

**CONTRACT REPORT**

**PLUME MONITORING OF RAPPAHANNOCK AND YORK SPIT CHANNELS,  
BALTIMORE HARBOR AND CHANNELS**

**(PHASE 1)**

by

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## Executive Summary

Field monitoring of hopper dredging in the Rappahannock Shoals channel of mid-Chesapeake Bay, Virginia reveals two turbidity plumes: (1) a near-bottom plume caused by draghead agitation, (2) an upper plume at mid-depth and near the surface caused by overflow processes. The plumes were monitored May 14, 1987 for 11 hours over six dredge cycles as the dredge moved along the channel length. Hydrographic and acoustical observations were made from three fixed stations, a tracking vessel as well as the dredge vessel, M/V Stuyvesant. Key parameters include total suspended sediment (solids), turbidity, acoustical scattering (300 kHz), current speed and direction and thickness of deposited layers. Background concentrations before dredging are in the range from 2.6 to 17.0 mg/l.

The near-bottom plume is largely confined to the channel and elongate-shaped along the dredge track. Concentrations in the near-bottom plume reached 1,560 mg/l, or about 150 times background. They returned to near-background levels about 75 minutes after dredging. The upper plume is confined to the channel and elongate-shaped near slack tidal current. It is widely dispersed however, <sup>through drifting of</sup> by fast tidal currents and by internal wave activity in near-surface water. Typically, concentrations in the plume average more than 300 mg/l. As the plume evolves with settling and dispersion of sediment, it becomes thinner through loss of the suspended load at mid-depth, and it develops a layered structure as it is carried down-current. Layered remnants 1 to 2 m thick extend more than 800 m from the dredge track and last one hour in near-surface water.

SPI imagery found measurable amounts of settled dredged material at all stations sampled, up to 1,600 feet or 488 m from the channel edge. The range in dredged material thickness is 0.5 to 19.8 cm. For the most part the entire sampled grid is covered with at least 6 cm of dredged material. The grain size distribution of the settled dredged material is virtually identical to the background sediments. Benthic communities in the sampled area appear to be unaffected by any thickness of settled dredged material. Several possibilities exist as to why communities have not obviously reacted to the dredged material: (1) the rate of deposition of dredged material was low, occurring over the period of several months. (2) The grain size of the dredged material is the same as natural sediments in the area. (3) Species making up the communities are very flexible in life history strategies and able to cope with the rate at which the new sediment was supplied.

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## 1. Introduction

A major element and concern necessary for evaluating the environmental impact of dredging operations is the dispersion of fine-grained dredged material. The turbid plume generated by draghead agitation and by overflow processes from a hopper dredge can dictate the degree of potential adverse effects. Under certain environmental and aesthetic circumstances control of the plume may be advisable. Although turbid plumes produced by open water disposal operations have been evaluated in many investigations (e.g. Barnard, 1978), detailed field assessments of plumes produced by hopper dredging operations are scarce.

## 2. Purpose

This investigation aims to observe the temporal and spatial distribution of turbid plumes generated by hopper dredging operations. It aims to delineate the geometry and structure of the plume and to distinguish the turbid anomaly from background turbidity. It also aims to estimate the extent of subsequent deposition as suspended sediment settles out on the bottom. The results should permit engineers to make better predictions about the extent and intensity of similar plumes elsewhere.

## 3. Sources of Turbidity

During a hopper dredge operation, as the dredge moves forward, the bottom sediment is hydraulically lifted from the channel floor through a draghead and up the dragarm. Subsequently, it is pumped into a hopper bin in the ship's hull and temporarily stored. The dredge vessel M/V

Stuyvesant monitored in this investigation, has two dragarms mounted on each side of the dredge. Its sediment storage capacity is  $7,038 \text{ m}^3$  ( $9,200 \text{ yds}^3$ ) but actual loads are about  $4,560 \text{ m}^3$  ( $6,000 \text{ yds}^3$ ) in each load. During late stages of hopper filling, the dredged material slurry is pumped past overflow to maximize the load of solids in lower parts of the hopper. Consequently, turbidity is caused not only by the dragheads as they are pulled along the bed but also by a high force discharge of turbid water from the hopper overflow which discharges mainly at  $\sim 6 \text{ m}$ . Some spillage occurs near the surface. Besides draghead agitation and hopper overflow, turbidity can be generated by tidal current stress on the natural bed or on the recently dredged bed.

#### 4. Site Description

The Rappahannock Shoals Channel, which is one segment of the Baltimore Ship Channel, cuts across a shallow sill in central Chesapeake Bay (Figure 1). The controlling navigation depth prior to the present dredging was  $12.8 \text{ m}$  (42 feet) whereas the new desired depth is  $15.2 \text{ m}$  (50 feet). Tidal currents are the chief agent of fine sediment dispersion. Normal tidal current speed reaches  $0.4 \text{ m/s}$  (0.8 knots) and reverses direction from flood (northerly) to ebb (southerly) every 6.3 hours. The site is exposed to wind waves from all directions and wave fetch exceeds  $14.5 \text{ km}$  (9 miles). Because of the everchanging conditions of tidal currents, waves and salinity as well as of dredging operations, dispersion of dredged material is a highly transient affair. With time as the plume "ages", it can lose its integrity and disperse in patches. At times multiple plumes can develop, i.e. near the surface and near

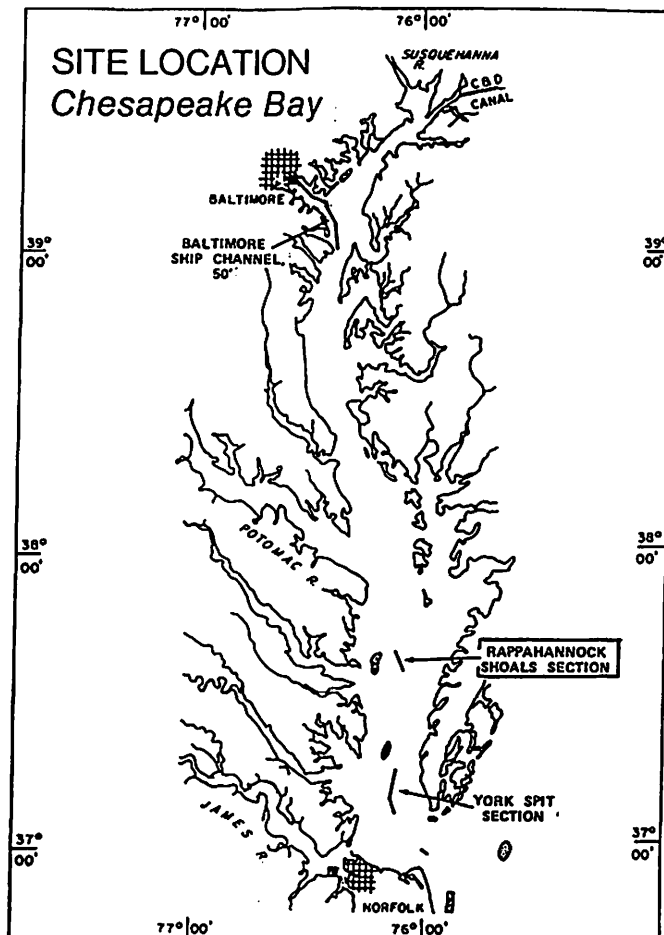


Figure 1. Location of dredge plume monitoring site, Rappahannock Shoals, Chesapeake Bay.

the bottom, as conditions change and as the dredge "back tracks".

Normal background concentrations of total suspended material in the Rappahannock Shoals area are relatively low. Monthly average suspended period concentrations throughout the water column range from 2.6 to 17.0 mg/l during a year (Nichols *et al.*, 1982). However, during spring tide range when currents are fast, natural "background" concentrations can reach 30 to 40 mg/l in the water column and 68 mg/l one meter above the bottom (E.P.A. monitoring data). Much of the suspended material is

enriched in organic detritus and diatoms. Organic content makes up from 30 to 60 percent of the total suspended material. Therefore, the potential mass of inorganic sediment available for deposition is in the range of 40 to 70 percent of the total concentrations of suspended material.

Bottom sediments are dominantly clayey silt with patches of fine sand. Mean grain size is 0.031 mm (Byrne et al., 1982). Analyses reveal the surface sediment is poorly to very-poorly sorted and bulk density ranges from 1.16 to 2.00 g/cm<sup>3</sup> (Harrison et al., 1964).

#### 5. Design of Monitoring Observations

The monitoring observations consisted of four components:

1. Sampling dredged material from the hopper and from the hopper overflow at 5-minute time intervals. Recording dredge operation data of the M/V Stuyvesant.
2. Sampling the plume in the water column from fixed anchor stations occupied by two garveys and intermittently at the one station by the boat "Ulysses".
3. Sampling the plume from a tracking vessel, "Langley", on lateral and longitudinal transects with measurements from towed sensors and intermittent "dip" samples from the water column.
4. Sampling the bottom for deposition of dredged material and benthos.

For components 1 through 3, observations were made <sup>during hopper overflow stage</sup> throughout each cycle of dredging (and disposal) lasting about 90 to 120 minutes.

Therefore, the plume was monitored in the dredged channel 15 minutes before the dredge pass <sup>the garvey stations</sup> as well as during the dredge pass and continuing to 60 to 105 minutes after the dredge pass. The garvey anchor stations were located in the channel at a position where the dredge hopper was in

an overflow stage. Zero sampling time in the dredge cycle was designated as the time when the M/V Stuyvesant crossed the garvey transect. Figure 2a summarizes the general plan of monitoring observations. Design of the plan is complicated because the dredge produced two plumes within 30 minutes as it back tracked on the same or opposite side of the channel.

Sampling of the plume from the fixed garvey stations and from the "Ulysses", was planned to proceed at 15-minute intervals and at three depths, surface, mid-depth, 7 m (23 feet) and at one meter above the bottom. Sampling of a dredge cycle began 15 minutes before the M/V Stuyvesant crossed the garvey transect. Sampling continued at 15-minute intervals until the next dredge cycle. A total of six dredge cycles was monitored over a period of about 11 hours.

For component 4, a 24 station grid was set on either side of the channel and sampled once with the SPI camera system. Quantitative box core samples were collected once at half the stations (Figure 2b).

## 6. Instrumentation and Methods

Field Instrumentation. Positioning was accomplished by different types of units. For the dredge, M/V Stuyvesant, the vessel's del Norte navigation system provided nearly continuous positions along the vessel's course. Additionally, the del Norte was used to position the garvey anchor stations, the fixed current buoy, SPI camera stations, and box core stations.

For the sampling vessel "Ulysses" at station A, positions were taken on the vessel from the garveys by rangefinder and sextant

bearings. Whereas at other stations, e.g. A, C and D, the vessel's Loran C was used.

For the roving vessel, "Langley", positions were taken by the vessel's North Star Loran C, a unit that normally achieves an accuracy better than  $\pm 20$  m.

Sampling depths for pumping, i.e. surface, mid-depth (7 m), were determined by a marked line on the pump hose. The lower-most sampling depth was determined by feeling bottom with a lead weight and sampling from a pump fixed one meter above the weight. Water depth was determined by Raytheon DE-719B survey fathometers with a 200 kHz frequency. The fathometers were run continuously at the fixed garvey stations in an attempt to detect dense suspensions.

### PLUME MONITORING PLAN

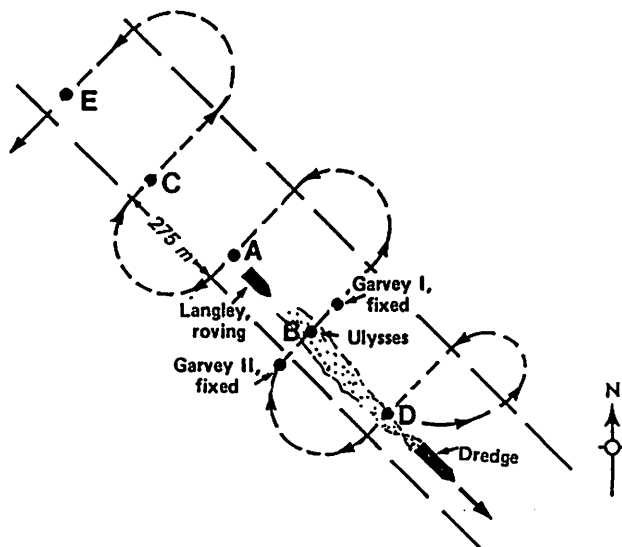


Figure 2b. General plan of monitoring observations from fixed and roving vessels in relation to hopper dredge course.

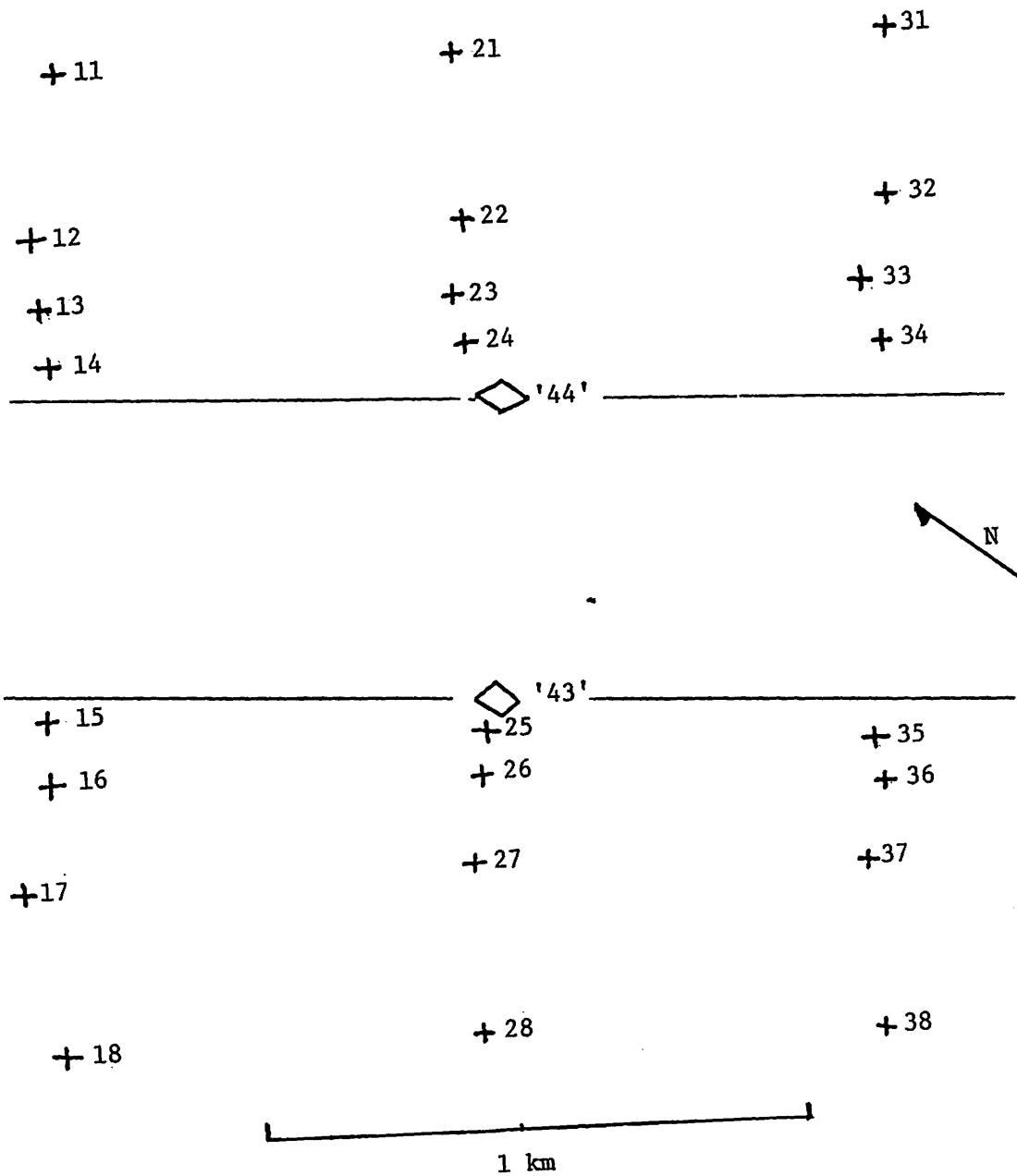


Figure 2b. Location of SPI and box core stations around the dredged channel near buoys '43' and '44'. *Nos = Sample nos.?*

Time was recorded to the nearest minute on standard Casio module 587/596 timepieces. These timepieces were initially synchronized to M/V Stuyvesant time. X

Water samples were obtained from the plume with Rule 2000 submersible pumps, <sup>or Yu Pump</sup>. The pumps were flushed for 45 seconds prior to sampling. Water samples for suspended sediment analyses were placed in plastic cubet containers and stored in an ice chest for transport to VIMS laboratory.

Water temperature was determined <sup>Every dredge cycle</sup> in situ with a VIMS thermister-<sup>C + D</sup> unit having an accuracy better than  $\pm 0.1^{\circ}\text{C}$ . The unit was calibrated in a VIMS tank prior to deployment.

Current measurements for speed and direction were obtained at two depths, 2.4 m and 9.1 m, with Endeco current meters ~~on a taut mooring~~. ~~The current meters were calibrated in a VIMS flume prior to deployment.~~ 5-4

Turbidity was measured in situ at mid-depth (7 m) by towing a Parteck optical transmissometer (beam transmission) with a sensor in the range of 0 to 1,000 ppm. The unit was calibrated prior to deployment in a tank by using natural bottom sediment from the dredge site and diluting it with water while stirring to maintain a uniform suspension. Aliquots of the suspension were obtained from the tank and analyzed gravimetrically in the lab by filtration (see "laboratory procedure"). Figure 3 shows the linear response obtained in a calibration curve. An alternate calibration line was determined by assuming zero percent transmittance and zero suspended sediment concentration. Additionally, the units were checked in the field prior to deployment to obtain a

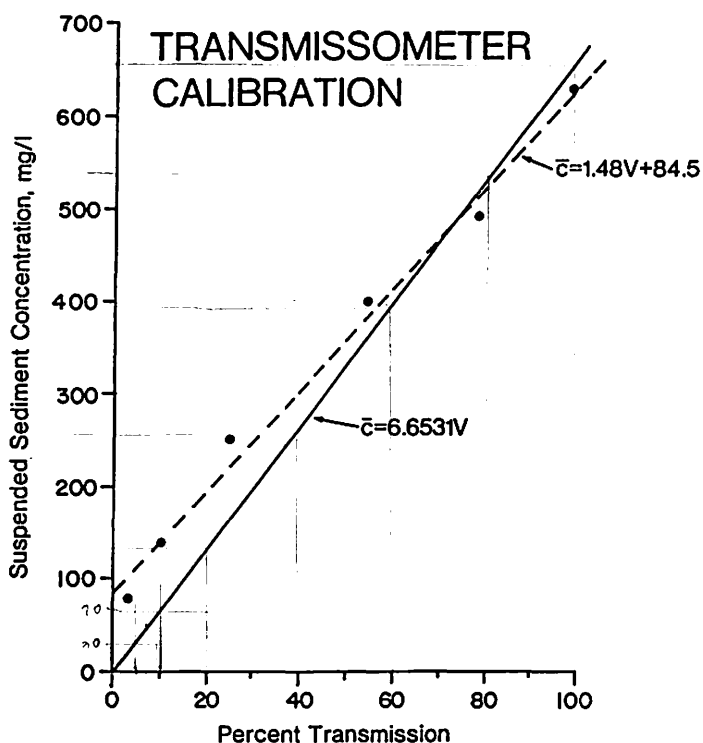


Figure 3. Transmissometer calibration curve for Parteck transmissometer, 0-1000 ppm range. Regression line 1 assumes zero percent transmission at zero percent solids.

"clear water zero" and to compare the transmittance with stock suspensions of known suspended sediment concentrations.

The plume was also detected by acoustic tracking using a dual frequency Datasonics DFS-2100 remote sensing system with frequencies of 27 and 300 kHz. The transducer was towed just beneath the surface at 1 m depth along lateral and longitudinal transects through the plume. Table 1 summarizes the settings used on the Datasonics unit. Table 2 summarizes all the equipment used by parameter and vessel.

The hopper overflow was sampled with a scoop type pipe sampler while samples from mid-depth were obtained with the vessel's dip sampler. Since a syringe type sampler on a pole was not feasible on the

Table 1. Summary of instrument settings used on DataSonics DFS-2100 unit.

Parameter	Channel 1	Channel 2
Transmitter frequency	27 kHz	300 kHz
Output attenuation	0 db	0 db
Pulse length	0.2 milli sec	0.2 milli sec
Band width, receiver	2 kHz	2 kHz
Gain control	0	0
TVG rate, receiver (time varied gain)	off	on
Output	10 kHz, 20 log R	10 kHz, 20 log R
Key mode	externally from EPC "A"	externally from EPC "B"
Recorder	EPC 3200, AC	EPC 3200, AC
Sweep	1/32 sec	1/32 sec
EPC Gain	500	500 (alternate 700 on EPC 4000)
Print	Polar <u>+</u>	Polar <u>+</u>
Threshold	0	0
Chart advance	200	200
Contrast	~ 3:30	~ 3:30

Table 2. Schedule of sampling devices by parameter and by vessel.

Parameter	Dredge Vessel Hopper & Overflow	Anchor Station Vessels Cruiser "Ulysses"			Roving Vessel "Langley"	Fixed Mooring
		Garvey I	Plume Axis	Garvey II		
Location		Rangefinder & sextant	Loran C	Rangefinder & sextant	Loran C, North Star	
Sampling Depth	Marked line	Marked line	Marked line	Marked line	Marked line	
Time	Watch	Watch	Watch	Watch	Watch	
Suspended Sediment Concentration	Core & scoop	Submersible pump	Submersible pump	Submersible pump	Submersible pump	
Salinity		+ Samples	Returned to	Laboratory	For Analysis →	
Turbidity					Turbidometer recorder	
Acoustic Scattering of Suspensions		Survey Fathometer (200 kHz)	Survey Fathometer (200 kHz)	Survey Fathometer (200 kHz)	Datasonics acoustic profiler at 27 and 300 kHz	
Current						Endeco current meters (2)
Temperature			Thermister			
Ancillary Data Wind Waves				Anemometer Visual observations		

M/V Stuyvesant a 30-pound gravity corer was used to retrieve near bottom sediment samples.

A modified Benthos model 37 sediment profile camera and Benthos 372-382 standard camera and strobe were used to collect three replicate photographs at each grid station. Modifications to the cameras and general operation of the SPI system are described in Schaffner and Diaz (1987). A 0.06 m<sup>2</sup> spade box core was used to collect replicate samples at every other grid station. Cores were cut at 15 cm depth and all sediment washed through a 0.5 mm sieve. Prior to sieving, sediment samples were taken from each core at 0 to 5 and 5 to 15 cm intervals. Details of sample processing procedures can be found in Diaz et al. (1985).

Laboratory Procedures. In the laboratory water samples collected for salinity were run on a Beckman Induction Salinometer, model RS-10 that normally achieves an accuracy of  $\pm 0.05$  ppt. Samples collected for suspended sediment concentrations were processed gravimetrically by vacuum filtration following procedures of APHA (1981). Gelman filters with a 0.45  $\mu$  pore size were used. The method achieves an accuracy of 33 percent at concentrations of 15 mg/l and 10 percent at concentrations of 242 mg/l. For concentrations more than  $\sim 3$  g/l, samples were analyzed by weight loss on drying as for water content analyses of soils (Dawson, 1959).

## 7. Observations and Results

### Dredge Operation Data and Hopper Characteristics. Table 3

summarizes the dimensions of the dredge vessel M/V Stuyvesant and its hopper together with pertinent operation data. The track of the dredge through the monitoring zone during each dredge cycle is shown in Appendix I. A computerized list of dredge locations for the first three dredge cycles is provided in Appendix II. Dredge operation data for the draghead and pump is provided in Appendix III while a daily report is provided in Appendix IV. Graphs of water level in the hopper versus time recorded on the M/V Stuyvesant are provided in Appendix V along with interpretative notes by the dredge operations manager, Ray Champagne. The concentrations of solids obtained from surface scoop samples near the overflow wier, and at various depths in the hopper, are provided in Appendix VI.

Monitoring Observations and Results. Monitoring data for temperature and total suspended material (solids) as well as salinity is provided in Appendices VII and VIII. Appendix IX gives the location of fixed stations and "dip" stations of the monitoring data, while Appendix XI give weather observations during the monitoring period. Appendix X gives the background current speed and direction data recorded by the Endeco current meters.

Although suspended sediment concentrations taken near the surface of the hopper overflow weir are quite high, e.g. in the range 75,100 to 286,100 mg/l, the concentrations observed in water samples at mid-depth (7.0 m) just behind, and along side the dredge, are reduced to about 115 to 838 mg/l. Most values are less than 100 mg/l at the Garvey stations

Table 3. Dimensions of hopper and dredge vessel, M/V Stuyvesant, and pertinent dredge operation data during the monitoring period.

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Vessel length overall	113.4 m (372 ft)
Beam moulded	21.9 m ( 72 ft)
Draft lightship	5.8 m ( 17 ft) ) <sup>9</sup>
Draft loaded	8.8 m ( 29 ft)
Displacement loaded	16,500 tons
Cargo capacity	7,038 m (9,200 yds <sup>3</sup> )
Propulsion	Two 6,900 HP engines Variable pitch propellers at ~ 7.6 m (25 ft) depth
<del>Bottom doors</del>	40 hydraulically operated
Suction pipes	Two 0.9 m (35 in) diameter
Pump capacity (2)	168 m <sup>3</sup> (220 yds <sup>3</sup> ) solids per minute 337 ^ 444
Hopper length	46.0 m (151 ft)
Hopper width	13.7 m ( 45 ft)
Hopper depth	13.5 m (44.4 ft) top of combing to doors
<del>Upper overflow elevation</del>	12.6 m (41.3 ft) above doors
<del>Lower overflow elevation</del>	9.1 m (30.0 ft) above doors
Overflow discharge depth	6.0 m (20 ft)
<sup>e</sup> Dredging speed <sup>across</sup> <sub>bottom</sub>	75 m/min (256 ft/min) to 114 m/min (374 ft/min) Average, 104 m/min (342 ft/min) over 6 dredging cycles

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35 minutes after passage of the dredge and return to background concentrations 75 minutes after passage of the dredge (Figure 4). Although concentrations near the bottom are more than two times greater than at mid-depth, the "loss" of solids with time is relatively rapid (Figure 5). The rapid loss of solids indicates the material is rapidly dispersed by diffusion, advection and settling out.

Figures 6 and 7 display the distributions of turbidity in plan view. Those are based on transmissometer tows at the 7.0 m depth during periods of weak tidal current, early flood and early ebb. The basic pattern reflects the dredge track with highest concentrations along the axis of the track along both sides of the channel. Intermediate levels occur between the dredge tracks in the channel axis whereas background concentrations occur 80 m from the dredge tracks to the northeast and southwest. In dredge cycle 3 (Figure 7), the axis of maximum turbidity, as well as the plume edge, is shifted slightly southwest by the early ebb tidal current. In other dredge cycles, i.e. 2, 4 and 5, the turbidity plume at the 7.0 m depth is indistinct and patchy, a characteristic likely produced by strong flood and ebb tidal currents combined with rapid settling from mid-depth. The plume geometry during these cycles however, is best displayed in acoustic records.

The results of acoustic tracking are displayed in a series of representative segments of records (Figures 8 - 12). There are two important aspects of these records. First, the records contain artifacts of instrumentation and scattering from features other than sediment particles in the plume. Second, the records display scattering

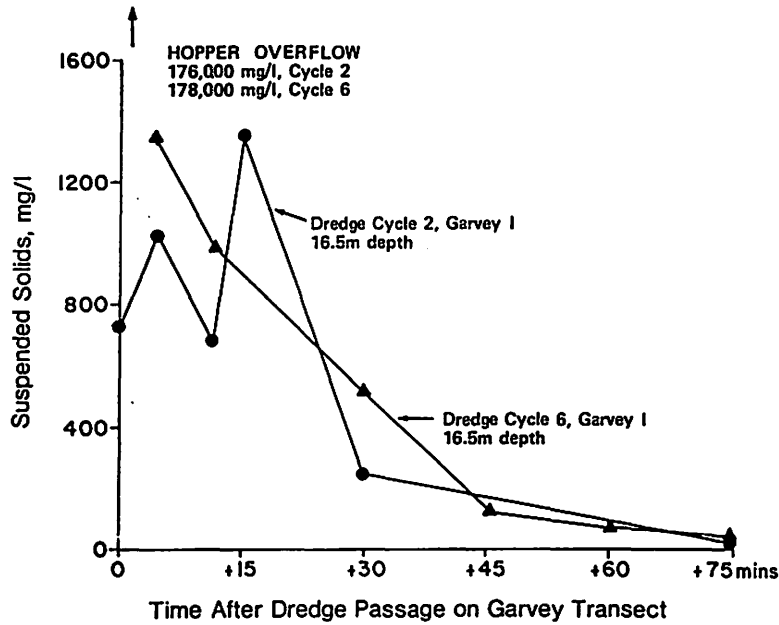


Figure 4. Temporal distribution of mean suspended sediment concentrations from 3 vessels on the Garvey transect, at mid-depth, 7 m and dredge cycles 2 and 6, May 14, 1987, in relation to average hopper overflow concentrations during sampling period.

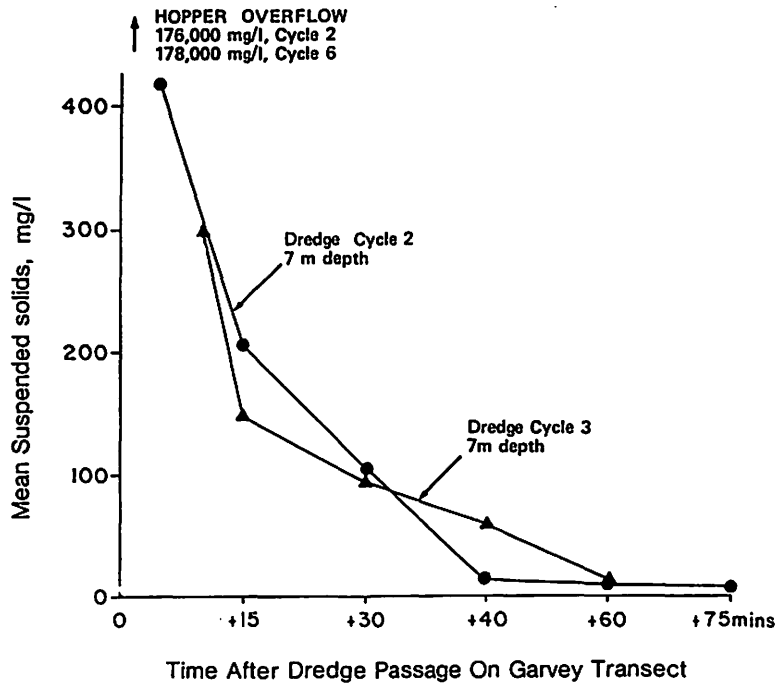


Figure 5. Temporal distribution of suspended sediment concentrations at Garvey I station, one meter above the bottom, dredge cycles 2 and 6, May 14, 1987, in relation to average hopper overflow concentrations during sampling period.

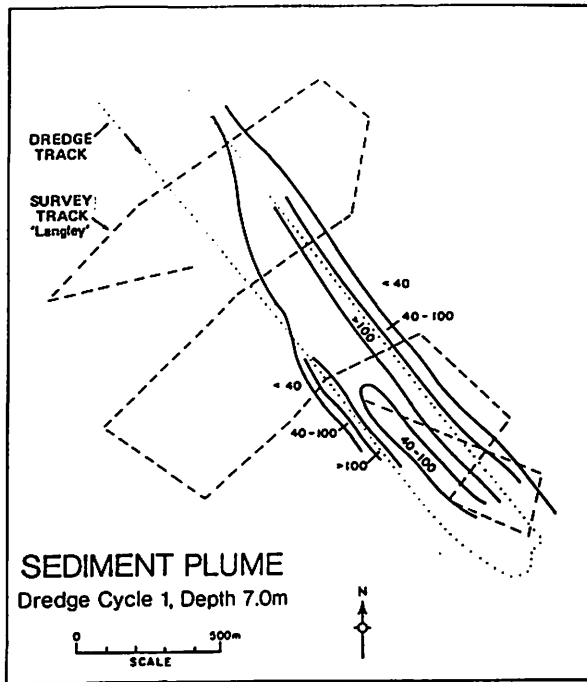


Figure 6. Geometry of turbidity plume produced by M/V Stuyvesant, dredge cycle 1, May 14, 1987, between 10:47 and 11:15 or 8 to 40 minutes after the Stuyvesant crossed the Garvey transect. Based on transmissometer tows (dashed) by R/V Langley at 7.0 m depth during early flood tidal current. Values represent estimated suspended sediment concentrations, mg/l, above background. Dredge track, dotted.

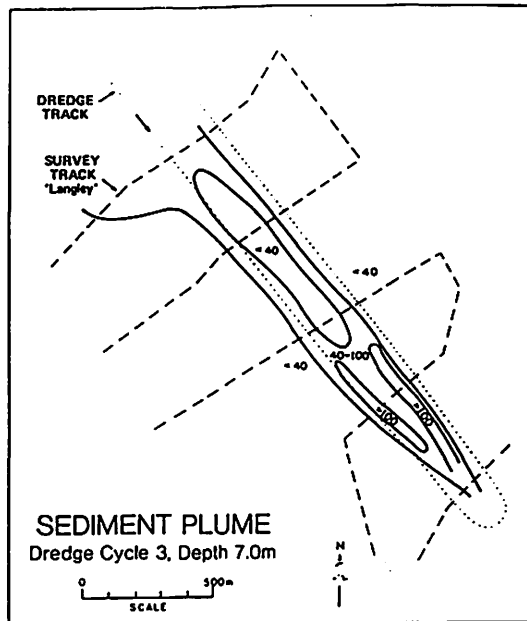


Figure 7. Geometry of turbidity plume produced by M/V Stuyvesant, dredge cycle 3, May 14, 1987 between 14:48 and 15:40 or 13 to 15 minutes after the Stuyvesant crossed the Garvey transect. Based on transmissometer tows (dashed) by R/V Langley at 7.0 m depth about one hour after slack before ebb tidal current. Values represent estimated suspended sediment concentrations, mg/l, above background. Dredge track, dotted.

*The designated plume boundaries are taken at 5% transmissometer or equivalent to about 7 mg/l*

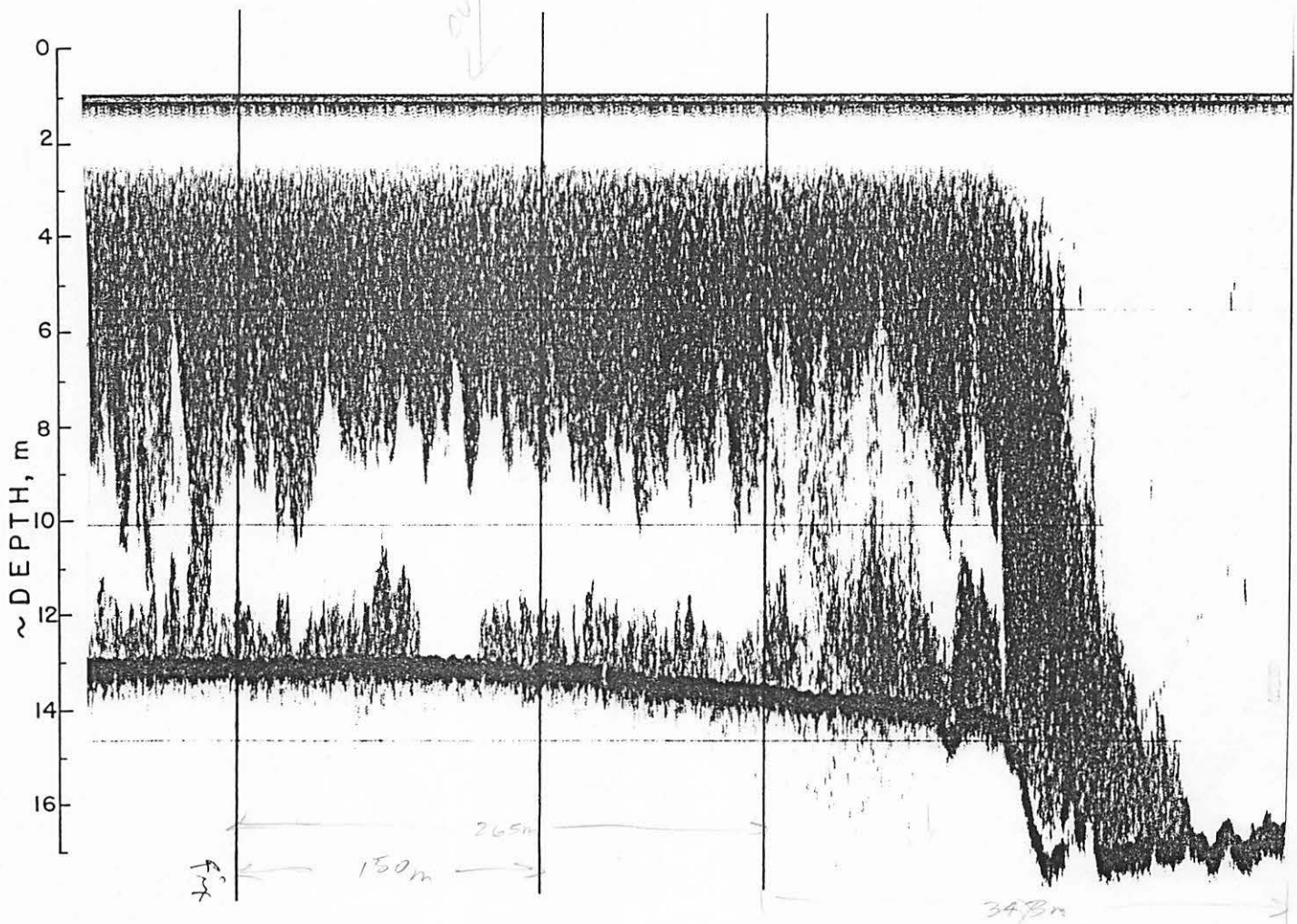


Figure 8. Acoustic record obtained at 300 kHz frequency taken three minutes after passage of M/V Stuyvesant, dredge cycle 5, 18:54, May 14, 1987. Record shows fresh discharge of suspended dredge material from hopper overflow forming upper plume and from draghead agitation forming near-bottom plume in channel at 16 m depth. Dark-toned patches above the bottom at about 12 m represent suspended material produced by draghead agitation and by settling from upper plume. Depth scale in meters, approximate.

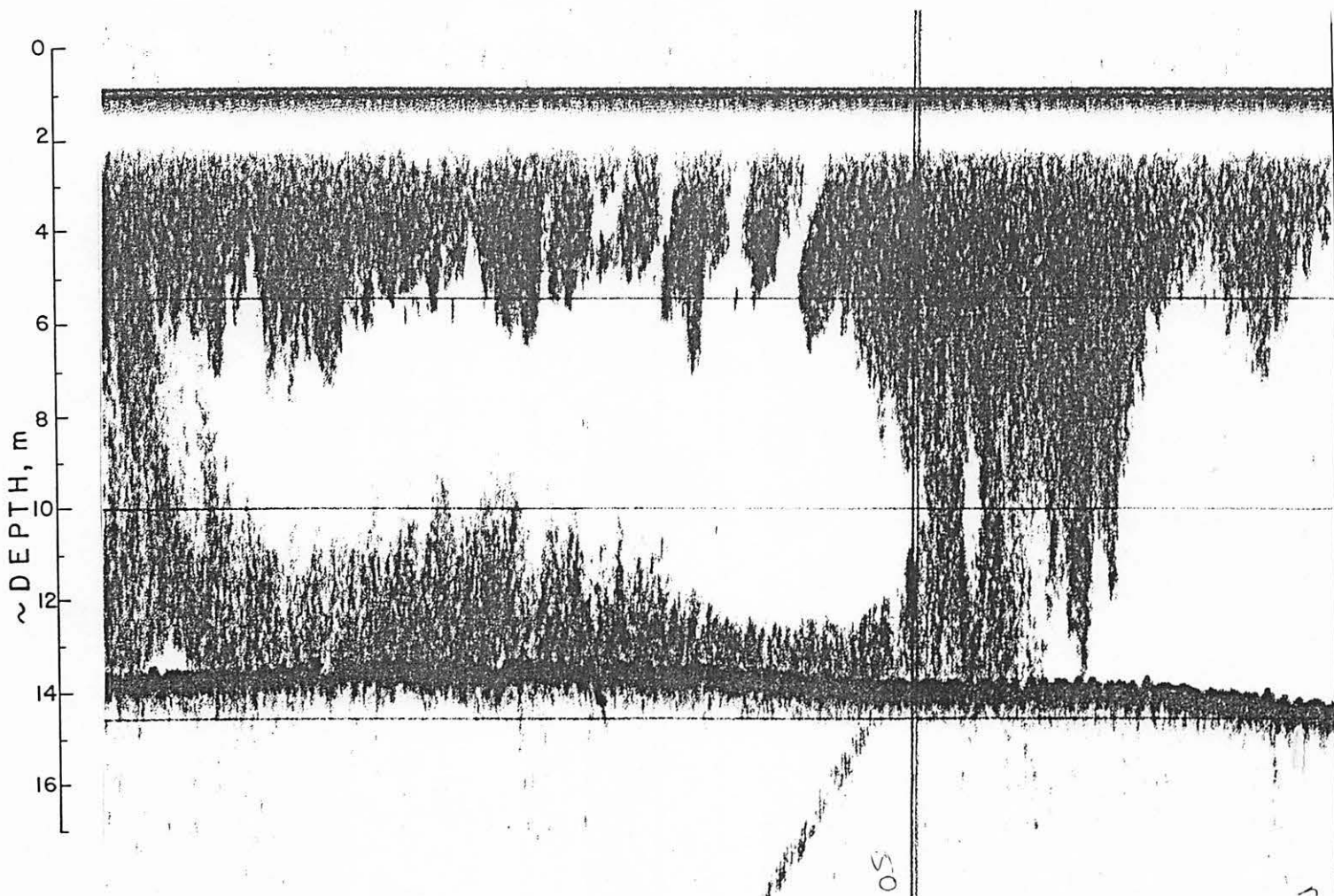


Figure 9. Acoustic record displaying two sediment plumes, upper plume and lower plume, along a track behind the M/V Stuyvesant but over the channel shoulder. Record obtained from 300 kHz system, 3 to 4 minutes after dredge passage, dredge cycle 3, 14:40, May 14, 1987. Depth scale in meters, approximate.

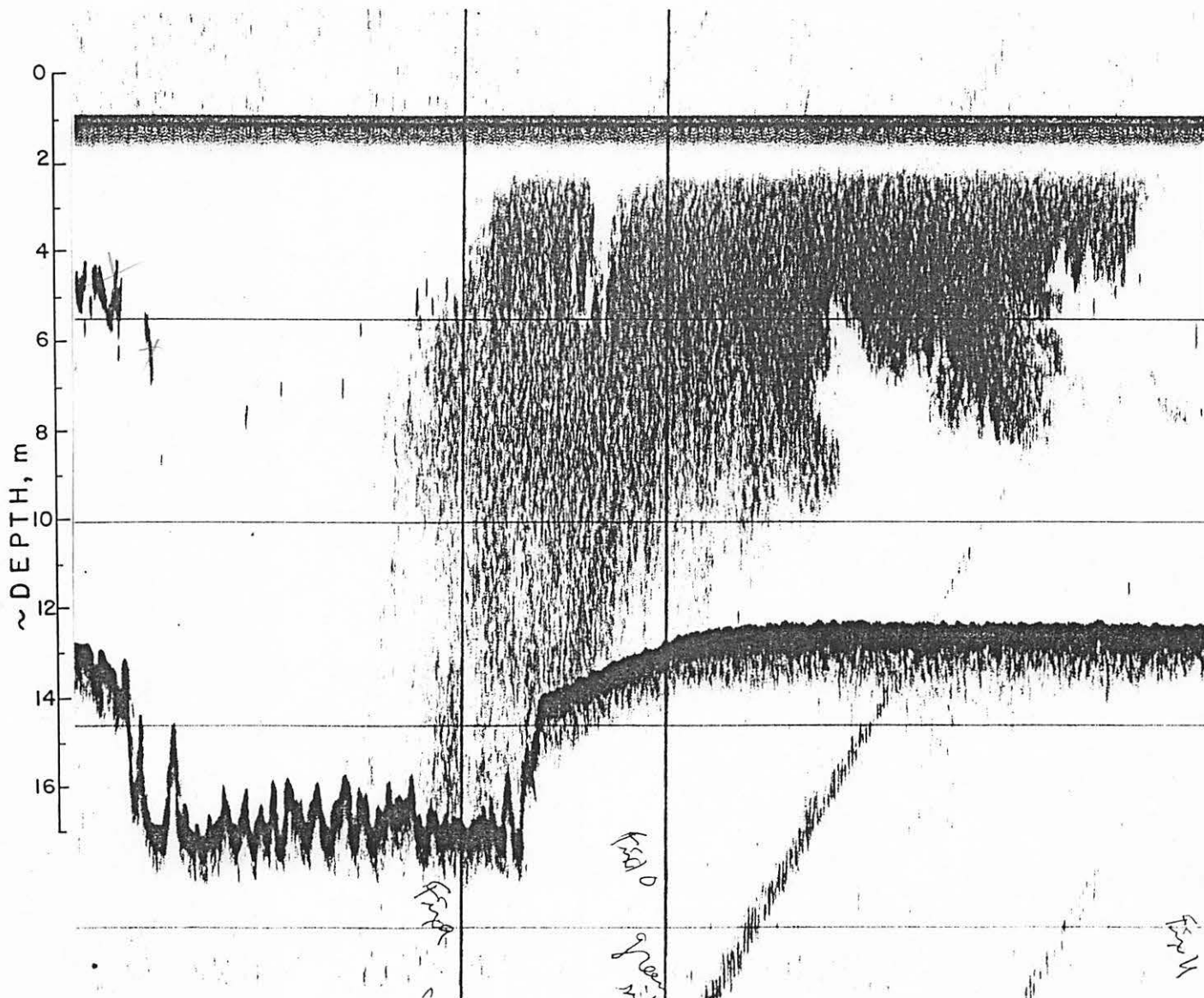


Figure 10. Acoustic record obtained 8 to 10 minutes after passage of M/V Stuyvesant and transverse to the dredge cut showing drift of the main mass of the upper plume over adjacent channel shoulder (right) extending about 170 m, with "trail" of settling suspensions leading from dredge cut. Record transverse to channel from 300 kHz system, dredge cycle 5, 19:02, May 14, 1987. Depth scale in meters, approximate.

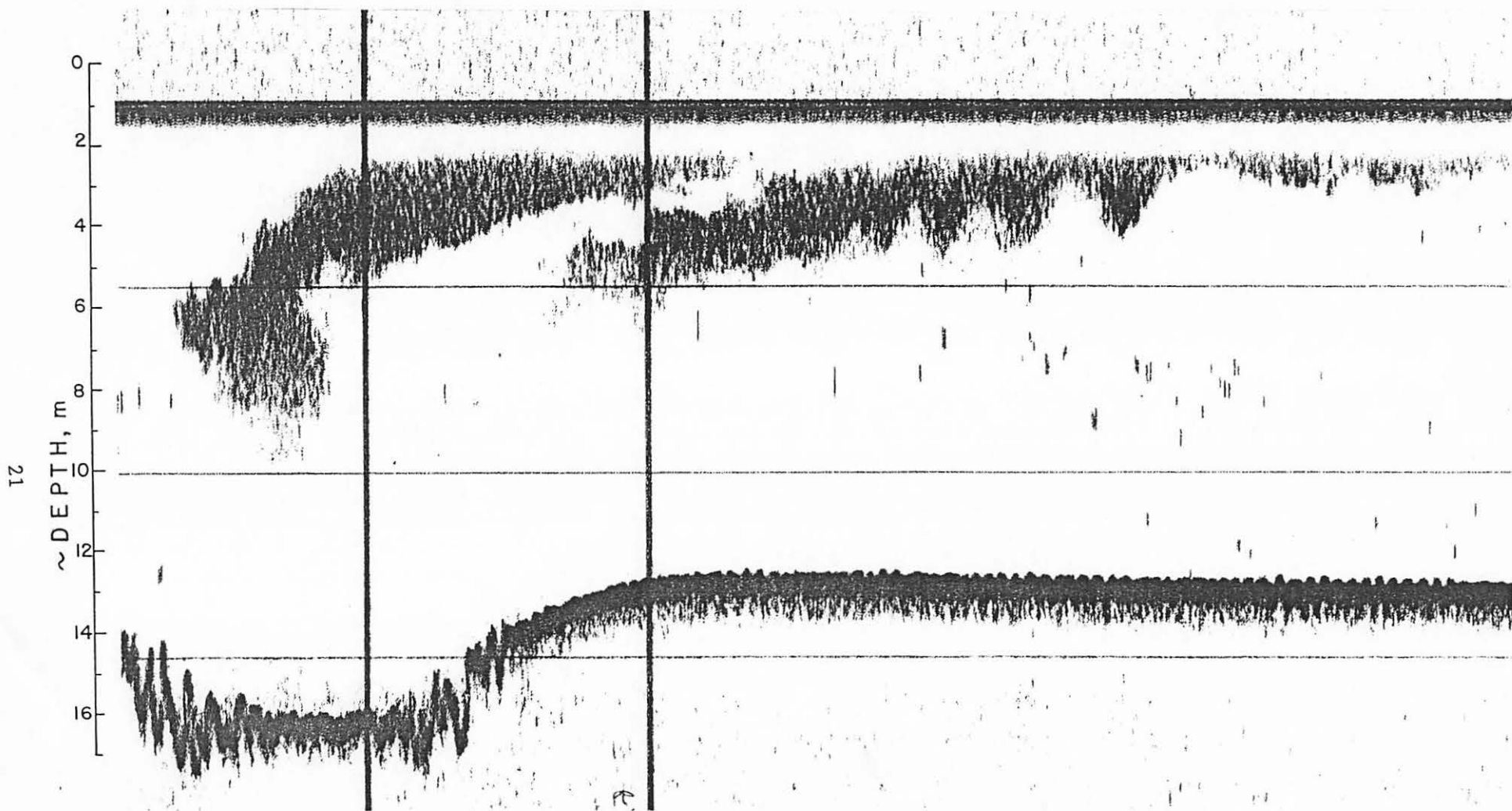


Figure 11. Acoustic record showing two plumes of different age; left, 15 minutes after passage of M/V Stuyvesant; and right, 32 minutes after passage of dredge along backtrack on opposite side of channel. The older plume (right) extends 600 m southwestward in near-surface water and displays an undulating structure indicative of internal waves. Note thinning and lighter tone trace with distance southwestward. Record transverse to channel from 300 kHz system, dredge cycle 3, 15:04, May 14, 1987. Depth scale in meters, approximate.

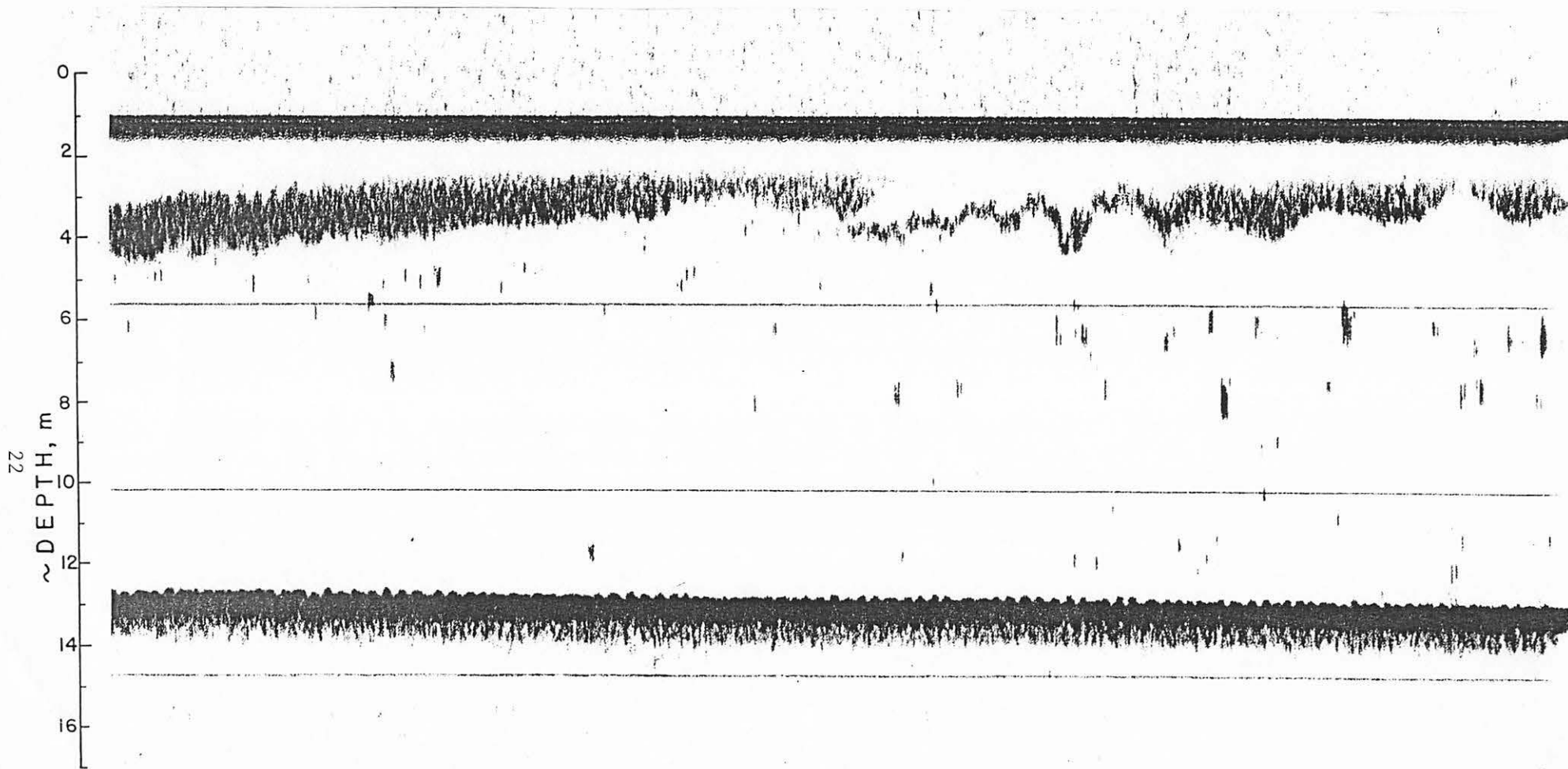


Figure 12. Acoustic record showing two plumes of different age, left, dark-toned 29 minutes after passage of M/V Stuyvesant and right, 52 minutes after passage of M/V Stuyvesant. The older plume (right), extends 800 m southwestward; it displays thinning and broken undulating structure indicative of dissipating internal waves. Record transverse to channel from 300 kHz system, dredge cycle 3, 15:30, May 14, 1987. Depth scale in meters, approximate.

from particles indigenous to the plume. These display the two-dimensional structure and thickness of the plume. With time, changes in geometry of the plume can be interpreted in terms of plume evolution as the plume "ages".

The artifacts consist of: (1) a line trace in the 27 kHz channel at about 4.5 m depth with a void zone above the 4.5 m depth. This likely is caused by shallow water transducer "ringing" with resultant blanking out of the receiving pulse. (2) Point scatters throughout the 300 kHz channel that may relate to either fish or possibly settling of sediment as clumps or aggregates. (3): Diagonal traces in both channels represent noise or acoustic instrument interference. (4) Continuous opaque dark-toned patches with blank-out of bottom relief, represent wakes (bubbles) from the M/V Stuyvesant's ship propellor or turbulence from overflow discharge or draghead suction.

The fresh discharge of dredged material from the hopper overflow as well as from agitation of the draghead is illustrated in Figures 8 and 9, a traverse behind the dredge (3 min after passage) and along the dredge track during dredge cycle 5. In its initial stage the plume appears as irregular dark reflecting patches or vertical opaque zones through the water column. The dark patches extending downward indicate dredged material is <sup>bubbles</sup> forced downward and continues to settle to the 8 to 10 m (25 to 31 ft) depth. Estimated concentrations above background from transmissometer measurements at mid-depth (7.0 m) are in the range of 100 to 200 mg/l. In contrast, the dark patches extending upward above the bottom suggesting either rapid settling from clouds along

sides of the channel or from clouds stirred up 2 to 3 m (6.2 to 9.3 ft) above the bed by the draghead.

From 7 to 10 minutes after passage of the dredge the plume acquires integrity in mid-depth and near-surface water but has a "trail" of particle scattering leading to the dredge cut and to bottom along the channel shoulder, light-toned zones in Figure 10. The main mass of suspensions represented by dark tones in the cloud at about 5 m depth has been carried 170 m to the southwest by strong (maximum) ebb tidal currents.

Later stages of plume evolution are illustrated in Figures 11 and 12, dredge cycle 3 a time 15 to 32 minutes after dredge passage and at early ebb current. Two plumes are evident; <sup>the older</sup> one produced by the first dredge passage (+ 32 minutes), extends over 600 m to the southwest between 2.5 and 5 m depth. The wave-like features are likely internal waves <sup>Along density surfaces</sup> that retard sediment settling. They suggest that the fine particles remaining in suspension accumulate in density gradient "surfaces" in the upper water column. The overall effect therefore is to promote widespread dispersion. The second plume is darker-toned and thicker (2 to 8 m) than the first plume and closer to its source over the dredge cut. Subsequent passes at 29 to 52 minutes after dredge passage, Figure 12, display thinning of the plumes to 2 m thickness and dispersion more than 800 m from the dredge track. After 60 minutes, most plumes were no longer detectable in the 300 kHz channel.

<sup>Bottom Sediments</sup>  
Surface and Profile Imagery. SPI images indicated that there were layers of dredged material at every grid station. All of the 69 images that were analyzed contained very clear layers of dredged material (see

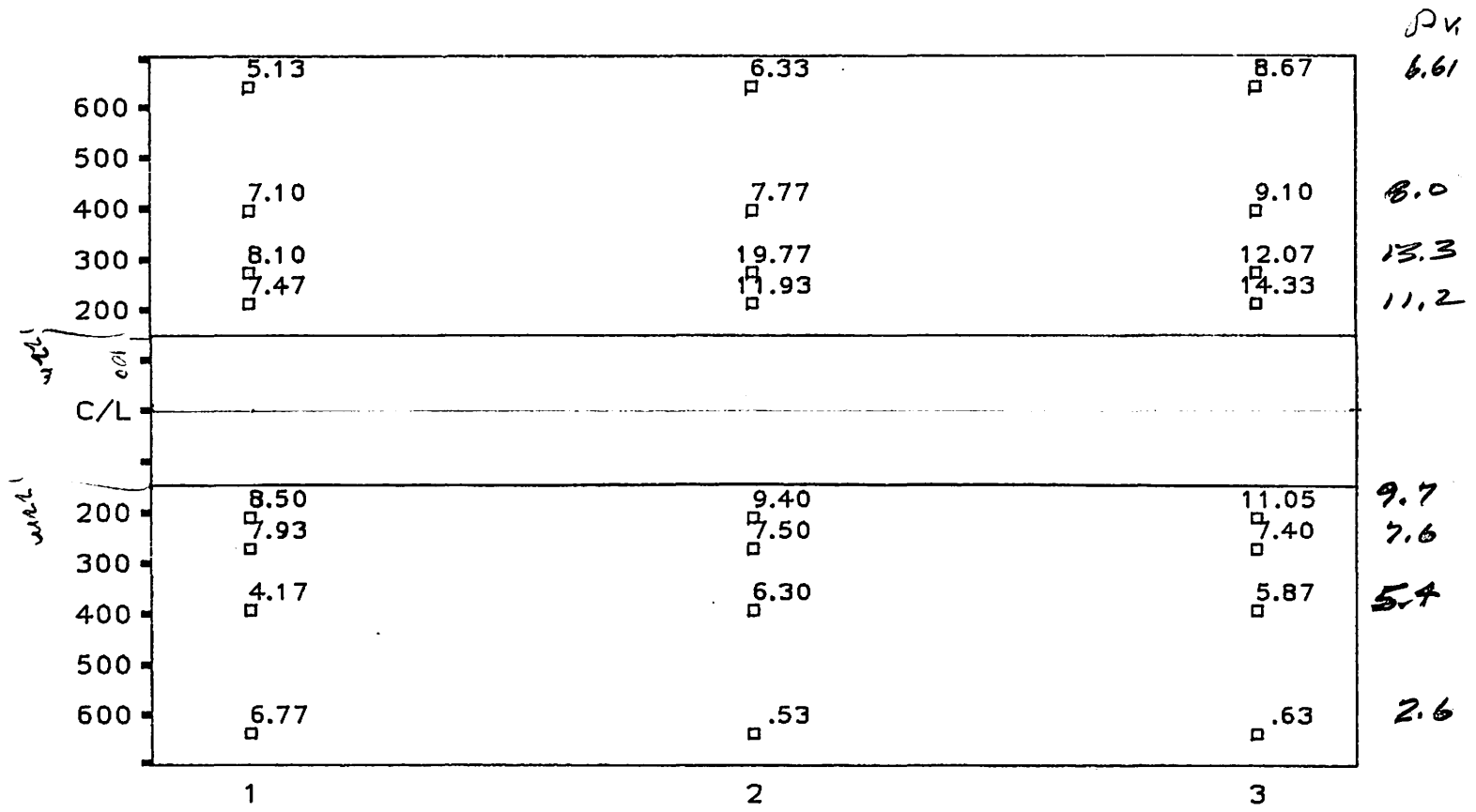
Appendix XII for data). The thickness of the dredged material ranged from 0.5 to 19.8 cm. The southwestern ends of transects 2 and 3 had the thinnest layers (Figure 13). Thickest layers were found north of the channel. There was a general thinning of the dredged material with distance from the channel. Penetration depth of the profile camera prism, an indication of sediment compaction, was reasonably uniform ranging from 16.5 to 23.0 cm with deepest penetration close to the channel. *because of poor dispersion*

The dredged material was greyer, lighter in tone, and more uniform in texture than the background sediments, which tended to be olive-grey and mottled. Surface images all indicated a uniform colored smooth surface with many small polychaete tubes (likely Paraprionospio pinnata). Surface relief from the profile images ranged from 0.2 to 1.2 cm and was due to smooth depressions in the surface. These depressions showed up as circular pits in the surface images. No lumps of dredged material were seen in any SPI image.

The redox-potential discontinuity (RPD) depth, an indication of oxygenation of sediments, appeared to be very thin in most SPI images. The RPD averaged less than 1 mm at all but three stations (transect 1 stations 7 and 8, transect 2 station 4). The thinness of the apparent RPD was likely due to the advanced diagenic state of the dredged material. Having been recently deposited in the active mixing zone the dredged material is low in labile organics that would give a clear visual signature (brownish color for oxic organics and dark grey-black for reduced organics). SPI surface images indicated that none of the

AVERAGE THICKNESS OF DREDGED MATERIAL  
 LAYER IN CM FROM SPI IMAGES  
 RAPPAHANNOCK SHOALS CHANNEL

METERS FROM CHANNEL CENTER LINE



TRANSECT

Orientation

Figure 13. Average thickness of settled dredged material layer in cm from SPI images. Transects were 2,000 ft. or 610 m apart. Horizontal lines represent channel edge.

stations were anoxic even though no aerobic area was identified in the SPI profile images.

SPI images showed that worms were burrowing in the dredged material layer and background sediments. Worms were seen at 14 of 24 stations with 3 stations (transect 2 station 4, transect 3 stations 5 and 6) having worms in the dredged material layer. The entire sample grid appeared to be colonized by small tube building polychaetes.

Benthos. Communities within the area around the channel sampled were dominated by polychaetes (67% of all individuals) and gastropods (17%). Nemertean (5%), bivalves (4%), amphipods (2%), and oligochaetes (1%) were also abundant at one or more stations (see Appendix XIII for data). Table 4 summarizes the taxonomic distribution of individuals at all stations. Cluster and ordination analysis of these data did not produce any spatial patterns of the stations or distribution patterns of the species that could be related to the thickness of the dredged material layer or distance from the channel. Rank correlation (spearman's  $r$ ) between total abundance and thickness of the dredged material layer was also not significantly different than zero.

The 10 top dominant species (Table 5) were very similar to those found in the Rappahannock Shoals area by Diaz et al. (1985) and typify macrobenthic communities for this region of the Bay. None of these 10 species showed any consistent pattern of increase or decrease in abundance with thickness of dredged material or distance from the channel (Table 6). Similar lack of clear pattern was found for community structure parameters and dredged material thickness. Total wet weight biomass showed no pattern with depth of dredged material or

TABLE 4.  
MEAN DENSITIES OF MAJOR TAXONOMIC GROUPS IN ALL CORES

VARIABLE	MEAN	STD DEV	MINIMUM	MAXIMUM	VALID N
POLYCHAETA	128.333	52.293	45.00	278.00	24
OLIGOCHAETA	2.000	4.653	.00	22.00	24
PELECYPODA	7.417	5.348	.00	23.00	24
GASTROPODA	30.625	59.822	2.00	305.00	24
PERACARIDA	4.208	4.032	.00	17.00	24
DECAPODA	.292	.550	.00	2.00	24
OTHER CRUSTACEA	.125	.448	.00	2.00	24
OPHIUROIDEA	.417	.881	.00	3.00	24
ENTEROPNEUST	.292	.550	.00	2.00	24
ASCIDIACEA	.458	1.141	.00	5.00	24
NEMERTEAN	8.833	4.229	3.00	18.00	24
PHORONIDA	2.208	3.134	.00	12.00	24
POLYCLADIA	.667	1.090	.00	4.00	24
TOTAL	185.875	81.484	88.00	445.00	24

TABLE 5.  
 RAPPAHANOCK SHOALS CHANNEL - PLUME STUDY  
 MEAN DENSITIES OF EACH TAXA FOR ALL CORES

MEAN	STD DEV	MINIMUM	MAXIMUM	VALID N	SPECIES
55.625	24.934	0	98	24	PARAPRIONOSPPIO PINNATA
18.875	57.894	0	288	24	CYCLOSTREMISCUS PENTAGONA
17.667	17.310	1	60	24	PSEUDEURYTHOE PAUCIBRANCHIATA
11.875	17.514	0	66	24	STREBLOSPPIO BENEDICTI
11.542	18.233	0	63	24	MEDIOMASTUS AMBISETA
7.125	4.142	1	17	24	TUBULANUS PELLUCIDUS
7.000	9.802	0	46	24	BHAWANIA HETEROSETA
6.708	4.339	1	16	24	ANACHIS LAFRESNAYI
4.417	3.035	0	10	24	NEPHTYS CF. CRYPTOMMA
3.792	3.599	0	11	24	SIGAMBRA TENTACULATA
3.458	2.413	0	8	24	YOLDIA LIMATULA
3.083	2.083	0	8	24	PECTINARIA GOULDII
2.708	3.532	0	15	24	ASABELLIDES OCULATA
2.458	3.635	0	12	24	MYTILIDAE
2.292	4.939	0	24	24	ODOSTOMIA ENGONIA
2.208	3.134	0	12	24	PHORONIS
2.167	3.130	0	14	24	IDUNELLA BARNARDI
2.125	2.559	0	9	24	POLYDORA CORNUTA
2.000	4.653	0	22	24	OLIGOCHAETA
1.875	2.213	0	9	24	ACTEOCINA CANALICULATA
1.417	1.742	0	6	24	LOIMIA MEDUSA
1.375	1.555	0	5	24	MICRURA RUBRA
1.333	2.761	0	12	24	PRIONOSPPIO PERKINSI
.958	1.197	0	4	24	ETEONE HETEROPODA
.875	1.393	0	5	24	AMPELISCA
.875	.741	0	2	24	TURBONILLA INTERRUPTA
.833	1.239	0	5	24	MACOMA TENTA
.708	.806	0	3	24	NEREIS GRAYI
.625	1.056	0	4	24	STYLOCHUS ELLIPTICUS
.625	.824	0	3	24	LEUCON AMERICANUS
.583	.974	0	3	24	GLYCIDAE SOLITARIA
.542	1.103	0	4	24	MALMGRENIELLA SP. A
.500	.659	0	2	24	GLYCERA AMERICANA
.458	1.141	0	5	24	MOLGULA MANHATTENSIS
.417	.881	0	3	24	MICROPHIOPHOLIS ATRA
.375	.647	0	2	24	ORBINIIDAE
.333	.565	0	2	24	ASYCHIS ELONGATA
.292	.550	0	2	24	SACCOGLOSSUS KOWALEWSKII
.250	.532	0	2	24	OGYRIDES ALPHAEROSTRIS
.208	.415	0	1	24	TELLINIDAE
.208	.509	0	2	24	AMPHIPORUS BIOCULATUS
.208	.588	0	2	24	CAPITELLA CAPITATA
.208	.415	0	1	24	AMPELISCA ABDITA

TABLE 5. CONTINUED

MEAN	STD DEV	MINIMUM	MAXIMUM	VALID N	SPECIES
.167	.637	0	3	24	CIRRATULIDAE
.167	.816	0	4	24	MULINIA LATERALIS
.167	.381	0	1	24	CLYMENELLA TORQUATA
.125	.448	0	2	24	ANADARA OVALIS
.125	.448	0	2	24	CHAETOPTERUS VARIOPEDATUS
.125	.448	0	2	24	LEPIDAMETRIA COMMENSALIS
.125	.338	0	1	24	OWENIA FUSIFORMIS
.125	.338	0	1	24	NEREIS SUCCINEA
.083	.408	0	2	24	MALDANIDAE
.083	.408	0	2	24	PELECYPODA
.083	.282	0	1	24	SQUILLA EMPUSA
.083	.282	0	1	24	CIRRIFORMIA GRANDIS
.083	.282	0	1	24	OXYUROSTYLIS SMITHI
.083	.282	0	1	24	RHYNCHOCOEL SP A
.083	.282	0	1	24	MACROCLYMENE ZONALIS
.083	.282	0	1	24	GONIADIDAE
.083	.282	0	1	24	PARACAPRELLA TENUIS
.083	.282	0	1	24	SPIOCHAETOPTERUS OCULATUS
.042	.204	0	1	24	SABELLARIA VULGARIS
.042	.204	0	1	24	BALANUS IMPROVISUS
.042	.204	0	1	24	PARAMETOPELLA CYPRIS
.042	.204	0	1	24	GLYCERA
.042	.204	0	1	24	HESIONIDAE
.042	.204	0	1	24	PODARKEOPSIS LEVIFUSCINA
.042	.204	0	1	24	SPIOPHANES BOMBYX
.042	.204	0	1	24	PINNIXA RETINENS
.042	.204	0	1	24	COROPHIUM TUBERCULATUM
.042	.204	0	1	24	ALIGENA ELEVATA
.042	.204	0	1	24	MELINNA MACULATA
.042	.204	0	1	24	NEPHTYS
.042	.204	0	1	24	MACOMA BALTHICA
.042	.204	0	1	24	CEREBRATULUS LACTEUS
.042	.204	0	1	24	EUPLANA GRACILIS
.042	.204	0	1	24	ERICHTHONIUS BRASILIENSIS
.042	.204	0	1	24	IDUNELLA CLYMENELLAE

TABLE 6.  
MEAN DENISTIES FOR THE DOMINANT SPECIES ALONG TRANSECT POSITIONS

*PARAPRIONOSPIO PINNATA*

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	66.0000	11.4018	5.7009	53.0000	77.0000	47.8575 TO 84.1425
2	2	76.5000	16.2635	11.5000	65.0000	88.0000	-69.6213 TO 222.6213
3	4	40.7500	29.8817	14.9409	15.0000	74.0000	-6.7978 TO 88.2978
4	2	35.0000	11.3137	8.0000	27.0000	43.0000	-66.6496 TO 136.6496
5	4	29.7500	22.7505	11.3752	.0000	49.0000	-6.4505 TO 65.9505
6	2	75.0000	15.5563	11.0000	64.0000	86.0000	-64.7682 TO 214.7682
7	4	73.0000	20.7043	10.3521	55.0000	98.0000	40.0554 TO 105.9446
8	2	62.0000	1.4142	1.0000	61.0000	63.0000	49.2938 TO 74.7062
TOTAL	24	55.6250	24.9344	5.0897	.0000	98.0000	45.0961 TO 66.1539

*CYCLOSTREMISCUS PENTAGONUS*

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	13.5000	10.4722	5.2361	2.0000	27.0000	-3.1633 TO 30.1633
2	2	4.0000	5.6569	4.0000	.0000	8.0000	-46.8248 TO 54.8248
3	4	77.0000	140.7195	70.3598	3.0000	288.0000	-146.9130 TO 300.9130
4	2	1.5000	2.1213	1.5000	.0000	3.0000	-17.5593 TO 20.5593
5	4	5.2500	5.5603	2.7801	.0000	11.0000	-3.5975 TO 14.0975
6	2	12.5000	16.2635	11.5000	1.0000	24.0000	-133.6213 TO 158.6213
7	4	2.0000	1.8257	.9129	.0000	4.0000	-.9051 TO 4.9051
8	2	13.0000	15.5563	11.0000	2.0000	24.0000	-126.7682 TO 152.7682
TOTAL	24	18.8750	57.8937	11.8175	.0000	288.0000	-5.5714 TO 43.3214

*PSEUDEURYTHOE PAUCIBRANCHIATA*

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	8.5000	9.0000	4.5000	1.0000	21.0000	-5.8208 TO 22.8208
2	2	25.5000	23.3345	16.5000	9.0000	42.0000	-184.1523 TO 235.1523
3	4	16.2500	18.2460	9.1230	2.0000	41.0000	-12.7830 TO 45.2830
4	2	23.0000	24.0416	17.0000	6.0000	40.0000	-193.0054 TO 239.0054
5	4	10.5000	9.8826	4.9413	1.0000	20.0000	-5.2253 TO 26.2253
6	2	35.0000	35.3553	25.0000	10.0000	60.0000	-282.6550 TO 352.6550
7	4	18.5000	19.2959	9.6480	1.0000	46.0000	-12.2037 TO 49.2037
8	2	21.0000	22.6274	16.0000	5.0000	37.0000	-182.2992 TO 224.2992
TOTAL	24	17.6667	17.3096	3.5333	1.0000	60.0000	10.3575 TO 24.9759

TABLE 6. CONTINUED

## STREBLOSPIO BENEDICTI

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	6.7500	8.0571	4.0285	.0000	16.0000	-6.0704 TO 19.5704
2	2	2.5000	3.5355	2.5000	.0000	5.0000	-29.2655 TO 34.2655
3	4	.2500	.5000	.2500	.0000	1.0000	-.5456 TO 1.0456
4	2	15.5000	21.9203	15.5000	.0000	31.0000	-181.4461 TO 212.4461
5	4	27.2500	26.2980	13.1490	8.0000	66.0000	-14.5953 TO 69.0953
6	2	35.5000	7.7782	5.5000	30.0000	41.0000	-34.3841 TO 105.3841
7	4	.7500	.9574	.4787	.0000	2.0000	-.7735 TO 2.2735
8	2	19.0000	26.8701	19.0000	.0000	38.0000	-222.4178 TO 260.4178
TOTAL	24	11.8750	17.5135	3.5749	.0000	66.0000	4.4797 TO 19.2703

## MEDIONASTUS AMBISETA

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	27.5000	32.4191	16.2096	.0000	63.0000	-24.0853 TO 79.0853
2	2	1.0000	1.4142	1.0000	.0000	2.0000	-11.7062 TO 13.7062
3	4	.2500	.5000	.2500	.0000	1.0000	-.5456 TO 1.0456
4	2	6.5000	7.7782	5.5000	1.0000	12.0000	-63.3841 TO 76.3841
5	4	14.7500	10.9962	5.4981	3.0000	26.0000	-2.7472 TO 32.2472
6	2	30.0000	24.0416	17.0000	13.0000	47.0000	-186.0054 TO 246.0054
7	4	.5000	1.0000	.5000	.0000	2.0000	-1.0912 TO 2.0912
8	2	15.0000	21.2132	15.0000	.0000	30.0000	-175.5930 TO 205.5930
TOTAL	24	11.5417	18.2327	3.7217	.0000	63.0000	3.8427 TO 19.2407

## TUBULANUS PELLUCIDUS

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	9.2500	5.3151	2.6575	5.0000	17.0000	.7927 TO 17.7073
2	2	12.0000	7.0711	5.0000	7.0000	17.0000	-51.5310 TO 75.5310
3	4	5.5000	3.0000	1.5000	4.0000	10.0000	.7264 TO 10.2736
4	2	6.5000	2.1213	1.5000	5.0000	8.0000	-12.5593 TO 25.5593
5	4	6.2500	3.3040	1.6520	2.0000	10.0000	.9926 TO 11.5074
6	2	10.0000	4.2426	3.0000	7.0000	13.0000	-28.1186 TO 48.1186
7	4	4.5000	4.0415	2.0207	1.0000	10.0000	-1.9308 TO 10.9308
8	2	6.0000	1.4142	1.0000	5.0000	7.0000	-6.7062 TO 18.7062
TOTAL	24	7.1250	4.1422	.8455	1.0000	17.0000	5.3759 TO 8.8741

TABLE 6. CONTINUED

## BHAWANIA HETEROSETA

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
1	4	1.0000	2.0000	1.0000	.0000	4.0000	-2.1824 TO	4.1824
2	2	4.0000	5.6569	4.0000	.0000	8.0000	-46.8248 TO	54.8248
3	4	12.5000	5.8023	2.9011	7.0000	20.0000	3.2674 TO	21.7326
4	2	3.0000	1.4142	1.0000	2.0000	4.0000	-9.7062 TO	15.7062
5	4	3.5000	2.6458	1.3229	1.0000	7.0000	-.7099 TO	7.7099
6	2	1.5000	.7071	.5000	1.0000	2.0000	-4.8531 TO	7.8531
7	4	17.0000	19.4251	9.7125	6.0000	46.0000	-13.9092 TO	47.9092
8	2	7.5000	9.1924	6.5000	1.0000	14.0000	-75.0903 TO	90.0903
TOTAL	24	7.0000	9.8024	2.0009	.0000	46.0000	2.8608 TO	11.1392

## ANACHIS LAFRESNAYI

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
1	4	3.2500	1.7078	.8539	1.0000	5.0000	.5325 TO	5.9675
2	2	4.0000	2.8284	2.0000	2.0000	6.0000	-21.4124 TO	29.4124
3	4	9.7500	4.5000	2.2500	4.0000	15.0000	2.5896 TO	16.9104
4	2	8.0000	8.4853	6.0000	2.0000	14.0000	-68.2372 TO	84.2372
5	4	9.5000	5.9722	2.9861	2.0000	16.0000	-.0029 TO	19.0029
6	2	7.5000	4.9497	3.5000	4.0000	11.0000	-36.9717 TO	51.9717
7	4	5.0000	.8165	.4082	4.0000	6.0000	3.7008 TO	6.2992
8	2	6.0000	1.4142	1.0000	5.0000	7.0000	-6.7062 TO	18.7062
TOTAL	24	6.7083	4.3387	.8856	1.0000	16.0000	4.8763 TO	8.5404

## NEPHTYS CF. CRYPTONMA

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN	
1	4	4.0000	3.5590	1.7795	1.0000	8.0000	-1.6631 TO	9.6631
2	2	4.0000	.0000	.0000	4.0000	4.0000	4.0000 TO	4.0000
3	4	5.2500	2.2174	1.1087	2.0000	7.0000	1.7217 TO	8.7783
4	2	2.5000	2.1213	1.5000	1.0000	4.0000	-16.5593 TO	21.5593
5	4	3.2500	2.9861	1.4930	.0000	7.0000	-1.5014 TO	8.0014
6	2	1.5000	.7071	.5000	1.0000	2.0000	-4.8531 TO	7.8531
7	4	7.2500	2.5000	1.2500	4.0000	10.0000	3.2720 TO	11.2280
8	2	5.5000	6.3640	4.5000	1.0000	10.0000	-51.6779 TO	62.6779
TOTAL	24	4.4167	3.0348	.6195	.0000	10.0000	3.1352 TO	5.6982

TABLE 6. CONTINUED

## SIGAMBRA TENTACULATA

STATION	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	MINIMUM	MAXIMUM	95 PCT CONF INT FOR MEAN
1	4	1.2500	1.8930	.9465	.0000	4.0000	-1.7621 TO 4.2621
2	2	1.5000	2.1213	1.5000	.0000	3.0000	-17.5593 TO 20.5593
3	4	1.7500	1.7078	.8539	.0000	4.0000	-.9575 TO 4.4675
4	2	6.0000	5.6569	4.0000	2.0000	10.0000	-44.8248 TO 56.8248
5	4	5.5000	4.0415	2.0207	2.0000	11.0000	-.9308 TO 11.9308
6	2	9.5000	.7071	.5000	9.0000	10.0000	3.1469 TO 15.8531
7	4	3.2500	3.2016	1.6008	1.0000	8.0000	-1.8443 TO 8.3443
8	2	5.0000	4.2426	3.0000	2.0000	8.0000	-33.1186 TO 43.1186
TOTAL	24	3.7917	3.5993	.7347	.0000	11.0000	2.2718 TO 5.3115

distance from the channel. However, there was a trend for lower annelid biomass near the channel when the data were averaged by station. This trend was not significant (Table 7.)

The percent sand and mean grain size of sediments at all stations was virtually identical with depth (0 to 5 and 5 to 15 cm layers) of sediment and spatially (Table 8). The range in the 0 to 5 cm layer was 12.3 to 19.0% and 6.7 to 7.2  $\phi$ , and 11.8 to 19.0% and 6.6 to 7.2  $\phi$  in the 5 to 15 cm layer. The percent weight phi size distributions were also very similar (Appendix XIII). At the four stations (transect 1 stations 1 and 7, 2-8, and 3-7) where the dredged material layer was less than 6 cm the difference between the 0 to 5 and 5 to 15 cm layers averaged 1.8% sand and less than 0.1  $\phi$  units in mean grain size. The sand fractions were predominantly fine sands in both the 0 to 5 and 5 to 15 cm layers. At three stations (transect 2 station 4, 3-3, and 3-5) where the dredged material was over 10 cm thick the average difference in sand between 0 to 5 and 5 to 15 cm layers was 3.3% and 0.3  $\phi$  units in mean grain size.

Several possibilities exist as to why the macrobenthos communities have not obviously reacted to the dredged material: (1) the rate of deposition of dredged material was low, occurring over the period of several months. (2) the grain size of the dredged material was the same as natural sediments in the area. (3) species making up the communities are very flexible in life history strategies and able to cope with the rate at which the new sediment was supplied.

Table 7. Wet weight biomass from box cores by major taxonomic group.

Wet Weight (G) Biomass of Macrobenthic Invertebrates per 0.06 m<sup>2</sup>

STA.	ANN.	GAS.	PEL.	CRU.	NEM.	TUR.	PHO.	ECH.	MIS.	TOTAL
11-A	2.1378	0.1293	0.0086	0.0180	0.0209	0.0	0.0061	0.0	4.5321	6.8528
11-B	2.4493	0.1013	0.0011	0.0065	0.0308	0.0	0.0	0.0	0.0	2.5890
13-A	2.4169	0.1666	0.0046	0.0014	0.0094	0.0	0.0	0.0	0.0	2.5989
13-B	2.0518	0.0560	0.0262	0.0040	5.1206	0.0037	0.0212	0.0	0.0	7.2835
15-A	1.1320	0.2969	0.0362	0.0215	0.0185	0.0	0.0478	0.5230	0.0	2.0759
15-B	0.2364	0.0214	0.0038	0.0	0.0048	0.0	0.1171	0.0	0.0	0.3835
17-A	1.9772	0.1108	0.0662	0.0112	0.0036	0.0	0.0353	0.0	1.8390	4.0433
17-B	2.4370	0.1177	0.0	0.2605	0.0218	0.0126	0.0240	0.4254	0.7418	4.0408
22-A	1.5502	0.3345	0.0012	0.0043	0.0	0.0122	0.0	0.0	0.0066	1.9090
22-B	3.2527	0.0292	0.2538	0.0007	0.0047	0.0	0.0437	0.0	0.0	3.5848
24-A	2.2429	0.0452	0.0030	0.0054	0.0016	0.0053	0.0206	0.0	0.0	2.3240
24-B	0.6613	0.3014	0.0017	0.0049	0.0076	0.0	0.0	0.0	0.0	0.9769
26-A	1.1365	0.1542	0.2608	0.0021	0.0251	0.0	0.0	0.0040	0.0076	1.5903
26-B	2.1921	0.1701	0.0493	0.0127	0.0504	0.0	0.0057	0.0	0.0	2.4803
28-A	2.3714	0.1136	0.0040	0.0688	0.0013	0.0030	0.0074	0.0	0.0	2.5695
28-B	1.0690	0.2266	0.0156	5.1887	0.0262	0.0035	0.0239	0.0	0.0	6.5535
31-A	3.2083	0.0889	0.0023	0.0055	0.0031	0.0	0.0	0.0	0.0	3.3081
31-B	1.1068	0.1603	0.0161	0.0009	0.0081	0.0	0.0542	0.0	0.0311	1.3775
33-A	2.6958	0.1250	0.0250	0.0045	0.0492	0.0117	0.0	0.0	0.6168	3.5280
33-B	2.7569	1.1720	0.0119	7.1270	0.0127	0.0023	0.0	0.0	2.4628	13.5456
35-A	0.5487	0.1227	0.0198	0.0183	8.9322	0.0	0.0	0.5632	0.2591	10.4640
35-B	0.9070	0.1078	0.0293	0.0008	0.0050	0.0	0.0679	1.2541	0.0228	2.3947
37-A	2.6314	0.0553	0.0064	0.0	0.0038	0.0144	0.0	0.0	0.0	2.7113
37-B	3.1087	0.0789	0.0968	0.0156	0.0090	0.0	0.0952	0.3971	1.077	4.8786

STA. = STATION; ANN. = ANNELIDA; GAS. = GASTROPODA; PEL. = PELECYPODA; CRU. = CRUSTACEA; NEM. = NEMERTINEA; TUR. = TURBELLARIA; PHO. = PHORONIDA; ECH. = ECHINODERMATA; MIS. = MISCELLANEOUS; ANTHOZOA WERE NOT FOUND.

Table 8. Percent sand and mean grain size of sediments from box core stations.

Station		Transect 1		Transect 2		Transect 3	
1	0- 5 cm	12.5%	7.1 $\Phi$			14.0%	7.2 $\Phi$
	5-15 cm	11.8%	7.1 $\Phi$			13.1%	7.1 $\Phi$
2	0- 5 cm			16.9%	7.3 $\Phi$		
	5-15 cm			18.6%	6.8 $\Phi$		
3	0- 5 cm	13.8%	6.9 $\Phi$			12.3%	7.2 $\Phi$
	5-15 cm	17.0%	6.7 $\Phi$			15.3%	6.9 $\Phi$
4	0- 5 cm			11.5%	7.1 $\Phi$		
	5-15 cm			14.2%	6.8 $\Phi$		
5	0- 5 cm	15.4%	6.7 $\Phi$			12.4%	6.9 $\Phi$
	5-15 cm	19.0%	7.1 $\Phi$			16.6%	6.6 $\Phi$
6	0- 5 cm			15.0%	6.8 $\Phi$		
	5-15 cm			15.0%	6.9 $\Phi$		
7	0- 5 cm	15.1%	7.0 $\Phi$			19.0%	6.8 $\Phi$
	5-15 cm	12.0%	7.2 $\Phi$			17.6%	6.8 $\Phi$
8	0- 5 cm			14.5%	6.9 $\Phi$		
	5-15 cm			16.6%	7.0 $\Phi$		

8. Conclusions

- a. Hopper dredging operations produce two simultaneous plumes:  
(1) a near-bottom plume caused by draghead agitation and (2) an upper plume at mid-depth and near the surface caused by overflow processes.
- b. The near-bottom plume is confined to the channel and forms an elongate tongue along the dredge track. It lasts about 75 minutes after dredging.
- c. The upper plume is confined to the channel and elongate-shaped near slack current but is widely dispersed laterally by tidal currents and internal waves.
- d. As the plume evolves with settling and dispersion of fine sediment, it becomes thinner, less massive and more layered. Layered remnants 1 to 2 m thick last 60 minutes after dredging and extend more than 800 m from the dredge track during fast tidal currents.
- e. Turbidity can be reduced by any operational procedure that will reduce the solids concentration in the overflow. Discharge of the overflow <sup>vertically downward</sup> closer to the bottom with minimal bubbles would aid sediment settling and reduce sediment dispersion in the water column.
- f. Grain size distribution of settled dredged material and background sediments is virtually identical.

- g. SPI imagery found settled dredged material at all stations ranging from 0.5 to 19.8 cm thick. The surface of the bottom is smooth and populated by many small worm tubes (likely Paraprionaspis pinnata).
- h. The macrobenthic communities within the sampled grid did not appear to be adversely effected by any thickness of dredged material found.

## 9. References

- American Public Health Association, 1981. Standard Methods, 1134 pp.
- Barnard, W.D., 1978. Prediction and control of dredged material dispersion around dredging and open-water pipeline disposal operations. DMRP Synthesis of Research Results, Tech. Rept. DS-78-13, 112 pp.
- Byrne, R.J., C.H. Hobbs, and M.J. Carron, 1982. Baseline sediment studies to determine distribution, physical properties, sedimentation budgets and rates in the Virginia portion of the Chesapeake Bay. U.S. E.P.A. Chesapeake Bay Program contract report.
- Dawson, R.F., 1959. Laboratory manual in soil mechanics, N.Y. Pitman, 177 pp.
- Diaz, R.J., L.C. Schaffner, R.J. Byrne and R.A. Gammisch, 1985. Baltimore Harbor and channels aquatic benthos investigations. Final Report to Baltimore District, U.S. Army Corps of Engineers, Baltimore, MD, 255 pp.
- Harrison, W., M.P. Lynch, and A.G. Altschaeffl, 1964. Sediments of lower Chesapeake Bay, with emphasis on mass properties. Jour. of Sed. Petrol. 34:727-755.
- Nichols, M., R. Harris, G. Thompson, and B. Nelson, 1982. Metal inventory and fate of suspended sediment in Chesapeake Bay.
- Schaffner, L.C. and R.J. Diaz, 1987. Results of a SPI (Surface and Profile Imaging) camera survey of Long Island Sound. Report to NOAA, NOS, Rockville, MD, 45 pp.