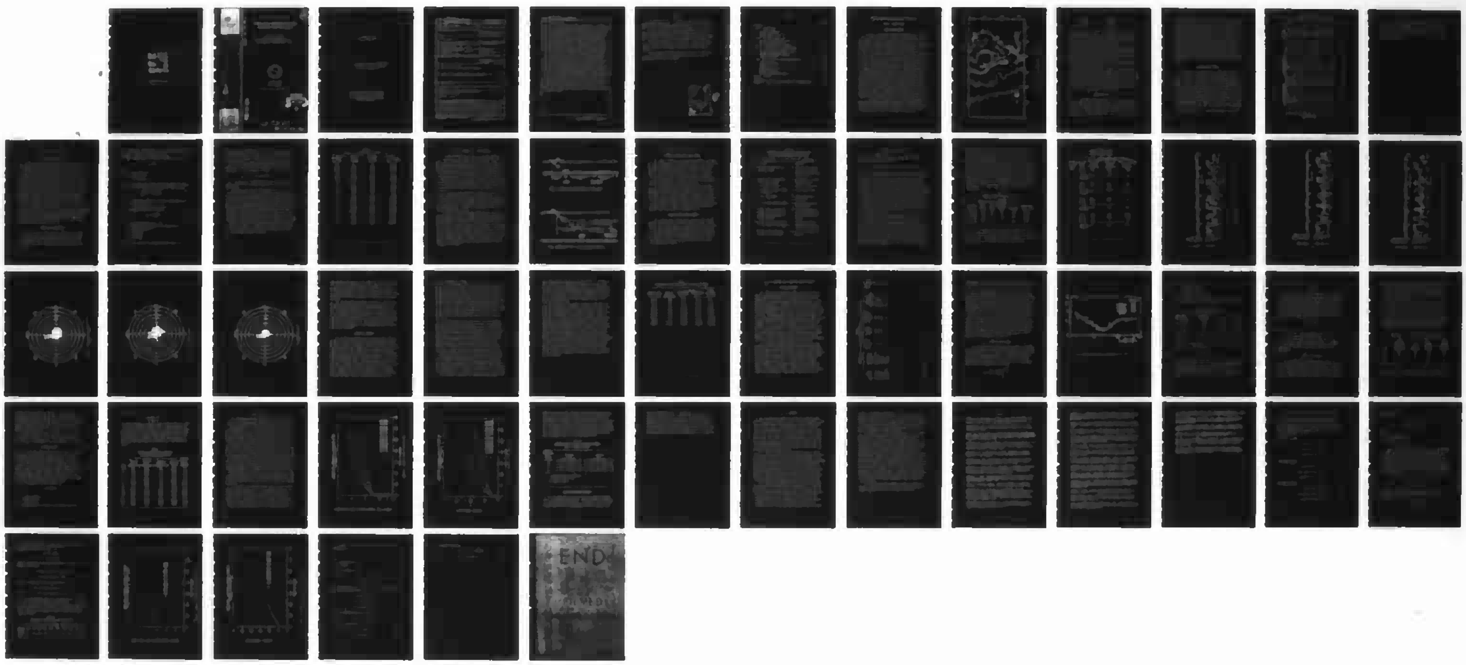

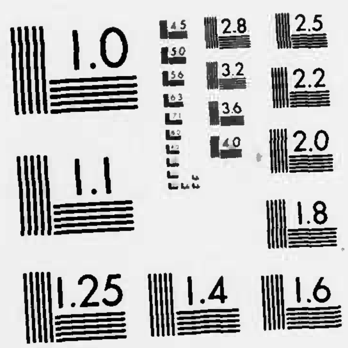

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TAMPA BAY DREDGED MATERIAL DISPOSAL SITE ANALYSIS

by

David T. Williams

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October 1983

Final Report

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Prepared for U. S. Army Engineer District, Jacksonville
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The Jacksonville District is considering an open-ocean disposal site, designated as Alternative Site 4, for placing dredged material from the Tampa Bay Channel Deepening Project and from the annual maintenance of that project. Initial dredging would remove 3.6 million cu yd. The annual maintenance dredging to be placed at the site is predicted to be 0.4 million cu yd. The proposed disposal site is a square, 2 n.m. on each side, located in the Gulf of Mexico 17 n.m. offshore in water 72 ft deep. The material to be disposed is

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predicted to be 35 percent silt and clay, 43 percent sand, and 22 percent gravel. Currents in the area are produced by wind stress, the Gulf loop current, tides, and tropical storms. Of these mechanisms, the first two dominate in time but hurricane currents dominate in magnitude. WES collected current data during a 2-month period, 9 March through 12 May 1983, but no other field data are available for currents. General guidance published in the literature, cite normal Gulf currents of up to 1 knot, and hurricane-generated currents of up to 4 knots can be expected in this vicinity. Wave data for 29 years are available at Fort Myers. Using these data bases, probability density function curves of wave conditions and current speed were developed from which the expected annual value of sediment transport was calculated using a bed shear stress approach. This study was undertaken to predict both the short-term and the long-term fate of sediment placed in Alternative Site 4. The short-term fate refers to the fate of the turbidity plume which forms as the water column entrains sediment during disposal. In this case, the short-term fate was analyzed using a numerical model. The plume was tracked for 15,000 ft (4-1/2 km) from the dump, and by that distance the average concentration had reduced to 2 mg/ℓ, which is the background concentration for ocean water at Site 4. At the point where the plume crossed the boundary of Site 4, the average concentration was 4 mg/ℓ. The amount of sediment entrained in the plume is predicted to be 35 to 40 cu yd per dump or about 2-1/2 percent of the load. Long-term fate refers to the resuspension, transportation, and redeposition of sediment from the primary deposition mound. The critical shear stress approach was used to predict when particles of a given size would become mobile. Both waves and currents were included in the computation of bed shear for resuspension using a Bijker-type equation, but only currents under resuspension conditions were considered in the transportation analysis. Five size classes were identified ranging from clay/silts (0.03-mm particle diameters) to gravels (32-mm diameter). Because the larger particles move more slowly and less frequently than the smaller ones, sorting and armoring processes were included in the analysis. The predicted depth of scour is 0.1 ft (30 mm) per year. In the early years of disposal, this amounts to about 3 percent of the annual volume disposed. By 40 to 45 years, the predicted scour (resuspension) rate will increase to about 20 percent of the annual disposal volume. By about the year 70, the edge of the disposal mound will have reached the boundary of the disposal site and the depth at the center will be 18 ft (5-1/2 m), indicating a useful life for Site 4 of about 70 years. Procedures have been developed to predict the growth of the disposal mound and annual loss rate should the annual maintenance rate change at any point in time.

PREFACE

The determination of short- and long-term fate of open-ocean disposal of dredged material off Tampa Bay, Florida, documented by this report, was performed for the U. S. Army Engineer District, Jacksonville.

The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period March 1983 to August 1983 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. M. B. Boyd, Chief of the Hydraulic Analysis Division.

The work was performed by Mr. D. T. Williams. Technical assistance of Mr. S. B. Heltzel, Mr. W. (Tony) A. Thomas, Dr. R. H. Multer, and Mr. W. H. McAnally is gratefully acknowledged. This report was prepared by Mr. Williams.

Commander and Director of WES during the conduct of this work and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

TAMPA BAY DREDGED MATERIAL DISPOSAL SITE ANALYSIS

PART I: INTRODUCTION

Problem Description

1. The U. S. Army Engineer District, Jacksonville (SAJ), is proposing a new open-water disposal site for Tampa Harbor dredged material. This site, shown in Figure 1, would receive 3.6 million cu yd of dredged material from the Tampa Harbor channel deepening project plus an estimated 0.4 million cu yd/year of maintenance dredging. Approximately 0.7 million cu yd/year will be placed in diked areas with expected life of 25 to 30 years. The purpose of this study is to predict the short- and long-term fate of the disposed sediment material in the open-water site and the resulting useful life of the site. Short-term fate refers to the turbidity plume formed during the dump operation as sediment descending through the water column is entrained into the water. Only a small percent of the dump is of sufficiently small particles to be susceptible to forming a turbidity plume. Long-term fate refers to the possible resuspension of the disposed sediment due to wave/current interaction and its potential subsequent removal from the dump site by currents. The scope of this study includes all energy forces acting at the proposed site but is limited to the physical properties of the sediment material and not its chemical or water quality properties. The approach combines field observations at the proposed site, field observations at the existing disposal site, and field observations at other disposal sites with analytical techniques for calculating the size and movement of a sediment plume, the size of the dynamic collapse zone, and the resuspension of a sediment mass in which sorting by particle size and armoring are important.

2. Information in paragraphs 2 and 3 was obtained from Draft, Environmental Impact Statement for Tampa Harbor, Florida (EPA 1982). The proposed site, designated Alternative Site 4, is 17 nautical miles (n.m.) from shore and is square shaped with lengths of 2 n.m. on each side covering an area of 4 sq n.m. The boundary coordinates are:

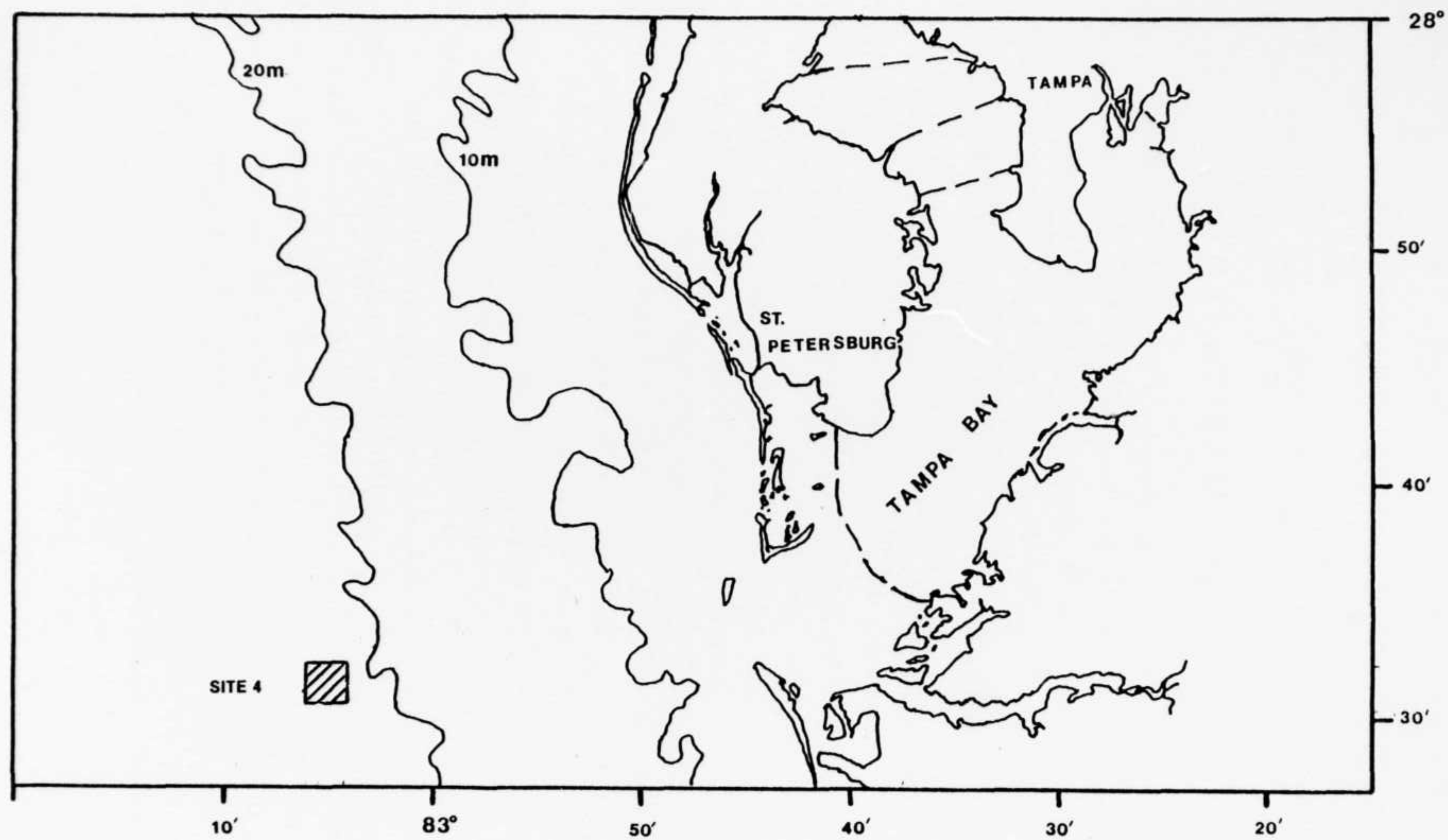

Figure 1. Location of proposed Alternative Site 4

27°32'27" N	83°03'46" W
27°30'27" N	83°03'46" W
27°30'27" N	83°06'02" W
27°32'27" N	83°06'02" W

The continental shelf gradient is generally 0.0005. Water depth at the site is 22 m with very little variation. The sea bottom consists mostly of gently rolling sand with occasional shell fragments. Irregularly, the bottom has a thin veneer of unconsolidated fine sediments. No shipping lanes are near enough to affect operations.

3. Currents in this area have two distinct seasons--summer and winter. Circulatory currents are generally southward in the winter and northward in the summer and tidal currents are generally in east-west directions. Monthly average currents are 10 cm/sec and are influenced mainly by detached cyclonic eddies (fluctuating from 10 to 30 cm/sec) from the Gulf loop current and by wind inducement. Although bottom currents are generally parallel to the surface currents, occasionally a vertical shear of 180 deg can occur.

4. From 9 March 1983 to 12 May 1983 the U. S. Army Engineer Waterways Experiment Station (WES) and SAJ deployed recording current meters at the dump site. ENDECO 105 current meters were placed at two locations, approximately 1 mile apart, oriented north-south in the center of Alternative Site 4. Meters located at the center of the site were placed at 3 ft and 9 ft from the bottom. Another pair of meters, located 1 mile south of the center, was placed at 3 ft and at middepth. Current information is discussed in more detail in paragraph 20.

Disposal Operation

5. The dredging season is generally from February/March to August. For the channel deepening project the material is to be collected by clamshell and loaded for transport into dump scows having a 3,100-cu-yd capacity. The actual load is approximately 2,100 cu yd. The maintenance material will be handled by clamshell/scow equipment or by hopper dredge. One round trip to Alternative Site 4 will require about 6 hr and can be

broken down into the following phases. The loading operation will require about 55 min plus another 10 min to get under way. Although the actual travel time depends on the dredge location, the average travel time to the disposal site is 3 hr. The dump operation involves opening two bin doors on the bottom of the vessel allowing the load to dump. It takes about 5 min with an additional 7 to 8 min to wash the hopper with seawater if material clings to the walls and doors. The return trip requires approximately 2 hr. Within a 24-hr period, 18 hr is usually the actual operation period with 6 hr for maintenance and idle time. Dredging is scheduled as needed and is sometimes discontinued in response to environmental considerations such as migration of marine animals through the disposal area. Disposal activities are halted during significant meteorological events such as frontal systems, tropical storms, and hurricanes and are resumed when conditions are favorable for disposal operation. The information above was obtained from Ms. Barbara Lancaster, Operations Division, SAJ.

Sediment Characteristics

6. Material to be disposed has a low bulking factor of 1.0-1.2 (ratio of volume of water-sediment mixture to volume of sediment). A bulking factor of 1.2 corresponds to a percent moisture content (PMC) of 50 percent (ratio of weight of water to weight of sediment x 100 percent) assuming a specific gravity of sediment of 2.5 relative to seawater. Although sediment gradation variation can be expected, depending on location, the sediment can generally be expected to consist of 22 percent coarser than 2 mm, 43 percent between 2 mm and 0.062 mm, 5 percent between 0.062 mm and 0.004 mm, and 30 percent finer than 0.004 mm (Figure 2).* The writer visited Site 4 and inspected samples of the bottom sediments obtained by divers. The samples were generally composed of medium to coarse sand with a small portion of shell fragments. EPA (1982) has also collected bottom samples at Alternative Site 4 and gradations have been published.

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* Personal Communication, Dr. Lloyd Saunders (January 6, 1983), SAJ.

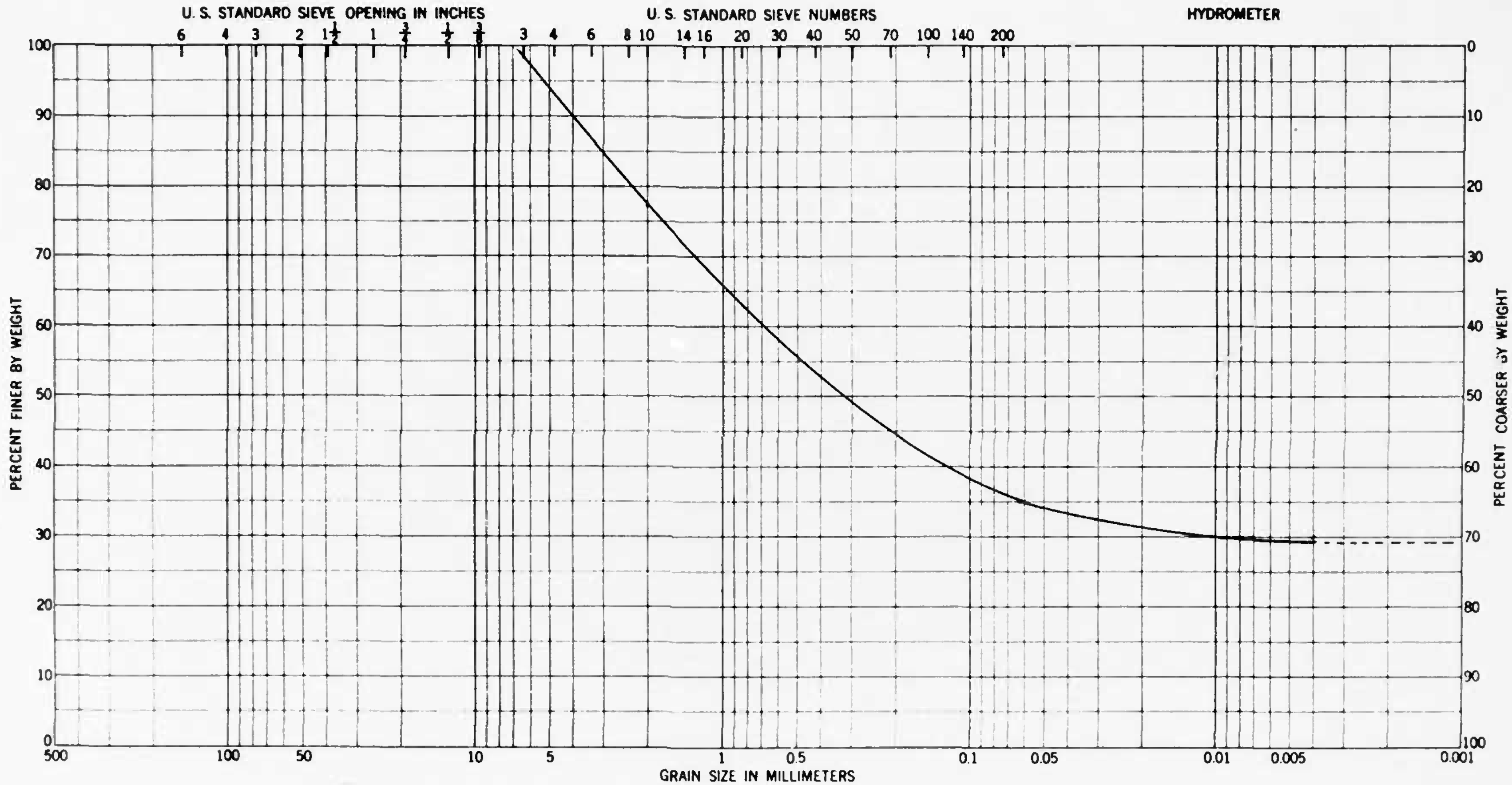

Figure 2. Average grain-size distribution of proposed dredged material

The writer went to EPA in Washington, D. C., and viewed their video tapes of the ocean floor. These tapes were made by dragging a camera-mounted sled in a uniform crisscrossing pattern across the existing sites as well as Site 4. The basic characteristics of the bed are large areas of sand ripples and small dunes, occasional rock outcrops, and unconsolidated fines in the troughs of the dunes. This agrees with the descriptions given by EPA (1982.)

PART II: OCEAN BED CONDITIONS

Review of Available Information

7. Wave data summarized in a Navy Oceanographic Atlas (U. S. Naval Oceanographic Office, 1963) for the Gulf north of 25^{o} N and east of 85^{o} W show that moderate conditions exist over this area most of the time. Monthly differences are small between October and April with about 65 percent of the observations showing wave heights less than 3 ft, 25 percent between 3 and 5 ft, 9 percent between 5 and 12 ft, and 1 percent greater than 12 ft. During May through August, the observations show 85 percent of the wave heights were less than 3 ft, 11 percent were between 3 and 5 ft, 4 percent were between 5 and 12 ft, and less than 1 percent was greater than 12 ft. Values intermediate to those presented were reported in September. Predominant wave directions were from east and northeast from September through February and from east and southeast from March through August. Waves from north and northwest, especially in the fall and winter, tend to have greater heights than those from other directions. Wave periods greater than 9 sec were indicated in only 5 to 6 percent of the sample.

8. Ocean currents at Alternative Site 4 are produced by four energy mechanisms: wind stress, the Gulf loop current, tides, and tropical storms. The combined wind stress, Gulf loop current, and tidal current are generally less than 1 knot. Tropical storms and hurricanes produce strong bottom currents (3 to 4 knots), which can disturb the natural as well as disposal material at Site 4 (EPA 1982).

Shear Stress Computations

9. The transport of bottom sediments is related to the magnitude of the bed shear stress, and both currents and waves are significant; that is, oscillatory fluid motion resulting from surface waves exerts shear stresses on the bottom that are often several times larger than shear stress produced by unidirectional currents of the same magnitudes.

In other cases, the bed shear stress produced by wave motion puts sediment particles into suspension where they can be transported by currents of a magnitude insufficient to initiate sediment motion.

10. Bed shear stress is related to bed shear velocity as follows:

$$\tau_b = \rho u_*^2 \quad (1)$$

where

τ_b = bed shear stress
ρ = water density
u_* = shear velocity

For this study a Bijker-type equation (McAnally and Thomas, in preparation) for total shear velocity caused by waves and currents was used:

$$u_* = \sqrt{\frac{1}{2} f_c u^2 + \frac{1}{4} f_w U_{om}^2} \quad (2)$$

where

f_c = shear stress coefficient for currents, 0.003 (Sternberg 1972)
u = current velocity
f_w = shear stress coefficient for waves
U_{om} = maximum orbital velocity of waves

$$f_w = 2/R_e^{1/2} \quad (3)$$

where

R_e = wave Reynolds number = $U_{om} \cdot A/\nu$
A = maximum horizontal excursion = $0.5 \cdot H/\tanh(2\pi d/L)$ L
ν = kinematic viscosity
H = wave height
d = water depth
L = wavelength

To evaluate this equation it is necessary to know both shear stress coefficients and both velocities. Observations of wave heights and periods from 29 years of wave data (U. S. Naval Weather Service Command 1970) at Fort Myers (25° to 27° N and 81° to 83° W) were used to help develop a percent exceedance curve for wave-induced shear stresses. Although Site 4 is just outside the Fort Myers region, it was more representative of deep-water wave conditions than the nearshore region of Apalachicola. Using the method in Beauchamp (1974), the maximum orbital velocities, U_{om}, were calculated as follows:

$$U_{om} = (\pi \cdot H/T)/\sinh(2\pi d/L) \quad (4)$$

Where T is wave period. The maximum orbital velocities were ordered by frequency and a percent exceedance frequency curve for orbital velocities was developed.

11. Current meter data for only a 2-month period, collected by WES from 9 March to 12 May 1983, were available for the study area. Currents of 1 knot and 4 knots were cited in the literature as discussed in paragraph 8. From these three data sources, the current velocities were plotted on probability paper forming a percent exceedance curve for current velocity. Assuming the same exceedance frequency for current velocities and wave energy (orbital velocity), then for a given exceedance frequency the current velocity and orbital velocity can be obtained; and using Equation 2, the total bed shear stress can be calculated for that frequency. The orbital and current velocities, bed shear stress, and associated frequencies are shown in Table 1. The assumption of a frequency relationship between current velocities and wave energy is more conservative than the assumption of an independent relationship. Conservative is meant to be a greater scour potential. The highest current (4 knots) is associated with hurricane conditions which according to EPA (1982) have occurred about 1 percent of the time.

Table 1

Frequency of Shear Stress and Current Velocity

Exceedance Frequency, Percent	Current Velocity ft/sec	Orbital Velocity ft/sec	Bed Shear Stress $lb/ft^2 \times 10^{-3}$
99.0	--	--	0.000
87.1	0.17	0.09	0.216
59.2	0.20	0.13	0.313
56.6	0.22	0.29	0.788
28.5	0.33	0.40	1.000
20.3	0.38	0.48	1.143
18.6	0.39	0.61	1.361
12.2	0.50	0.63	1.808
11.0	0.55	0.68	2.334
8.3	0.75	0.80	2.988
7.9	0.81	0.91	3.287
6.6	0.90	0.97	4.033
5.4	0.98	1.08	5.095
5.0	1.20	1.19	6.264
4.7	1.28	1.36	7.115
4.0	1.30	1.37	7.826
3.2	1.50	1.66	10.166
2.9	1.60	1.70	11.245
2.6	1.70	2.05	12.700
2.5	1.80	2.07	13.988
2.3	1.90	2.29	15.612
2.2	2.00	2.55	17.333
2.1	2.10	2.84	19.072
2.0	2.20	2.89	20.548
1.8	2.30	3.24	22.520
1.7	2.40	3.53	24.603
1.6	2.50	4.11	27.185
1.5	2.60	4.38	29.896
1.4	2.75	5.11	33.394
<0.6	6.70	5.77	143.537

PART III: DISPOSAL OPERATION PHENOMENA

12. When the hopper doors are opened, the dredged material behavior can be separated into three phases: convective descent, dynamic collapse, and passive diffusion (Figure 3). The convective descent is characterized by the dredged material acting as a distinct sediment fluid mixture falling under the influence of gravity (negative buoyancy). As this cloud descends, a vortex ring occurs in which the central region of the cloud moves downward and the outer region moves upward with a net movement downward. The downward motion of the central region tends to maintain the cloud as a unit; however, the upward motion of the outer region enhances the entrainment of ambient water into the cloud which aids in the dispersal of the material before it reaches the bottom. The short-term fate of the material entrained by this phenomenon is analyzed in PART IV.

13. Dynamic collapse occurs when the cloud, as it spreads during descent, either reaches the bottom or the density difference of the cloud and ambient water is small enough to achieve a buoyant state. The vertical descent of the cloud is stopped and horizontal spreading occurs. This sets the stage for the settlement of particles if dynamic collapse occurs above the bottom. Figure 4 shows an idealized example of dynamic collapse above the bottom.

14. When the horizontal spreading during dynamic collapse reduces to a magnitude on the order of spreading due to turbulent diffusion, passive dispersion becomes the predominant mechanism of sediment movement. Passive dispersion is important only when the dynamic collapse occurs above the bottom. When this happens, sediment particles settle according to their fall velocities resulting in the deposition of large particles near the disposal position and smaller particles farther out. The final spatial distribution of the deposited sediment due to disposal operation phenomena becomes the initial conditions for determining the long-term fate of the dredged material. Excellent detailed descriptions of the dynamics of disposal operations are in Johnson and Holliday (1978) and Pequegnat et al. (1978).

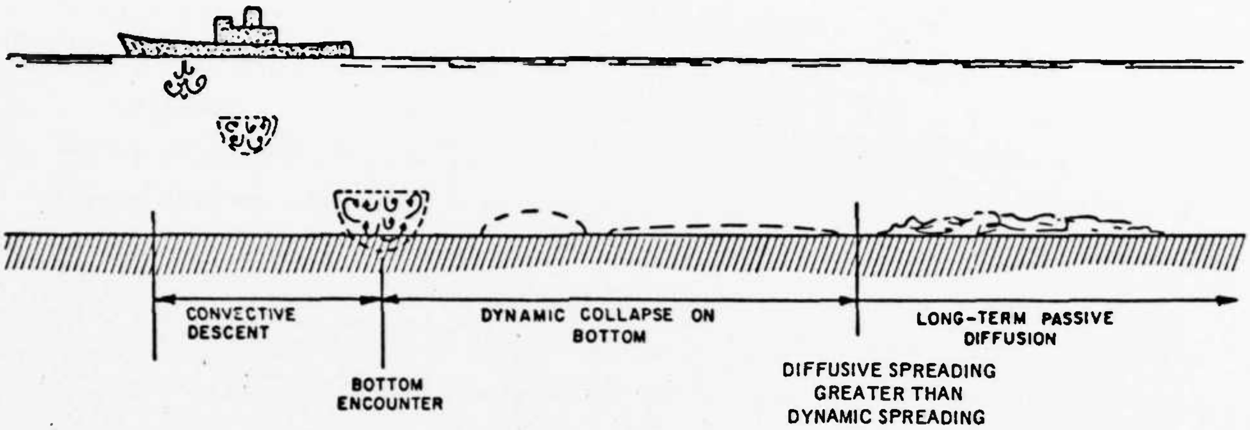

Figure 3. Idealized illustration of phases of dredged material after instantaneous disposal (From Brandsma and Divoky 1976)

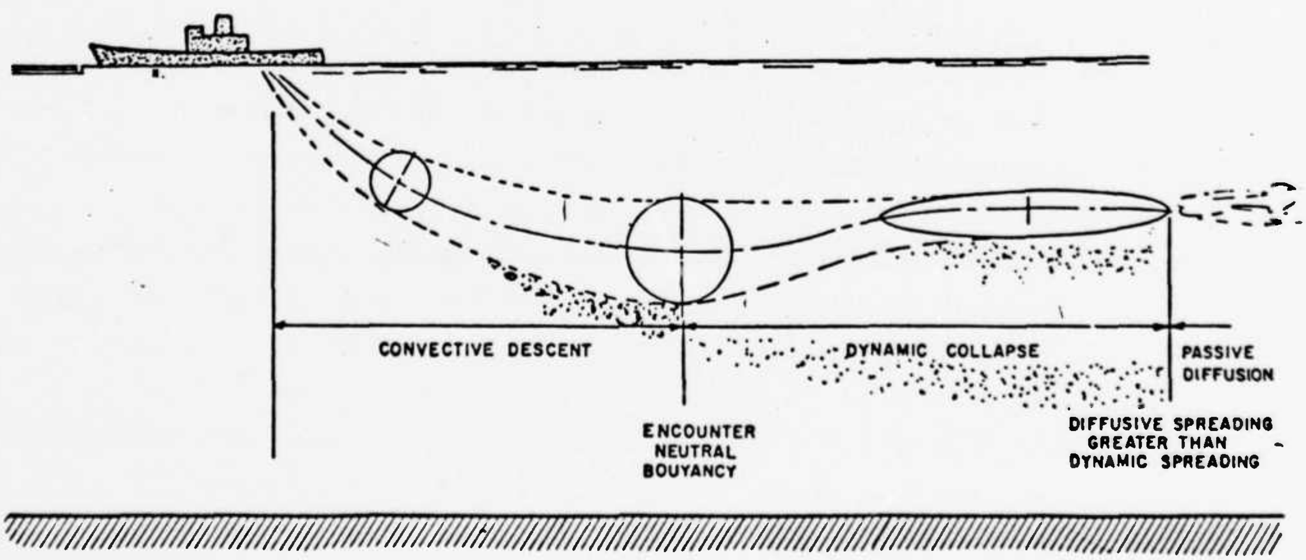

Figure 4. Idealized illustration of phases of dredged material with dynamic collapse above sea floor (From Brandsma and Divoky 1976)

PART IV: SHORT-TERM FATE OF TURBIDITY PLUME

Sediment Characteristics and Behavior

15. Because of clamshell and hopper dredge operation, the dredged material (see paragraph 6) is very dense with a PMC of 50 which indicates characteristics similar to a bulk solid. Tests performed by the JBF Corporation (JBF Scientific Corporation 1975) indicate that during disposal, very little entrainment of material occurs in either silt or clay up to PMC = 100. Table 2 describes the behavior of sediments in the solid and liquid modes. This indicates that disposal operation will impart very little material to the water column, i.e., a small turbidity plume, and dynamic collapse will occur at the bottom.

16. To determine the fate of the turbidity plume, the amount of material entrained by the water must be determined. Gordon (1974) after measurements in Long Island Sound, concluded that less than 1 percent of the dredged silt in the dump was entrained. Bokuniewicz et al. (1978) found that less than 5 percent is generally lost during disposal operation and Tavolaro (1982) found that an average of 4 percent was lost during operations outside New York Harbor. Based upon the above and a PMC of 50, an estimated value of 2.5 percent of the dump will be entrained as a turbidity plume during disposal at Alternative Site 4.

Turbidity Plume Numerical Model

17. A computer code developed under contract for WES to study turbidity plumes was used to trace the short-term fate of the dumped material. This code, described in detail by Wechsler and Cogley (1977), predicts the downstream concentration gradient of silt and colloidal-size fractions of dredged sediments discharged in waters characterized by unidirectional constant flow, essentially infinite width, constant depth, and infinite length. Density gradient settling, salt wedges, narrow channels, tidal flows, and complex circulation patterns are beyond the scope of the model.

Table 2

Comparison of Properties of Disposal Material in Solid and Liquid Modes (JBF Corp. 1975)

Solid Mode	Liquid Mode
1. Low PMC.	1. High PMC.
2. Observed in barge filled by clamshell dredge.	2. Observed in material of the upper few feet of hopper dredge (much affected by transit time).
3. Usually found in the bottom half of hopper dredge	3. Characteristic of pipeline dredged material.
4. Falls as solid blocks.	4. Falls as a liquid cloud.
5. Rapid descent, no deceleration before impact.	5. Slower descent phase.
6. Little cloud growth.	6. Cloud expands due to entrainment.
7. Trails a small turbidity plume.	7. Deceleration of descent rate is significant.
8. Little spread of material on bottom after impact, but this depends upon cohesiveness of material disposed.	8. Horizontal momentum on bottom considerable, producing laterally spreading cloud.
9. Pycnocline has effect only on small trailing turbidity plume.	9. Pycnocline has effect on falling cloud, possibly producing first collapse.
10. Generally some mounding on bottom, even in deep water	10. Little or no mounding on bottom.

Boundary and Initial Conditions

18. For an average load of 2,100 cu yd, a bulking factor of 1.2, and 2.5 percent entrainment, the volume of sediment in the turbidity plume can be calculated as follows:

$$(2{,}100 \text{ yd}^3/1.2) \times 0.025 \text{ X } 27 \text{ ft}^3/\text{yd}^3 = 1{,}180 \text{ ft}^3/\text{load} \qquad (5)$$

Since the computer code requires a constant sediment load rate, the load from one scow was assumed to be spread over a time equal to the round trip time for one load (6 hr). The equivalent load rate then becomes 0.055 ft^3/sec. Christodoulou, Leimkuhler, and Ippen (1974) used this technique with good success in which a continuous load was simulated by distributing a single load over 6 to 8 hr. Vanoni (1977) showed that the initial specific weights of deposited sediments found by various researchers ranged from 86 lb/ft^3 for 0.062-mm size particles to 55 lb/ft^3 for 0.004-mm size particles. Because 85.6 percent of the turbidity plume is expected to be clays (see Table 3), an average density of 60 lb/ft^3 is adopted for the deposited specific weight. This lends credence to the assumption that a concentration of 10^6 mg/ℓ, which generates an error of only 4 percent, is representative of the suspended sediment after it is deposited. This allows the depth of deposits to be determined by the difference in concentration between two points.

19. The grain sizes that would be in the turbidity plume would primarily consist of clays and silts (less than 0.062 mm) and represents 35 percent of the total load. The larger particles have sufficient fall velocities such that they would readily deposit in less than 3 hr at a 72-ft depth (22 m) and would travel less than 900 ft at an average current velocity of 0.25 ft/sec. From Figure 2, 35 percent of the material is finer than 0.062 mm. As mentioned before, 2.5 percent of the material is assumed to be entrained and assuming that the silts and the clays are the only size fractions to be entrained, 7.1 percent of the silts and clays will be in the turbidity plume and 92.9 percent will reach the bottom as colloidal clumps or aggregates. This phenomenon is typical of material

obtained from clamshell and hopper dredge operation (Pequegnat et al. 1978). The grain-size ratios of the entrained material is assumed to be in proportion to grain-size ratios of the silt and clay fraction of the total load. Utilizing five size classes, the fall velocities of each were obtained from column settling tests of Hillsborough Bay core borings (USAED, Jacksonville). The tests were performed using 20 parts per thousand (ppt) salinity solutions at 23°C. The salinities at the disposal site ranged from 31.1 to 37.5 ppt (EPA 1982). Actual fall velocities of the clays and silts at the site would be higher than those obtained by the laboratory tests because the higher salinity and vertical velocity gradient would enhance aggregation which in turn creates larger effective particles with higher fall velocities. The core borings were taken in the areas to be dredged and the individual particle characteristics are considered to be representative of the area. Table 3 summarizes the sediment input to the turbidity model.

Table 3

Sediment Input to Turbidity Plume Model

Size Range mm	Geometric Mean Diam., mm	Percent of Total Load	Percent Less Than 0.062 in Turbidity Plume	Fall Vel 10^{-3} ft/sec	Model Loading Rate, cfs
0.002-0.004	0.003	15	42.9	0.0272	0.0236
0.004-0.008	0.006	15	42.9	0.107	0.0236
0.008-0.016	0.012	1	2.8	0.431	0.0015
0.016-0.031	0.024	2	5.7	1.75	0.0031
0.031-0.062	0.047	2	5.7	6.81	0.0031

20. Water movement from the current meters (Figures 5-10) was generally omnidirectional. Table 4 shows statistics obtained from analysis of current velocity and directions obtained from 30 days of sampling at 30-min intervals. Due to mechanical failure, no information was available from a meter placed at middepth 1 mile south of the site center. The

Table 4

Current Meter Statistics

(Data Collected by WES)

Quadrant Interval deg	Velocity Range Kt	Meter Position and Location: Center of Site 3-ft Depth Percent Frequency	Center of Site 9-ft Depth Percent Frequency	1 Mile South of Center, 3-ft Depth Percent Frequency
0-90	0.0-.2	92.2	82.3	99.4
	0.2-.4	7.8	16.9	0.6
	0.4-.6		0.8	
	Percent in Quadrant	14.6	19.1	12.3
90-180	0.0-.2	76.5	67.2	96.5
	0.2-.4	23.1	31.7	3.5
	0.4-.6		1.0	
	Percent in Quadrant	37.2	42.2	34.8
180-270	0.0-.2	89.2	88.9	98.2
	0.2-.4	10.5	11.1	1.8
	0.4-.6	0.3		
	Percent in Quadrant	20.5	20.6	28.6
270-360	0.0-.2	71.0	75.8	88.8
	0.2-.4	24.4	23.0	10.9
	0.4-.6	4.4	1.2	.3
	0.6-.8	0.3		
	Percent in Quadrant	27.7	18.1	24.4

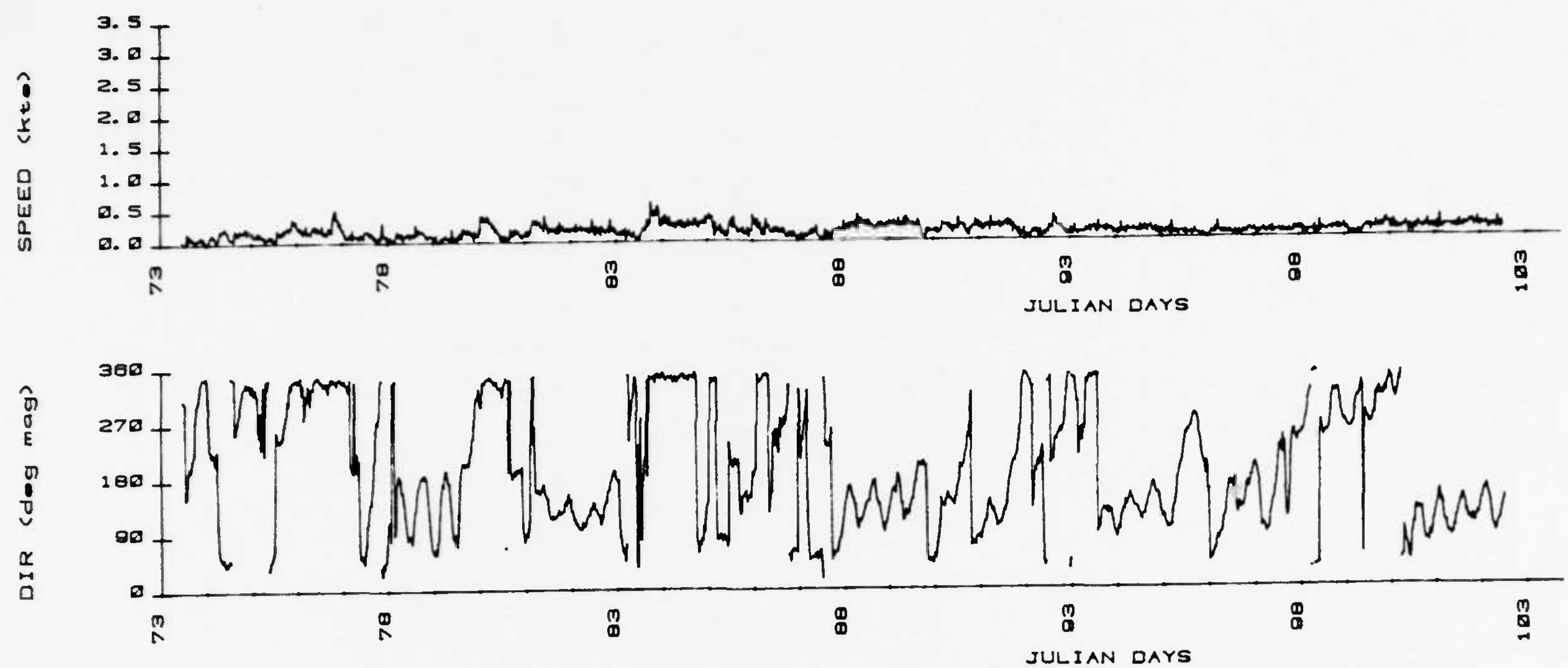

Figure 5. Current speed and direction at 3-ft depth, center of disposal Site 4

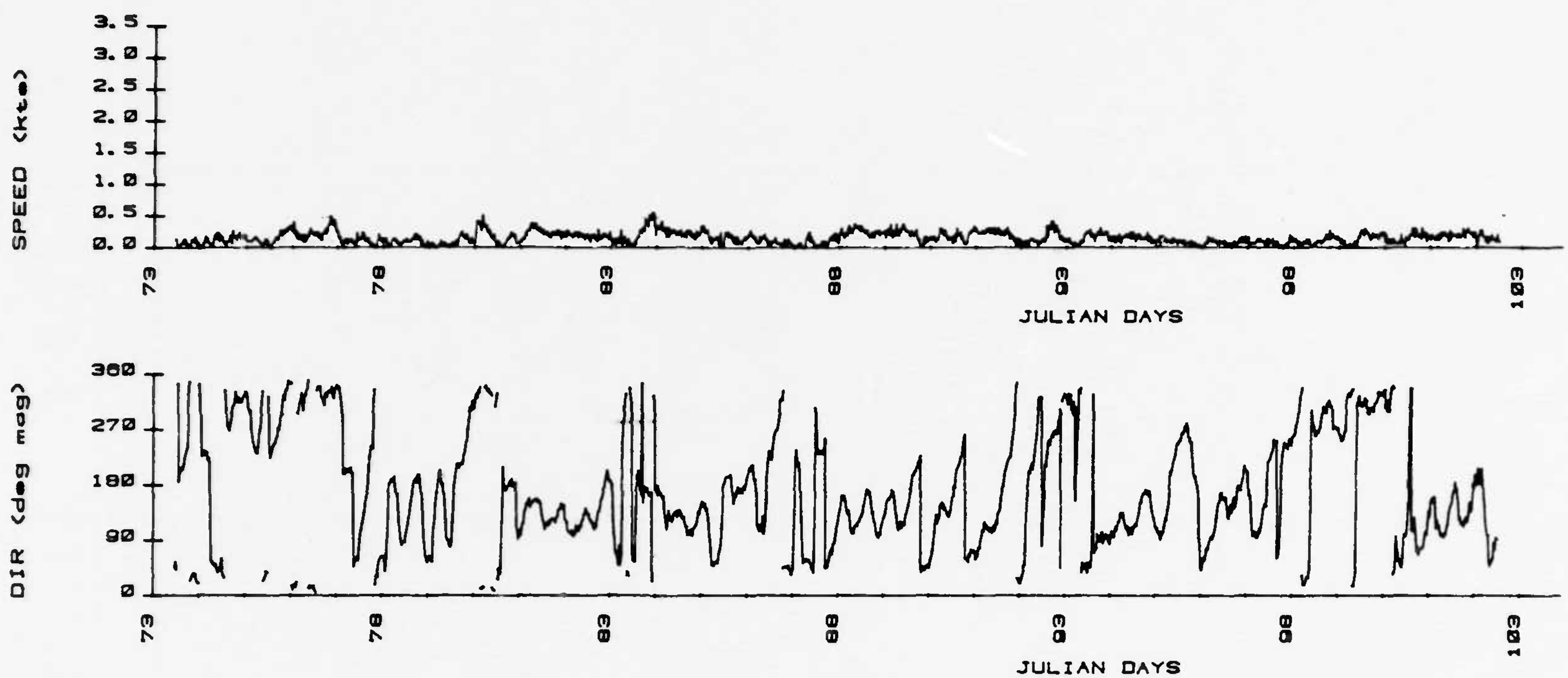

Figure 6. Current speed and direction at 9-ft depth, center of disposal Site 4

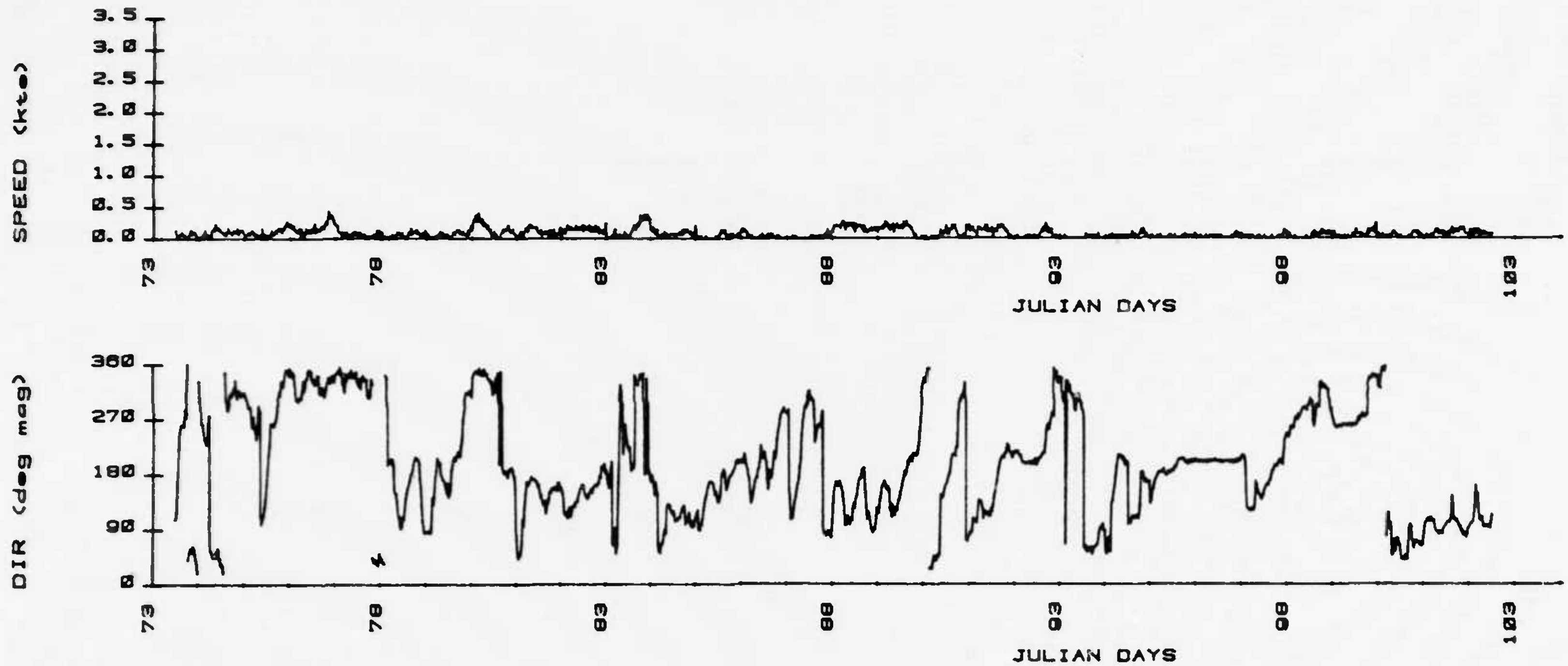

Figure 7. Current speed and direction at 3-ft depth, 1 mile south of center of disposal Site 4

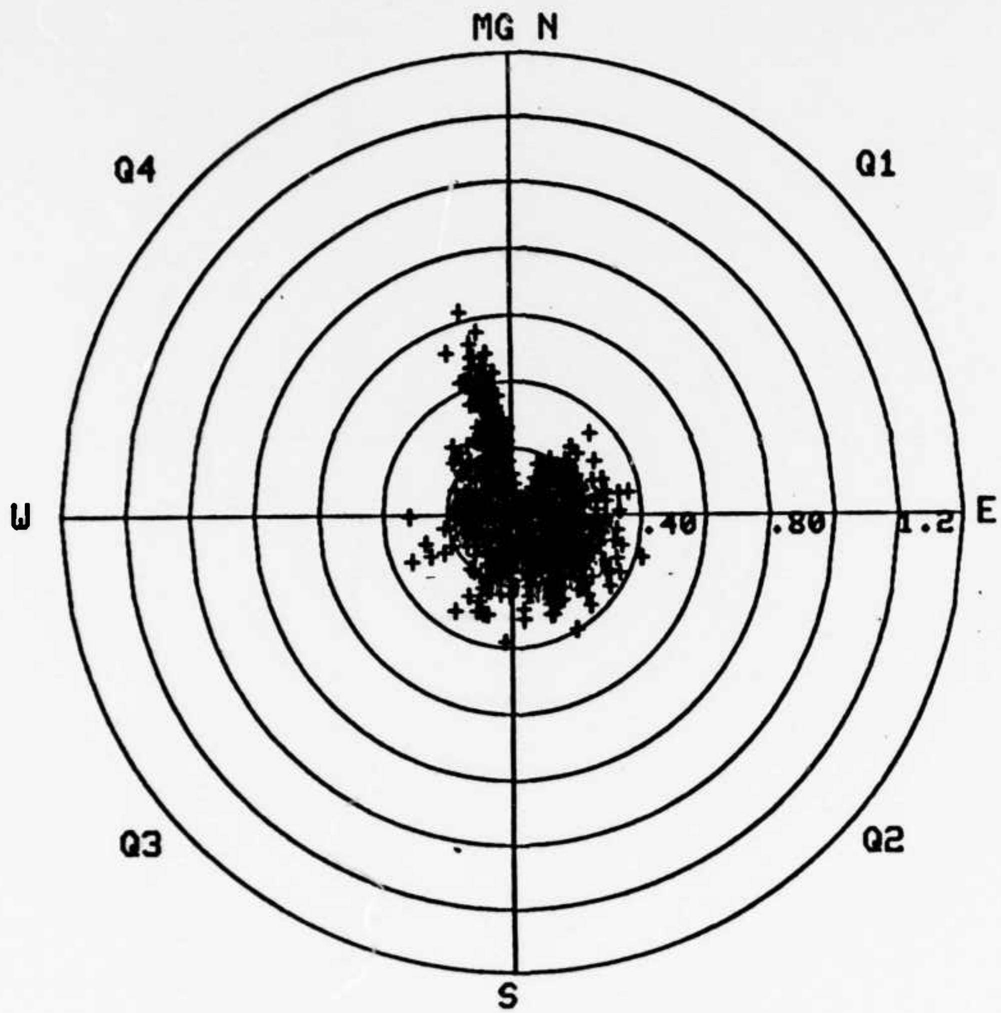

Figure 8. Rose chart of data from 3-ft depth, center of Site 4

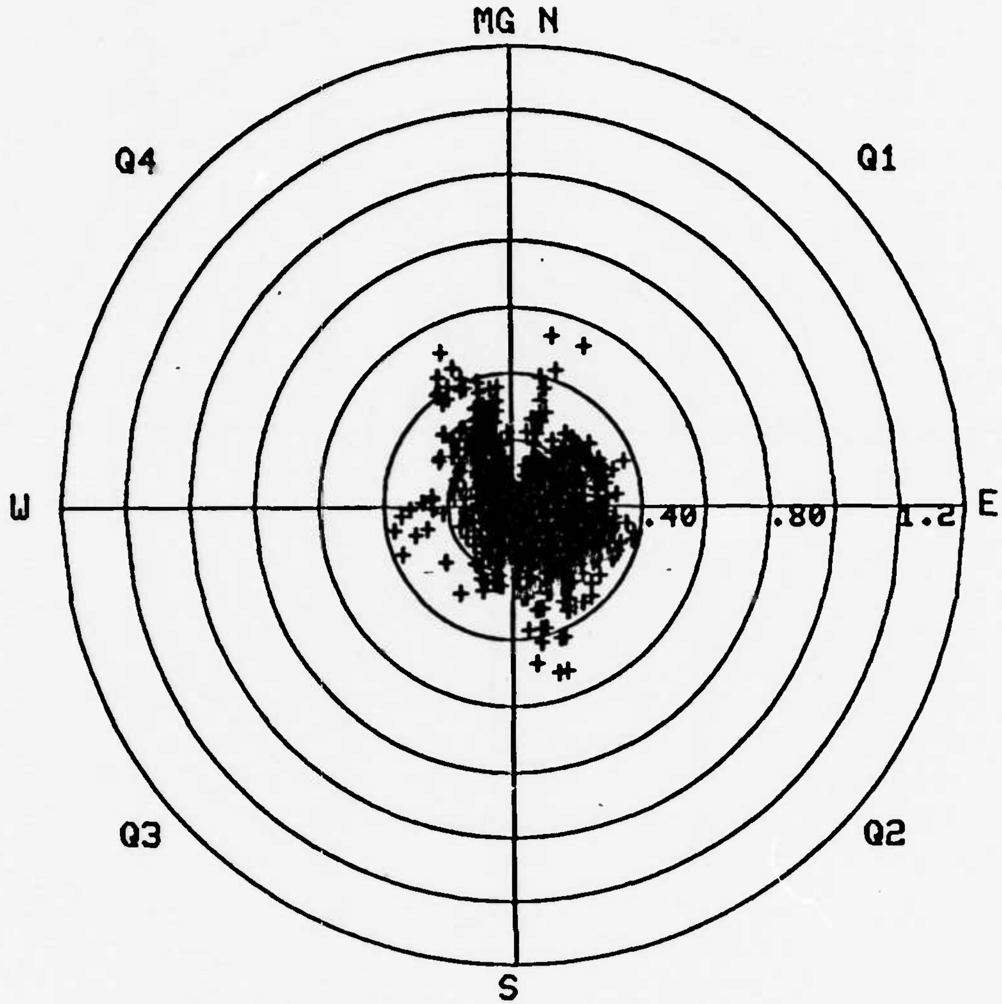

Figure 9. Rose chart of data from 9-ft depth, center of Site 4

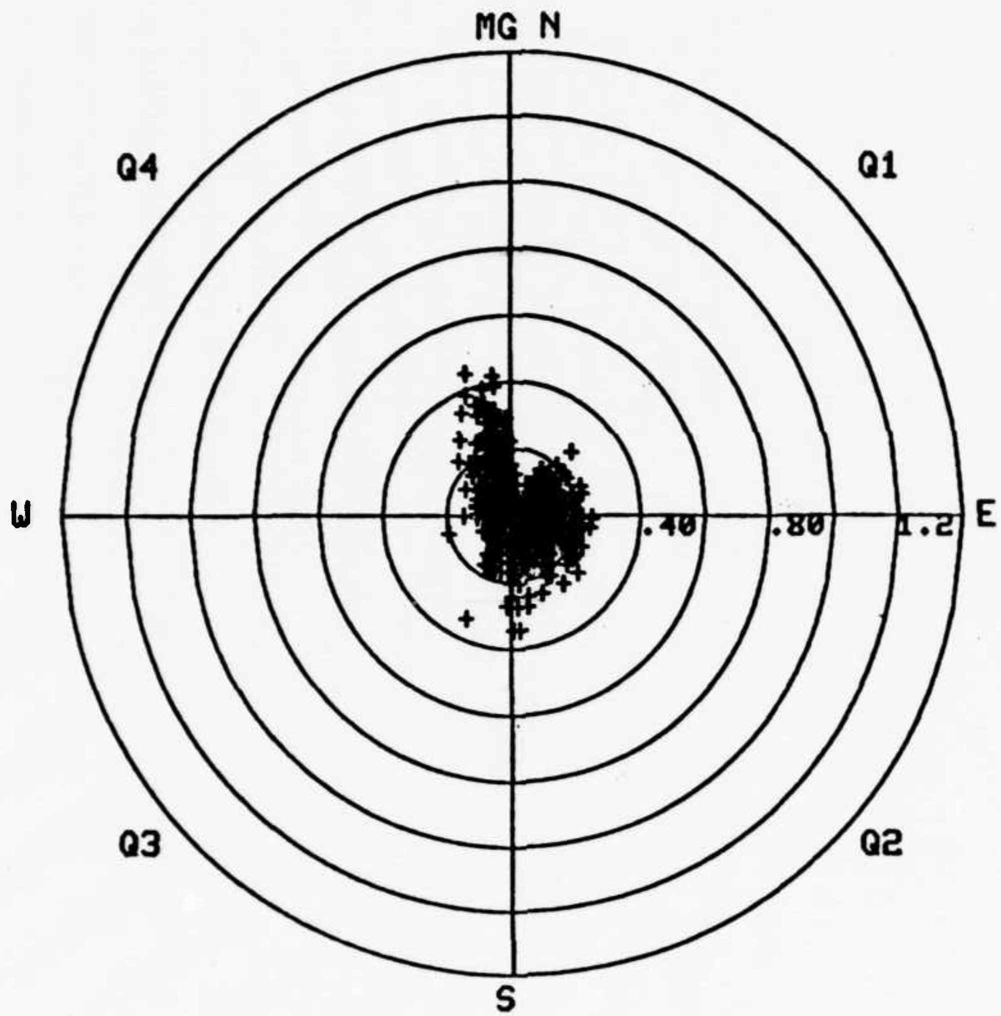

Figure 10. Rose chart of data from 3-ft depth, 1 mile south of center of Site 4

time-weighted current velocity at the center of Site A was 0.226 ft/sec (6.9 cm/sec) and is comparable to the monthly average of 10 cm/sec (0.328 ft/sec) mentioned in paragraph 3. Since the monthly average included higher currents due to winter storms during which there would be no disposal operations, 0.25 ft/sec (7.6 cm/sec) current velocity was considered to be the most representative of conditions during disposal operations.

21. The water depth was assumed to be constant at 72 ft (22 m). Because of the low PMC, the material would stay relatively intact as it is dumped until it reaches about the lower one-third depth. In the model, the material was released to the water at a vertical zone of 8 to 24 ft from the bottom. The initial diameter of the plume at the vertical zone of release was assumed to be 120 ft, which is comparable to plumes calculated by Johnson and Holliday (1978) for the New York Bight disposal operation in water depths of 26 m. The computational grid extended 15,000 ft in 300-ft increments from the disposal site and was 1,200 ft wide in 40-ft increments.

Analysis of Results

22. No prototype information on the lateral dispersion rate was available for model calibration; therefore the results were compared with values found in the literature. Brooks (1960) defined a turbulent dissipation parameter which ranged from 0.00015 for open seas to 0.005 for a dynamic estuary. From the model results, a turbulent dissipation parameter value of 0.00022 was calculated. This value is comparable to what would be expected for open seas of moderate depths. Wilson (1979) computed diffusion velocities for plumes in seawater up to 3 m deep and found them to be about 1 cm/sec. The computed diffusion velocity for the model is 0.38 cm/sec. Because the water depth for the model is 22 m, the lower diffusion value is in the range expected. The lower the lateral dissipation, the higher the concentration is at any distance from the source; and since the lateral dissipation is on the lower end of Brooks and Wilson's results, the resulting concentrations will

tend to be conservative (higher).

23. If the disposal occurs at the center of the site, the shortest distance to the site limits is 1 n.m. The calculated average concentration of the plume at 1 n.m. from the center is 3.6 mg/ℓ with a maximum concentration of 20.5 mg/ℓ and the plume is approximately 720 ft wide. When the concentration in the turbidity plume drops to the same order of magnitude as the ambient concentration, the water can then be considered "unaffected" by the disposal (Christodoulou, Leimkuhler, and Ippen 1974). EPA (1982) found the natural suspended particle matter at Site 4 to be 0.55 to 2.97 mg/ℓ. When the plume concentration during disposal reached 2 mg/ℓ, it was considered to have reached background concentration. The disposal simulation predicted that distance to be 15,000 ft (2.5 n.m.) from the center of the site with a peak concentration of 12.8 mg/ℓ at the center.

24. Calculations were made to determine the maximum depth of deposits from the turbidity plume before the deposits are resuspended. Mantz (1977) found that a critical bed shear stress of 0.0016 lb/ft^2 would initiate the movement of a deposited material in the silt range (0.03 mm) and Krone (1962) found the critical bed shear stress to range from 0.0008 to 0.0014 lb/ft^2 for San Francisco Bay mud (silt and clay) deposited at concentrations of less than 300 mg/ℓ. Using a relatively strong value of 0.002 lb/ft^2 for the critical shear stress of the sediment deposited from the turbidity plume, the shear stress can be expected to be exceeded 12 percent of the time (see Table 1) or about 44 days out of a year. Therefore about 320 days of the year, but not necessarily consecutively, the ocean conditions are sufficiently mild so deposits from the plume will not be resuspended and will accumulate. The probable maximum consecutive number of days for such conditions is 60. This number was determined by analyzing monthly wave observations and determining the maximum length of time the combined wave/current bed shear is less than the critical value for resuspension. When conditions are sufficiently severe to resuspend, it is assumed that the total depth of the plume deposit is resuspended and that the currents (bottom speeds of up to 4 knots for hurricanes) will completely mix the sediments with

the natural background turbidity in the water column. The currents, as seen in Figures 5-10, are generally omnidirectional with the longest duration in one direction quadrant being about 3 days. Based upon this observation, the 60-day plume deposits are distributed radially from the center of the disposal site to determine the maximum depth of deposits due to the turbidity plume. Table 5 shows the results of the analysis for a single disposal and for continuous disposal operation (i.e., 1 dump every 6 hr) for 60 days.

25. Approximately 35 cu yd/dump is expected to leave Site 4 in the turbidity plume. This translates to 2 percent of each dump. These figures are based upon particle fall velocities from the analysis of particles in quiescent water of relatively low salinity. Krone (1962) has shown that "effective" fall velocities can increase an order of magnitude due to flocculation of clay and silt particles under chemical and physical action; therefore these results can be considered to be under maximum probable conditions with the actual quantity of sediment leaving the site somewhat lower than shown. Although the relationships between loading rates, concentration, and depth of deposits are not exactly linear, a good approximation of concentrations and depths of deposit for different loading rates can be made by taking the ratio of the load rates and applying it to the concentrations or depth of deposits. For example, if there were two scows being used and disposal occurred every 3 hr (double the load rate), the average concentration at the disposal site limits would be 7.2 mg/ℓ (2 x 3.6 mg/ℓ) with a 60-day depth of 0.0488 mm (2 x 0.0244 mg/ℓ from Table 5) at 6,000 ft from the center. The lateral dissipation is essentially the same, regardless of the concentration.

Table 5

Sediment Distribution of Deposits from a Turbidity Plume

		One Disposal		After 60 Days
Distance from Disposal Point ft	Width of Plume for One Disposal	Avg Depth of Deposits mm	Maximum Depth of Deposits mm	Avg Depth of Deposits mm
1,500	480	0.0472	0.260	1.15
3,000	560	0.0117	0.064	0.125
4,500	640	0.007	0.039	0.0466
6,000	720	0.0047	0.026	0.0244
7,500	800	0.0034	0.018	0.0152
9,000	880	0.0026	0.014	0.0105
10,500	920	0.0021	0.012	0.00771
12,000	960	0.0018	0.010	0.00601
13,500	1,000	0.0016	0.0089	0.00485
15,000	1,040	0.0015	0.0080	0.00405

PART V: LONG-TERM FATE OF DEPOSITED DREDGED MATERIAL

Initial Conditions

26. After the passive dispersion phase, all material not in the turbidity plume has deposited on the ocean floor in a radial pattern (Bokuniewicz and Gordon 1980) with a diameter dependent on various factors such as water depth, volume of release, and composition of the material being released. A comparison of the radius of deposit from different disposal sites is shown in Table 6 with the Alternative Site 4 characteristics included at the bottom. New Haven, with a radius of 250 m, has the characteristics closest to Site 4 for water depths and volume of release. The organic marine silt-clay of New Haven would spread farther than the dredged material at Site 4 because of the higher buoyancy of organic sediments at New Haven. Rochester and Ashtabula are also comparable to Site 4 with initial deposit radii of 160 m and 200 m, respectively. Based upon Table 6, the initial radius of the deposit at Site 4 is estimated to be 250 m. A single disposal, 46,100 ft^3 (2,100 cu yd corrected for bulking and loss to the turbidity plume) of dredged material, if spread evenly, would cover 2,113,700 ft^2 to an average thickness of 0.02 ft. In reality, there would be a mound at the disposal center with a tapering slope (Bokuniewicz 1982) out to 250 m.

27. Literature (EPA 1982) indicates net regional currents are northsouth in direction; however, currents during the period measured by WES exhibited an omnidirectional pattern with only a slight tendency to a north-south pattern. No strong correlation between current velocity, direction, and waves could be made from the limited on-site data which, in turn, limited any correlation of bed shear stress and direction the eroded material would travel. At extreme events, the current would be dominated by the northsouth components that would cause the pattern of deposits to be similar to an ellipse with the major axis oriented in a north-south direction. However, the nature of the ellipse cannot be determined without a significantly longer time period of

Table 6

Comparison of Disposal Site Characteristics (Bokuniewicz et al. 1978)

Name	Water Body	Water Depth m	Currents cm/sec	Volume of Each Release cu yd	Nature of Sediment	Radius of Deposit, m
New Haven	Long Island Sound	18	10-40	2,000	Organic marine, silt-clay	300
Rochester	Lake Ontario	17	0-20	902	River silt	160
Ashtabula	Lake Erie	18	0-20	902	Sandy silt	200
New York Bight	Atlantic Ocean	26	0.5-2.5	8,000	Marine silt	180
*Alternative Site 4	Gulf of Mexico	22	0-10	2,100	Sand, silty clay	---

* From EPA (1982)

measurements, including significant storms; therefore, the dredge material was assumed to deposit and radiate in the shape of a right circular cone.

28. At the Mud Dump Site outside of New York, the top slope of the deposits were typically 0.3 to 1 percent with local slopes up to 10 percent (Freeland and Merrill 1976). Material disposed in Chesapeake Bay had an average top slope of 0.12 percent with a maximum of 0.59 percent (Biggs 1970). Fine-grained sands disposed in Lake Erie had a maximum slope of 0.3 percent (Alther and Wyeth 1980). Laboratory tank tests performed by Chase (undated) to simulate dredged material disposal resulted in slopes averaging 0.3 percent. At Existing Site A, located 13 n.m. offshore of Tampa Bay and in 10- to 17-m depth, the slope of the deposits ranged from 0.3 to 1 percent. Based upon this information, a value of 0.3 percent (0.003) was adopted as the equilibrium slope. For a cone with a base extended to the limits of the disposal site (radius of 6,076 ft) and side slopes of 0.003, the volume would be 26.1 million cu yd with a maximum height of 18.2 ft (5.6 m) at the center. Higher local slopes near the center would probably be only within the 250-m radius of the disposal position and the volume of this portion in relationship to the total is small and was not considered in the analysis.

Critical Shear Stress

29. Each grain-size fraction was analyzed separately to determine the critical bed shear stress at which the representative particle of the fraction begins to move. The critical shear stresses were calculated by a revised wave Shields diagram (Figure 11) proposed by Sleath (1978) which took into consideration experimental results of wave-induced thresholds of particle movement. For a particle size, a nondimensional grain size, D_*, is calculated by the equation:

$$D_* = \left(\frac{(\rho_s - \rho) g}{\rho \nu^2} \right)^{1/3} D \qquad (6)$$

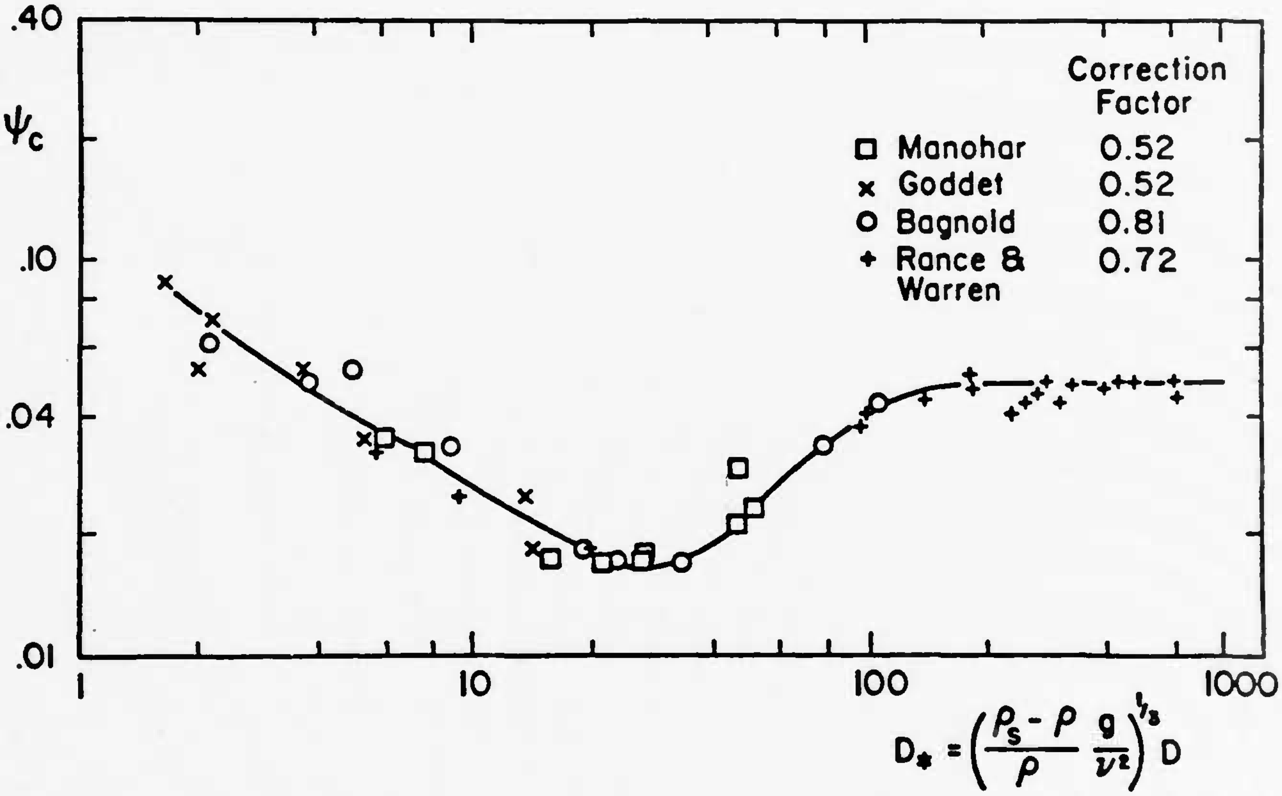

Figure 11. Modified Shields curve for oscillatory flow (Sleath 1978)

where

ρ_s = density of particle

ρ = density of water

g = acceleraton due to gravity

ν = kinematic viscosity

D = diameter of particle

For the calculated D_*, the dimensionless critical shear stress, ψ_c, is determined by Figure 11. Table 7 shows the results of the calculations.

Table 7

Dimensionless Bed Shear Stresses

Grain Size Range, mm	Geometric Mean, mm	D_*	ψ_c
< 0.0625	0.03	0.785	0.20
0.0625- 0.25	0.125	3.28	0.055
0.25 - 1.0	0.50	13.1	0.023
1.0 - 4.0	2.0	52.6	0.025
4.0 -16.0	8.0	210.0	0.047
16.0 -64.0	32.0	841.0	0.048

For any given bed shear stress, τ, and particle size, the dimensionless shear stress, ψ, can be calculated by

$$\psi = \frac{\tau}{(\rho_s - \rho)gD} \quad (7)$$

Knowing ψ_c, the critical shear stress for motion, τ, is calculated using equation 7 and Table 1 is used to determine the exceedence frequency at which each grain size fraction in the bed is mobilized. The bed shear stress was found to exceed the critical stress at 12% exceedence frequency for 0.03 mm particle size, 11.5 percent for 0.125 mm, 6.9 percent for 0.50 mm, 2.3 percent for 2 mm, and 1.3 percent for 8 mm. The

32 mm size is stable even during hurricanes.

Armoring

30. Vanoni (1977) and other researchers have found that for beds with large sand fractions, prolonged scouring with only mild fluctuations will gradually coarsen bed sediments leading to armoring of the bed. Analysis of the current data revealed gradual increases and decreases in current velocity with sustained time periods (∿hours) when scouring velocities occurred. These conditions and the fact that the majority of the sediment is sand are conducive to bed armoring. Thomas (1977) describes a method to obtain the depth of scour that occurs before an armor layer is fully developed. The equation is:

$$D_{se} = (2/3) \frac{D}{PC} \tag{8}$$

where

D_{se} = depth of scour to equilibrium armor layer

D = largest particle diameter scoured

PC = percent coarser than D, as a fraction

When the particle critical bed stress is exceeded, it is assumed that all material finer than the particle is eroded and leaves the disposal site. The depth of this scour was calculated using the above relationship.

Annual Depth of Scour

31. The annual depth and volume of scour are based upon one dump scow operating or one disposal occurring every 6 hr, which was considered to be the worst condition for scour potential. Scouring conditions are fairly infrequent with the smallest representative particle, 0.03 mm, scouring only 12 percent of the time. There could be many consecutive days of calm before ocean conditions caused scour to occur

again. During this period, a number of dredged material loads could have been dumped. When a scour condition occurs, only the last disposal is subject to erosion and the material underneath would not be affected. This is a reasonable assumption because each disposal will contain particles that would not erode even under hurricane conditions; therefore the most recent disposal will always have enough large particles to protect the deposits underneath it.

32. Correcting for the bulking factor, each load of 2,100 cu yd would actually contain 1,750 cu yd of material. The average annual maintenance operation will require 229 loads of dredged material per year (i.e., 0.4 million cu yd divided by 1,750 cu yd/load). During the channel deepening portion, the annual dredged material placed at Site 4 will be 1.8 million cu yd for 2 years requiring 1,029 loads per year, necessitating the use of more than one scow. For the first 2 years, the analysis was based on two scows in operation. The resulting potential for armoring depends on the number of calm days between storms; therefore average annual conditions were developed as shown in Table 8.

Table 8

Computation of Number of Loads Subject to Scour per Year

(1) Grain Size mm	(2) Exceedance Frequency at Critical Sheer Stress percent	(3) Number of Days Critical Exceeded	(4) Number of Days Between Critical Events	(5) Number of Loads Exposed to Scour per Year
0.03	12	44	8.3	9.2
0.125	11.6	42	8.6	8.9
0.5	7	25	14.5	5.3
2.0	2	8	43.5	2.0
8.0	1	5	167	1.0

For the five grain size classes shown in column 1, the exceedance frequency and number of days the bed shear stress exceeds critical are shown in columns 2 and 3, respectively. Assuming that both the critical days and the dredging operation reflect average annual conditions, the number of days between critical days is shown in column 4. At three dumps per day (18 hr operation per day/6 hr per disposal), the number of loads exposed to scour per year (229/(3x8.3) for grain size class 0.03) is shown in column 5. Entrainment is considered to be instantaneous for that size material which can be removed.

33. The annual depth of scour for each grain size is found by multiplying the armoring depth of each grain size by the annual number of loads the bed is exposed to scour. The total annual depth of scour, 0.1165 ft/year, is the summation of the scour depths for each grain size.

Volume of Scour

34. As each dump reaches the ocean floor, it initially surges radially until it reaches a radius of about 250 m. This process is reported in the literature as the "dynamic collapse." It will then slowly spread until it reaches an equilibrium slope of 0.003 ft/ft.

35. The volume of scour is the scour depth times the surface area available for scour of the disposal cone. As each load reaches the ocean floor, the dynamic collapse will produce a radius of about 820 ft (250 m) followed by a gradual spreading to a top slope of 0.003 ft/ft. A reasonable estimate of the surface area available for scour is half the distance from the dynamic collapse (radius of 250 m) to the leading edge of the cone (the radius having a slope of 0.003).

36. The volume of a right circular cone is:

$$V = (1/3)\pi r^2 h \qquad (9)$$

where

V = volume deposited

r = radius of cone

h = height of cone

Using the relationship of $h = 0.003 \times r$, the radius of the leading edge of the cone is:

$$r = \left(\frac{V}{0.001\pi} \right)^{1/3} \qquad (10)$$

The volume of sediment to be dredged during the first 2 years is 3.6 million cu yd from the channel deepening project. Spread equally in time and corrected for the 2.5 percent loss in the turbidity plume, the radius of the cone is shown in Table 9 along with the annual rate of scour and the percent loss. The volume of sediment remaining in the site at the end of the period is the sediment in the site at the beginning of the period plus that added during the period minus that scoured during the period.

Table 9

Volume Scoured and Volume Remaining in Site 4 as a Function of Time

Year	Cumm Vol Placed million cu yd	Rate of Scour per Year million cu yd	Cumm Vol Remaining million cu yd	Radius of Deposits ft	Percent Loss of Placed Material
0.5	0.9	0.06	0.9	1,960	3.3
1	1.8	0.08	1.7	2,457	3.9
2	3.6	0.12	3.4	3,092	5.2
3	4.0	0.05	3.7	3,171	6.0
4	4.4	0.06	4.0	3,264	6.8
5	4.8	0.06	4.4	3,350	7.4
7	5.6	0.06	5.1	3,524	8.7
10	6.8	0.07	6.1	3,751	11.6
13	8.0	0.08	7.1	3,937	11.6
16	9.2	0.08	8.0	4,103	12.8
20	10.8	0.09	9.4	4,314	14.2
25	12.8	0.10	10.9	4,548	15.8
30	14.8	0.10	12.4	4,742	17.2
35	16.8	0.11	13.8	4,917	18.5
40	18.8	0.12	15.2	5,077	19.6
45	20.8	0.12	16.6	5,224	20.7
50	22.8	0.13	17.9	5,360	21.7
55	24.8	0.13	19.2	5,487	22.7
60	26.8	0.14	20.5	5,606	23.6

Analysis of Results

37. Computations were made based upon not only the estimated 0.4 million cu yd annual maintenance but also using 0.2, 0.6, and 0.8 million cu yd, allowing interpolation for different annual rates. Results for annual maintenance of 0.4 million cu yd are presented in Table 9, and in Figures 12 and 13, results using 0.2, 0.4, 0.6, and 0.8 million cu yd are presented. Because of the wide range of particle sizes and the abundance of coarse particles in the dredged material, natural armoring quickly shields much of the disposed volume of sediment from erosive forces for all but the most intense storms. Initially, resuspension of the disposed sediment amounts to only 3.3 percent of the amount dumped. As the cone grows the surface area increases, thereby exposing more of each dump; as a result, the amount of each dump which is resuspended increases with time. By year 40 the volume resuspended has become about one-fifth of the material disposed. Sometime after year 60, the leading edge of the cone has reached the edge of Site 4 (6,000 ft). The maximum height at the center is predicted to be 18 ft (5.5 m). The annual dredged material volume to be placed in the disposal site could change at any time in the future, particularly if the land disposal sites reach capacity earlier than planned and material is diverted to Site 4. The appendix outlines procedures to develop curves such as those in Figures 12 and 13 for cases when annual maintenance rates change at any point in time. Results shown in Figures 12 and 13 were used to develop general equations to determine radius and percent loss at any given time after 2 years and are presented in Table 10.

38. Variations from the best estimate curves in Figures 12 and 13 depend on several factors: particle size, placement, cohesiveness and consolidation, and shear velocity. If the general gradation of the dredged material is finer than that shown in Figure 2, more material would be lost but the useful life of the site would be greater; the reverse is true if the gradation is coarser. As suggested by Bokuniewicz (1982), if very coarse dredged material is available, this material could be spread out over the disposal site to "cap" the finer material and

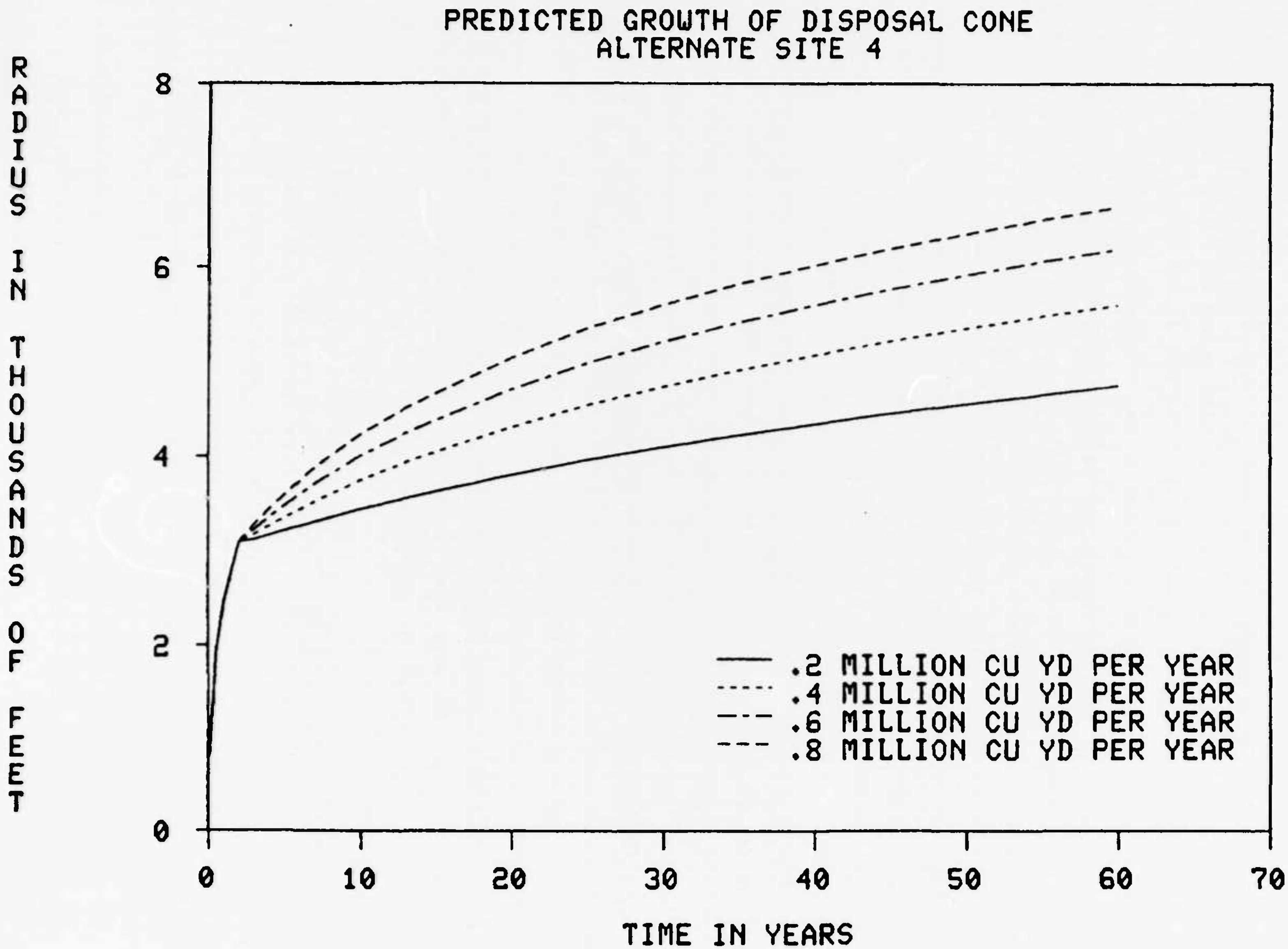

Figure 12. Predicted growth of disposal cone

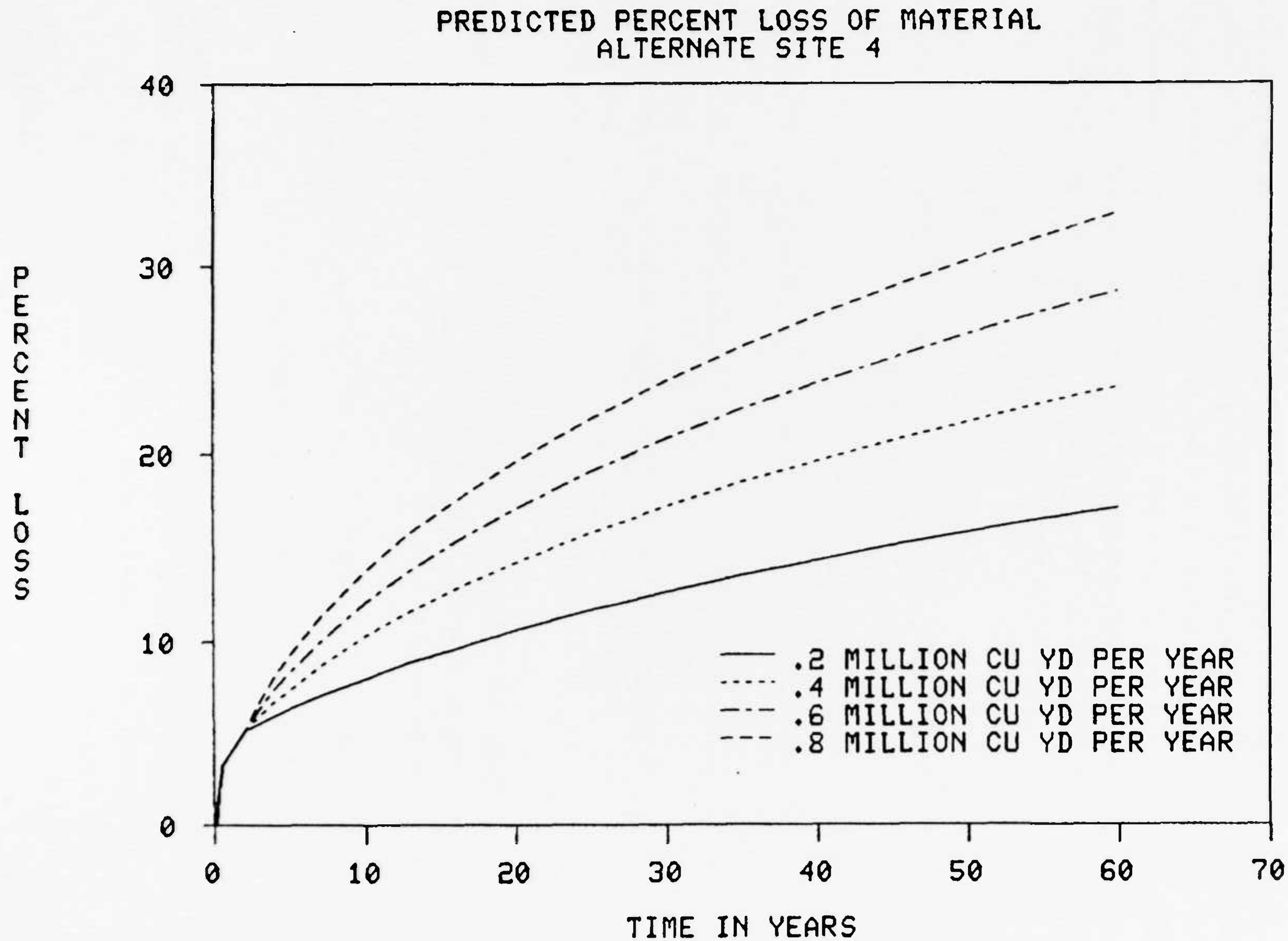

Figure 13. Predicted percent loss from Site 4

reduce the scour potential. Placement of the material was assumed to be near the center of the site and variation from this would increase the area exposed to scour because previous disposals could not be covered. Cohesiveness and consolidation of the deposited material were not included in the analysis. Cohesiveness would decrease the amount of scour because the scour threshold of a cohesive bed is greater than that of a noncohesive bed. Consolidation of fines was considered negligible because only 35 percent of the dredged material is clay and silt and the maximum this part would consolidate is about 10 percent (Bokuniewicz 1982).

Table 10

General Equations for Radius Growth and Percent Loss as a Function of Time

Annual Maintenance Rate million cu yd	Equation for Radius Growth	Equation for Percent Loss
0.2	$r = -3.18 + 1.75 \ln(y + 34)$	$PL = -34.24 + 11.43 \ln(y + 30)$
0.4	$r = -2.23 + 1.82 \ln(y + 17)$	$PL = -29.09 + 12.18 \ln(y + 15)$
0.6	$r = -1.66 + 1.85 \ln(y + 11.3)$	$PL = -27.10 + 13.05 \ln(y + 10)$
0.8	$r = -1.31 + 1.89 \ln(y + 8.5)$	$PL = -25.79 + 13.81 \ln(y + 7.5)$

where:

y = years from start of disposal

r = radius in 1000's of ft

PL = loss in percent

Fate of Resuspended Particles

39. The particle size and current velocity determine the destination of resuspended sediment particles. Precise tracking is not necessary to illustrate the lack of significance. For example, a particle 0.03 mm in size is small enough to be resuspended 12 percent of the time. For

a net drift velocity of 2 cm/sec (EPA 1982) and a particle behavior similar to that calculated for the turbidity plume, the annual dispersion could cover 1.10 x 10^{10} sq ft (11 km^2). The annual volume of resuspended particles in that size class amounts to less than a tenth of a millimeter when spread over that surface area. Moreover, when ocean currents are sufficient to suspend the coarser fractions, sediment from outside the disposal area will be in suspension already and the impact from the addition of material from the disposal area would be negligible.

PART VI: SUMMARY

40. The Jacksonville District is considering an open-ocean disposal site, designated as Alternative Site 4, for placing dredged material from the Tampa Bay Channel Deepening Project and from the annual maintenance of that project. Initial dredging would remove 3.6 million cu yd. The annual maintenance dredging to be placed at the site is predicted to be 0.4 million cu yd. The proposed disposal site is a square, 2 n.m. on each side, located 17 n.m. offshore in water 72 ft deep. The existing bed in the disposal area is gently rolling sand with occasional shell fragments as reported by divers and viewed on videotape coverage. Planned dredging operations will run from February through August, and the material to be disposed is predicted to be 35 percent silt and clay, 43 percent sand, and 22 percent gravel.

41. Currents in the area are produced by wind stress, the Gulf loop current, tides, and tropical storms. Of these mechanisms, the first two dominate in time but hurricane currents dominate in magnitude. WES collected current data during a 2-month period, 9 March through 12 May 1983, but no other field data are available for currents. General guidance published in the literature, cite normal Gulf currents of up to 1 knot, and hurricane-generated currents of up to 4 knots can be expected in this vicinity. Wave data for 29 years are available at Fort Myers. Using these data bases, probability density function curves of wave conditions and current speed were developed from which the expected annual value of sediment transport was calculated using a bed shear stress approach.

42. This study was undertaken to predict both the short-term and the long-term fate of sediment placed in Alternative Site 4. The short-term fate refers to the fate of the turbidity plume which forms as the water column entrains sediment during disposal. In this case, the short-term fate was analyzed using the computer program developed for WES by Wechsler and Cogley (1977). The plume was tracked for 15,000 ft (4½ km) from the dump, and by that distance the average concentration had reduced to 2 mg/ℓ, which is the background concentration for ocean water at Site 4. At the point where the plume crossed the boundary

of Site 4, the average concentration was 4 mg/ℓ. The amount of sediment entrained in the plume is predicted to be 35 to 40 cu yd per dump or about 2½ percent of the load. If all of that sediment deposited within 15,000 ft of the site at the calculated dispersion rate, it would amount to a uniform-depth layer of about 0.0001 ft (0.03 mm) per year. However, the size of sediment in the plume, classified as silts and clays, is conducive to resuspension and further dispersion.

43. Long-term fate refers to the resuspension, transportation, and redeposition of sediment from the primary deposition mound. The critical shear stress approach was used to predict when particles of a given size would become mobile. Both waves and currents were included in the computation of bed shear for resuspension using a Bijker-type equation, but only currents under resuspension conditions were considered in the transportation analysis. Five size classes were identified ranging from clay/silts (0.03-mm particle diameters) to gravels (32-mm diameter). Because the larger particles move more slowly and less frequently than the smaller ones, sorting and armoring processes were included in the analysis. The predicted depth of scour is 0.1 ft (30 mm) per year. In the early years of disposal, this amounts to about 3 percent of the annual volume disposed. By 40 to 45 years, the prediced scour (resuspension) rate will increase to about 20 percent of the annual disposal volume. By about the year 70, the edge of the disposal mound will have reached the boundary of the disposal site and the depth at the center will be 18 ft (5½ m), indicating a useful life for Site 4 of about 70 years.

44. Procedures have been developed to predict the growth of the disposal mound and annual loss rate should the annual maintenance rate change at any point in time and are presented in Appendix A.

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APPENDIX A: EXAMPLE PROBLEM FOR CHANGE IN MAINTENANCE RATE

1. Suppose that the annual dredge maintenance was 0.2 million cu yd/yr from year 3 to year 20 and then it changed to 0.6 million cu yd/year from year 21 to year 60. What would the radius and percent loss be at any year? Results of computations to determine radius growth, years to reach a certain radius, and percent loss were found to fit general equations as follows.

<u>0.2 million cu yd/yr</u>

$$r = -3.18 + 1.75 \ln (y + 34) \tag{1}$$

$$PL = -34.24 + 11.43 \ln (y + 30) \tag{2}$$

$$y = e^{(r/1.75 + 1.82)} - 34 \tag{3}$$

<u>0.4 million cu yd/yr</u>

$$r = -2.23 + 1.82 \ln (y + 17) \tag{4}$$

$$PL = -29.09 + 12.18 \ln (y + 17) \tag{5}$$

$$y = e^{(r/1.82 + 1.22)} - 17 \tag{6}$$

<u>0.6 million cu yd/yr</u>

$$r = -1.66 + 1.85 \ln (y + 11.3) \tag{7}$$

$$PL = -27.10 + 13.05 \ln (y + 10) \tag{8}$$

$$y = e^{(r/1.85 + 0.90)} - 11.3 \tag{9}$$

0.8 million cu yd/yr

$$r = 1.31 + 1.89 \ln (y + 8.5) \tag{10}$$

$$PL = -25.79 + 13.81 \ln (y + 7.5) \tag{11}$$

$$y = e^{(r/1.89 + 0.71)} - 8.5 \tag{12}$$

where

r = radius in thousands of ft

PL = loss in percent

y = years

e = natural logarithm base

2. For the year 3 to 20, the radius and percent loss are determined from Equations 1 and 2, respectively. The nature of the radius and percent loss curves from year 21 to 60 would be similar to that shown in Figures 12 and 13 of the main report for 0.6 million cu yd/yr. Graphically, the continuation of the radius curve from year 20 can be determined by superimposing the 0.6 million cu yd/yr radius curve such that it intersects the 0.2 million cu yd/yr curve at year 20 and continuing along the 0.6 million cu yd/yr curve. This procedure is also used to obtain the percent loss curve.

3. Analytically, the radius at year 20 is obtained by Equation 1.

$$r = -3.18 + 1.75 \ln (20 + 34)$$

$$r = 3.79 \times 1000 \text{ ft}$$

From Equation 9, the corresponding year at which a 3,790-ft radius is reached for an annual maintenance dredging rate of 0.6 million cu yd is determined.

$$y = e^{(3.79/1.85 + 0.900)} - 11.3$$

$$y = 7.84 \text{ years}$$

The difference between 20 and 7.84 years represents the number of years the 0.6-million-cu-yd curve was shifted to the right so that it intersected the 0.2 million-cu-yd curve.

$$\Delta y = 20 - 7.84$$

$$\Delta y = 12.16 \text{ years}$$

Equation 7 is shifted by 12.16 years and represents the equation for the radius after 20 years.

$$r = -1.66 + 1.85 \ln (y + 11.3 - 12.16)$$

$$r = -1.66 + 1.85 \ln (y - 0.86) \qquad (13)$$

Equation 8, percent loss curve, is also shifted by 12.16 years.

$$PL = -27.10 + 13.05 \ln (y + 10 - 12.14)$$

$$PL = -27.10 + 13.05 \ln (y - 2.14) \qquad (14)$$

Note that if the maintenance rate went from a high rate to a lower rate, Δy would be positive, not negative as in this example.

4. For the first 20 years Equations 1 and 2 are used to determine the radius and percent loss. For years past 20, Equations 13 and 14 are used. Selected years are computed in Table A1 and shown graphically in Figures A1 and A2.

Table A1

Computation of Radius Growth and Percent Loss

	Year									
	2	5	10	15	20	25	30	40	50	60
Radius, 1000 ft	3.09	3.23	3.44	3.63	3.79	4.23	4.58	5.12	5.55	5.89
Percent loss	5.37	6.40	7.92	9.27	10.47	13.74	16.32	20.32	23.38	25.86

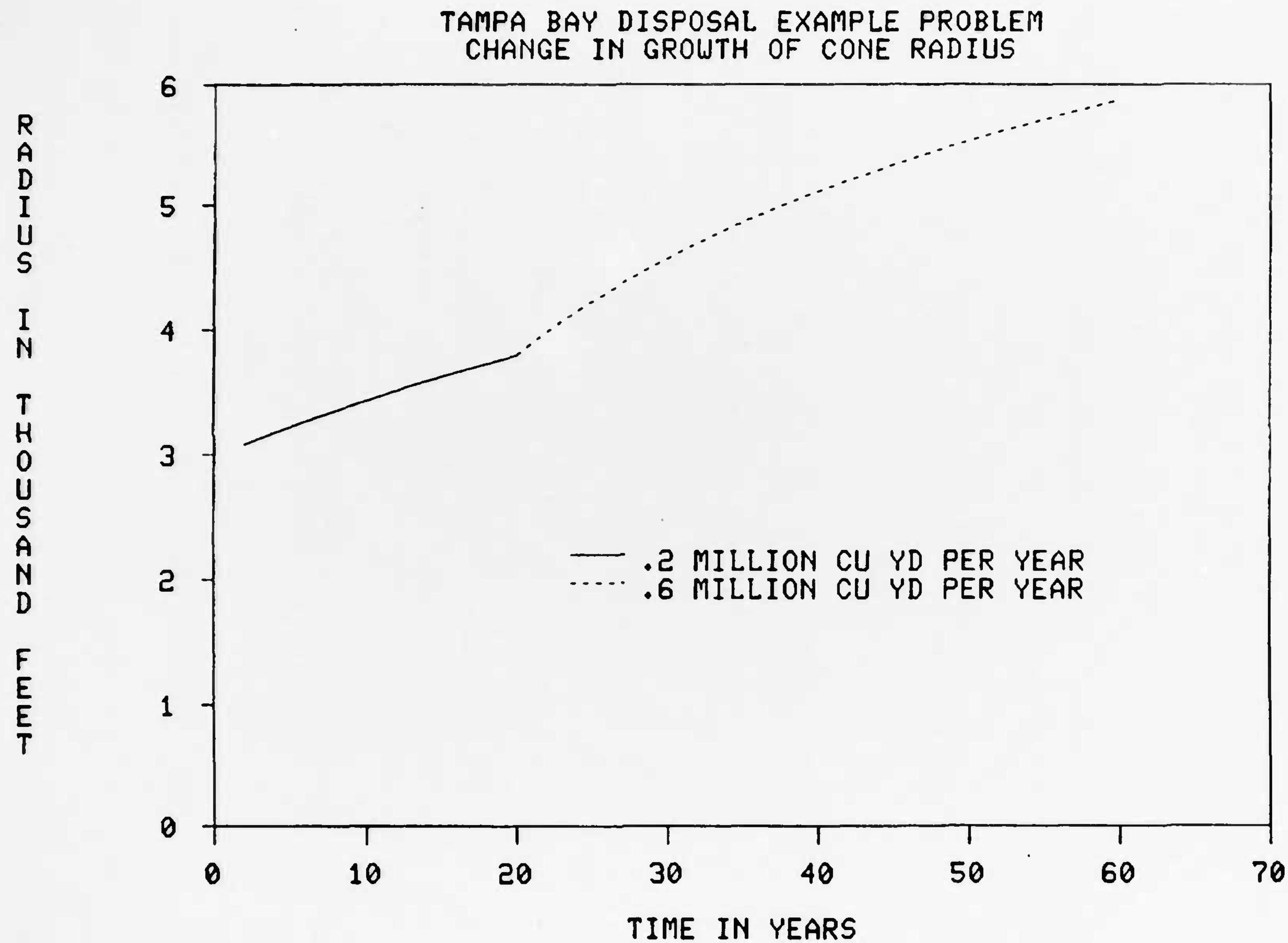

Figure A1. Example problem, change in radius with time

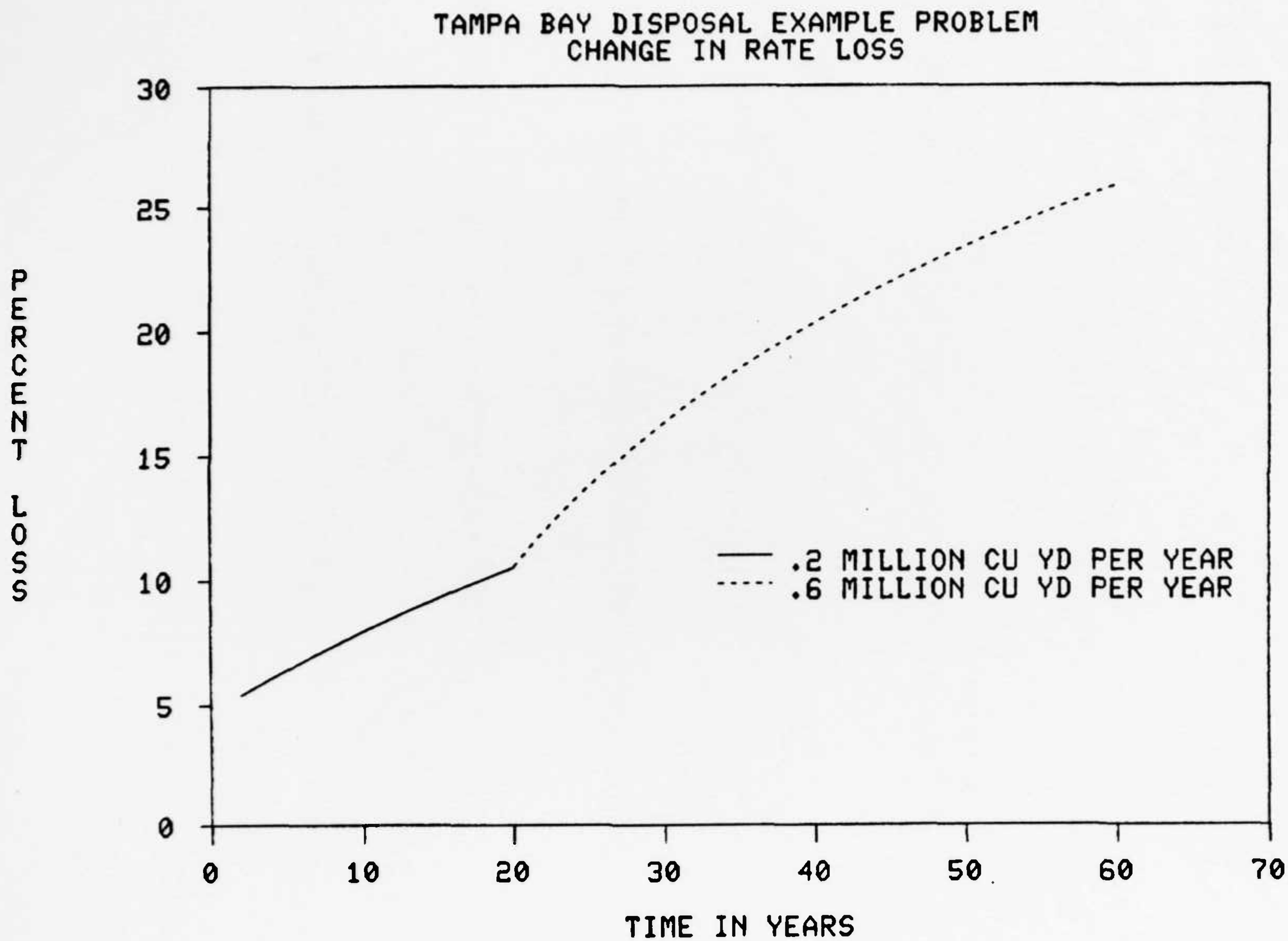

Figure A2. Example problem, change in percent loss with time

5. The volume placed in the disposal site at 0.2 million cu yd/yr is expressed by

$$V = 3.6 + 0.2(y - 2) \quad (23)$$

where

V = volume in million cu yd

y = years

At year 20, the volume placed is

$$V = 3.6 + 0.2(20-2) \quad (24)$$

$$V = 7.2 \text{ million cu yd} \quad (25)$$

The volume remaining in Site 4, V_r , at year 20 is calculated using Table A1 and the following equation.

$$V_r = V(100 - PL)/100$$

$$V_r = 7.2(100 - 10.48)/100$$

$$V_r = 6.45 \text{ million cu yd} \quad (26)$$

The volume placed after year 20 is determined by

$$V = 7.2 + 0.6(y -20) \quad (27)$$

The volume placed by year 60 is

$$V = 7.2 = 0.6(60 - 20) \quad (28)$$

$$V = 31.2 \text{ million cu yd} \quad (29)$$

and the volume remaining is

$$V_r = 31.2(100 - 25.85)/100 \quad (30)$$

$$V_r = 23.13 \text{ million cu yd} \quad (31)$$

END

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