



# DREDGED MATERIAL RESEARCH PROGRAM



TECHNICAL REPORT D-78-40

## A FIELD STUDY OF FLUID MUD DREDGED MATERIAL: ITS PHYSICAL NATURE AND DISPERSAL

by

Maynard M. Nichols, Galen S. Thompson

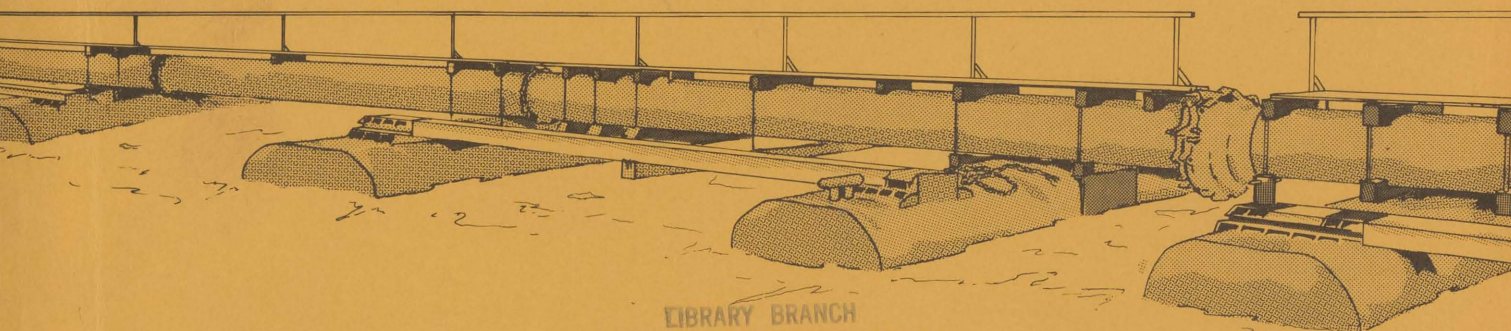
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July 1978  
Final Report

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1. The technical report transmitted herewith represents the results of one research effort (work unit) initiated as part of Task 6C (Turbidity Prediction and Control) of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 6C, part of the Disposal Operations Project of the DMRP, was concerned with investigating the problem of sediment resuspension around dredging and disposal operations; developing methods to predict the nature, extent, and duration of the turbidity and fluid mud; and evaluating methods of controlling the generation and dispersion of turbidity and fluid mud.
2. Although there are still many questions about the direct and indirect effects of different levels of turbidity on aquatic organisms, fluid mud generated from open-water pipeline disposal has been shown to produce an adverse, although perhaps not long-term, environmental impact in the disposal area. Prior to the DMRP, very little research had been conducted and little was known about the physical nature and dispersal of fluid mud. In order to gain a better understanding of the phenomenon, the study reported herein, conducted under contract by the Virginia Institute of Marine Science, Gloucester Point, Virginia, was undertaken. The study attempted to determine in the field the significance of fluid mud in the dispersal of dredged material and in the generation of turbidity.
3. Dense suspensions of fluid mud with concentrations of 10 to 480 g/l were studied at field sites in Mobile, Alabama, and the James River, Virginia. The bulk of the dredged material (more than 99 percent at the Mobile Bay site) was dispersed in the form of fluid mud near the bottom whereas less than 1 percent was dispersed through the water column. As suspended solids flocculate and settle, they contribute to the fluid mud. In turn, fluid mud resists resuspension and reduces turbidity.
4. Disposal operations created a deposit of fluid mud that spread over an area 5 to 13 times the dredged area in the channel. Disposal raised the bed, forming dense layers in mounds 0.8 to 2.2 m high, having slopes from 1-to-125 to 1-to-2000. Broad spreading at the Mobile site was associated with a high discharge rate over a short period, a low discharge angle, and mounds with high plastic and liquid limits. Mounding at the James River site

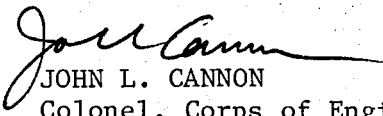
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was associated with a moderate discharge rate over a long period, a vertically oriented discharge configuration, and muds with a moderate plastic limit and relatively low liquid limit. After disposal the fluid mud consolidated, bulk density increased, and slopes decreased. Height and volume of the James River mound decreased about 50 percent in a year.

5. The results of this study, in conjunction with laboratory studies being conducted as part of another work unit in Task 6C, will be used to develop final guidelines for predicting the extent and duration of fluid mud generated by open-water pipeline disposal operations. The final guidelines will be contained in the DMRP synthesis report of Task 6C.

  
JOHN L. CANNON  
Colonel, Corps of Engineers  
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20. ABSTRACT (Continued).

1 percent was dispersed through the water column. As suspended solids flocculate and settle, they contribute to the fluid mud. In turn, fluid mud resists resuspension and reduces turbidity.

Disposal created a deposit that spread over an area 5 to 13 times the dredged area in the channel. Disposal raised the bed, forming dense layers in mounds 0.8 to 2.2 m high having slopes 1:125 to 1:2000. Broad spreading at the Mobile Bay site was associated with a high discharge rate over a short period, a low discharge angle, and muds with high plastic and liquid limits. Mounding at the James River site was associated with a moderate discharge rate over a long period, a vertically oriented discharge configuration, and muds with a moderate plastic limit and a relatively low liquid limit. After disposal, the fluid mud consolidated, bulk density increased, and slopes decreased. Height and volume of the James River mound decreased about 50 percent in a year. More field investigations of the movement of fluid mud are needed for a detailed understanding of its dynamics.

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## PREFACE

This study discusses the significance of fluid mud in the dispersal of dredged material and the generation of turbidity. It was performed under Contract No. DACW39-75-C-0121, dated 1 July 1975, between the U. S. Army Engineer Waterways Experiment Station (WES) and the Virginia Institute of Marine Science (VIMS). The work was part of the Dredged Material Research Program (DMRP) Task 6C, "Turbidity Prediction and Control," Work Unit 6C07, "A Field Study of Fluid Mud Dredged Material: Its Physical Nature and Dispersion." The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was monitored by the Environmental Laboratory (EL), WES.

The U. S. Army Engineer District, Mobile, and the U. S. Army Engineer District, Norfolk, assisted with field operations.

The contract was monitored by Dr. William D. Barnard, Disposal Operations Project (DOP), EL, under the general supervision of Mr. Charles C. Calhoun, Jr., DOP Manager, and Dr. John Harrison, Chief, EL. Contracting Officer's Representative was Mr. Calhoun.

Directors of WES during the conduct of this study and the preparation and publication of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.



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A FIELD STUDY OF FLUID MUD DREDGED MATERIAL:  
ITS PHYSICAL NATURE AND DISPERSAL

PART I: INTRODUCTION

Background

1. Dense suspensions of sediment, with concentrations of 10 to 480 g/l that are discharged from an open-water pipeline, often spread beyond designated dredging disposal limits. These dense suspensions are variously called "fluff" (Krone, 1962), "la creme de vase" (Allen et al., 1974), "sling mud" (Demerara Coastal Investigation, 1962), or "fluid mud" (Inglis and Allen, 1957). When fluid mud spreads over a broad area, it may backfill dredged channels and threaten clam and oyster beds. Because fluid mud adsorbs heavy metals, its pollution potential is also a concern.

2. Although fluid mud is a common product of many open-water pipeline disposal operations, there have been few systematic field observations concerning its physical nature and dispersal. Most studies have been directed toward turbidity clouds, while the bulk of the dredged material, in the form of fluid mud, has been ignored.

Objectives

3. This investigation aimed to determine the significance of fluid mud in dispersal of dredged material and in the generation of turbidity. This objective contributed to the overall objective of the U. S. Army Corps of Engineers' Dredged Material Research Program "to provide more definitive information on the environmental effects of dredging and dredged material disposal operations."

4. The immediate objectives of the present study were:
- a. To observe the nature, extent, and thickness of fluid mud in relation to its source and to turbidity at several open-water disposal sites.
  - b. To measure the dynamic conditions of water and mud movement in the vicinity of a dredged material discharge site.
  - c. To determine the physical properties of the mud that affect its dispersal, stability, and persistence with time.
  - d. To prepare recommendations for control and avoidance of problems arising from fluid mud dispersal.

#### Approach

5. The rationale behind the approach to this investigation lies in the simple sedimentologic concept of sediment source and dispersal. Dredged material slurries that are discharged from a dredge pipe into open water enter the ambient water mass and are dispersed in three distinct fractions: (a) fine dispersed suspended sediment in the form of plumes; (b) dense suspensions of fluid mud; and (c) consolidated masses. The fine-grained clay fraction, in low concentrations, settles very slowly through the water column and therefore is carried a relatively long distance by ambient currents. By contrast, the fluid mud fraction settles quickly to the bottom. This fraction may either pile up or spread outward and downslope. In some situations, a pressure head may develop whereby the mud is pushed away like syrup on a platter (May, 1973).

6. Field observations of this investigation were made at two sites: (a) Central Mobile Bay, Alabama; and (b) Windmill Point, Upper

James River Estuary, Virginia. These sites were selected for study because the time of dredging coincided with the time of this investigation and because the dredging was likely to produce fluid mud.

## PART II: INSTRUMENTATION AND METHODS

### Field Instrumentation

7. To measure the speed and concentration of moving mud slurries during a disposal operation required fabrication of special equipment. The dispersion field is extremely dynamic. Not only is the pipeline discharge rapidly changing in speed and concentration, but the receiving water is rapidly changing according to variations in the wind, waves, and tide. As dredged material is deposited, water depths decrease, fluid mud becomes thicker and the mud-water interface rises. As fluid mud accumulates, the slope of the depositing surface changes and the mud may spread outward from the discharge point. Measurement of fluid mud is hampered by disturbance of the mud during sampling and by the difficulties of shipboard retrieval and laboratory processing. Therefore, sensors were deployed to measure the mud in situ.

### Apparatus

8. The unit built especially for this work consists of a tripod frame with a hydraulic cylinder in the head (see Figure 1). The unit, called a sediment-water interface probe, is constructed of 1.9-cm-round hot-rolled steel. It stands 3.7 m tall, is 1.8 m wide at the base, and weighs 56.7 kg without the sensors. The hydraulic cylinder is housed in a galvanized pipe braced by the welded steel round. To prevent excessive sinking into the mud, steel pads are fitted to the lower ring and articulated with elastic cord to lock in a horizontal position. When the unit is lifted from the bed, the pads fold downward to break suction

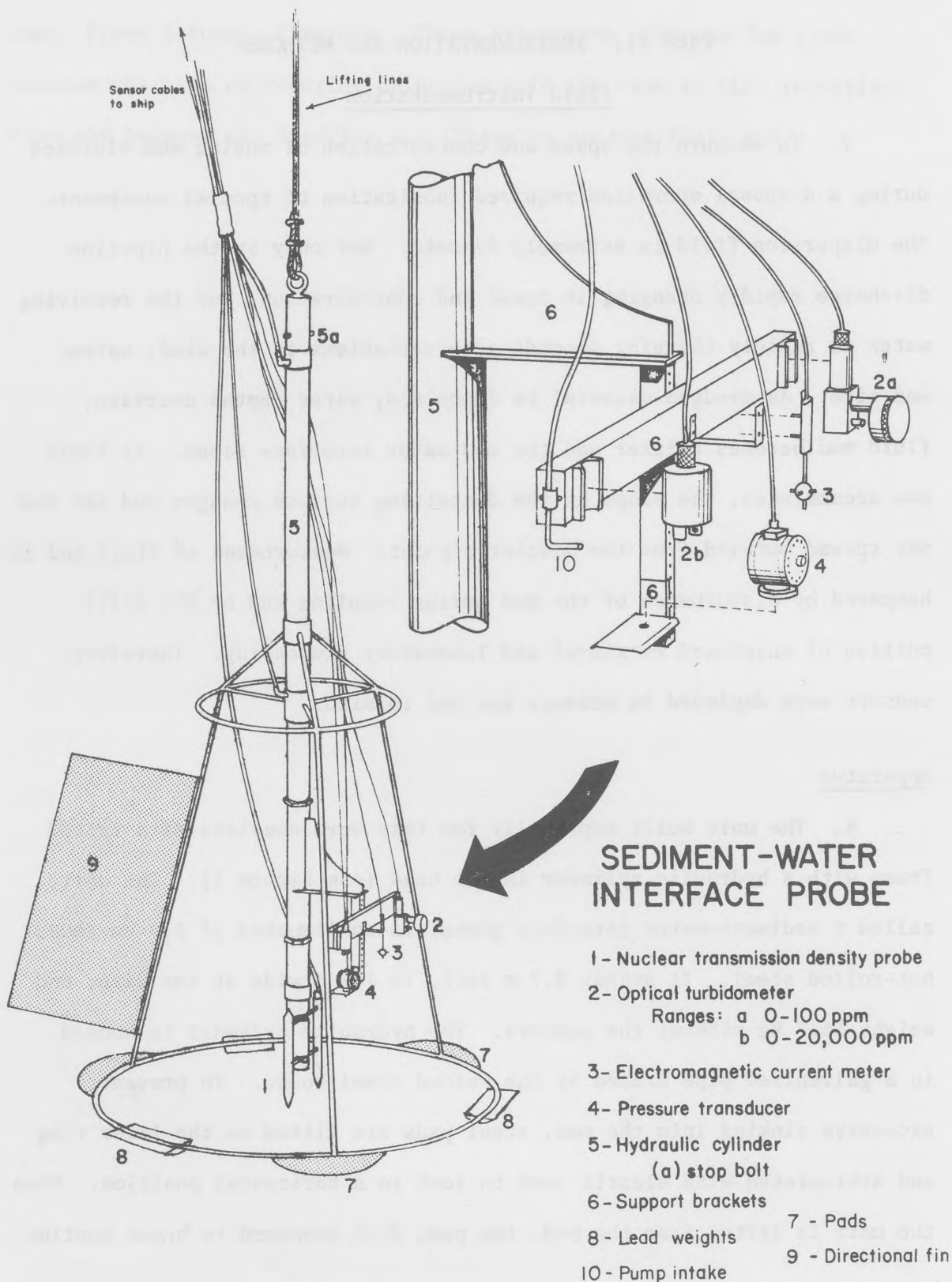


Figure 1. Schematic diagram of the sediment-water interface probe and sensors.



with the mud. A swivel link and a fin permit alignment of the sensors with the mean flow.

9. The hydraulic cylinder consists of a brake unit commonly used in trucks. It is manufactured by Advance Automation Company, Inc., and marketed as the Challenger. The cylinder is 7.6 cm in diameter, 1.5 m long, and operates under a pressure of 3447.4 kPa. It is driven by a 12-V DC motor pump via hydraulic hose containing hydraulic fluid. The cylinder is powered in and out over a vertical distance of 144 cm. A variable-pressure regulating valve provides a range of penetration speeds from nearly zero to more than 5 cm/sec.

#### Sensors

10. Six sensors are mounted on the lower end of the hydraulic cylinder for simultaneous measurement of sediment density, turbidity, and current speed with depth:

- a. Harwell nuclear transmission density gage.
- b. Partech optical turbidimeters with ranges of 0-100 ppm, 0-5,000 ppm and 0-20,000 ppm.
- c. Marsh-McBirney electromagnetic current meter.
- d. Bell and Howell pressure transducer.

11. The nuclear transmission density gage built by the Hydrology and Coastal Sediment Group, Harwell, Great Britain, is a two-legged stainless steel probe. A radioactive point source in one leg consists of 3 millicuries of barium-133, while a photomultiplier detector in the other leg consists of a sodium iodide crystal. Source and detector spacing is 150 mm. Attenuation of gamma radiation between source and

detector is a function of the bulk density of the sediment with its content of water, gas, and sediment particles. The count rate is displayed on deck in a linear rate meter with a percentage scale. Time constants of 1 and 5 sec were used. The bulk density equivalent to the count rate is derived from calibration curves. A continuous profile of density versus depth is recorded on an X-Y plot by coupling signals of the density probe with that of a pressure transducer. The effect of response time and varying time constants on interpretation of profiles is given by Parker, Sills, and Paske (1975).

12. The pressure transducer, manufactured by Bell and Howell, type 4-351-0054, is a bidirectional differential unit. A reference port compensates for changing atmospheric pressure while the positive port senses the hydrostatic pressure as a function of depth. The sensor has a sensitivity of 1.21 mv/m of water with a maximum working pressure of 344.7 kPa, or 3.4 atm.

13. The pressure sensor was calibrated in situ by lowering it to a known depth and adjusting the signal conditioner and recorder to respond to a desired scale. The procedure was continued at 0.3-m intervals until the unit was calibrated to the greatest depth in the sample field. Since the signal conditioner had no direct readout, the depth indicated on the recorder was noted against a marked depth on the interface probe for each cast.

14. The Partech turbidimeter, built by Partech Electronics, Ltd., Cornwall, Great Britain, consists of a deck signal conditioner and optical sensors in ranges of 0-100, 0-5,000, and 0-20,000 ppm.

The sensors use a low-wattage incandescent lamp and one or more photoelectric cells. The signal conditioners are scaled in percent absorption. The units were calibrated with samples of dredged material mud collected from each dredge site. Stock suspensions were prepared by successive dilutions from maximum concentrations for each sensor to a clear-water zero on the scale. The suspensions were analyzed gravimetrically by Millipore filtration with 0.8- $\mu$  pore-size filters. When the unit is coupled with a pressure transducer, a continuous profile of turbidity versus depth is recorded on an X-Y plot. Use of the turbidimeter for relatively dilute suspensions coupled with the density probe for dense suspensions provides measurements over a range of suspensions with solid concentrations of less than 10 mg/l to greater than 200,000 mg/l.

15. The current meter consists of an electromagnetic unit constructed by Marsh McBirney, Inc., Rockville, Maryland. The meter consists of a portable deck signal processor or readout, Model 711, and a current speed sensor, Model 511. The sensor is a 3.8-cm-diameter sphere that senses flow in two vector components, X and Y, oriented horizontally. As water and mud flow by the field, created by the internal electromagnet, it creates an electromotive force that is sensed by two electrode components, X and Y. Accuracy is rated at  $\pm 0.02$  cm/sec. The current meter was precalibrated by the manufacturer, and speeds were verified in a flume at the Virginia Institute of Marine Science. Each axis has a readout in the signal conditioner of either positive or negative with zero at center. Data were reduced by vector analysis of the

two responses to derive a final current speed value. Direction of surface water movement was determined visually in the field as "flood" or "ebb."

16. The distribution of fluid mud was also traced acoustically using a dual-frequency Raytheon fathometer with frequencies of 22.5 and 200 kHz. Transducers were mounted on the hull. The 200-kHz frequency recorded the approximate position of the fluid mud surface whereas the 22.5-kHz frequency recorded the approximate position of the fluid mud base at about 1.30 density.

#### Field Operation

17. The sediment-water interface probe was deployed in three ways:

- a. Dip stations. These were occupied for vertical profiles that determined the vertical distribution of dense suspensions. Deployment of the probe required anchoring at each station. It was first stabilized with the instruments at the water surface. All instruments were checked and their respective recorders set to zero. Upon completion of the surface check, the probe was lowered at a steady rate until it rested on the sediment bed. The hydraulic pump then was activated to continue vertical profiling into the sediment bed until the maximum penetration of the hydraulic cylinder had been reached. The optimum rate of penetration was 1.3 cm/sec. The nuclear density gage was fixed a set distance (30-60 cm) below the other sensors to provide a measurement of the sediment density before it was disturbed by the upper instruments during penetration into the bed.
- b. Anchor stations. Anchor stations were conducted near the end of the dredge pipe to determine the fluctuations in concentrations and movement of mud slurries near the source. After the probe was lowered to the bottom, the hydraulic cylinder was set at a desired level and the instrument package was lowered into the mud. The records obtained on strip charts indicated the changes in concentration and movement of suspended sediment and fluid mud at a single depth with time.

- c. Towed traverses. The distribution and concentration of the suspended sediment was determined by towing turbidity sensors across the discharge plume. The sensors were attached to a weighted towing body or "fish" and pulled through the water from a boom.

#### Water samples

18. Water samples were obtained by pumping water with a submersible Little Giant pump. Samples were withdrawn for gravimetric analyses of suspended sediment concentration and for salinity measurements.

19. Short cores were obtained with a corer which consisted of a 7.5-cm-diameter plastic tube fitted into a trip device of a Kemmerer water bottle. The cores together with bottom grabs were analyzed for physical properties of the mud.

#### Positioning

20. Stations were established on a basic 240-m-square grid and marked in the field with buoys and stakes. Supplemental stations were established at various intervals between the basic stations. Positioning was accomplished by ranging on buoys and sighting on landmarks and by sextant and pelorus bearings.

#### Observation period

21. Field observations were scheduled before, during, and after dredging operations. They were taken under different environmental conditions of wind, waves, and tide. The following tabulation gives the observation periods at each site.



<u>Site</u>	<u>Before Dredging</u>	<u>During Dredging</u>	<u>After Dredging</u>
Mobile Bay, Alabama	28 May 1976 through 4 Jun 1976	4 Jun 1976 through 11 Jun 1976	-- --
James River, Virginia	1 Aug 1975 through 11 Jul 1976*	11 Jul 1976 through 25 Jul 1976	25 Jul 1976 through 21 Sep 1976*

\*Intermittently during these periods.

### PART III: LABORATORY PROCEDURES

22. Sediment parameters that were measured in the laboratory included:

- a. Organic carbon.
- b. Grain size; by Hydrometer Method and Coulter Counter.
- c. Specific gravity (grain density) ( $\gamma_s$ ).
- d. Unit wet weight (bulk density) ( $\gamma_t$ ).
- e. Water content (dry weight basis) (w).

23. Derived parameters based upon measured properties included:

- a. Void ratio (e).
- b. Porosity ( $\eta$ ).

24. Other aspects of the sediments that were measured in the laboratory included:

- a. Atterberg limits (liquid and plastic limits).
- b. Suspended sediment concentration.
- c. Shear strength.

Description of the analyses performed and the calculations involved can be found in Appendix A.

## PART IV: RESULTS OF MOBILE BAY STUDY

### Site Characteristics

25. Along the U. S. gulf and east coasts, channels are often dredged landward through major estuaries from the ocean to coastal cities. Because sediments accumulate in these channels at a relatively fast rate, frequent maintenance dredging is necessary. The Corps of Engineers maintains the navigation channel through Mobile Bay to a depth of 12.6 m and a width of 120 m (Figure 2).

26. The disposal site observed is located in open water at water depths ranging from 3.05 m to 3.81 m (Figure 2). As shown in Figure 3, the bathymetry before disposal consists of broad "swells" and troughs with a maximum relief of 0.61 m. This represents the topography produced by disposal in former years and subsequently modified by waves and tidal currents during a two-year period.

27. Hydrodynamic conditions and significant sediment characteristics of the site as given by Ryan and Goodell (1972), May (1973), and Brett and April (1976) are listed in Table 1. The dredged material is cohesive silty clay with a 3.2- $\mu$  mean particle size. It has a relatively high water content, averaging 165 percent dry weight. Fluid mud with a density less than 1.3 g/cm<sup>3</sup> fills the channel about 1.2 m thick.

### Dredging operations

28. Each year an average of more than 4 million m<sup>3</sup> of sediment is dredged from the Mobile navigation channel. The chief type of dredge employed is the hydraulic cutterhead dredge. The dredged material is broken mechanically by the cutter, lifted hydraulically through a suction

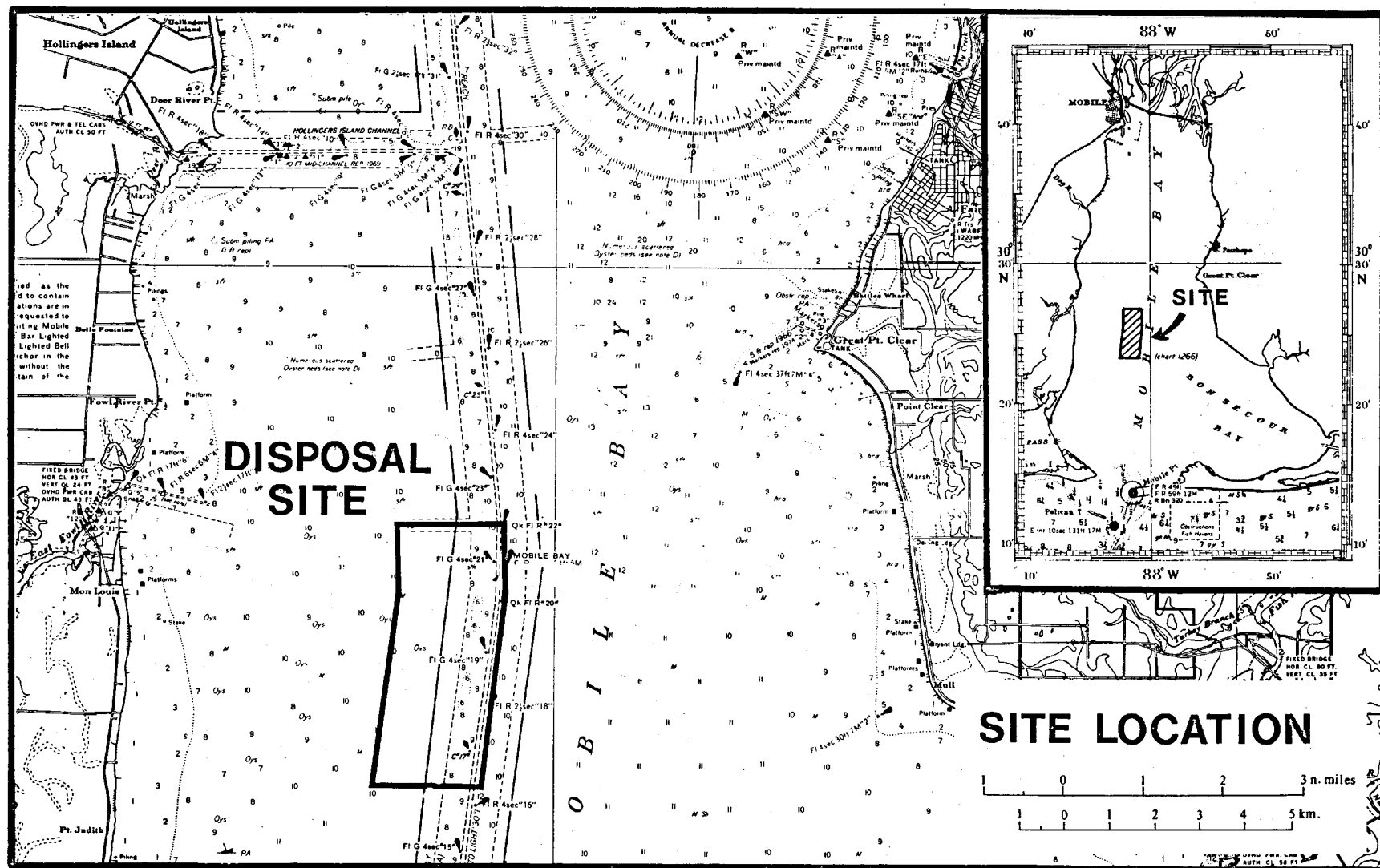


Figure 2. Location of disposal site, Mobile Bay, Alabama, from National Ocean Survey chart 1266.

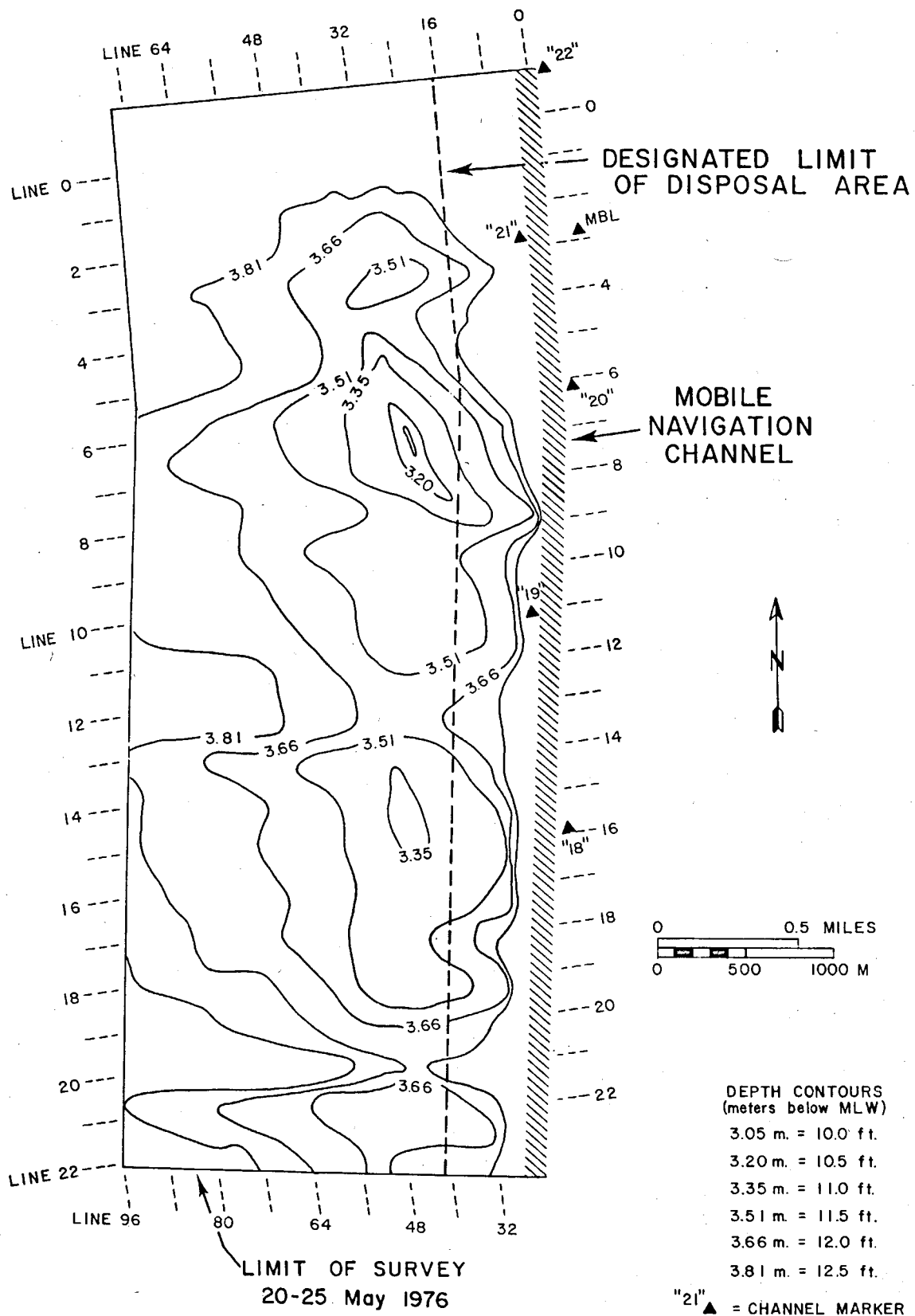


Figure 3. Bathymetry of the Mobile Bay site before disposal. From survey of the U. S. Army Engineer District, Mobile, 20-25 May 1976.

pipe, and transported through a pipeline to the open-water disposal site. Although pumping normally proceeds on a continuous basis, 24 hours per day, it is interrupted several times each day by mechanical breakdowns and to relocate the pipeline in the disposal area. While pumping, the dredge swings from side to side across the channel and alternately raises and lowers the head. Thus, the flow velocity and suspended sediment concentration of the slurry vary widely. Operation data are given in Table 2.

#### Hydraulic regime

29. At the time of observations, the upper layer of bay water over the disposal area was relatively well mixed. Salinity ranged from 0.9 ppt at the surface to 2.7 ppt at a depth of 3.2 m. Channel water was stratified at middepth. Salinity increased from 15.0 to 20.3 ppt between depths of 11 and 15 m. Winds blew 4 to 10 m/sec from the northwest, northeast, and east most of the time. Estimated wave heights ranged from 0.3 to 1.3 m. Diurnal tides prevailed and tidal currents varied from nearly zero at slack water to 43 cm/sec at maximum strength. Tidal currents reversed direction with the flood and ebb, parallel to the axis of the disposal area (north-south). Figure 4 summarizes the distribution of predicted tidal currents in relation to observational periods.

30. Suspended sediment concentrations prior to dumping in the disposal area varied within narrow limits. They ranged mainly from 27.2 mg/l on the surface to 54 mg/l near the bottom. A few samples reached over 100 mg/l near the bottom. Figure 10a shows the vertical distribution of suspended sediment concentrations across a portion of the disposal area.

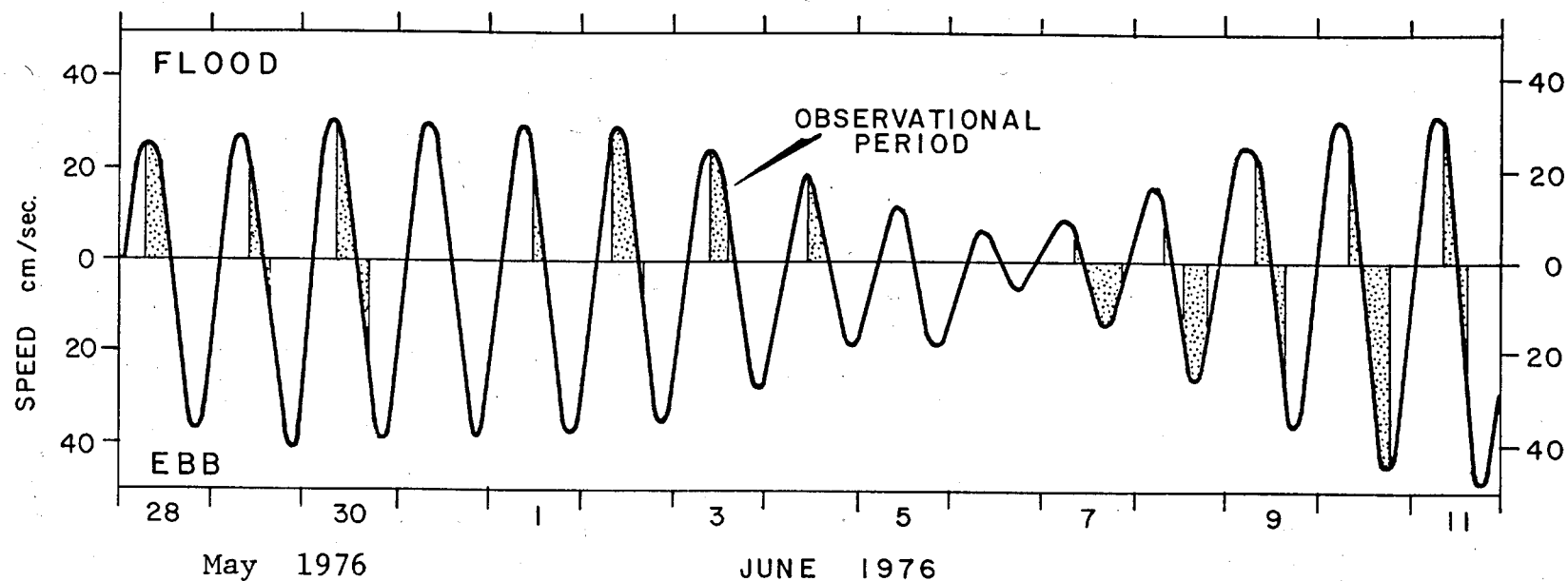


Figure 4. Distribution of tidal current speeds with time in Mobile Bay, 28 May-11 June 1976. Stippled zones indicate the periods of disposal observations. Data from National Ocean Survey tidal prediction tables.

## Physical Characteristics of Sediments

### Textural classification

31. Sediments were classified on the basis of relative percentages of sand ( $> 0.062$  mm), silt ( $0.0039 - 0.062$  mm), and clay-sized ( $< 0.0039$  mm) particles. These percentages are plotted on a ternary diagram (Shepard 1954) that has been subdivided into 10 distinct textural classes (Figure 5). The sediment can be described as a silty clay or clayey silt, depending upon its position within the diagram.

32. Figure 5 shows the position of 15 sediments from Mobile Bay on the ternary diagram of Shepard (1954). They include new dredged material and old consolidated sediment, probably older dredged material. The sediments are classed primarily as silty clay; however, a few are clay. No distinction between old consolidated sediment or new dredged material could be observed. The silt clay ratio averages 30:70. Sand-sized particles are lacking from most samples analyzed, occurring in only two samples (maximum of 2 percent). The distribution of the silty clay corresponds to that shown by Ryan and Goodell (1972, plate 17).

### Atterberg limits

33. The following tabulation presents average values for Atterberg limits for samples from Mobile Bay. Two groups of samples are compared, the new dredged material and the old consolidated sediment ( $W_L$ ) = liquid limit;  $W_p$  = plastic limit; and  $I_p$  = plasticity index).



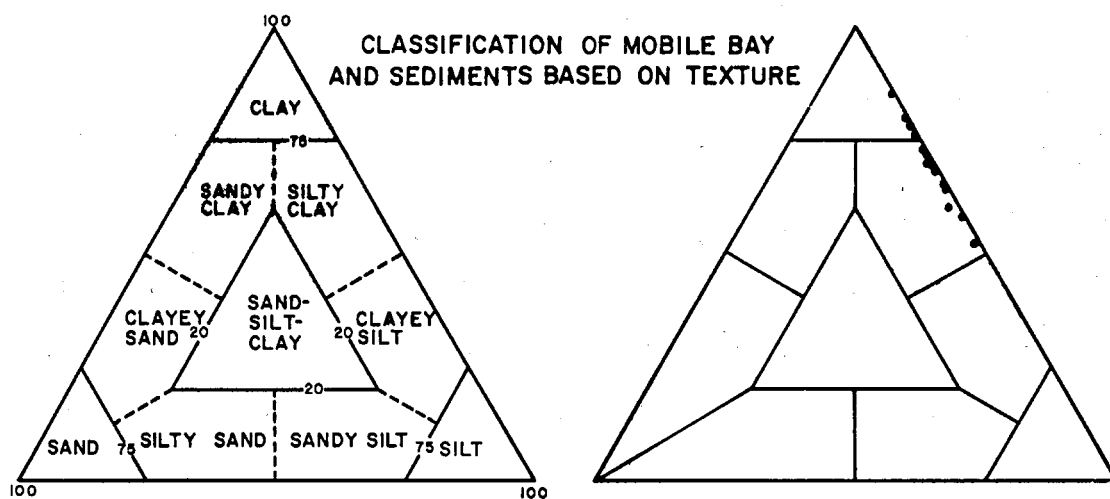


Figure 5. Textural classification of sediments from the Mobile Bay disposal area including new dredged material and old consolidated sediment. Ternary diagram from Shepard (1954).

#### New Dredged Material

<u>Statistical parameter</u>	<u>W<sub>L</sub></u>	<u>W<sub>p</sub></u>	<u>I<sub>p</sub></u>
$\bar{x}$	156.6	39.3	117.3
s	42.2	5.9	41.3
n	5.0	5.0	5.0

#### Old Consolidated Sediment

$\bar{x}$	115.4	31.3	81.7
s	18.5	6.1	20.1
n	18.0	17.0	17.0

34. Differences exist in the liquid limit between the two groups that are also shown in the plasticity index. The liquid limit is very high in the new dredged material, perhaps reflecting an increase in surface area of the clay particles due to disruption of interparticle bonds. The plastic limit for the two groups of samples is nearly the same.

#### Organic matter

35. Organic matter of all samples averaged 1.96 percent ( $s = 0.75$ ,  $n = 18$ ). It occurred in microscopic detrital particles, uniformly distributed throughout the sediment. No distinction was made between the new dredged material and the old consolidated sediment. Decomposition seemed nearly complete, resulting in unidentifiable amorphous material and refractory material. The form of organic matter in the sediments influences the engineering properties significantly. Rashid and Brown (1975) showed that addition of 4 percent humic acid to a muddy sand increased plasticity and remolded shear strength, and almost doubled the liquid and plastic limits of the sediment. On the other hand, the rate of consolidation of their samples decreased, as did the rate of

permeability. These characteristics are evident in the new dredged material of Mobile Bay.

#### Activity of clay-sized sediment

36. Activity refers to the increased surface activity of the clay fraction ( $< 2 \mu$ ) of a sediment, e.g., the increased ion exchange capacity and adsorption of water with decreasing grain size. Skempton (1953) defined this ratio in terms of the direct linear relationship between the plasticity index ( $I_p$ ) and the clay fraction as:

$$a_c = \frac{I_p}{\text{percent clay fraction } < 2 \mu}$$

He defined three classes of clays: inactive clay,  $a_c < 0.75$ ; normal clay,  $a_c = 0.75 - 1.25$ ; and active clay,  $a_c > 1.25$ .

37. Activity values of Mobile Bay sediments are shown in Figure 6. They show activities between 1.25 and 1.50, with a few samples between 0.90 and 1.25, and one sample at 1.75. They are classified as active clays according to Skempton (1953). The type of clay mineralogy in the sediments determines the level of activity. Mobile Bay sediments consist primarily of montmorillonite and kaolinite, with montmorillonite occurring in much greater abundance (approximately four times greater) in the northern part of the estuary (Ryan and Goodell 1972). This clay mineral distribution is reflected in the narrow range of activities (1.25 - 1.75) for the Mobile Bay (Figure 6).

38. High montmorillonite content is responsible for the extreme value of liquid limit  $W_L$  for the new dredged material from Mobile Bay.

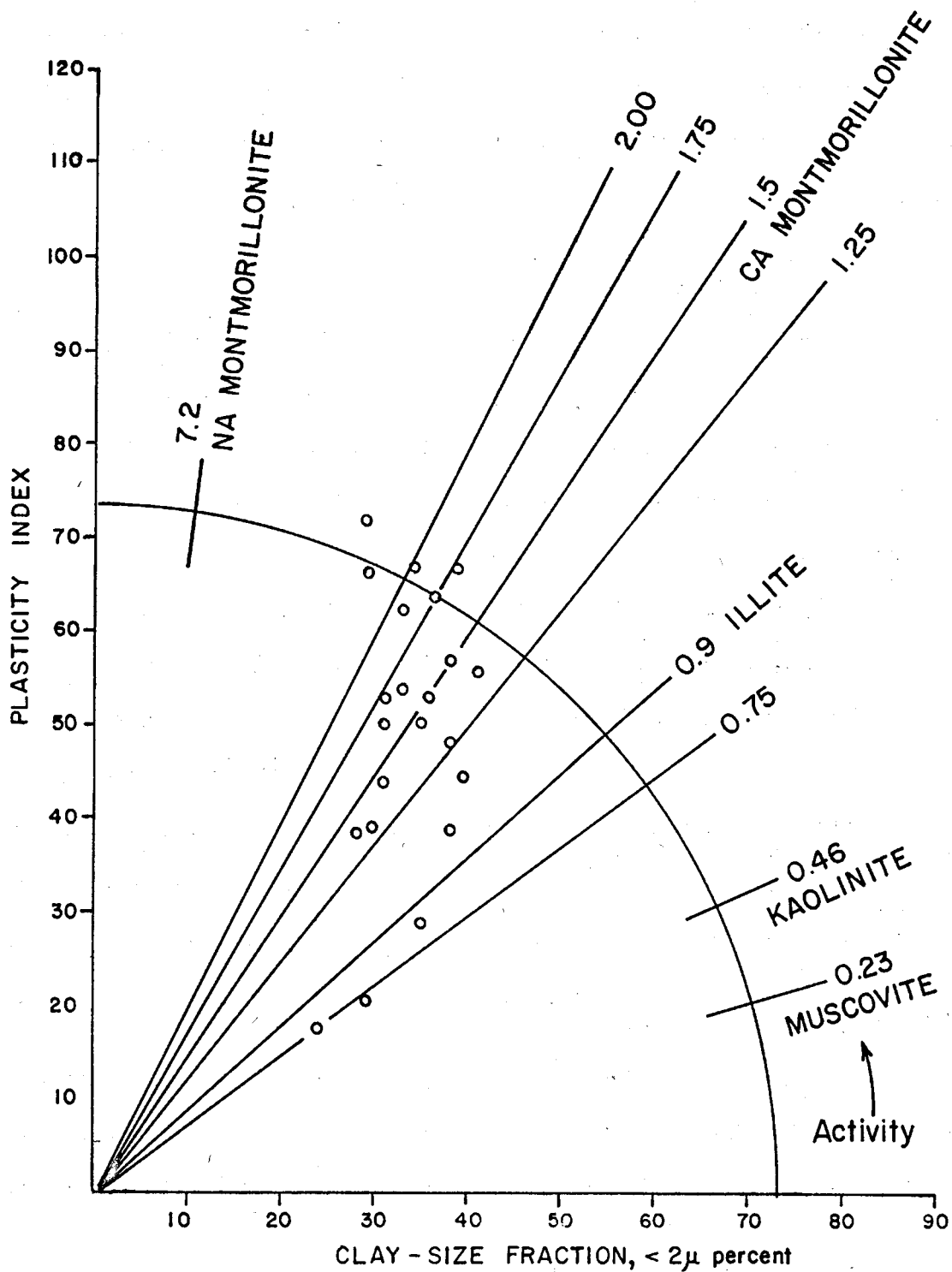


Figure 6. Activity of new dredged material and old consolidated sediments in relation to plastic index and clay-size fraction, Mobile Bay sediments.

Because of the great increase in surface area per mass with decreasing particle size (montmorillonite =  $1,000 \text{ m}^2/\text{g}$ ), large amounts of water are attracted to the particles. This results in a sediment characterized by high levels of both adsorbed and free water.

#### Classification of sediments

39. The sediments were classified for engineering purposes according to the Unified Soil Classification System (Wagner, 1957). The system is based upon the grain size and plasticity characteristics of a sediment and places sediment in a specific category according to its liquid limit and plasticity index.

40. Figure 7 shows the position of the Mobile Bay sediments on the plasticity chart. Most sediments fall above the A-line, which separates organic from inorganic sediments, and within the field designated CH. The new dredged material generally plots higher on the diagram than the old consolidated sediment, indicating a greater degree of plasticity in the new dredged material. According to the Unified Soil Classification System, CH sediments are "inorganic clays of high plasticity, fat clays."

#### Bathymetry after dredging

41. A depth survey conducted by the U. S. Army Engineer District, Mobile, 5 to 10 days after completion of disposal, reveals the distribution of the main mass of dredged material. Vertical and horizontal positioning

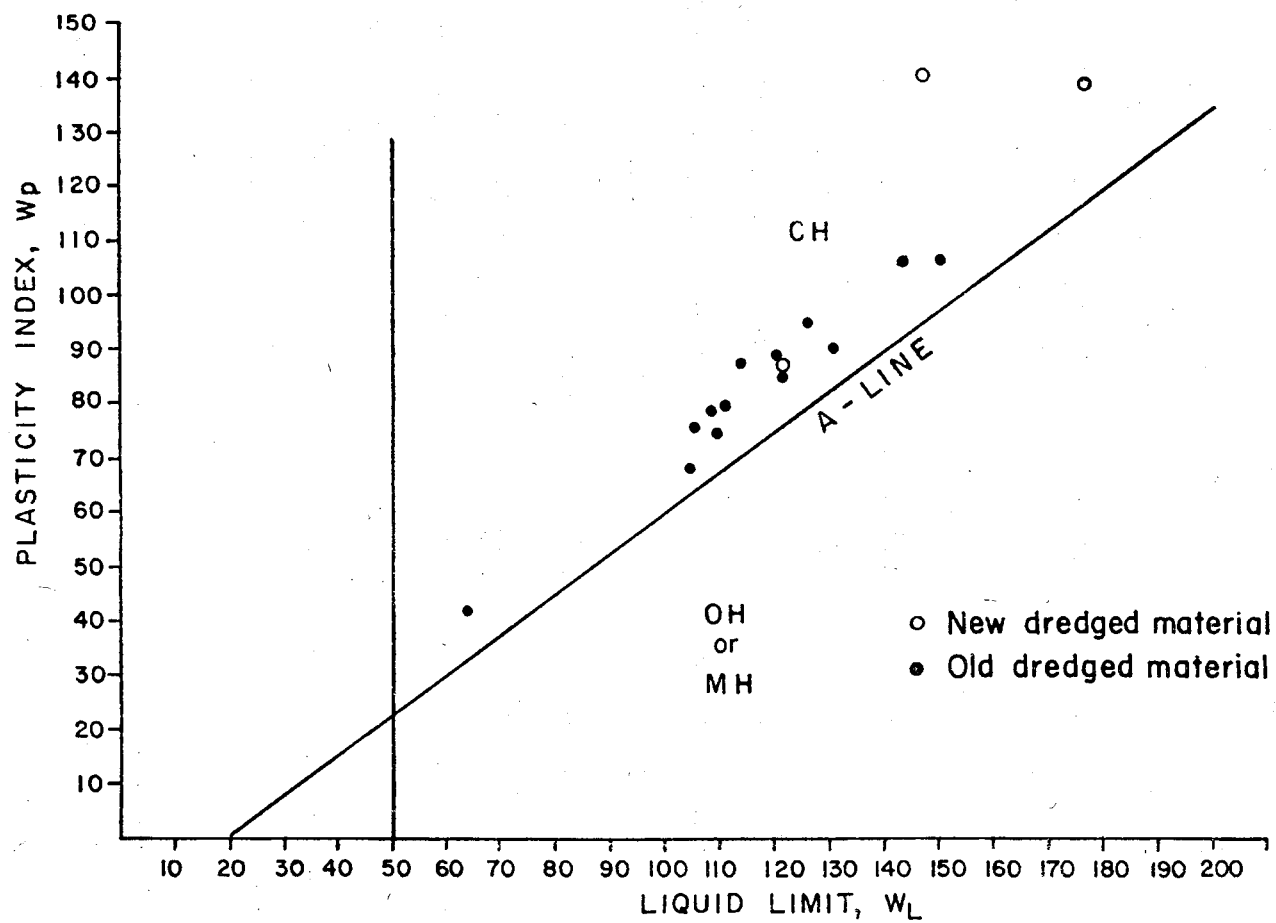


Figure 7. Plasticity chart for Mobile Bay sediments.

of fathometer soundings limits accuracy of charted depths to an estimated  $\pm 15$  cm. Therefore, the distribution of the main mass of dredged material is delineated by a break in slope displayed by the fathograms rather than by depth changes alone. Figure 8 shows the approximate thickness and extent of dredged material along selected profiles. Disposal raised the bed about 30 cm and increased the average bed slope from 1:3000 to 1:2000. The dredged material formed a broad swell interrupted by small conical hills 0.6 m high and by scour pits 0.4 m deep that formed close to the discharge point.

42. The shape and distribution of bed topography created by disposal is displayed in Figure 9. The main mass of dredged material covered a zone more than 800 m wide parallel to the channel axis (shaded area, Figure 9). It covered an area of 4,562,000 m<sup>2</sup> between line 0 (north) and line 18 (south). This area is 13 times the dredged area in the channel. An estimated eighteen percent of the dredged material covered an area along the east side outside the designated disposal area even though the discharge point was always within the limits of the disposal area. The main mass of dredged material extended farther to the west of the discharge points than to the east. Such asymmetry is probably caused by the westward orientation of the discharge pipe.

#### Suspended sediment and turbidity

43. Suspended sediment concentrations, estimated from light transmission measurements, were mainly less than 40 mg/l before disposal (Figure 10a). Concentrations in the discharge slurry ranged from 134,000

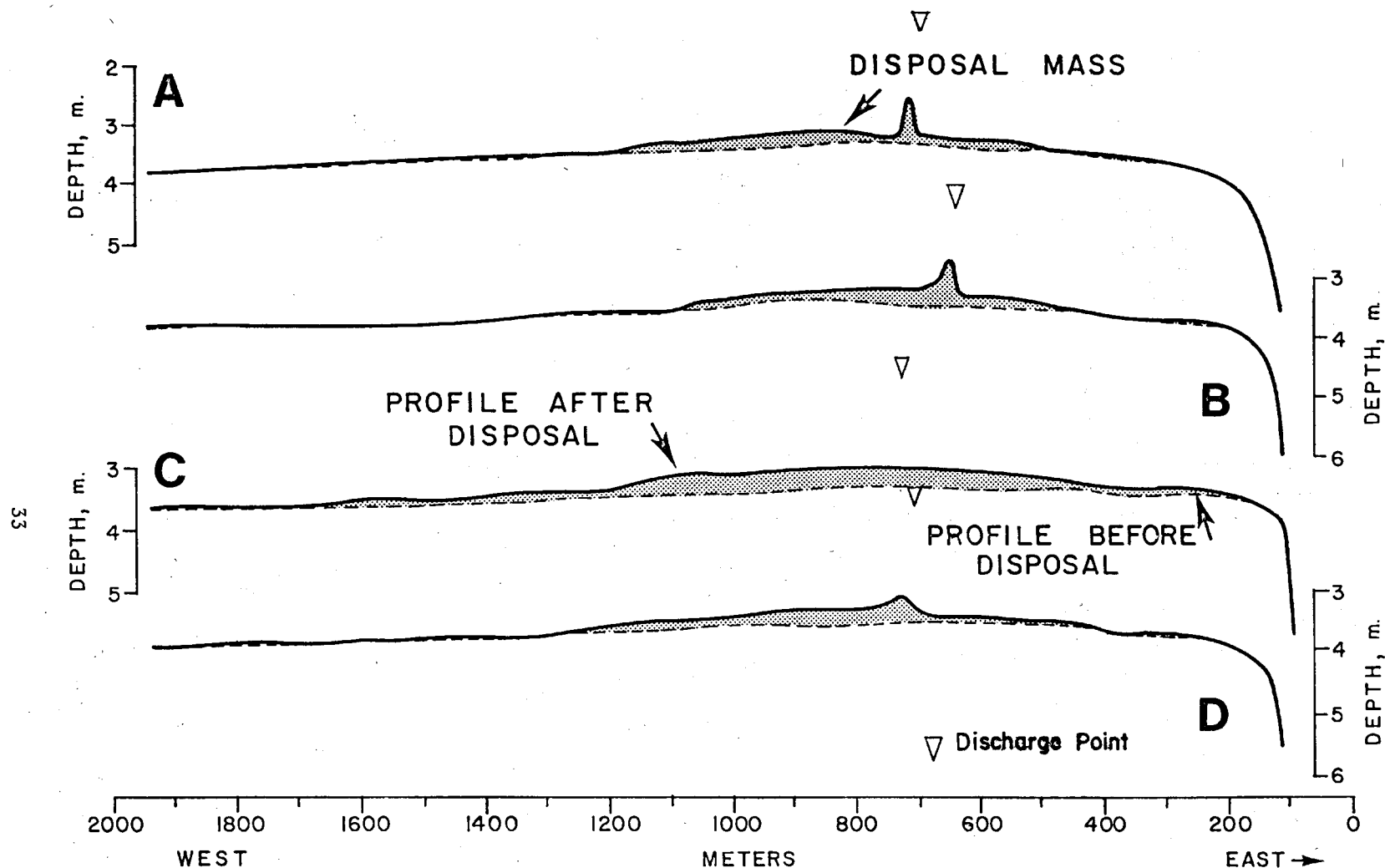


Figure 8. Bathymetric profiles across selected survey lines of the Mobile Bay disposal area, surveyed by the U. S. Army Engineer District, Mobile, 20-25 May 1976 and 17-21 June 1976. For location of profile sections, see Figure 9. Vertical exaggeration 100 times.



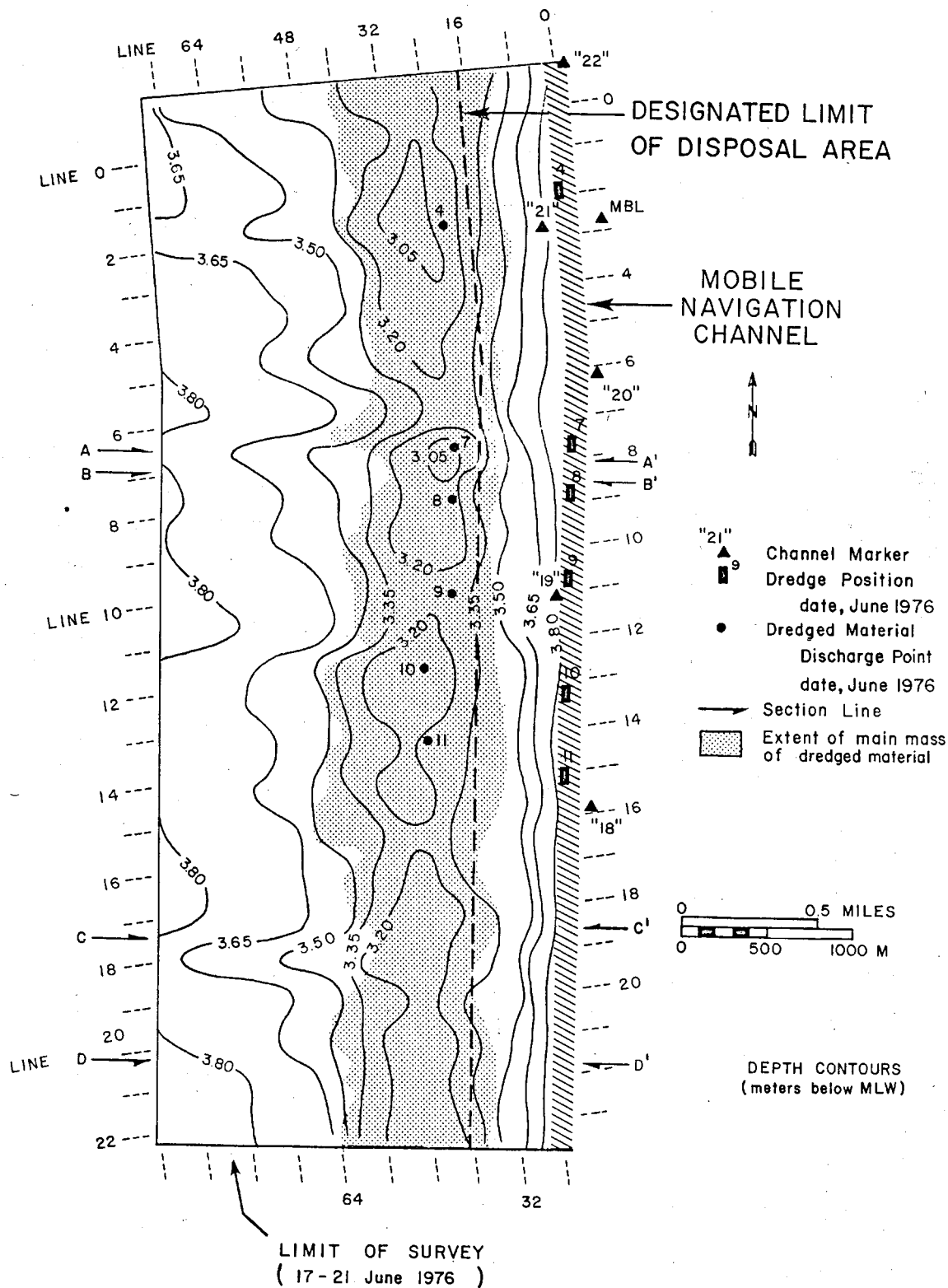


Figure 9. Bathymetry of the central Mobile Bay site after disposal 17-21 June 1976.

to 259,000 mg/l. A near-surface plume extended southwestward more than 300 m. This direction is the component resulting from the interaction between the ebb tidal current directed south and the momentum discharge from the pipe directed west.

44. Concentrations in near-bottom water exceeded 40 mg/l over a broad area extending more than 500 m from the discharge point. Additionally, concentrations exceeded 100 mg/l over 300 m from the discharge point and they extended 80 cm above the water-sediment interface, which is designated at 10 g/l (Figure 10b). When discharge of dredged material stopped, the sediment plume disappeared within 2 hours.

45. It is of note that the zone of suspended sediment concentrations which exceeded background values represents a distribution at one period in time. The obvious conclusion is that the distribution of turbidity is confined to the environs of the dredge or discharge point. This is a relatively small zone in proportion to the size of the channel or the disposal area. However, the zone of excess concentrations is carried along with the pipeline discharge as it moves through the area. Consequently, during progress of disposal, about 30 percent of the total disposal area of dredged material is affected.

#### Fluid mud distribution and movement

46. The bulk of the dredged material slurry was deposited as dense suspensions of fluid mud, whereas the standing load of sediment above background levels after eight hours of discharge is 48.1 metric tons. The amount of fluid mud deposited is 52,250 metric tons or more than 99 percent of the total

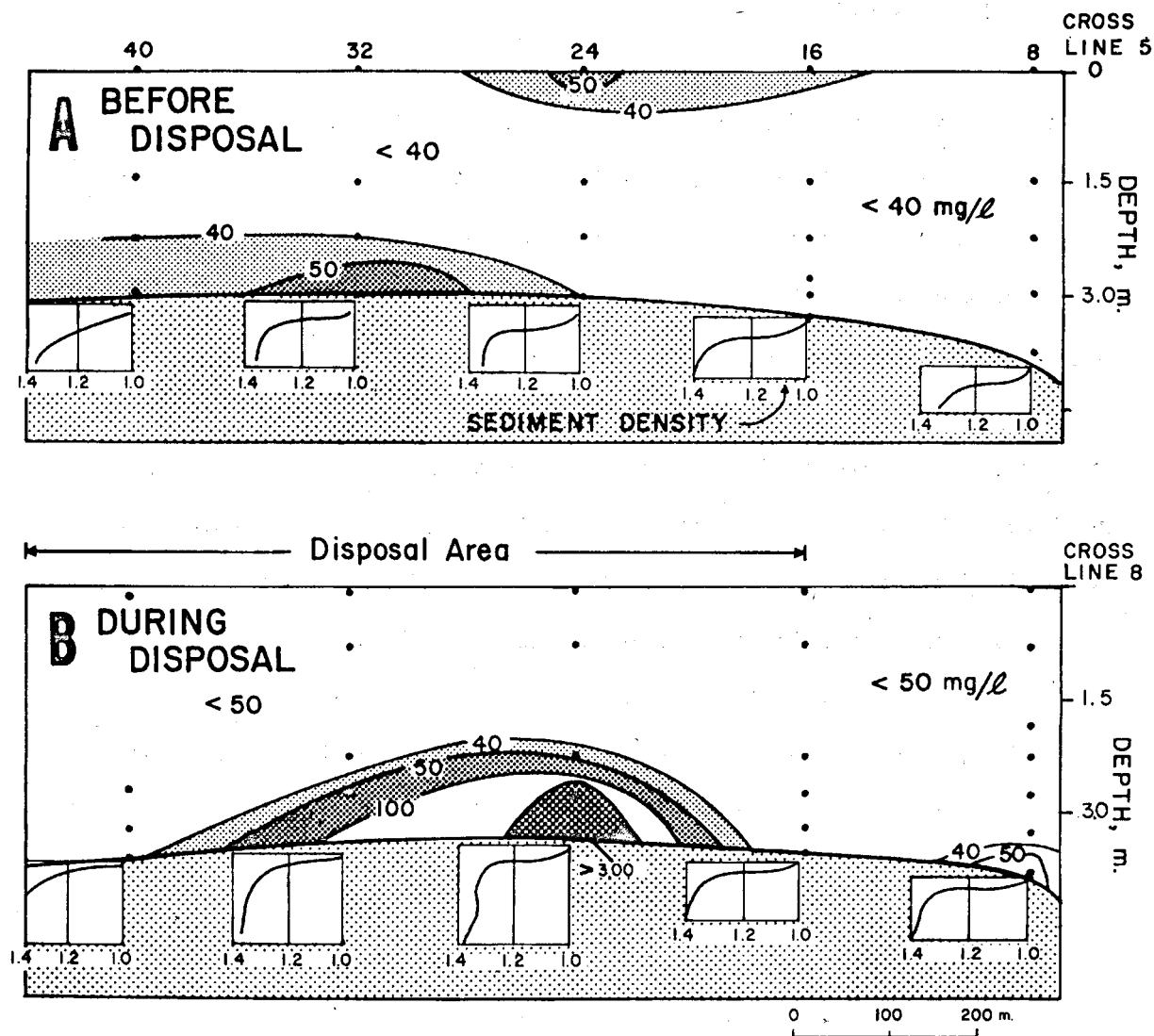


Figure 10. Vertical distribution of estimated suspended sediment concentration in the disposal area, (A) before disposal 30 May 1976 along cross line 5; and (B) during disposal 8 June 1976 along cross line 8, Mobile Bay. For location of cross lines, see Figure 9.

amount discharged. Floccules were commonly observed in the water of fresh cores from the fluid mud near the discharge point. The layer of fluid mud was more than 30 cm thick near the discharge point (Figure 11). At a distance of 200 m from the point, it attained a thickness of 24 cm and at 500 m a thickness of 12 cm.

47. The vertical distributions of current speed and sediment density in upper parts of the fluid mud and in overlying water are given in Figure 12. Generally, speeds diminish with depth and with increasing density of the mud. The areal distribution of speed values in upper parts of the fluid mud with densities less than  $1.10 \text{ g/cm}^3$  showed no systematic pattern in relation to distance from the discharge point.

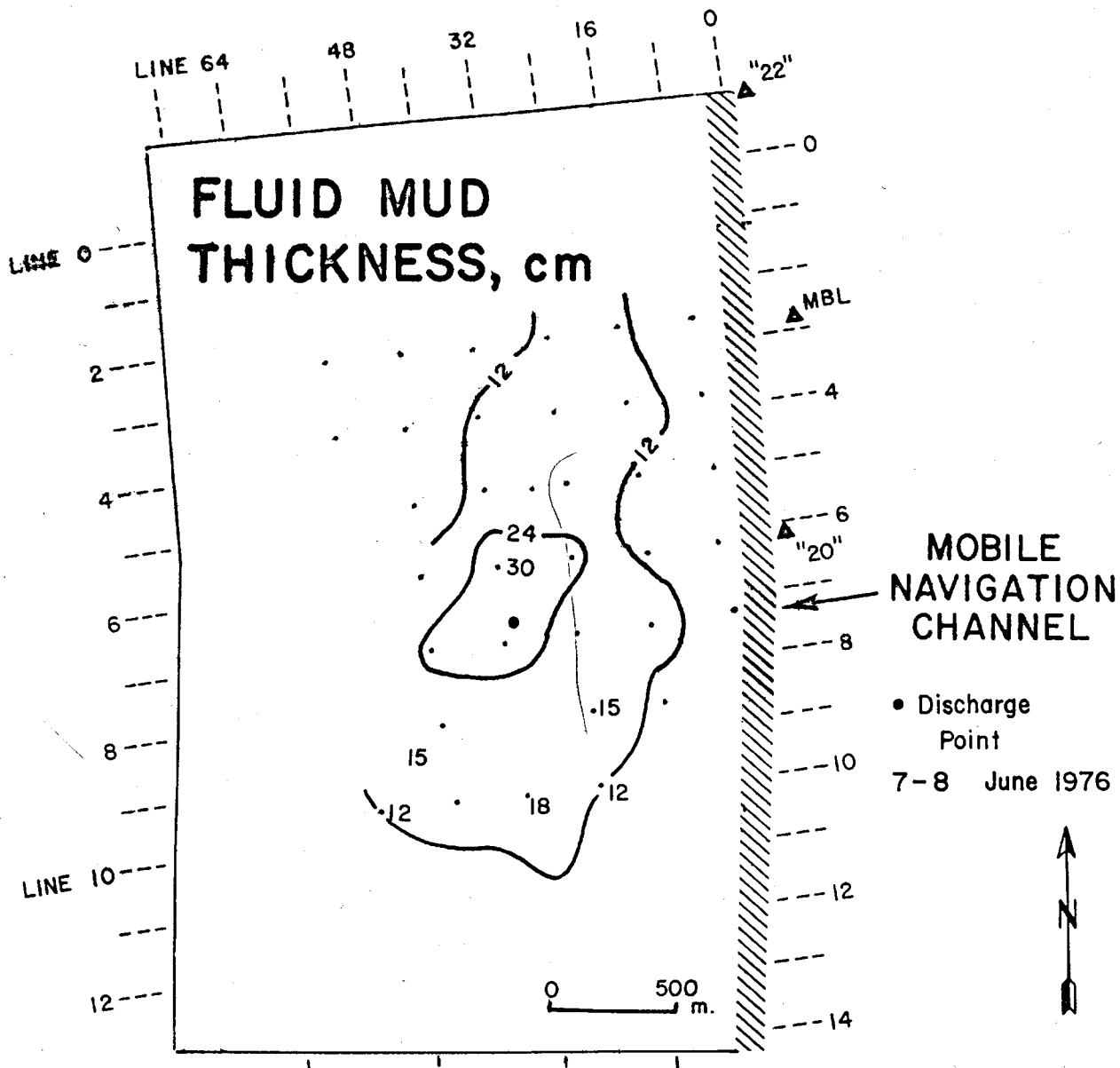


Figure 11. Distribution of fluid mud thickness from acoustical profiles and nuclear density probes, 8 June 1976.

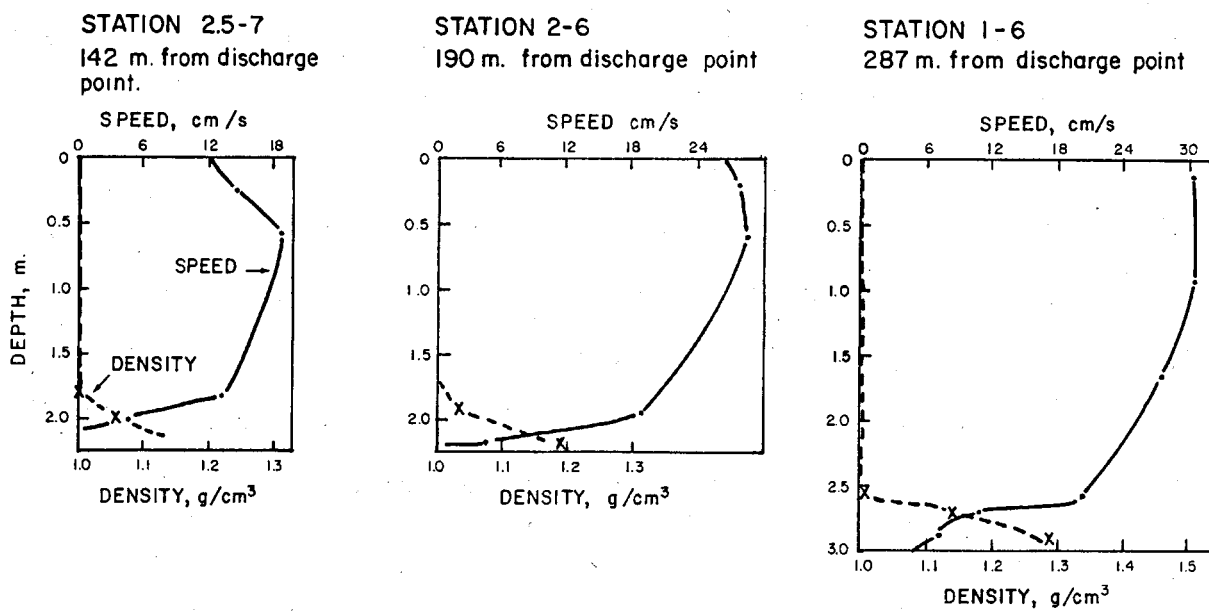


Figure 12. Vertical distribution of current speed and water and sediment density at selected stations around the discharge point during disposal 8-10 June 1976, Mobile Bay.

## PART V: RESULTS OF JAMES RIVER STUDY

### Site Characteristics

48. The Corps of Engineers maintains a navigation channel from Newport News to Richmond, Virginia, at a depth of 7.5 m and a width of 90 m. Each year, on the average, more than 700,000 m<sup>3</sup> of sediment is dredged from the channel floor. Relatively fast sedimentation, about 60 cm per year, occurs on three shoals between Hog Point and Hopewell. The Windmill Point shoal, Figure 13, is located in a meander bend where sediments fill the channel mainly on the north side.

49. The disposal site monitored is located in open water (Figure 13) at depths ranging from 2.4 to 3.6 m. As shown in Figure 17a, the bathymetry before disposal consisted of a low, flat-topped ridge flanked by shallow channels. The north channel had been partly filled off Bucklers Point by former disposal operations. Elsewhere, bed topography has been produced by former dredged material disposal and modified by tidal currents.

50. Significant hydrodynamic conditions and sediment characteristics are presented in Table 3. A complete summary of environmental conditions in the James River is given by Nichols (1972a, 1972b). In brief, hydrodynamic conditions for sediment dispersal are good, and waters are fresh and relatively well mixed most of the year. Measurements of current in the James River hydraulic model and field observations on the site indicate that flood current predominates over ebb current. This trend is produced by the local geometry of the meander bend at Windmill Point. The dredged material is cohesive clayey silt with 12- $\mu$  mean size. It has

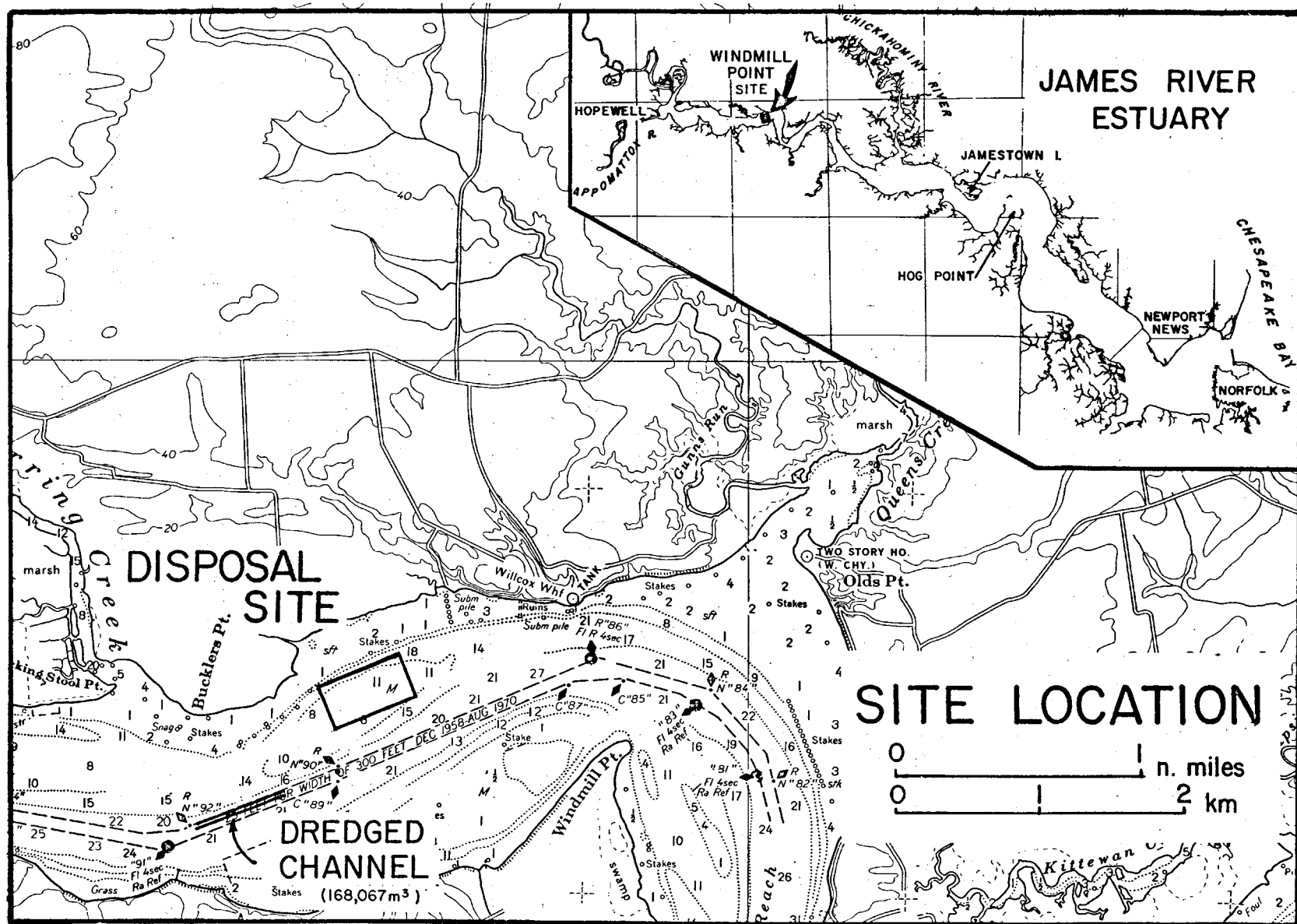


Figure 13. Location of the Windmill Point disposal site, James River estuary, Virginia.



a high water content averaging 108 percent. Sediment fills the channel sides more than 1.5 m above the controlling navigation depth.

#### Dredging operations

51. Channel sediment was dredged with a hydraulic cutterhead for this dredging operation that pumped mud through a 0.46-m-diameter pipe for a distance of 1,524 m. The operation was similar to that described for the Mobile Bay site; however, the discharge point was not moved a great distance but confined to a small area for the 10-day period of disposal. Relevant operation data are given in Table 4.

#### Hydraulic regime

52. At the time of observation, the river water was fresh and relatively well mixed. Winds blew from different directions at speeds less than 6 m/sec most of the time. Wave heights were mainly less than 0.4 m except during storms. Semidiurnal tides prevailed and tidal currents reached 50 cm/sec at maximum strength in the channel. The currents flowed parallel to the axis of the channel and mainly parallel to the shoreline.

53. Suspended sediment concentrations prior to disposal were mainly less than 50 mg/l. They normally range from 24 to 120 mg/l near the bottom except in times of flood, when they may exceed 250 mg/l.

### Physical Characteristics of Sediments

#### Textural classification

54. James River surface sediment samples are chiefly clayey silt with a few samples falling into the silty clay range according to the

classification of Shepard (1954). Some samples contained as much as 18 percent sand-sized particles; however, most contained less than 5 percent. The samples included new dredged material and old consolidated sediment and a sediment core from station 2.5-7 (see Figure 17). No textural differences were observed between new dredged material and old consolidated sediment. The single sample of sand-silt-clay (49.5 percent sand) is from station 2.5-6, located at the northern edge of the disposal mound, and likely includes a mixture of new dredged material and normal shallow-water sand. The sediments appear slightly coarser than those from the upper James estuary, which are predominantly silty clay with a silt:clay ratio of 1:2, and variable quantities of sand as shown by Nichols (1972a).

#### Atterberg limits

55. The following tabulation presents average values for Atterberg limits for samples from the James River. The sediments have been differentiated into two groups: one composed of new dredged material, the other composed of old consolidated sediment.

##### New Dredged Material

<u>Statistical parameter</u>	<u>W<sub>L</sub></u>	<u>W<sub>p</sub></u>	<u>I<sub>p</sub></u>
$\bar{x}$	95.9	48.0	47.9
s	17.1	5.8	13.2
n	9.0	9.0	9.0

##### Old Consolidated Sediment

$\bar{x}$	91.4	41.3	50.1
s	13.2	3.6	11.4
n	9.0	9.0	9.0

The Atterberg limits reveal little difference between the new dredged material and old consolidated sediment.

#### Organic matter

56. Organic matter in James River sediments averages 1.92 percent ( $s = 0.40$ ,  $n = 23$ ). Organic matter often occurs as recognizable fragments of leaves and small twigs, in addition to large and small pieces of unidentifiable material. This material often occurs in distinct zones at various intervals throughout cores from the old consolidated sediment. In the newly deposited dredged material, organic matter occurs as finer particulate material disseminated through the deposit.

57. The engineering properties of the new dredged material may reflect the particulate nature of the organic matter. Humic acids have been shown to increase plasticity and other water-related properties of a remolded sediment (Rashid and Brown 1975). Lack of these acids in the remolded sediment would allow the new dredged material to rapidly acquire the characteristics of the parent material from which it was derived.

#### Gas generation in sediment

58. The occurrence of organic matter in distinct concentrations establishes conditions for the generation of gases in the James River sediments. A layer of new dredged material overlying a concentration of organic matter would allow anoxic conditions to develop rapidly.

59. James River sediments were observed to release gases during dredging. In many areas, gas caused a blurring of the subsurface

fathometer traces. Ebullition of gases increased during the summer as the water became warmer and solubility of the gases decreased. Nearly all sediment cores of old consolidated sediment from the disposal area showed large numbers of open and interconnected voids within the upper 50 cm. These voids may represent either bioturbated zones or voids created by in situ gas generation.

60. Production of voids due to gas generation within the sediment will affect the mass physical properties, specifically the unit weight and water content. The engineering behavior of the sediment will also be affected due to the generation of excess pore pressures, which would decrease the effective normal stress in the sediment mass. Salem and Krizek (1973), in laboratory consolidation tests of dredging slurries, observed gas pressures in excess of the applied pressures developing within a week. Gas generation can significantly alter the physical properties of sediments.

61. Figure 14 shows properties of the upper 60 cm of core 2.5-7, sampled on 20 July 1976, and analyzed during October 1976. An attempt was made to determine the void volume percentage in the upper 50 cm. The core liner was composed of transparent Plexiglas. A sheet of transparent acetate was wrapped around the core liner, and the position and shape of each void drawn on the acetate with India ink. The liner containing the core was cut, leaving the sediment core intact. A thin piano wire cutter was used to cut across the sediment core to avoid obliterating the voids. Tracings were made of the horizontal void distribution at 10-cm intervals with India ink on acetate. The size distribution of the

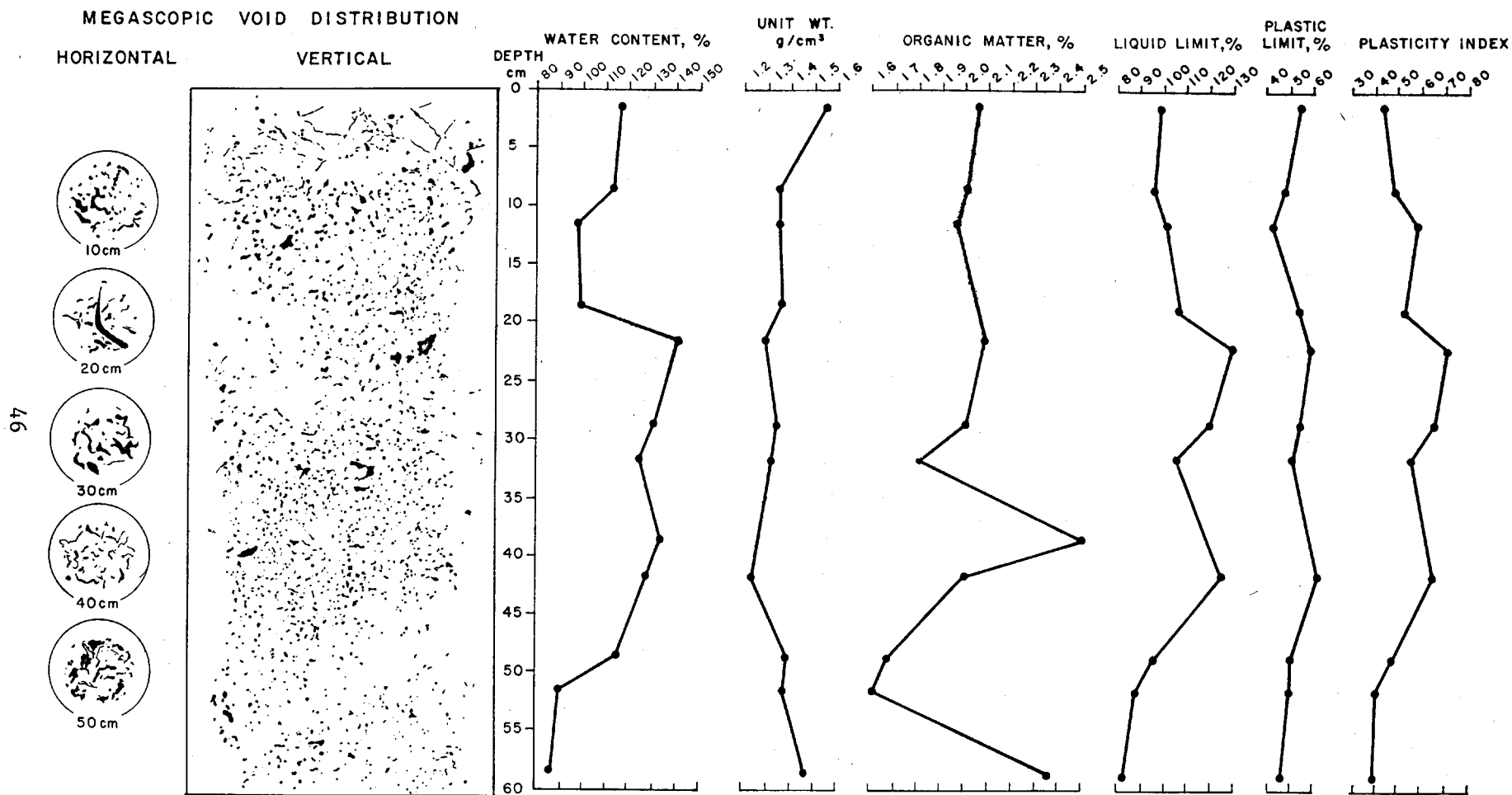


Figure 14. Sediment properties and Atterberg limits for core 2.5-7 from the disposal site after dredging, upper 60 cm.

voids across each cross section was estimated using the dot counting logic technique of Kaye and Murphy (1970-1971). The following tabulation gives the percentage of area occupied by voids at each cross section. The data indicate the amount of voids found in the sediment and not the amount of gas. Pressure and temperature effects will ultimately determine the amount of gas contained in the sediment. Void volume would indicate the maximum volume of gas if all voids were filled.

Total area of cross section =  $37.1 \text{ cm}^2$

<u>Depth, cm</u>	<u>Void area, <math>\text{cm}^2</math></u>	<u>% Void area</u>
10	4.9	13.2
20	5.6	15.2
30	5.7	15.4
40	4.2	11.2
50	7.8	21.0
$\bar{x}$	5.6	15.2
s	1.3	3.7

62. The total volume of the upper 50 cm of the sediment core is  $1,855 \text{ cm}^3$ . Using 15.2 percent of void area as the average through the upper 50 cm of the core, a total void volume of  $278.2 \text{ cm}^3$  is obtained.

63. Figure 14 shows a relationship between the distribution of the void spaces and the unit weight, water content, and liquid limit. Water content and liquid limit are highest between 20 to 50 cm and unit weight is lowest. Water content below 50 cm tends to decrease with a regular increase in unit weight.

64. The general effect of dredging sediments with large voids filled either with gas or water is that the true unit weight of the sediment removed will be greater than the apparent unit weight of a bulk

mass of the sediment. A measurement of unit weight with a nuclear density probe will not provide information concerning percentage of gas- or water-filled voids.

#### Activity of clay fraction

65. Figure 15 shows the activity of the James River sediments. They span a broad activity range, from 0.75 to greater than 2.0, the majority possessing activity between 1.25 to 1.75, defined as active (Skempton 1953). Nichols (1972a) has shown that illite and chlorite are the dominant clay minerals in the James River sediments, with montmorillonite and kaolinite being more abundant in the upper freshwater portion of the estuary.

66. Atterberg limits of new dredged material are believed to be the result of the activity of the various clay minerals within the sediment. However, the contrast between the new dredged material and the old consolidated sediment is on the order of a few percent. Lack of abundance of clay minerals and the fact that flocculation is taking place in a freshwater environment causes new dredged material to resemble the parent material. Because of its reduced specific surface, kaolinite leads to a decrease in the amount of adsorbed and free water in the floccules. Reduced water layers around the floccules cause an increase in interparticle attraction, resulting in van der Waals' bonding and the development of a cohesive sediment. Such a process may stabilize new dredged material rather quickly.

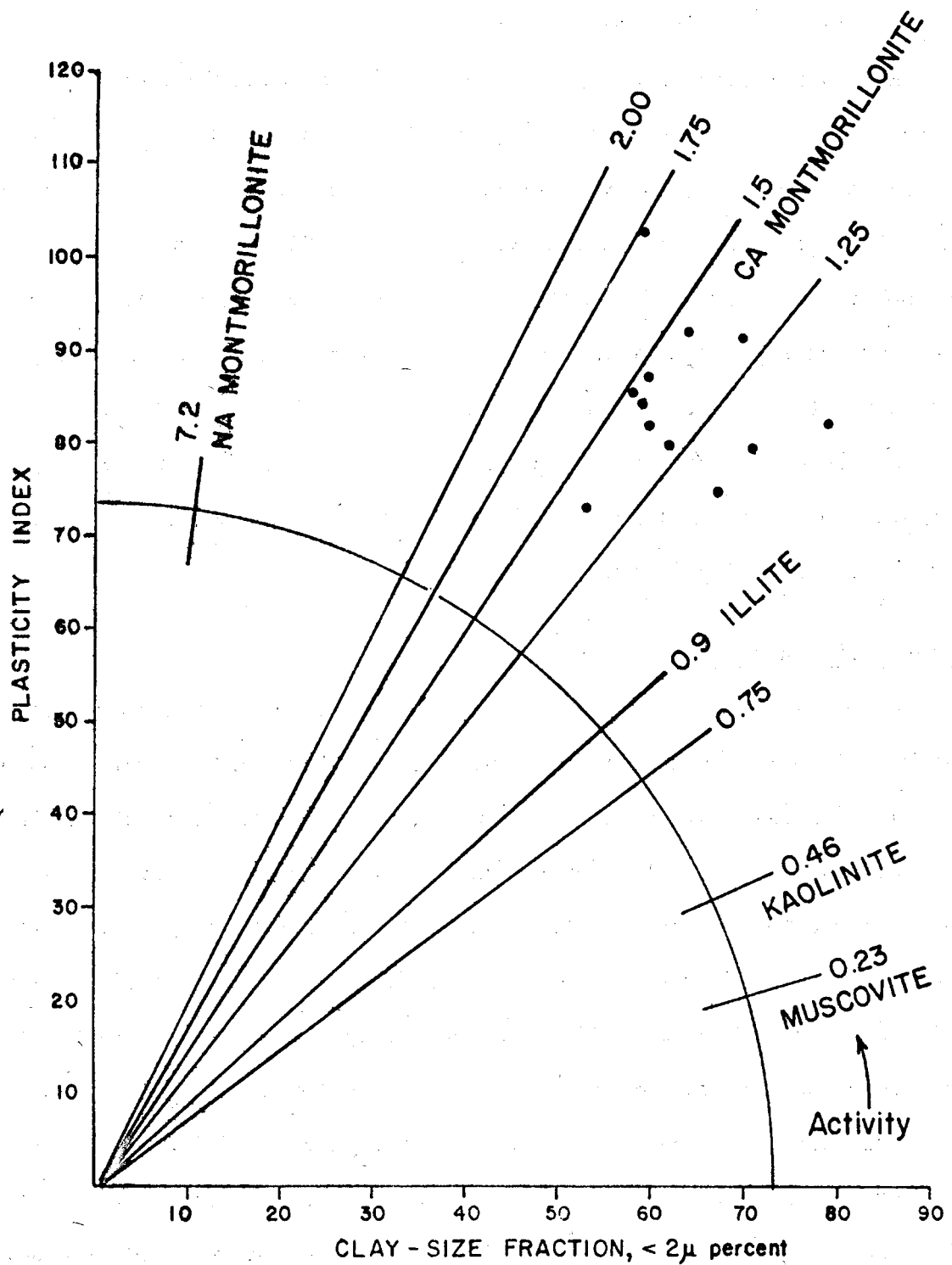


Figure 15. Activity of dredged material and sediment in relation to plastic index and the clay fraction, James River sediments.



### Unified soil classification

67. James River sediments are classified as either OH (organic clays of medium to high plasticity) or MH (inorganic silts, micaceous or diatomaceous fine, sandy or silty soils, elastic silts) according to the Unified Soil Classification System (Wagner 1957). Figure 16 shows the position of new dredged material and old consolidated sediment on the Casagrande plasticity chart. Little distinction can be observed, except all the new dredged material samples fall below the A-line and four of the old consolidated sediment samples plot either on, or slightly above, the A-line. All have relatively low values for liquid limit and plasticity index.

### Bathymetric changes

68. Results of depth surveys conducted before and after dredging were compiled into bathymetric charts (Figures 17a and b, Figures 18a and b). Disposal raised the bed 1.8 m near the discharge point and less than 0.3 m along the 2.4-m-depth contour. The dredged material is shaped into a low elongate mound centered close to the discharge point. Bottom slopes increased from essentially zero before disposal to 1:166 and 1:200 after disposal. The east side is steeper than the west side, reflecting the predominant flood current at the site. The main mass of dredged material above the 3.6-m-depth curve covered an area of 54.7 hectares. This area is more than 5 times the area of the dredged channel. About 45 percent of the dredged material lies outside the designated disposal area, mainly on the west side.

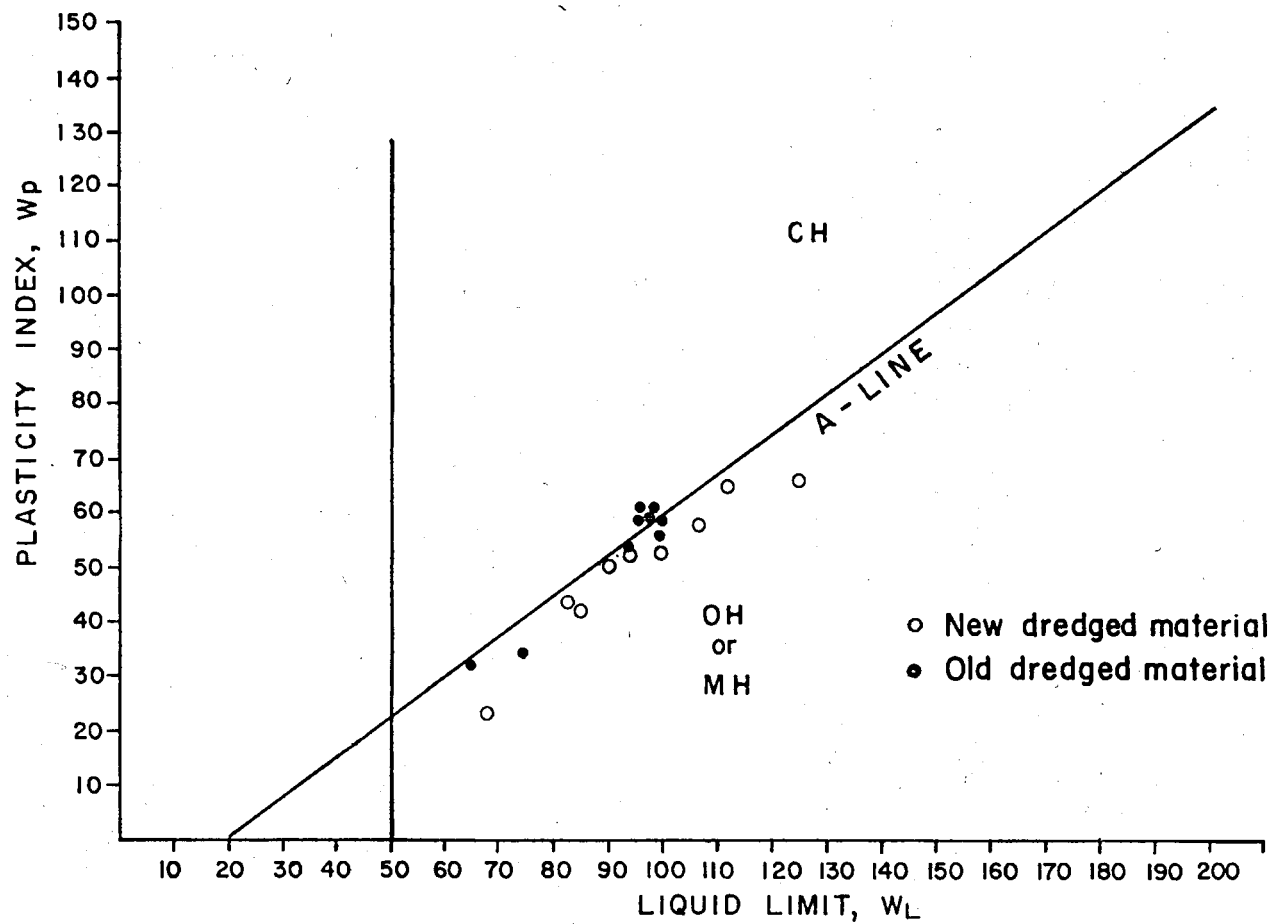


Figure 16. Plasticity chart for James River dredged material and old consolidated sediment.

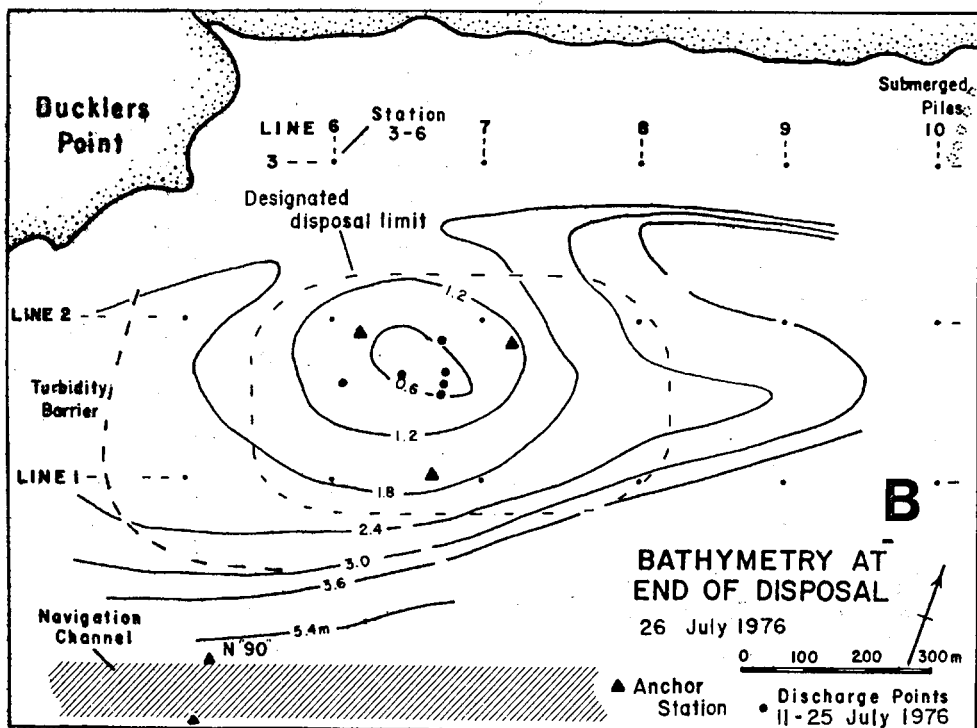
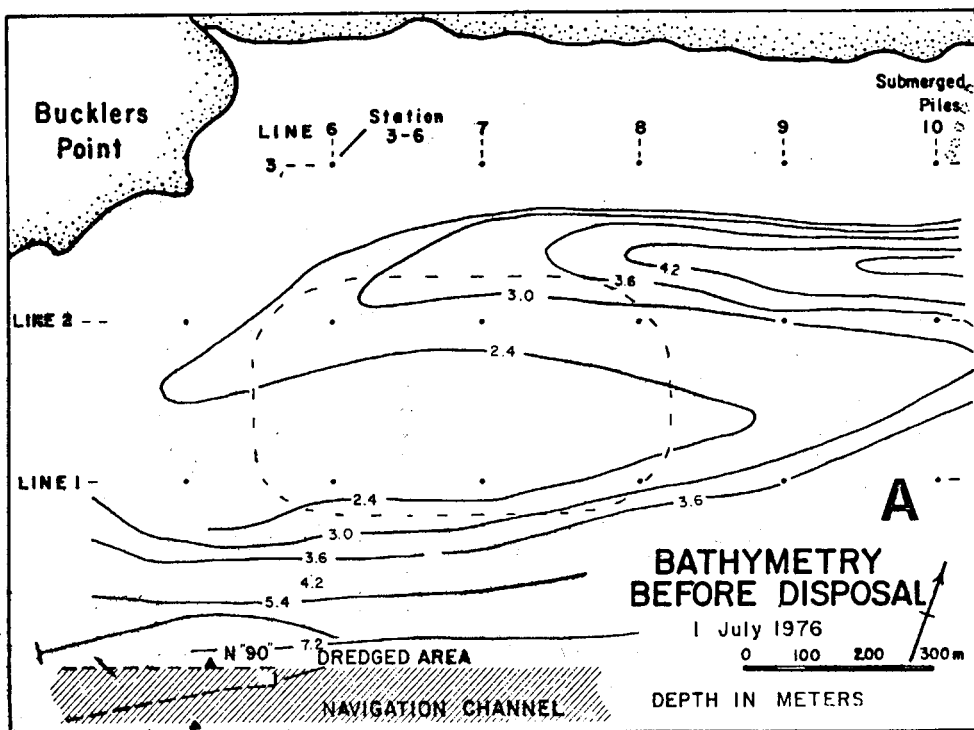


Figure 17. Bathymetry of the Windmill Point disposal site, James River, (A) before disposal 1 July 1976; and (B) at end of disposal 26 July 1976.

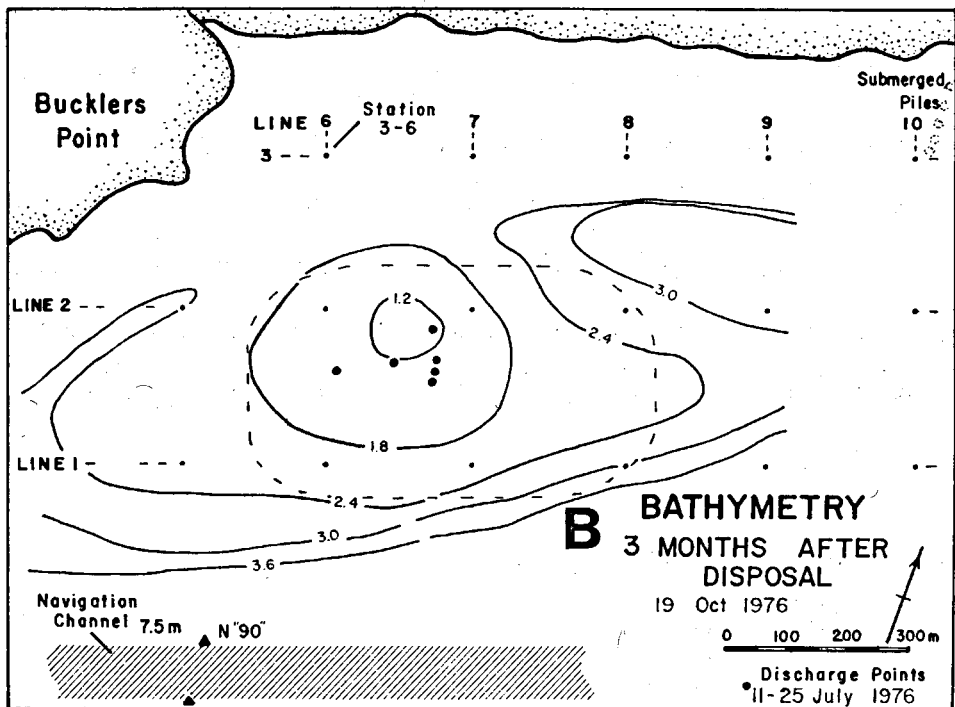
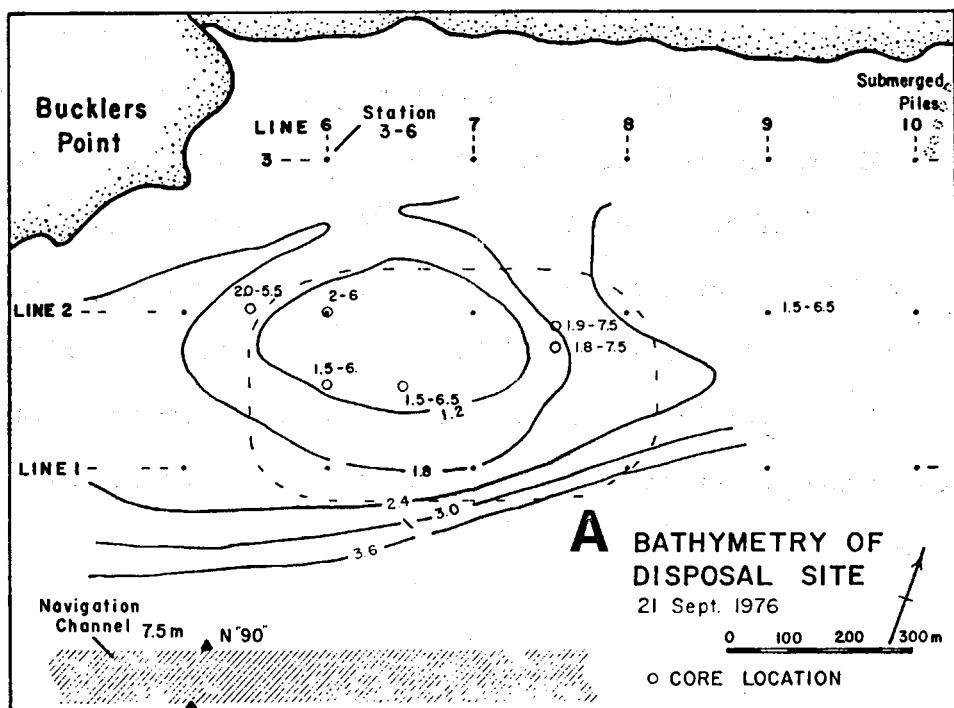


Figure 18. Bathymetry of the Windmill Point disposal site, James River, (A) 2 months after disposal, 21 September 1976; and (B) 3 months after disposal, 19 October 1976.

69. The change in bathymetry after disposal is illustrated by comparing successive profiles 2 weeks to nearly one year after disposal. As shown in Figure 19, the greatest change with time took place during the first 2 weeks after disposal. Between 26 July and 11 August, the west slope and crest were lowered about 22 cm on the average. After nearly one year on 21 June 1977, height of the mound was reduced by about one-half its initial height and 48 percent its initial volume. The following tabulation gives the volumetric changes for the entire dredged material mass.

<u>Date</u>	<u>Estimated volume above 2.4-m-depth contour, m<sup>3</sup></u>
26 Jul 1976	248,402
11 Aug 1976	204,680
21 Sep 1976	155,269
19 Oct 1976	148,878

At the end of disposal 26 July 1976, there was 20,638 m<sup>3</sup> less in the disposal mound than in the dredged channel. The apparent loss of 8 percent of the material may represent (a) release of gas from channel sediments during dredging; (b) survey error; (c) compaction during the period of disposal; and (d) escape of sediment from surveyed parts of the mound during disposal, either in the form of turbid plumes or as near-bed mud flows.

#### Suspended sediment and turbidity

70. The distribution of turbidity, derived from optical transmission measurements along tow traverses (Figure 20a), indicates the extent of turbidity on the flood tide at a depth of 1.3 m. The isopleth (equivalent

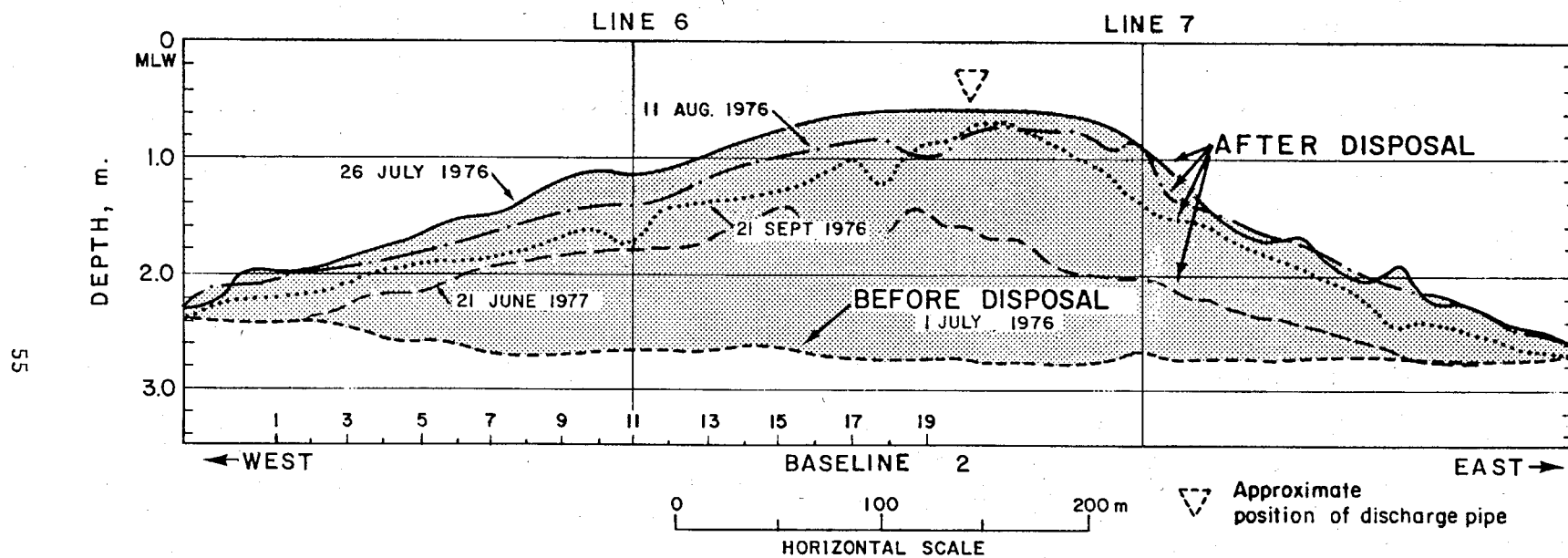


Figure 19. Bathymetric profiles of the Windmill Point disposal site, James River, showing changes with time. Baseline numbers 1 through 19 represent points where consolidation rates were computed.

to 25 mg/l) delineates turbidity values above the background level. The line extends 2,000 m westward from the discharge point at the end of the flood current. Corresponding data for tow traverses at maximum ebb tide indicate that the 22-mg/l isopleth extends 550 m eastward, Figure 20b.

71. Visual observations of surface water around the discharge point delineated gyral and eddylike patterns about 80 m across extending 200 to 300 m from the discharge point. The eddies were not connected, and they were enhanced by brown surface foam. The patterns were most likely created by pulses of slurry discharge interacting with the tidal current.

72. The depth distribution of suspended sediment from a drift station over a portion of the flood and ebb tides is illustrated in Figures 21a and b. The observations were made by repetitive sampling near a drogue as it drifted from the discharge point beginning at maximum flood current and at early ebb current. These data simulate the history of a parcel of a dredged material slurry as it disperses and settles in the tidal current. The track of the excursion parallels the shore and channel axis (Figure 21c). During flood current, concentrations greater than 50 mg/l in near-surface water extended 2,400 m from the discharge point in 2.1 hours. Near the bottom, 50-mg/l concentrations were observed to extend 3,600 m from the discharge point in a period of 3 hours. Beyond this distance, concentrations maintained normal background levels. Corresponding observations during ebb current indicated a patchy distribution at the 50-mg/l level. However, the 200-mg/l isopleth extended 1,700 m from the discharge point along the bottom. Particle size of the non-dispersed suspended sediment averaged 12  $\mu$  and

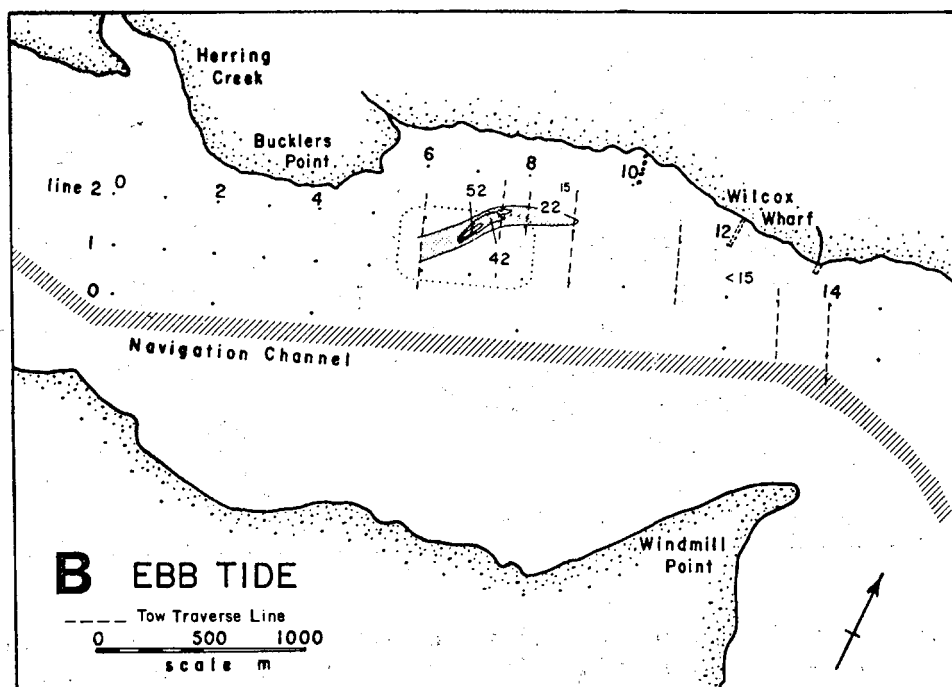
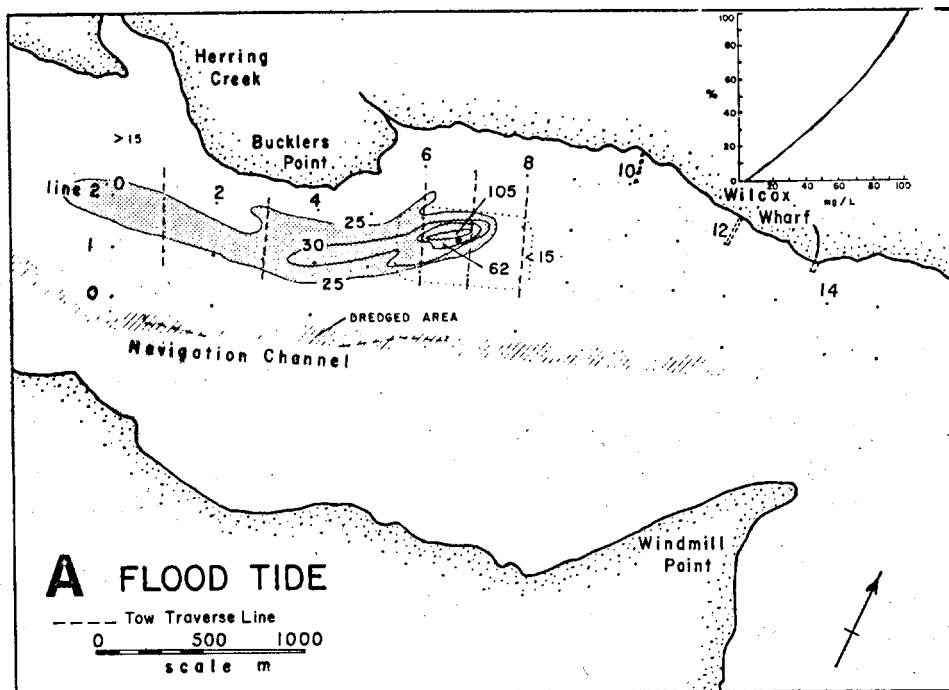


Figure 20. Distribution of estimated suspended sediment concentrations, (A) flood tide 14 July 1976; and (B) ebb tide 15 July 1976, James River. Inset upper right gives relationship between optical units based on percent full scale and sediment concentrations in mg/l.



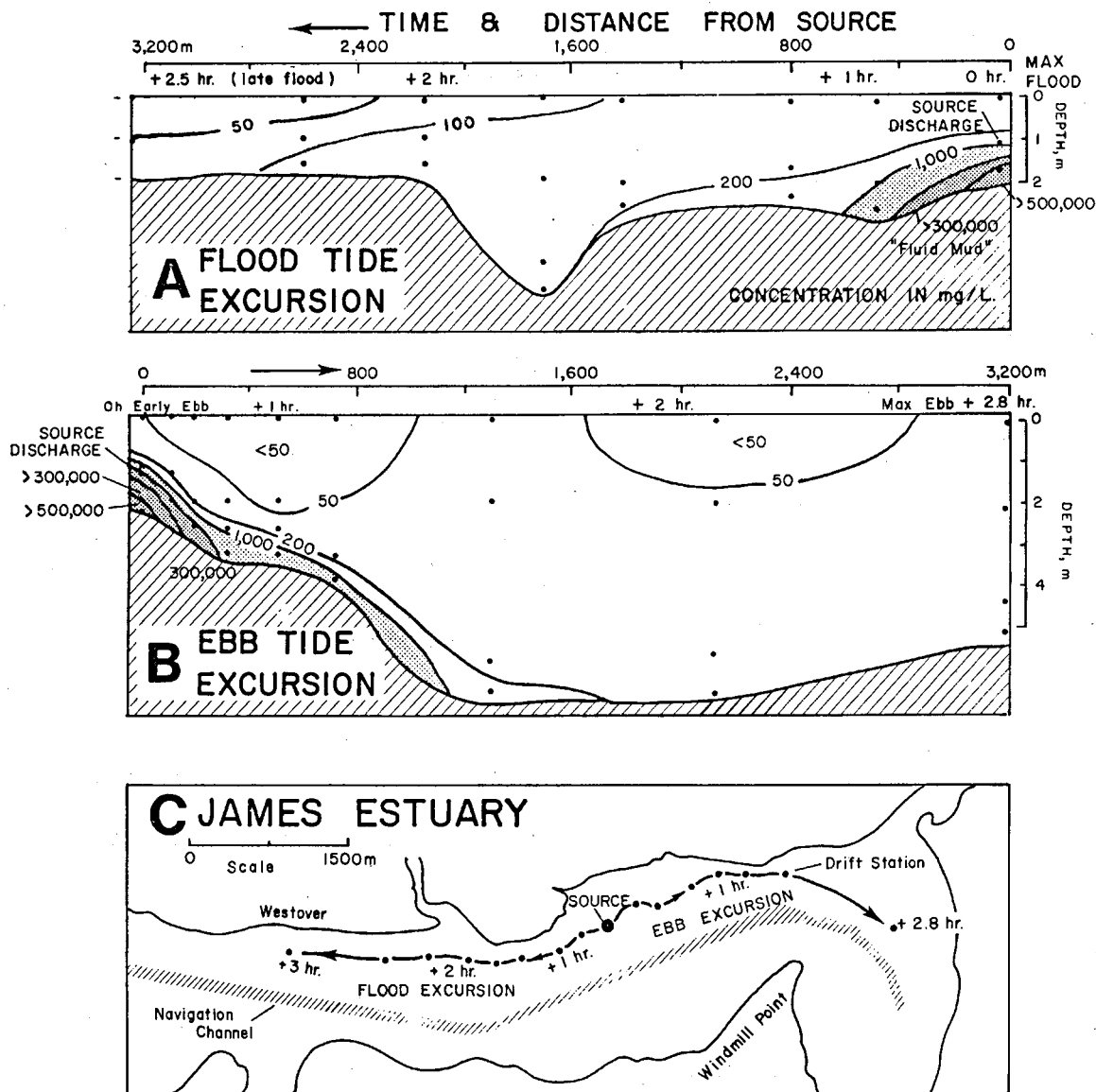


Figure 21. Distribution of suspended sediment concentrations in mg/l from a drift station, (A) during a flood tide excursion 14 July 1976; and (B) during an ebb tide excursion 15 July 1976, James River. Horizontal path of the excursions is shown in inset (C).

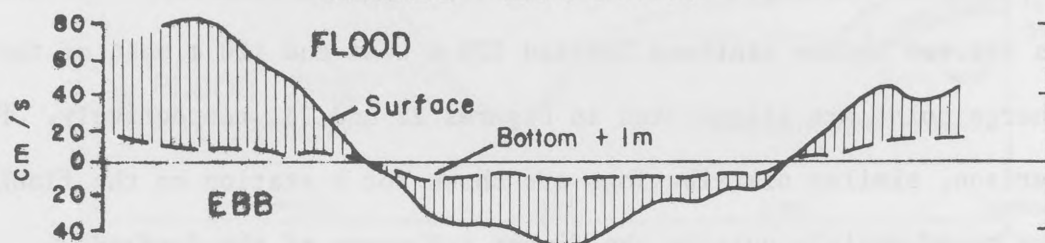
was remarkably uniform during the short-term dispersal history. This uniformity suggests that currents are competent to support the suspended load and there is little settling of fines. The diminished concentrations with distance outward are mainly caused by dilution and diffusion by the tidal current.

73. The time-depth distributions of suspended sediment concentrations for two anchor stations located 120 m west and 120 m east of the discharge point are illustrated in Figures 22 and 23, respectively. For comparison, similar distributions are shown for a station on the flank of the mound, mainly outside the direct influence of the dredged material dispersal field, Figure 24. The latter distribution shows that concentrations throughout the water column generally increased and decreased with the strength of the current. This is a normal trend of local erosion, resuspension, and deposition induced by reversing tidal currents. However, the near-bed concentrations were 3 to 4 times greater than average in the James River. By contrast, resuspension was not observed at station 1.9-6.5 (Figure 22) close to the discharge point. Instead, the suspensions were stratified, with a near-bed layer of fluid mud having concentrations greater than 300,000 mg/l above the firm bed. Currents measured in the mud 1.0 m above the bed were very slow, less than 10 cm/sec, and the directions indicated tidal movement.

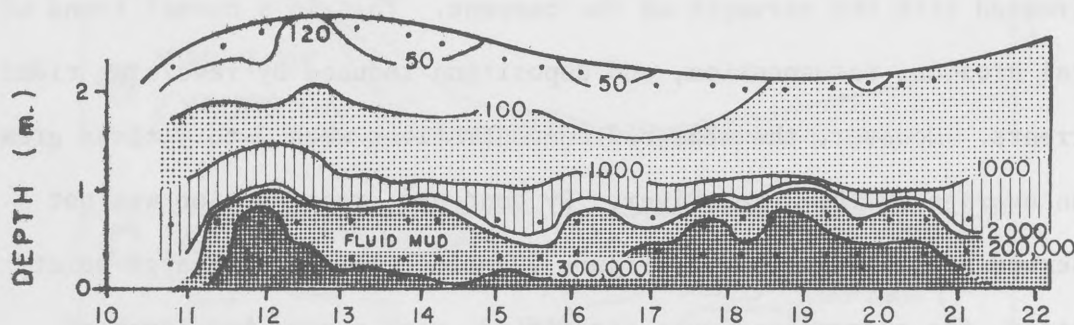
#### Fluid mud distribution and movement

74. Most of the dredged material slurry discharged from the pipe consisted of fluid mud with concentrations ranging from 10 to 300 g/l. Near the end of a 10-day discharge, the mud was deposited in a moundlike

ANCHOR STATION, 1.9-6.5  
LANDWARD OF DISCHARGE POINT  
JAMES ESTUARY



**A** CURRENT VELOCITY



**B** TOTAL SUSPENDED SOLIDS, mg/l.

Figure 22. Time-depth distribution of current speed (A) and suspended sediment concentrations (B) at anchor station 1.9-6.5, 120 m west (landward) of the discharge point 23 July 1976, James River.

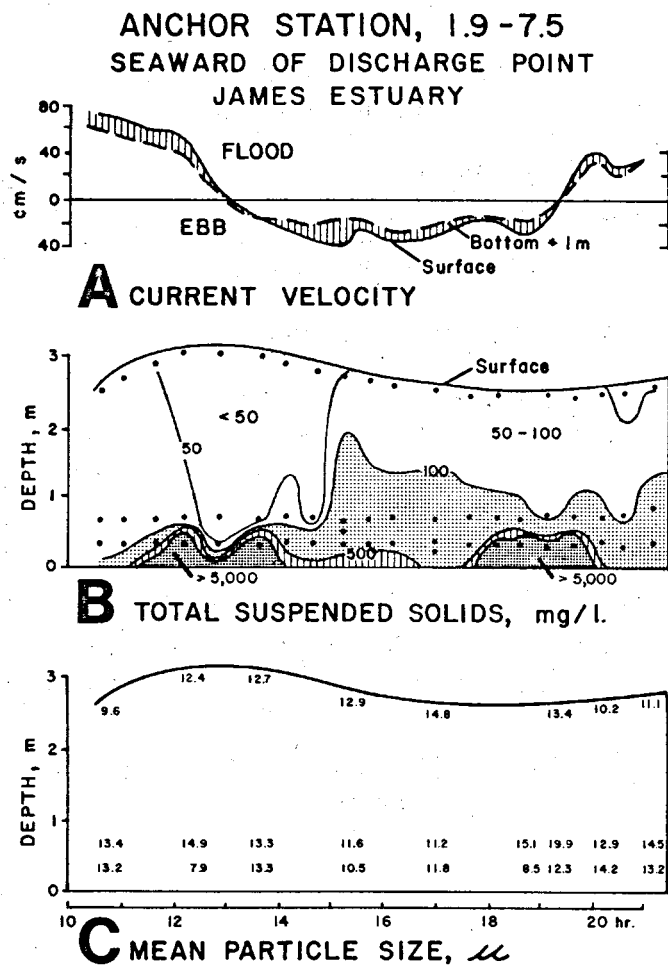


Figure 23. Time-depth distribution of current speed (A) and suspended sediment concentrations (B) at anchor station 1.9-7.5, 120 m east (seaward) of the discharge point, station 1.9-7.5, 23 July 1976, James River.

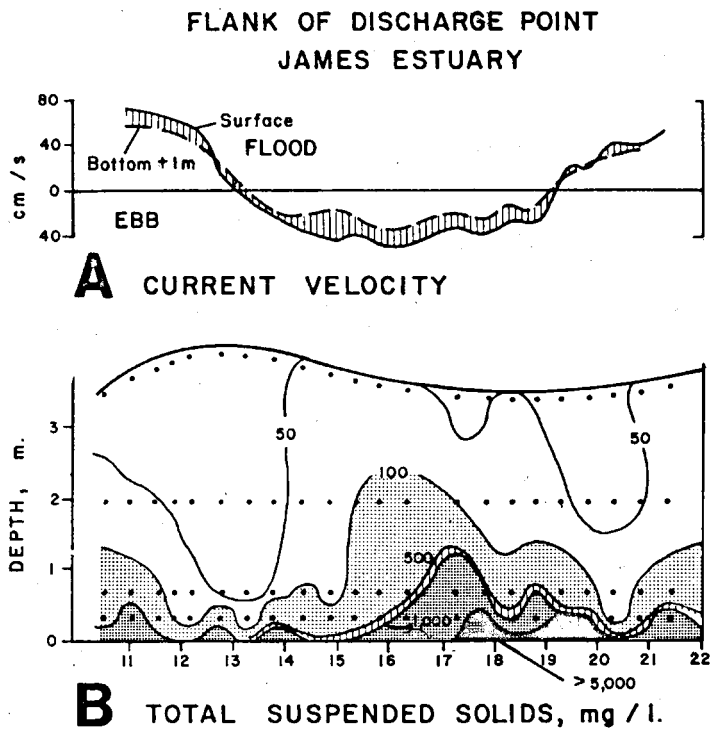


Figure 24. Time-depth distribution of current speed (A) and suspended sediment concentrations (B) at anchor station 1.0-6.7, 240 m south of the discharge on the flank of the dredged material mound 23 July 1976, James River.

layer. The layer was 1.8 m thick near the discharge point and less than 0.3 m at a distance of 450 m to the southwest, Figure 25. The fluid mud distribution during disposal, 19-21 July 1976, Figure 26, indicates that the layer was shaped essentially like a circular lens. Density profiles and fathograms show that the mud was stratified in sublayers 20 to 30 cm thick.

75. Temporal variations of the near-surface fluid mud layer show that the layer persisted within a narrow depth range over a tidal cycle, Figure 22. The layer was part of a stratified suspension gradient that increased with depth. The steepest concentration gradient occurred between concentrations of 200 and 200,000 mg/l. Water samples from this zone contained numerous floccules. It is assumed that flocculation was active and settling was rapid in the range from 1,000 to 200,000 mg/l. At greater concentrations, settling was slower and fluid mud accumulated.

76. Movement of the near-surface fluid mud was highly variable. Figure 27 presents measurements from selected stations taken directly with an electromagnetic current meter by vertical profiling. At low densities less than 1.10, speeds ranged from 4.2 to 18.7 cm/sec in upper parts of the mud. These speeds are much lower than in overlying water. At densities greater than 1.10, speeds were diminished. The areal distribution of velocity measurements lacks a coherent pattern in relation to the discharge source.

#### Rate of consolidation

77. The coefficient of consolidation  $C_v$  estimates the rate of settlement or rate of dissipation of pore pressure in a mass of sediment

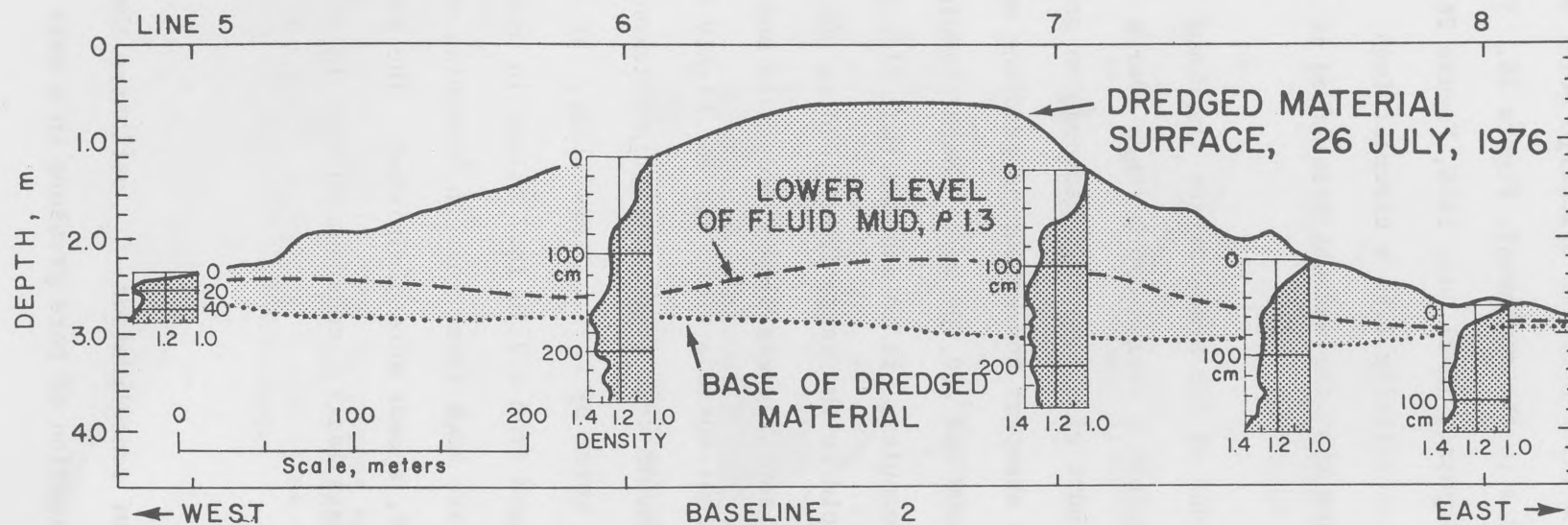


Figure 25. Vertical section through the Windmill Point disposal mound along baseline 2, after disposal. Figure shows thickness and extent of fluid mud with lower limit at density of 1.3, dashed line. Insets show vertical density profiles.

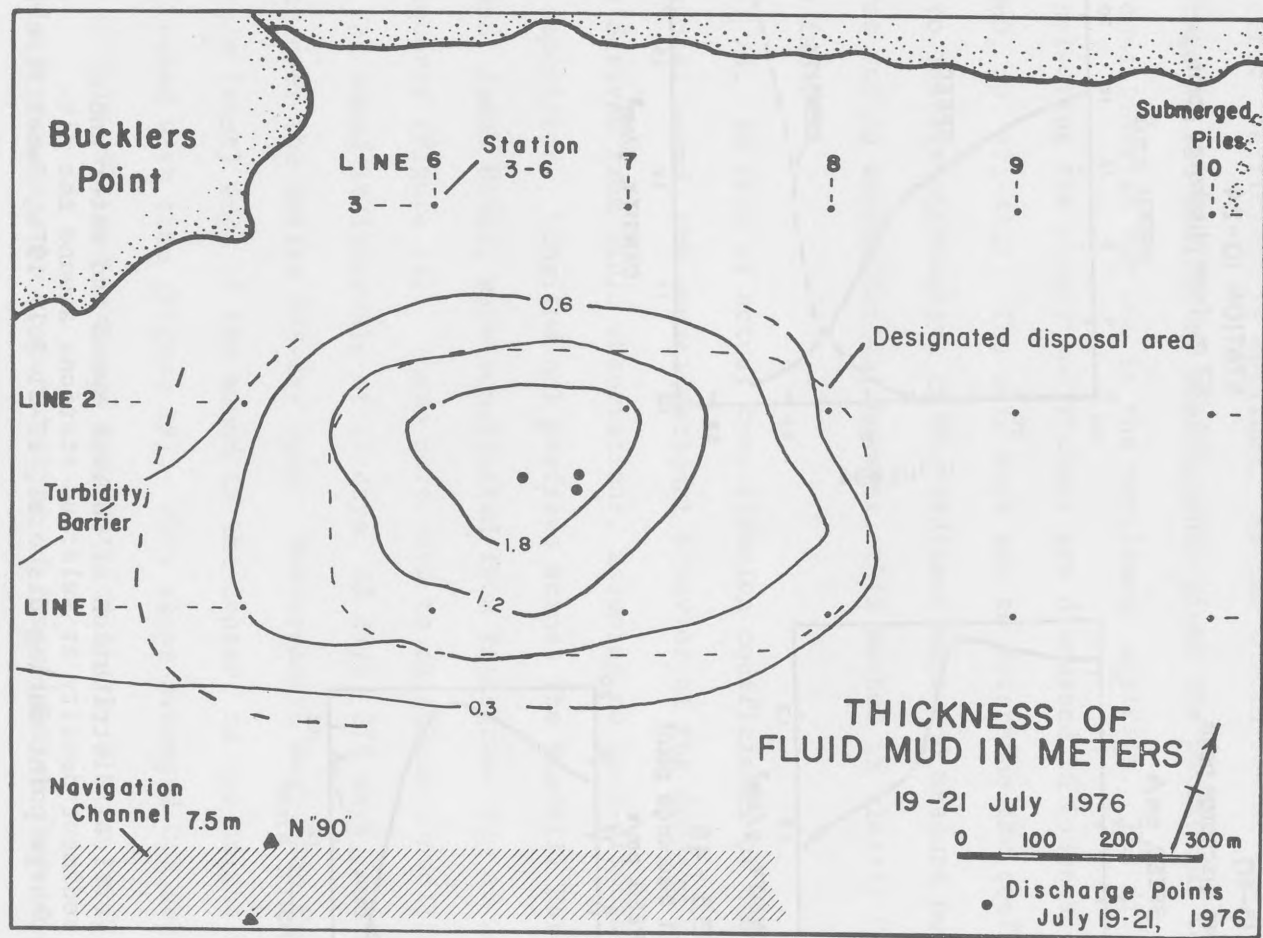
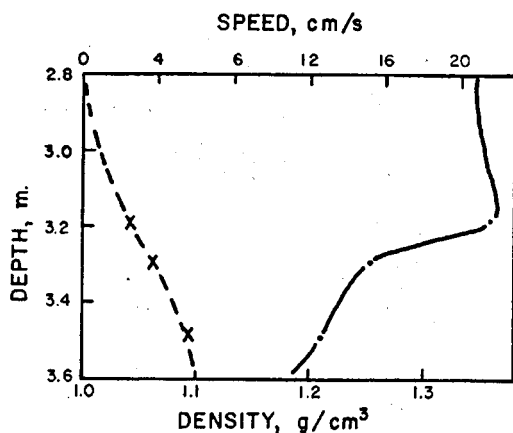


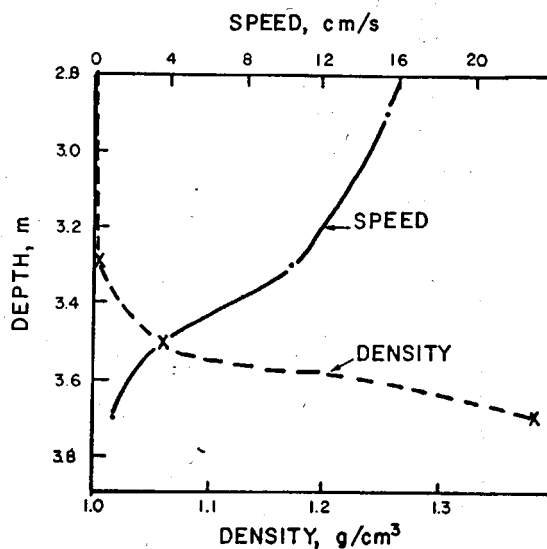
Figure 26. Horizontal distribution of fluid mud thickness during disposal 19-21 July 1976, Windmill Point disposal mound. Compiled from acoustic measurements.



STATION 13-40  
400m. from discharge point



STATION 10-24  
67 m. from discharge point



STATION 13.5 - 48  
103 m. from discharge point

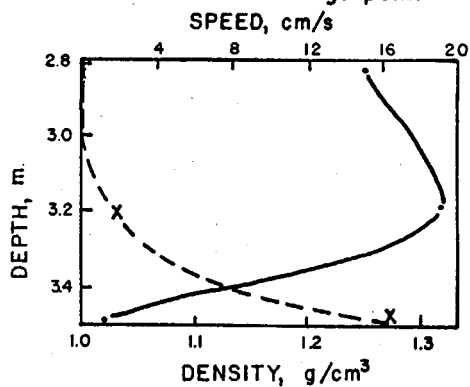


Figure 27. Vertical distribution of current speed and water and sediment density at selected stations around the discharge point during disposal, 20-21 July 1976, James River.

to which a load is to be applied. The coefficient is obtained from a laboratory test on an undisturbed sample of the sediment through application of successive loads with time. For each load applied, a specific coefficient is obtained. At the conclusion of the test, an average of the individual coefficients gives the particular coefficient of consolidation for use in the settlement analysis. The difficulties of selecting the proper coefficient are discussed in Lambe and Whitman (1969, pp. 411-412). The only sure way to determine the coefficient is to install piezometers in the sediment mass and measure pore pressures during consolidation; however, this method is clearly "after the fact."

78. In lieu of actual consolidation coefficients of the dewatering disposal mound, the consolidational behavior of the dredged material was derived from field observations, assuming no post-disposal erosion or deposition. Longitudinal profiles across the Windmill Point disposal mound, James River, were constructed from fathograms run at 200-kHz frequency (Figure 19). These were used to calculate consolidation rates of the mound at intervals of 17 days, 40 days, 275 days, and an average rate over the entire 332-day span. Measurements were made from the upstream (west) edge of the mound to the center, as the height of the mound decreased with time (Figure 19). This slope averaged 0.3 deg (1:200) on 26 July 1976 and remained constant for nearly a year to 21 June 1977. Table 5 presents the computed rates of consolidation from 18 measurements (indicated in Figure 19) perpendicular (vertical) to the predisposal surface measured on 1 July 1976.

79. Table 5 shows the average rate of consolidation for each time interval at each profile. In each case, the absolute rate of consolidation generally increased as the thickness of the dredged material increased, i.e. as the distance through which the interstitial water had to move became longer. Figure 28, constructed from Table 5, shows the changes in the rate of consolidation at each of the vertical profiles and for each time interval.

80. Rates of consolidation at the thin west edge of the mound (profile line 1) were nearly the same during the initial 17-day interval and also in the next successive 40-day interval. However, they diverged significantly at profile line 3, where the thickness of the mound exceeded 70 cm. The 17- and 40-day rates increased toward the thickest part of the mound. The rate of consolidation during the 40-day interval was reduced on the average of 42 percent from the rates occurring during the initial 17-day interval. During the final 275-day interval, an average rate of 0.08 cm/day was attained, only 7 percent of the initial 17-day consolidation rate. The maximum rate was still associated with the thickest part of the mound; however, the average had been reduced to 93 percent of the initial 17-day rate. The consolidation rate averaged over the entire 332-day span is shown for comparison.

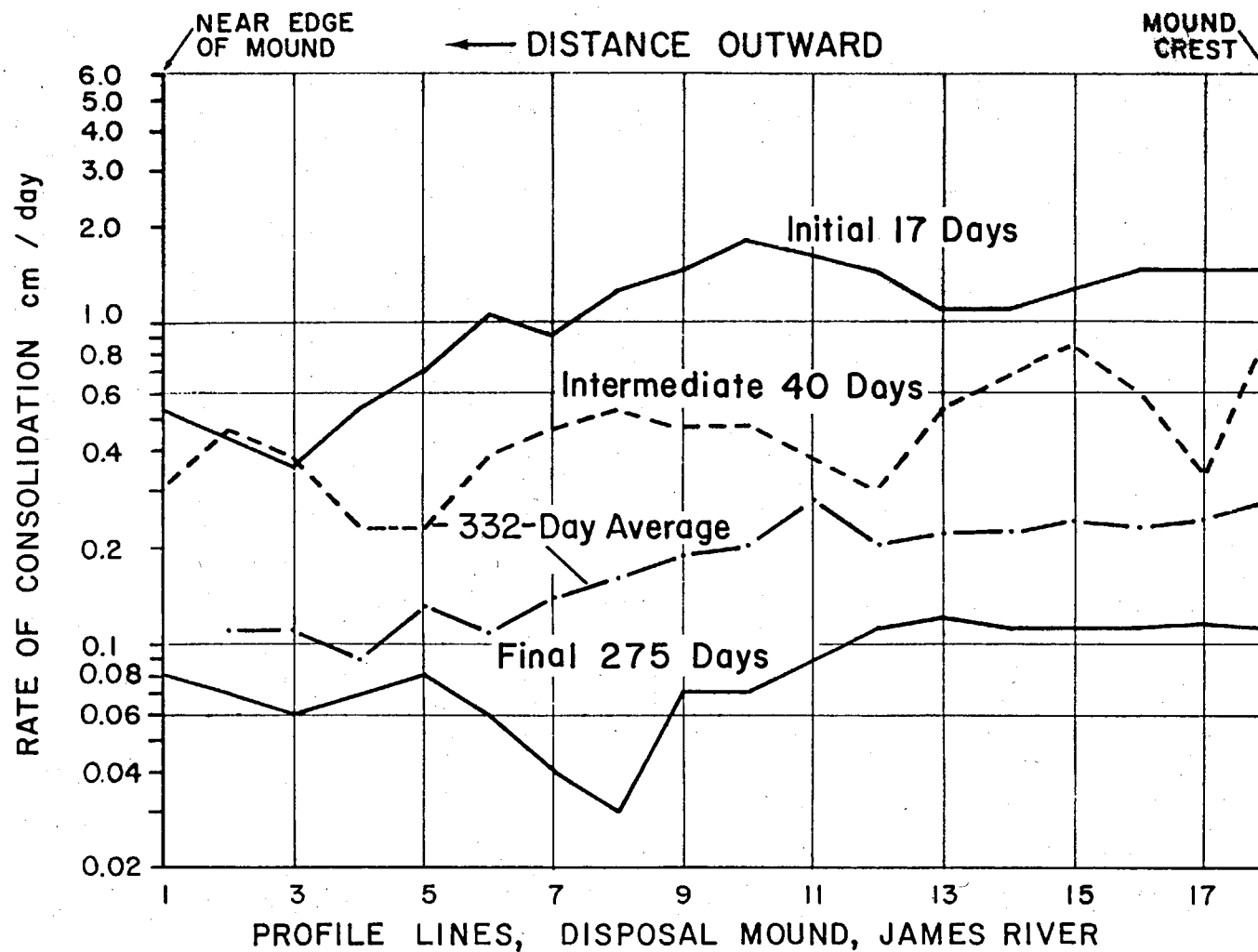


Figure 28. Rate of consolidation for various time intervals along profiles located in Figure 19, Windmill Point, James River.

## PART VI: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

81. The major results of observations at the Mobile site are as follows:

- a. Open-water disposal of dredged material along a line parallel to the dredged channel created a deposit of fluid mud spread over 456 hectares. This area is approximately 13 times that of the dredged area in the channel. An estimated 18 percent of the area covered by fluid mud was outside the designated disposal limits.
- b. Disposal raised the bed about 30 cm and increased surface slopes from 1:3000 to 1:2000 forming broad swells interrupted by small conical mounds and scour pits near the discharge point. The mound shape was asymmetrical extending about 2 times farther in the direction of discharge, a low angle to the west, than away from the direction of discharge (east).
- c. Disposal increased suspended solids in near-surface water above background levels in a zone extending 300 m along the axis of a plume from the discharge point. Corresponding near-bottom concentrations extended more than 600 m and laterally about 400 m from the discharge point. The zone of excess concentrations persisted with progress of disposal as the discharge point moved through the disposal area and affected about 30 percent of the total disposal area.
- d. An estimated 99 percent of the dredged material accumulated as dense suspensions of fluid mud with concentrations ranging from 10 to 480 g/l. The mud extended more than 500 m from the discharge point for a thickness of 12 cm.
- e. Movement of the mud was highly variable with time and space. Flow of the mud decreased rapidly with depth as bulk density increased from about 1.001 to 1.100 g/cm<sup>3</sup>. Flow is favored by high liquid limit of the mud and by the high rate of discharge at a relatively low angle to the water surface.

82. The major results of observations at the James River site are as follows:

- a. Disposal of a dredged material from a point source for 14 days created a circular mound of fluid mud 1.8 m high and about 900 m in diameter. It covered a 54.7-hectare area, about 5 times that of the dredged area in the channel. An estimated 45 percent of the area affected by mud disposal was outside the designated disposal area.

- b. Disposal created slopes up to 1:125. The mound shape was asymmetrical having a long low slope, 1:200, downstream from the discharge point in the direction of predominate flood tidal current.
- c. Disposal produced a turbid plume with near-surface concentrations above a background level of 25 mg/l extending 2,000 m west in the flood current direction and 550 m east in the ebb current direction. Concentrations of solids in the water column ranged from 25 to 10,000 mg/l. Relatively high concentrations decreased rapidly away from the discharge point as a result of dilution and dispersion. Solids were higher near the bottom than near the surface. Near-bottom solids attained higher concentrations around the discharge point at slack water than near maximum current.
- d. The main mass of fluid mud was deposited as dense suspensions with concentrations ranging from 10 to 480 g/l in stratified layers 20 to 30 cm thick. Most movement with speeds 4.2 to 18.7 cm/sec occurs near the fluid mud surface where concentrations range from 1 to 170 g/l.
- e. After nearly 1 year, the James River mound was reduced by about one-half its original height and 48 percent its original volume. Consolidation rates slowed down with time and with distance outward from the mound crest.

#### Recommendations

83. Based on findings of this study, it is recommended that dispersal of fluid mud and turbidity be reduced by planning disposal operations to take advantage of low energy environmental conditions. Dispersion is minimized by disposal in relatively quiet water zones, flat shallows, or backwaters away from the dredged channel, i.e., sites where sediments accumulate naturally.

84. Advantage can be taken of disposal at times of slack tidal current or periods of neap tide range, a time when currents are weaker than during mean or spring range. Any effort to maintain high concentrations close to the discharge source, which in turn increases floc-

culatation and settling, will deter fluid mud dispersal. Bottom slopes should be kept less than about 1:200. Since high discharge velocities may be expected to increase both the magnitude of ambient water and the initial velocity of the fluid mud, dispersion can be reduced through lowered discharge velocities.

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Table 1

Comparison of Significant Site Characteristics,Mobile Bay

<u>Attribute</u>	<u>Site Characteristics</u>
Location	Central bay, exposed
Geometry (before dredging)	Shoals, 3.0-3.8 m deep; Slope 1:3000; Channel straight, maintained to 12.6 m
Hydraulic regime	Low energy most of time; Vertically homogeneous- moderately stratified; Mean tide range, 0.46 m; Maximum tidal current, 44 cm/sec; Salinity, 3-15 ppt
Sediment characteristics (before dredging)	Silty clay; Clay mineralogy, montmorillonite/kaolinite; Mean particle size, 3.2 $\mu$ ; Average water content, 165%; Plasticity index, 88%; Organic content, 1.96%; Clay activity, 1.25-1.50

Table 2

Dredge Operation Data,  
Mobile Bay, 4-11 June 1976

<u>Characteristic</u>	<u>Magnitude and Range</u>
Type of dredge	Hydraulic suction with cutterhead
Width of dredged area (channel)	60 m
Pipe diameter	60 cm
Distance between dredge and disposal site (pipeline length)	840 m (pipeline on pontoons)
Pipe-end configuration	Submerged discharge 1.5 m below surface at approximately 30° angle with water surface
Slurry discharge speed	Range: 4.2-6.3 m/sec
Slurry discharge concentration	Range: 0.209-765 g/l Average: 156 g/l
Total volume of dredged material in channel (4-11 June 1976)	269.040 m <sup>3</sup> (351,900 yd <sup>3</sup> )
Area of channel dredged (4-11 June 1976)	33 hectares
Area of disposal site	920 hectares
Rate of pipeline and dredge advance	700 m/day
Thickness of dredged material	0-2.0 m
Area of dredged material mass in disposal area	450 hectares

Table 3

Comparison of Significant Site Characteristics,James River

<u>Attribute</u>	<u>Site Characteristics</u>
Location	Meander bend, partly protected
Geometry (before dredging)	Shoals, 2.4-3.6 m deep; Slope variable; Channel meanders, maintained to 7.5 m
Hydraulic regime	Low to moderate energy; Well-mixed, fresh water; Mean tide range, 0.69 m; Maximum current, 65 cm/sec; Salinity, 0.1 to 5 ppt
Sediment characteristics (before dredging)	Clayey silt; Clay mineralogy, illite/kaolinite; Mean size, 12 $\mu$ ; Water content, 108%; Plasticity index, 47%; Organic content, 1.92%; Clay activity, 1.25-1.75

Table 4

Dredge Operation Data,James River, 12-21 July 1976

<u>Characteristic</u>	<u>Magnitude and Range</u>
Type of dredge	Hydraulic suction with cutterhead
Width of dredged area (channel)	30.5 m
Pipe diameter	0.46 m
Distance between dredge and disposal site (pipeline length)	1,524 m
Pipe-end configuration	Submerged discharge 90° elbow and without diffuser approximately 1.1 m below surface
Slurry discharge speed	4.57-6.10 m/sec
Total volume of dredged material in situ 12-21 July 1976 (reported by Corps of Engineers)	212,608.5 m <sup>3</sup>
Area of channel dredged 12-21 July 1976	10.80 hectares
Area of disposal site	Approximately 23.96 hectares
Thickness of dredged material in channel	1.5-2.1 m
Area of dredged material mass within 3.6-m contour	54 hectares

Table 5

Computed Rates of Consolidation, cm/day

		<u>Vertical profile</u>								
Time	Interval	1	2	3	4	5	6	7	8	9
Initial	17 days	0.54	-	0.36	0.54	0.72	1.08	0.90	1.26	1.43
Intermediate	40 days	0.31	0.46	0.38	0.23	0.23	0.38	0.46	0.53	0.46
Final	275 days	0.08	0.07	0.06	0.07	0.08	0.06	0.04	0.03	0.07
	332 day average	-	0.11	0.11	0.09	0.13	0.10	0.14	0.16	0.18

		<u>Vertical profile</u>								
Time	Interval	10	11	12	13	14	15	16	17	18
Initial	17 days	1.79	1.61	1.43	1.08	1.08	1.26	1.43	1.43	1.43
Intermediate	40 days	0.46	-	0.30	0.53	0.69	0.76	0.61	0.38	0.99
Final	275 days	0.07	-	0.11	0.12	0.10	0.10	0.10	0.14	0.11
	332 day average	0.20	0.28	0.20	0.22	0.22	0.24	0.23	0.24	0.28

Mean and Standard Deviations, cm/day

Initial	17 days	$\bar{x} = 1.14$	$s = 0.41$
Intermediate	40 days	$\bar{x} = 0.48$	$s = 0.20$
Final	275 days	$\bar{x} = 0.08$	$s = 0.03$
	332 day average	$\bar{x} = 0.18$	$s = 0.06$



## APPENDIX A:

### LABORATORY PROCEDURES

#### Organic Carbon

The Walkley and Black technique (1934) was used. Gaudette et al. (1974) showed it to be comparable to other, more sophisticated techniques. It utilizes exothermic heating and oxidation with potassium dichromate and concentrated sulfuric acid of a clay-sized portion of the sample. The excess dichromate is titrated with 0.5 N ferrous ammonium sulfate to a sharp one-drop end point.

The following equation is used to obtain percent organic carbon:

$$\% \text{ Organic C} = 10(1-T/S) [1.0N(0.003)(100/W)] \quad (A1)$$

where

T = ml of ferrous solution used for sample

S = ml of ferrous solution used for blank

W = weight of dry sample

#### Grain Size Analysis

Sediments from cores and grabs were classified texturally according to Shepard (1954). The textural analysis was performed using the ASTM 152 H hydrometer (Bouyoucos 1962), which provides an approximate total size distribution curve. The analyses were performed on wet sediments that had undergone no previous treatment, e.g. removal of carbonates, or organic matter, except calgon was used as a dispersing agent. The analyses followed the procedure outlined in Lambe (1951).



### Specific Gravity

The specific gravity  $\gamma_s$  of a sediment is the ratio of the weight in air of a given volume of sediment particles to the weight in air of an equal volume of distilled water at a temperature of 4°C. The specific gravity is a fundamental property of a sediment and is dependent upon the cumulative specific gravities of the various minerals comprising the sediment. The analyses were performed according to Lambe (1951). Triplicate analyses were performed on each sample to provide an average value.

### Wet Unit Weight (Bulk Density)

Wet or mass unit weight  $\gamma_t$  is defined as the weight per unit of total volume of sediment mass, irrespective of the degree of saturation. It was determined by inserting a thin-walled cylinder of known volume into the sediment mass, extracting it, trimming off all excess sediment particles from the ends and sidewalls, and weighing it carefully. Unit weight is calculated from

$$\gamma_t = \frac{W_s - W_c}{V} \quad (A2)$$

where  $W_s$  is the weight of the sample plus cylinder,  $W_c$  is the weight of the cylinder alone, and  $V$  is the volume of sediment in the cylinder. Values are reproducible only to 0.1 because of the difficulty in eliminating very small voids between the sample and cylinder wall with con-

sequent loss of precision in the volumetric measurement. This method of bulk density determination was used for core analysis, whereas bulk density determinations in fluid mud suspensions were determined by the nuclear density probe.

#### Water Content

Water content  $w$ , as used in this report, is the ratio in percent of the weight of water in a given sediment mass  $W_w$  to the weight of the oven-dried solid particles  $W_s$ . It is determined by weighing a representative portion of the sample, oven-drying at  $110^\circ\text{C}$  overnight, cooling in a desiccator, and reweighing.

$$w = \frac{W_w}{W_s} \times 100 \quad (\text{A3})$$

#### Void Ratio

Void ratio  $e$  is the ratio of the volume of void space,  $V_v$  to the volume of solid particles  $V_s$  in a given sediment mass, or

$$e = \frac{V_v}{V_s} \quad (\text{A4})$$

Void ratio is determined in the laboratory from

$$e = \frac{\gamma_s V}{W_s} - 1 \quad (\text{A5})$$

where  $\gamma_s$  = unit weight of soil particles  
 $V$  = total bulk volume  
 $W_s$  = weight of soils

### Porosity

Porosity  $n$  is the ratio (expressed as a percentage) of the volume of voids in a given mass  $V_v$  to the total volume of the sediment mass  $V$  or

$$n = \frac{V_v}{V} \times 100 \quad (A6)$$

Porosity can also be computed from the measured void ratio using the relationship

$$n = \frac{e}{1 + e} \times 100 \quad (A7)$$

This ratio is little affected by minor numerical differences in the degree of saturation. At 100 percent saturation, water content is related to the volumetric weight or porosity (in percent) by

$$w = \frac{n}{(100 - n)\gamma_s} \times 100$$

### Atterberg Limits

The liquid limit  $W_L$  is defined as the water content at which two halves of a sediment cake will flow together in a brass cup for a distance of 1.25 cm along the bottom of a groove separating the two halves when the cup containing the cake is dropped 25 times for a distance of 1 cm at the rate of two drops/sec. The value so obtained is a measure of the water content of the sediment when it ceases to behave as a liquid.

The plastic limit  $W_p$  measures the lowest water content at which the sediment can be rolled on a glass plate into threads 3 mm in diameter without breaking. The value so obtained is a measure of the water content of the sediment when it ceases to behave plastically.

#### Suspended Sediment Concentration

Water samples were processed within 12 hours after retrieval by Milipore filtration. A 50-to 200-ml aliquot of water was filtered through a tared Milipore filter of 0.8  $\mu$  pore size. By this process, the suspended sediment concentration was determined gravimetrically to  $\pm 0.5$  mg/l.



In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Nichols, Maynard M

A field study of fluid mud dredged material: its physical nature and dispersal / by Maynard M. Nichols, Galen S. Thompson, Virginia Institute of Marine Science, Gloucester Point, Va., and Richard W. Fass, Lafayette College, Easton, Pa. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

74, [5], 5 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-78-40)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under Contract No. DACW39-75-C-0121 (DMRP Work Unit No. 6C07)

References: p. 73-74.

1. Dispersions. 2. Dredged material. 3. Fluid mud. 4. James River. 5. Mobile Bay. 6. Mud. 7. Open water disposal. 8. Sedimentation. 9. Turbidity. I. Fass, Richard W., joint author. II. Thompson, Galen S., joint author. III. Lafayette College, Easton, Pa. IV. United States. Army. Corps of Engineers. V. Virginia Institute of Marine Science, Gloucester Point. VI. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-78-40.  
TA7.W34 no.D-78-40



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