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AN ENVIRONMENTAL ASSESSMENT OF THE EFFECTS OF OPEN-WATER DISPOSAL OF MAINTENANCE DREDGED MATERIAL ON BENTHIC RESOURCES IN MOBILE BAY, ALABAMA

by

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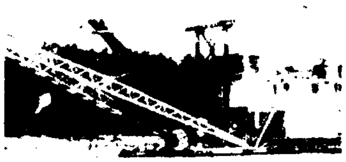

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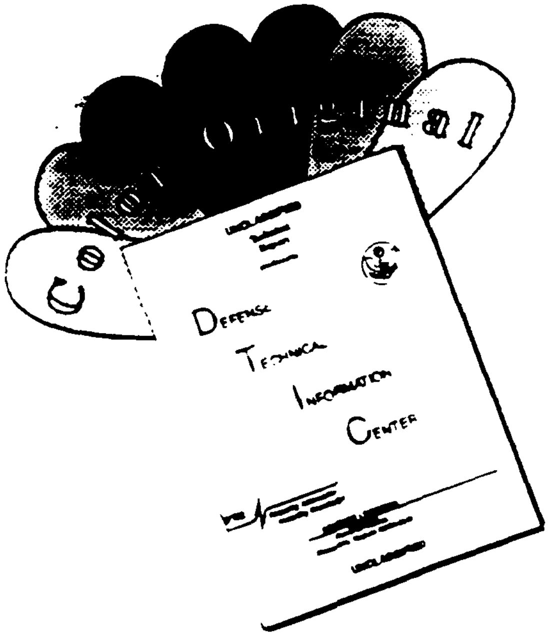
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13. ABSTRACT *(Maximum 200 words)*

Investigations were conducted to assess the spatial and temporal extent of impacts on benthic resources caused by open-water disposal of maintenance dredging materials in Mobile Bay, Alabama. Sediment profiling imagery was used in conjunction with conventional benthic grab samples to determine boundaries of a dredged material overburden and its effects on benthos immediately after disposal and at intervals of several months thereafter. Substantial effects were observed in terms of reduced benthic biomass, reduced redox potential discontinuity depth, and altered surface sediment relief. All effects were confined to within 1,500 m of the discharge point, and recovery of the benthos occurred within 12 weeks. Bay-wide surveys of benthic habitats yielded little evidence of cumulative effects of open-water disposal on benthic communities. Detected differences in benthic community parameters can be attributed to natural physical processes within the estuary, such as wind-driven circulation and sediment resuspension and prevailing salinity gradients, and do not appear to be present as a consequence of maintenance dredging open-water disposal practices.

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Contents

Preface

This report discusses work performed by the Environmental Laboratory (EL) of the US Army Engineer Waterways Experiment Station (WES) in response to the request and sponsorship of the US Army Engineer District (USAED), Mobile, Mobile, AL. Partial support for publication of this report was provided by the Headquarters, US Army Corps of Engineers (HQUSACE), under the Dredging Operations Technical Support (DOTS) Program. DOTS is managed through the Environmental Effects of Dredging Programs (EEDP) of the EL. Dr. Robert M. Engler was Manager of the EEDP; Mr. Thomas R. Patin was Manager of the DOTS Program. Technical Monitor was Mr. Joseph Wilson, HQUSACE.

The report was prepared by personnel of the Environmental Resources Division (ERD), EL. A supplementary report, prepared by the WES Hydraulics Laboratory, is included as Appendix D. Technical reviews were provided by Drs. Mark LaSalle and Gary Ray and Mr. Edward Pullen of the Coastal Ecology Group (CEG), ERD.

The WES gratefully acknowledges the assistance and direction of Mr. Dewayne Imsand, Project Manager for the USAED, Mobile. Dr. Robert Diaz of the Virginia Institute of Marine Science provided valuable support in collection, analysis, and interpretation of sediment profiling camera images. Mr. Michael Dardeau and personnel of the Vessel Operations staff of the Dauphin Island Sea Lab were helpful throughout the fieldwork phase of the study.

The report was prepared under the direct supervision of Mr. Edward J. Pullen, Chief, CEG, and under the general supervision of Dr. C. J. Kirby, Chief, ERD, and Dr. John Harrison, Chief, EL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	2.54	centimeters
miles (US statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms
ounces (mass)	28.34952	grams
square feet	0.09290304	square meters
tons (2,000 pounds, mass)	907.1847	kilograms

Summary

Benthic physical and biological conditions in Mobile Bay were examined to evaluate the potential impacts of open-water disposal of maintenance dredging material. The overall study consisted of two parts: an investigation of the spatial and temporal scale of alterations following an actual pipeline discharge, and a bay-wide survey to detect differences, if any, in the benthic conditions at disposal areas, shallow flats, and bottoms adjacent to the main navigation channel. Both components of the overall study involved sediment profiling imagery and conventional benthic grab sampling.

Sediment profiling camera surveys conducted in 1988-89 provided a composite depiction of summer benthic conditions within the Mobile Bay estuary. Transects were sampled in the upper, middle, and lower reaches of the estuary. A subset of the camera stations was sampled by replicated Petersen grabs to characterize dominant infaunal assemblages and provide a basis for interpretation of profile image features.

Open-water disposal at a test site in the middle portion of Mobile Bay had demonstrable direct effects on the benthos and physical conditions in the vicinity of the dredged material discharge point. These effects included significant immediate reduction in benthic biomass (particularly evident among bivalves), reduced redox potential discontinuity (RPD) depth, and altered surface relief. Substantial effects appeared to be limited to within 1,500 m of the discharge point. Recovery to predisposal conditions (examined by repeated sampling 12, 26, and 52 weeks after disposal) was essentially completed within 12 weeks.

Few patterns in RPD depth, surface relief, sediment type, or benthic community conditions were evident across habitat types within transects. Differences in community taxonomic composition, density, and biomass primarily reflected bivalve presence/absence among transects. Macrofaunal densities and biomasses were greatest for the lower bay transect and smallest for the middle bay transect. Diversity increased down the bay due to the increased number of taxa in the lower bay. Benthic communities were numerically dominated by polychaetes, primarily *Mediomastus* sp. A high correspondence between total benthic biomass and RPD depth was observed among transects. Benthic conditions within the estuary

indicate a system subject to frequent physical disturbances involving sediment resuspension events. These conditions reflect those expected for physically accommodated estuaries.

Patterns in benthic community structure in Mobile Bay can largely be explained by the prevailing salinity gradient and do not appear to be shifted or altered by detectable effects of open-water disposal. Based on comparisons with other shallow Southeastern estuaries, the benthic macrofauna of Mobile Bay can be considered "typical" of that found in shallow estuaries characterized by unconsolidated sediments. Quantitative studies to delimit the ecological consequences of short-term losses of benthic secondary production are unavailable. However, significant disruptions of benthic ecosystem functions, such as trophic support for demersal fishery resources or nutrient cycling, do not appear to be present as a consequence of open-water disposal.

1 Introduction

Mobile Bay, located in southwestern Alabama, is a large drowned river valley estuary. Approximately 30 miles[1] of open water lies between the river delta at its northern extent and the main pass to the Gulf of Mexico (Figure 1). East-west dimensions vary from about 9 miles in the upper portion of the bay to 22 miles in the lower portion. Mobile Bay is almost uniformly shallow, having an average depth of approximately 9.5 ft.

The city of Mobile and associated industrial, shipping, and other port facilities are largely situated at the head of the estuary. Consequently, access between the port and Gulf waters requires a lengthy navigation channel through the shallow bay bottoms along the north-south axis of Mobile Bay. The main navigation channel has been maintained by the US Army Corps of Engineers (USACE) at incrementally deeper and wider dimensions up to the present channel configuration of 45 by 400 ft.

Ryan (1969) estimated that annual suspended sediment loads entering Mobile Bay range from 2.1 to 8.3 million tons, with a mean of approximately 4.7 million tons. These high yearly sediment loads from river discharges and loads from within-bay bottom disturbance have necessitated periodic dredging to maintain the channel at authorized depths. Various disposal alternatives have been used for placement of the dredged material. Upland disposal has been the option used for dredging channel sections within the riverine upper harbor area. The sandy sediments in the entrance channel from the Gulf of Mexico and extending through the main pass into Mobile Bay are usually removed by hopper dredges and transported offshore.

Maintenance dredging for the within-bay channel sections typically involves the use of a hydraulic cutterhead dredge (Figure 2) linked by pipeline to discharge points in disposal areas on either side of the channel. The inner border of the western or eastern disposal area lies approximately 2,130 ft from the toe of the channel side slope. A typical maintenance

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vii.

dredging operation begins in the Lower Bay and progresses northward. Generally, in-bay open-water disposal begins with dredging of the channel section immediately north of the intersection with the Gulf Intracoastal Waterway. At regular intervals, determined by the length of available pipeline (usually 4,000 to 5,000 ft) and the rate of advance of the dredge, the discharge point is moved a set distance ahead. The dredge sweeps either the left or right half of the channel cross section for a distance of one to several miles before returning to sweep the opposite side. This allows ship traffic to bypass the dredge during the dredging operation.

At the discharge point the pipeline usually has a lateral terminus that allows the pumped sediment slurry to be jetted outward before falling to the water's surface. Occasionally the dredging contractor will affix a baffle plate to dissipate the energy of the jetted slurry, or use a downturned joint at the end of the pipeline such that the actual discharge occurs subaqueously (Figure 3).

Contracts for maintenance dredging of the main navigation channel are granted on an annual basis, with the upper and lower halves of the channel being dredged in alternate years. In recent years, open-water disposal practices have drawn the attention of resource agencies as potentially having detrimental effects on the ecological functions of bay bottom habitats. Potential effects such as the loss of foraging habitat for estuarine-dependent fishes and shellfishes and disrupted nutrient cycling have been mentioned.

Discerning the effects of open-water disposal apart from effects of other contributing factors (e.g. organic enrichment, urban and industrial development, commercial shrimping and shell dredging) would be exceedingly difficult even if long-term trends in the bay's biotic communities were known. Unfortunately, available scientific information on the status of Mobile Bay fauna, particularly benthic communities, has largely been gathered in the last 15 years.

The first overall evaluation of the environmental effects of open-water disposal in the bay was made by Brett (1975). Since that time, many studies have been conducted under contract to the USACE or independently performed. Most of these studies have been restricted to localized areas of the bay (see Vittor 1979) or were designed to address specific concerns such as the effects of turbidity plumes (e.g., May 1973).

Dredging has occurred in the bay system on almost a continuous basis for many decades. Even if alterations caused by individual dredging operations were subtle, the cumulative impacts of dredging might be expected to have become apparent over the course of these numerous and repetitive operations. Prevailing conditions in the bay should therefore reflect deleterious effects, if any, of past dredging and disposal operations. The objective of the present study was to examine maintenance dredging effects in a bay-wide context.

An examination of current bay conditions for evidence of dredging and disposal effects logically begins with a focus on those structural and functional components of the bay ecosystem that should presumably be most sensitive to long-term effects of dredging. Population abundances of most fishery resources are highly variable on both short and long time scales and are subject to influences of numerous factors other than dredging which would mask potential dredging and disposal impacts.

Consequently, resource agencies usually focus on benthic communities as indicators of long-term changes. Benthic fauna, by virtue of their intimate association with the sedimentary matrix, relatively sedentary habits, and role as a forage base for higher trophic levels, comprise the most likely component of the bay's fauna in which cumulative impacts of dredging and disposal might appear.

Dredging for navigation purposes in Mobile Bay began in the upper estuary in the 1820's.[1] Thus, dredging in Mobile Bay predates any environmental studies that would provide baseline information against which to measure changes in the bay's benthic resources. In the absence of baseline information, impacts must be inferred from differences in the spatial patterns of benthic fauna (Green 1979).

The approach taken in this study was to establish the present status of the estuary's benthic resources, and then to retrospectively look for spatial patterns within the estuary that would indicate dredging and disposal effects. *It was hypothesized that effects* on benthic communities should be most severe in those sections of the bay that have most frequently received the greatest volume of dredged material, i.e. bay bottoms used as disposal areas. If dredging and disposal have resulted in changes in benthic communities over time, these changes should be detectable by comparisons with benthos in areas removed from the influence of these processes. The magnitude of change detected in the benthos can be used to assess potential effects on other ecosystem components.

It might be argued that dredging and disposal have caused bay-wide changes in benthic community structure and function such that within-bay habitat comparisons would not reveal cumulative effects. This question can only be addressed by comparing the benthos of Mobile Bay to that of similar Southeastern estuaries, particularly those less influenced by dredging activities. This report uses both within- and between-estuary comparisons to assess the resilience of Mobile Bay benthic communities to alterations induced by dredged material disposal.

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[1] Personal Communication, Dewayne Imsand, US Army Engineer District, Mobile, Mobile, AL.

2 Methods

Objectives and Approach

Two sampling strategies were used in the present study. To assess short-term impacts of open-water pipeline disposal of dredged material, sediment profiling images and benthic grabs were obtained in the vicinity of a disposal operation in progress. The objectives of this first sampling were to define the acute impacts of disposal on the benthos, determine the spatial extent of dredged material dispersion from the discharge point, and follow the rate of recovery of the benthos. Second, a bay-wide survey of summer benthic conditions was conducted to yield a background against which the short-term impacts of open-water disposal could be used to assess the potential for long-term impacts.

Summer conditions (June-September) were chosen for the following reasons: (a) consistency with most prior studies of Mobile Bay benthos; (b) bioturbation rates are temperature dependent, and thus, maximum differences in sediment oxygen conditions due to changes in the benthic communities will be noted in the summer and early fall; (c) during summer, natural events (e.g., hypoxia, high water temperatures) may significantly influence the benthos such that additional stresses due to dredging and disposal might have the most severe effects; and (d) most intense utilization of the benthos by demersal fishes and crustaceans occurs during late spring, summer, and early fall.

Benthic Community Structure

The composition of benthic communities can be used to infer the status of an estuarine system with respect to its physical, chemical, and biological conditions. Pearson and Rosenberg (1978) and Rhoads and his colleagues (Rhoads, Aller, and Goldhaber 1977; Rhoads, McCall, and Yingst 1978; Rhoads and Boyer 1982; Rhoads and Germano 1986) have proposed a sequence of successional stages that benthic communities exhibit in response to disturbances of a physical or chemical nature, or of natural or anthropogenic origin.

According to this successional model, predictable temporal patterns in benthic macroinvertebrate functional group composition follow a disturbance. A diagrammatic representation is presented as Figure 4. Given that a disturbance results in the eradication of benthos at a given location, the recolonization process begins with the recruitment of opportunistic species. These pioneering, opportunistic species (typically small tube-dwelling polychaetes, oligochaetes, or bivalves) recruit or immigrate to the area and reach densities of 1,000 m^{-2} within a few days to weeks following the disturbance. Most of these early arriving species feed at the sediment-water interface or directly from the water column. The effect of these species on the sedimentary environment is therefore limited to the surficial layers of sediment. Disturbed sediments are often completely anaerobic. Newly recruited opportunistic species (e.g., the polychaetes *Capitella* or *Mediomastus*) rework or bioturbate the sediment surficial layers, causing these layers to become aerobic. This assemblage of species, typically designated Stage I, is eventually replaced by deeper burrowing deposit feeders. As these other benthic species become established and affect the sedimentary matrix, they occupy increasingly deeper sediments with a concomitant deepening of aerobic conditions.

These subsequent events are often divided into two arbitrary stages (II and III). Stage II species often consist of shallow-dwelling bivalves (e.g. *Mulinia*) or tubiculous amphipods (e.g. *Ampelisca*). Stage III species represent an equilibrium assemblage typically dominated by large conveyor-belt species that concentrate their feeding at depth. The feeding of this assemblage causes fluid and particle bioturbation to relatively great depths and results in a deeply oxygenated sediment that is heterogeneous with respect to particle size and surface relief, and often has feeding voids at depth. This equilibrium assemblage persists at the site until further disturbance.

Sediment profiling imagery data (SPI), described below, are currently interpreted in the context of this successional paradigm. Although actual responses of benthos to various forms of disturbance are complex, the sequence shown in Figure 4 provides a frame of reference for responses to dredging-related disturbances. Provided that dredged sediments contain no appreciable contaminants, dredged material disposal can be viewed as a physical disturbance. Given a dredged material overburden that is thick enough to prevent the survival of benthos by vertical migration, conditions should closely approximate those at the beginning of the successional model just described. The recovery process is constrained by the type (e.g. sediment size distribution) and magnitude of overburden and the timing of disposal with respect to the availability of recruits from benthic taxa.

The practical indicator of benthic condition that emerges from the use of sediment profiling imagery is the designation of the successional stage of the community at the site. This is, in turn, based on the presence of benthic taxa characteristic of particular successional stages (with their respective size and depth distributions) and the depth of the redox potential discontinuity (RPD, the boundary between aerobic and anaerobic sediments).

The standard tool used by regulatory agencies to assess anthropogenic perturbations has been a survey of macrobenthic community abundance and composition. Difficulties with these surveys (time lag between sampling and data analysis, effort and expense involved, taxonomic consistency, and uncertainties regarding their interpretation) have limited their usefulness.

Sediment profiling imagery provides a rapid and relatively inexpensive means to obtain an overview of benthic conditions (Revelas, Germano, and Rhoads 1987). The use of SPI as a reconnaissance tool also allows more efficient traditional benthic sampling. Coupled with limited traditional benthic sampling, SPI constitutes a powerful and practical approach to assessing anthropogenic perturbations.

Sediment Profiling Camera

A brief description of sediment profiling imagery procedures is given herein. Detailed descriptions can be found in Bosworth et al. (1980), Rhoads and Germano (1986), and Revelas, Germano, and Rhoads (1987). A Hulcher sediment profiling camera was used to document the condition of the bottom sediment during and after dredged material disposal events and to obtain in situ photography of the sediment-water interface across transects in the upper, middle, and lower portions of the bay. The Hulcher model sediment profiling camera consists of a bulk-film loading camera enclosed in a stainless steel pressure housing attached to a 45-deg prism. The prism contains a 15- by 23-cm clear Plexiglas face plate and a front surface mirror that reflects the image upward to the camera lens. The design of the camera is detailed in Figure 5, and the camera during deployment is shown in Figure 6.

During operation, the prism is filled with fresh water to prevent hydrostatic pressure from distorting the face plate. The camera is equipped with a 28-mm water-corrected Nikkor lens and a strobe to illuminate the sediment. During deployment (Figure 7), the camera housing and prism are mounted to a tubular aluminum frame and slowly lowered to the bottom until impact. Slack on the suspension cable then allows the housing and prism to fall into the substrate. As the unit drops, a trigger mechanism initiates a sequence of up to six photographs at predetermined time intervals.

In this study, the camera was set to take three to five photographs within a 15-sec span, thereby capturing the entire prism-penetration process. Three to five deployments of the camera system were made at each station, depending on operating conditions.

All stations were photographed using Fujichrome 100 color slide film. The original color slides were analyzed visually and by computer-enhanced image analysis. Photographic analysis was conducted by Dr. Robert Diaz of the Virginia Institute of Marine Science. During visual analysis, surface features (type of surface layers, tubes, epifauna, clasts, and bed forms) and subsurface features (sediment grain size, laminations, infauna, burrows, feeding voids, and gas voids) were identified and enumerated.

The computer image analysis was done in color using a red-green-blue Dage MTI series 68 instrumentation-grade video interfaced to an International Imaging Systems II^2 S model 75 image processor. Measurements obtained from the computer analysis include digitized image statistics by red, green, and blue color planes for areas of the various sediment features (e.g., aerobic and anaerobic layers, voids) and linear measurements for penetration depth, surface relief, depth of sediment layers, and depth of the apparent RPD layer. Table 1 summarizes each of these measurements and explains their usefulness.

Benthic Grabs

Benthic samples were collected using a 0.1-m^2 Petersen grab. Samples were fixed in the field using 10-percent buffered formalin, stained with Rose Bengal, and returned to the laboratory for processing and identification. Samples were sieved using a 0.5-mm sieve. Invertebrates were identified to the lowest possible taxon. Wet weight biomass was determined for all samples. Mollusc biomass data included shell weights. Benthic sample analysis was conducted by B. A. Vittor and Associates.

Statistical Analyses

Statistical analyses of the faunal data consisted of univariate and multivariate analyses. Data were log-transformed to better meet the assumptions of these procedures. Multivariate analyses consisted of Q-mode (normal) and R-mode (inverse) numerical classifications (cluster analysis). Data were reduced for the cluster analyses by eliminating those taxa that were not identified as a discrete taxonomic unit and those that occurred in only one replicate bay-wide. The Bray-Curtis similarity coefficient was used as the resemblance measure (Goodall 1973). Log-transformations ($\log(x + 1)$) of the data served to reduce the sensitivity of this coefficient to numerically dominant species. Flexible sorting (Lance and Williams 1967) was chosen as the linkage method; the cluster intensity coefficient (Beta) was set at the conventional value of -0.25 (Boesch 1977).

Pipeline Discharge Sampling

On 8 June 1988, sediment profiling imagery and benthic grab sampling were conducted in the immediate vicinity of an active pipeline discharge operation. The hydraulic dredge *Louisiana* was advancing northward along the western side of the main navigation channel between channel markers 37 and 41. This area lies in the middle reaches of Mobile Bay east and somewhat south of the entrance to East Fowl River, Alabama. Eighteen camera stations were occupied immediately north of the pipeline along three transects (Figure 8). The discharge point was located approximately 1,000 m west of the channel. Camera station locations extended approximately 900 m east and 600 m west of the discharge point. Loran-C coordinates for all stations are given in Appendix A.

On the following day, 9 June 1988, an attempt was made to revisit each camera station after the dredge and pipeline had advanced farther north. The discharge point, however, had advanced only about 500 m in the interim. The activity of tenders, who moved anchors and lines attached to the pipeline, prevented sampling along the northernmost transect. Twelve camera stations, representing the lower two transects, were sampled (Figure 9). To obtain information on the immediate impacts of disposal on the benthos, three replicate Petersen grabs were taken at each of four stations that were located within 500 m of the actual discharge point (Figure 10).

On 1 September 1988 (12 weeks after dredged material discharge), a repeat sediment profiling camera survey was performed at the pipeline discharge site. Fourteen stations were surveyed, including those along the northern and southernmost transects of the initial June survey. An additional station was added approximately 800 m to the west of each transect (approximately 1,600 m west of the discharge point) to ensure that the westernmost stations were beyond the lateral extent of dredged material dispersion from the discharge point (Figure 11, stations PDN-7 and PDS-7). This allowed a better assessment of the spatial extent of the influence of disposed material.

A second repeat sediment profiling survey was conducted at the pipeline discharge site on 6 December 1988 (26 weeks after dredged material discharge). All 14 of the stations occupied during the preceding survey were revisited. A final survey was conducted on 13 June 1989 (52 weeks after dredged material discharge). Again, all 14 camera stations were revisited. In addition to the sediment camera profiling, two replicate Petersen grabs were taken at eight of these stations (four within and four outside the disposal site boundaries) (Figure 11).

Bay-Wide Transects

In August 1988, a bay-wide survey of benthic conditions was conducted. Three east-west transects were established corresponding to the upper, middle, and lower reaches of the Mobile Bay estuary (Figure 1). The Upper Bay transect ran through channel marker 66, which placed it to the east and slightly south of the entrance to Dog River, Alabama. The Middle Bay transect ran through channel marker 43 and was east and slightly south of the entrance to East Fowl River. The Lower Bay transect ran through channel marker 27 and ran east of Cedar Point, Alabama. Stations were positioned along each transect to include three habitat types on both sides of the navigation channel: open flats outside of the historical disposal areas, disposal areas, and bottoms between the navigation channel and the disposal areas.

Stations selected for sediment profiling camera deployment extended both east and west away from the navigation channel. Each transect included sediment profiling camera stations at 250 and 650 m from the channel (representing "channel" habitat), 1,000 and 1,300 m from the channel (representing disposal area habitat), and 2,300 m from the channel (representing open-bay flats in both easterly and westerly directions).

Distances of additional open-bay stations were determined based on the geomorphology of the bay. On the Upper Bay transect, this included stations 3,550 m to the west and 5,800 and 8,870 m to the east of the channel. The Middle Bay transect included additional open-bay stations, 5,800 m both east and west of the channel. The Lower Bay transect included stations 5,800 m west of the channel and 5,800, 11,700 and 17,300 m east of the channel. Thirteen stations were sampled for the Upper Bay transect, 12 for the Middle Bay, and 14 for the Lower Bay transect. Loran-C coordinates for the sampled stations are given in Appendix B.

Benthic samples were collected from a subset of the above stations. Six stations were sampled for the Upper and Middle Bay transects; seven stations were sampled in the Lower Bay. Three replicate Petersen grabs were taken at each of the 250-, 1,000-, and 2,300-m stations for each transect, as well as at the 11,700-m east station on the Lower Bay transect. The additional sample in the Lower Bay transect was taken in Bon Secour Bay. Benthic sampling also encompassed the above habitats; typically, one station was sampled in each habitat east and west of the channel. Loran-C coordinates for these stations are also given in Appendix B.

3 Results

Dredged Material Disposal and Postdisposal Comparisons

Benthic community

Sampling of the macrobenthic community was conducted during the dredging and disposal operation in 1988 at four stations in the vicinity of the known pipeline discharge point (Figure 10). All four stations were within the disposal area boundaries. The objective of this sampling was to detect immediate, acute impacts of pipeline discharge and to provide "ground truth" for the interpretation of sediment profiling images taken on the same dates. Follow-up sampling was conducted approximately 10 months later at eight stations that straddled the disposal area boundaries (Figure 10). The spatial configuration of the follow-up stations allowed an assessment of the areal extent of pipeline disposal impacts to the macroinvertebrate community.

Acute impacts of pipeline disposal on the benthos

Total macroinvertebrate densities ranged from 443 to 1,410 individuals m^{-2} for this study. Examination of the retrieved grab samples at stations A and C revealed the presence of a substantial overburden of recently deposited dredged material. This finding was corroborated by evidence from the sediment profiles taken at these stations (described below). Densities at the 1988 stations A and C were significantly lower ($F = 5.22$; $P < 0.01$) than densities at B and D and the four within-disposal area stations for 1989 (Figure 11). Densities observed at the stations sampled in 1989 were comparable to those at stations B and D in 1988 (Figure 12), indicating that benthic communities had been effectively reestablished during the intervening 10 months.

Biomass averaged 0.34 g wet weight m^{-2} (standard deviation, SD = 0.27) and ranged from 0.07 to 0.95 g wet weight m^{-2} at the sampled stations. Biomass at the two impacted stations in the dredged material disposal area, stations A and C, was significantly lower (F = 13.89; P < 0.001) than at the remaining disposal area stations (Figure 13). Biomass differences between stations A and C and the unaffected stations resulted primarily from the absence of the bivalve component (Figure 13). Biomass at the 1989 N-B station was relatively high because of the inclusion of a large number of the bivalve *Macoma mitchelli* (Figure 13). Disposal appeared to completely eliminate the bivalve component of the community; however, bivalve biomass returned to previous levels within the 10-month time interval between samplings.

Community structure was affected by disposal activities on a short time scale, but did not appear to be permanently altered by disposal activities. Stations A and C in 1988 had significantly lower numbers of species; however, data showed a recovery to levels typical of the rest of the bay (by comparison to transect stations discussed below) by the 1989 sampling. The number of taxa collected ranged from 7 to 20 for all sampled stations (Figure 14). Shannon-Weaver diversity (H') values ranged from 1.11 to 2.21 (mean = 1.57) (Table 2). Evenness (J') values ranged from 0.39 to 0.73 (mean = 0.53) (Table 2). Margalef's diversity measure (D), an index that has no evenness component, ranged from 2.45 to 4.74 (mean = 3.51) (Table 2).

No spatial patterns were noted in the distribution of values of these community indices, indicating that the level of variability in these measures was greater than the potential effect of disposal activity on these measures. The community at the disposal-affected stations consisted of polychaetes and other taxa (primarily Rhynchocoela and Actiniaria) (Figure 14).

Taxonomic composition with respect to density and biomass at these stations appeared to return to a typical pattern within the duration of this study. *Mediomastus* sp. was the numerically dominant polychaete species in both 1988 and 1989. This subsurface deposit-feeder represented 58.86 percent (SD = 12.18%) and 53.20 percent (SD = 8.40%) of the benthic community in 1989 and 1988, respectively. No marked shift in polychaete species composition occurred as a result of dredging and disposal activities. The spionid *Paraprionospio pinnata*, two species of pilargid worms (*Sigambra tentaculata* and *S. bassi*), and the goniadid *Glycinde solitaria* were the most abundant polychaete species during both sampling periods; these species were also among the most abundant in the bay-wide transect stations.

The molluscan component of the benthic community was absent at stations A and C in 1988. This result was noted in the density, biomass, and taxonomic composition data (Figures 12-14). No changes in the dominant molluscan species were noted between 1988 and 1989, despite the apparent eradication of molluscs by disposal activities. In fact, the observed absence of bivalves at the "disturbed" stations may simply have resulted from a sampling artifact, specifically, reduced penetration of the grab caused by the presence of the dredged material overburden.

The dominant bivalve species during both sampling periods were *Macoma mitchelli* and *Mysella planulata*. *Nassarius acutus* and *Acteocina canaliculata* were the numerically dominant gastropod species during both sampling periods. Interestingly, the sampled stations showed some fidelity in the measured parameters from 1988 to 1989. Stations A, C, S-B, and S-C were more similar to each other than to stations B, D, N-B, and N-D for both sampling periods (Figures 12-14).

Lateral extent of dredged material disposal impacts

Benthic stations were occupied in 1989 to examine the spatial extent of impact on the benthos from the preceding year's disposal event. Total macroinvertebrate density among the eight 1989 stations averaged 904 (SD = 332) and ranged from 530 to 1,410 individuals m^{-2}. Densities in the disposal area (stations N-B, S-B, N-C, and S-C) were enhanced relative to the channel (stations N-A and S-A) and the flat-bottom (stations N-D and S-D) areas, which were similar (Figure 12). Densities were 1,198 (SD = 298), 600 (SD = 113), and 623 (SD = 136) individuals m^{-2}, for stations B and C (combined), A, and D, respectively.

The benthic community was dominated by polychaetes (average numerical percent composition = 87.45%); molluscs and other taxa (Rhynchocoela and Actiniaria) were numerically important, representing 3.50 and 7.94 percent of the community, respectively (Figure 12). No dramatic shift in community structure with lateral extent was noted. Differences in total density were due primarily to differences in polychaete density (Figure 12).

Benthic biomass in 1989 averaged 0.40 g wet weight m^{-2} (SD = 0.24) and ranged from 0.16 to 0.95 g wet weight m^{-2}. Biomass of benthos in the channel area (stations N-A and S-A) was generally lower (but not significantly different) than biomass at the remaining stations (Figure 13). Average biomass at the channel stations was 0.19 g m^{-2} (SD = 0.14) compared to 0.47 (SD = 0.28) g wet weight m^{-2} at the remaining stations. The high biomass observed at station N-B was due to the collection of a large number of *M. mitchelli*. The benthic community at the channel stations (N-A and S-A) exhibited a greater dominance by polychaetes (77.71%) than the community at the remaining stations (39.68%) (Figure 13). The biomass percent composition by taxa was similar for these remaining stations (N-B, N-C, N-D, S-B, S-C, and S-D) (Figure 14).

The community indices used in this study did not reveal a notable long-term effect of pipeline disposal activities. Shannon-Weaver diversity and evenness measures were somewhat lower in samples from the disposal area: H' ranged from 1.11 to 2.16, while J' ranged from 0.39 to 0.73 (Table 2). No differences were noted between the channel stations and the flat-bottom stations for these indices. Values of Margalef's diversity index ranged from 2.98 to 4.25 (Table 2); no lateral trends were noted. Thus, differences in H' and J' were the result of differences in the equitability of species distribution and not the number of species or the number of individuals. The number of taxa collected in the 1989 samples ranged from 12 to 19. No lateral trend in the number of taxa per sample was evident (Figure 14).

The relative community composition did not change with distance from the navigation channel, with the exception of the increased density and biomass of polychaetes in the channel stations. Polychaetes were the dominant taxon, representing 87.45 percent by number, 49.19 percent by weight, and 67.01 percent of the number of taxa. With respect to the number of taxa, molluscs represented 16.09 percent of the benthic assemblage; "other taxa," approximately 13 percent; and arthropods, 3.76 percent. No distinct lateral trends in species composition were observed; species composition did not vary with distance from the channel. *Mediomastus* sp. was the numerically dominant polychaete, and *M. mitchelli* was the numerically dominant mollusc in all samples.

Sediment profiling imagery

SPI surveys were conducted on five occasions within 1 year after disposal. On the first day of sampling the presence of disposed dredged material was noted in SPI images taken at five stations in the immediate vicinity of the discharge point (Figure 15). Maximum overburden thickness was detected at the station closest to the discharge point; overburden thicknesses decreased with distance from the discharge point (Figure 15). An example of dredged material overburden, as seen in profiling images, is provided as Figure 16. On the following day (sampling day 2), dredged material was observed at all stations west of the discharge point (Figure 17). There appeared to be no pattern in the amounts of overburden with distance from the discharge point. The variability in overburden thickness between successive drops of the camera within a station was very high. For example, thickness ranged from 3.8 to 20 cm at one station (Figure 17).

Twelve weeks following disposal, dredged material was barely discernible at three stations. No dredged material was noted in profiling images from December 1988 or June 1989. Even within the immediate vicinity of a pipeline discharge point, disposed dredged material became incorporated into the sediment matrix (or transported elsewhere) such that a dredged material "signature" did not persist for an extended period of time. In this shallow estuary, other forms of disturbance (wind energy, shrimp trawling, etc.) probably act to resuspend some portion of the material within a relatively short period of time.

The disposal of dredged material appears to increase surface heterogeneity (as evidenced by surface relief) in the short term. As the disposed material is resuspended and winnowed out, surface contours are smoothed out. Surface relief at disposal area stations approached background levels in a very short period of time. On the first day of sampling, surface relief was greatest at those stations nearest the discharge location; levels rapidly approached background values with distance from the area (Figure 18). On the second day of sampling, surface relief was high at only one station in the disposal area, ranging from 0.4 to 2.8 cm (Figure 19); dredged material was present at this station (Figure 17).

Surface relief at stations sampled in successive surveys (September 1988, December 1988, June 1989) reflected background or "natural" levels. Surface relief values tended to be lower in the winter, perhaps indicative of (a) lower levels of activity by the fauna due to lower water temperatures; (b) lower levels of anthropogenic activity; and (c) frequent intervals of sufficient wind energy to cause resuspension and sedimentation, resulting in an smoothing out of surface contours.

The disposal of dredged material caused the redox potential discontinuity depth to move from depth to the surface (RPD = 0) (Figures 20 and 21). RPD depths on the first day of sampling at those stations at which no disposal material was noted exhibited a large range, from 0.1 to 3.2 cm (Figure 20). No patterns in RPD depth with distance from the discharge point were noted; the within-station variability was as great as that between stations. On the day following disposal, all stations at which dredged material was observed had RPD depths near 0, indicating that the entire sediment column was completely anaerobic (Figure 21). Those stations east of the discharge point with no noticeable overburden had RPD depths similar to unaffected stations observed on the first day.

In September 1988, December 1988, and June 1989, RPD depths were generally shallower than those in July (Figures 22-24). In general, however, stations nearer the navigation channel appeared to have deeper RPD depths. Variability within near-channel stations was as great as between-station variability. Reasons for the shallower depths are unclear, but may be the result of bottom disturbance and oxidation of the sediments caused by navigation traffic. The RPD depths do not appear to be related to disposal events, as RPD depths on the first day of sampling were very similar.

During the disposal event the benthic community at most stations was characterized as successional stage I (Figure 25, Tables 3 and 4). Two stations had stage III species, and four stations immediately adjacent to the discharge point were classed as azoic (successional stage 0), as only dredged material was noted. On the second day of sampling, all stations in the disposal area were characterized as azoic; stations on the channel side of the discharge point were similar in their successional stage to those on the first day of disposal (Figure 26).

In September 1988, there appeared to be no discernible evidence of altered benthic conditions as a result of the disposal event that had occurred 12 weeks previously. Stations in the disposal area were represented by successional stages I, II, and III, whereas stations nearer the channel were characterized primarily by successional stages I and II (Figure 27). Stations west of the disposal area for which acceptable images were obtained were dominated by successional stage I. Reworked dredged material was noted in images from stations in the disposal area (Table 5) but did not appear to be related to successional stage. No lateral pattern in benthic successional stage was evident.

Stations surveyed in December 1988 were predominantly early successional stages (Figure 28). The prevalence of early successional stages probably resulted from the expected winter depression in biological activity and the increased frequency of sediment disturbance from winter weather patterns. Reworked dredged material was noted in images taken at stations in the disposal area during this survey (Table 6).

In June 1989, the pattern of successional stages at the surveyed stations (Figure 29) resembled that prior to disposal, again indicating no long-term effect of disposal in terms of this index of benthic community status. Reworked dredged material was again noted in images taken at the stations in the disposal area (Table 7).

Bay-Wide Transects

Benthic community

In July and August 1988, benthic sampling was conducted on three transects in the Upper, Middle, and Lower Bay (Figure 1), to investigate the bay-wide status of benthic communities and to establish baseline comparative data against which potential pipeline disposal impacts might be evaluated.

Bay-wide patterns

Total benthic densities were greatest for the Lower Bay stations and averaged 1,895 (SD = 622) individuals m^{-2}. Densities were least for the Middle Bay transect, averaging 996 (SD = 243) individuals m^{-2}, and intermediate for the Upper Bay, averaging 1,783 (SD = 921) m^{-2}. Densities were significantly lower at the Middle Bay stations ($F = 19.81$, $P < 0.0001$); densities for the Upper and Lower Bay stations were not significantly different.

Polychaetes were the numerically dominant taxon at all sampled stations, although they were less numerically dominant in the Lower Bay (Figure 30). Polychaetes represented 80.9, 80.9, and 58.4 percent of the benthic community in the Upper, Middle, and Lower Bay, respectively.

Molluscs were the second most numerically abundant taxon and reached their greatest densities in the Lower Bay, but were essentially absent from the Middle Bay area (Figure 30). Molluscs represented 12.1, 3.3, and 19.1 percent of the community in the Upper, Middle, and Lower Bay, respectively.

Arthropods were significant in number only at the Lower Bay stations (Figure 30); numerical percent compositions were 0.6, 1.8, and 3.3 percent for the Upper, Middle and Lower Bay transects, respectively. The percent of the benthic assemblage represented by miscellaneous taxa (indicated as "others") increased from the Upper to the Lower Bay (6.2, 13.8, and 18.8 percent, respectively) (Figure 30).

Benthic biomass was greatest for the Upper Bay stations and least for the Middle Bay stations. Average biomass, measured as grams wet weight m^{-2}, was 1.92 (SD = 1.74), 0.18 (SD = 0.08), and 0.62 (SD = 0.32), for the Upper, Middle, and Lower Bay stations, respectively. These values were significantly different ($F = 52.63$, $P < 0.0001$).

Polychaete biomass was similar for the Upper and Middle Bay stations, 0.08 (SD = 0.04) and 0.11 (SD = 0.06) g wet weight m^{-2}, but, on average, was greater for the Lower Bay stations, 0.20 (SD = 0.15) g wet weight m^{-2} (Figure 31).

Molluscan biomass was greatest for the Upper Bay stations and lowest for the Middle Bay stations (Figure 31). The molluscan biomass at the Upper Bay stations was dominated by *M. mitchelli* and, to a lesser extent, *Rangia cuneata* and *Mulinia pontchartrainensis*. Note, however, that molluscs were not shucked before weights were obtained.

If one considers only the nonmolluscan biomass, biomass at the Upper Bay stations was roughly equal to that of the Middle Bay stations and less than that for the Lower Bay stations (Figure 31). The Lower Bay stations had more major taxa represented than the Upper and Middle Bay stations; echinoderms and arthropods were collected in the Lower Bay samples. Biomass percent composition for echinoderms and arthropods was 0.0 and 0.01 percent for the Upper Bay, 0.0 and 1.72 percent for the Middle Bay, and 6.63 and 8.25 percent for the Lower Bay samples. The percent of the benthic biomass represented by other taxa increased from 2.62 percent (SD = 2.08) to 18.92 percent (SD = 9.40) to 20.91 percent (SD = 12.04) from the Upper to Middle to Lower Bay. Biomass appeared to be more evenly distributed among the taxa present for the Lower Bay samples (Figure 31).

There was a trend toward an increasing number of taxa per sample with distance down the bay (Figure 32). An average of 13.9 (SD = 2.7), 17.7 (SD = 5.0), and 25.1 (SD = 5.3) taxa were collected in samples from the Upper, Middle, and Lower Bay, respectively. This trend was primarily due to differences in the number of polychaete taxa, which increased from 13.7 to

18.7 to 24.1 in the downbay direction. However, the presence of echinoderms and the increased number of arthropod taxa also contributed to this result.

The variability of within-transect Shannon diversity values was as great as the variability between transects. On average, however, the sample diversity increased downbay (Table 8). Average diversity values were 1.77 (SD = 0.42), 2.16 (SD = 0.25), and 2.33 (SD = 0.31) for the Upper, Middle, and Lower Bay samples, respectively. There was no upbay-downbay trend in evenness J' (with values of 0.59, 0.66, and 0.63 for the Upper, Middle and Lower Bay transects, respectively), yet Margalef's diversity increased downbay (Table 8). These results indicated that the observed trend was predominantly due to the increased number of taxa in the Lower Bay, as noted above.

Normal-mode cluster analyses identified four major station groupings (Figure 33). Station groupings followed transect divisions, with two exceptions. The channel stations in the Upper Bay did not cluster with the remaining Upper Bay stations; these two stations clustered with the Middle Bay stations, a result of their relatively lower density (see below). The Bon Secour Bay station (easternmost station on the Lower Bay transect) did not cluster with the remaining Lower Bay stations, probably because of the low density of macrofauna. This single station may or may not be indicative of benthic conditions in the Bon Secour Bay area.

Inverse-mode cluster analyses identified five major species groups (Figure 34, Table 9). Group 1 consisted of oligohaline dominants, numerically abundant species that reached their highest density in the Upper Bay. Group 2 consisted of uncommon mesohaline to polyhaline species; densities for these species were typically highest for the Lower Bay stations. Group 3 consisted of moderately abundant mesohaline species. Group 4 represented species that reached their highest densities in disposal areas, primarily in the Middle Bay transect. Group 5 consisted of species that typically occur in high-salinity habitats; densities for these species were typically highest for the Lower Bay transect.

The relative abundances of the dominant species of the macrobenthic community in Mobile Bay in July and August 1988 are given in Table 10. The numerically dominant species in the Mobile Bay system was the polychaete *Mediomastus* sp., with average densities of 669 m^{-2}. In this study, *Mediomastus* sp. was most abundant at the Upper Bay stations, averaging 973 m^{-2}; abundances were 639 and 399 m^{-2} in the Lower and Middle Bay, respectively. Densities were significantly lower at the Middle Bay stations (F = 8.69, P = 0.008) than the Upper or Lower Bay stations, which were not significantly different. Other polychaete species that constituted greater than 5 percent of the total number of individuals at any one station in the Mobile Bay system included *Glycinde solitaria*, *Podarkeopsis levifuscina*, *Capitella capitata*, *Paramphinome* sp. B, *Sigambra tentaculata*, and the spionid *Paraprionspio pinnata*. Bay-wide densities and transect densities for these species are presented in Table 10.

The most abundant molluscs in the Mobile Bay samples were the bivalves *Macoma mitchelli* and *Mulinia lateralis* (Table 10). *Macoma mitchelli* was collected only from the Upper Bay stations; average density was 161 m^{-2}. *Mulinia lateralis* was collected primarily from the Lower Bay stations; average density was 341 m^{-2} for this transect.

Within-transect patterns

Upper Bay. Stations sampled along the Upper Bay transect had a mean density of 1,783 individuals m^{-2} (SD = 921). The flat-bottom stations generally had the highest densities and the channel stations the lowest; a three- to four-fold change in density was noted along the transect (Figure 30). Molluscs were most abundant in the disposal area (20.9 percent by number) and were least abundant adjacent to the channel (4.9 percent) (Figure 30). This distribution pattern reflected the presence of the bivalve mollusc *Macoma mitchelli,* and may be the result of this species' suspension-feeding requirements and avoidance of burial via siltation. Arthropods were collected only in the disposal area (Figure 30). "Other taxa" were represented primarily by Rhynchocoela and Actiniaria, and decreased in numerical importance from the channel to the flats stations (3.6, 5.4, and 9.7 percent for the shallow flat, disposal area, and channel stations, respectively) (Figure 30).

Benthic biomass averaged 1.92 (SD = 1.74) and ranged from 0.25 to 7.0 g wet weight m^{-2} for the Upper Bay stations. Within the Upper Bay transect, biomass was least for the channel stations and greatest for the disposal area stations (Figure 31). Polychaetes reached their highest biomass at the channel stations, representing 43.6 percent of the faunal weight compared with 2.7 percent at the flats and the disposal area stations (Figure 31). The distribution of overall biomass was dominated by the presence of molluscan biomass; molluscs represented 95.7 percent of the benthic community biomass in the disposal area and the flats stations, and 51.8 percent of the biomass adjacent to the channel. Disregarding molluscs, biomass was highest adjacent to the channel and lowest for the bay flats (Figure 31). The distribution of benthic density and biomass with respect to the channel position was relatively symmetrical.

No significant lateral trends within the Upper Bay transect were noted with respect to community diversity, evenness, or Margalef's index (Table 8). Polychaetes were the most important group with respect to the number of taxa, and averaged 69.1 percent at all stations within the transect (Figure 32). The notable trends in community composition within the transect (i.e., decreased importance of molluscs at the channel stations, occurrence of arthropods at only the disposal area stations, and the slight decrease in importance of polychaetes in the disposal area) have been discussed above.

Middle Bay. Benthic densities ranged from 660 to 1,366 and averaged 996 individuals m^{-2} (SD = 243) for the Middle Bay stations. These values were lower than those for the Upper Bay and Lower Bay transects. There was no significant within-transect pattern of benthic density with respect to either total density or density of polychaetes, molluscs, or "other taxa" (Figure 30). Polychaete densities averaged 806 (SD = 206) individuals m^{-2} and represented 80.9 percent of the community. No significant molluscan component was noted in the community in the Middle Bay (Figure 30). "Other taxa" was the second most numerically important taxonomic group and represented an average of 13.8 percent of the community in the Middle Bay (Figure 30). Arthropods were more abundant at the disposal area stations, representing 3.6 percent of the sample compared with 0.5 and 1.3 percent at the flats and channel stations, respectively.

Benthic biomass averaged 0.18 (SD = 0.08) and ranged from 0.06 to 0.26 g wet weight m^{-2} for the Middle Bay stations. Average biomass, like density, was lowest for the Middle Bay transect. Within the Middle Bay transect, biomass was lowest at the channel stations (Figure 31). Polychaetes dominated the benthic biomass; they represented an average of 63.8 percent of the biomass at each station. Polychaete biomass, like total biomass, was lowest in the channel stations (Figure 31). Molluscs were essentially absent from the channel stations, but averaged 20.8 percent of the biomass at the disposal area and flats stations (Figure 31).

No significant trends were noted with regard to distance from the navigation channel for community diversity, evenness, or Margalef's index in the Middle Bay (Table 8). The number of taxa was lowest at the channel stations (14.3) and highest for the disposal area stations (22.8) (Figure 32). The number of arthropod species reached its maximum in the disposal area, where they represented 12.7 percent of the community (7.4 percent at the flats and channel stations) (Figure 32). The importance of "other taxa" in community composition increased from the channel to the flats stations (6.5 to 12.4 percent of the number of taxa).

Lower Bay. Densities in the Lower Bay transect averaged 1,985 (SD = 622) and ranged from 716 to 2,613 individuals m^{-2}. The lowest within-transect densities were observed in the Bon Secour Bay samples. There were no strong within-transect patterns in faunal abundance for either total density or for any single taxonomic group (Figure 30). The most striking feature of the data was a trend toward greater densities east of the navigation channel. This trend was primarily the result of the increased abundance of molluscs (Figure 30).

Benthic biomass was highest at the flats stations and lowest at the channel stations, averaging 1.05 and 0.46 g wet weight m^{-2}, respectively. Biomass at the Bon Secour Bay station was similar to that of the channel stations (Figure 31). Biomass was more evenly distributed among taxa than in the Middle or Upper Bay transects (Figure 31). There were notable east-west differences in community composition. Molluscs reached a greater biomass west of the navigation channel, while polychaete and arthropod biomasses were greater east of the channel (Figure 31).

Community composition, with respect to major taxa, was similar within the transect (Figure 32). Similar numbers of polychaete, mollusc, and arthropod species were collected from the flats, disposal area, and channel stations. Shannon diversity values were greater for those stations east of the navigation channel (Table 8) as a result of the more equitable distribution of species at those stations. Lower diversity values at the channel stations resulted from the low numbers of species collected. These conclusions were corroborated by values of evenness and Margalef's index. The Bon Secour Bay station had the lowest number of taxa per sample (18), which was a consequence of both the lower number of arthropod and mollusc species and the greater number of "other taxa" collected (Figure 32).

Sediment profiling imagery

The predominant sediment type across all three transects sampled in Mobile Bay, as indicated by visual comparison of the images with known standards, was silt. This is consistent with the predominance of silty clays noted in a recent sedimentological survey of Mobile Bay[1] (see Appendix C). The similarity in sediment type was corroborated by the lack of variability in penetration depth (Table 11) between transects. The degree of surface relief was less for the Middle Bay transect than for the Upper and Lower Bay transects (Table 11).

This pattern was also observed in the RPD depth for the three transects; variation in RPD depth was greatest for the Upper and Lower Bay transects (Figure 35). The RPD depth for the Middle Bay stations was relatively shallow and averaged 0.9 cm. Successional stage is a qualitative measure of biological community development that integrates much of the data obtained from sediment profiling imagery (see Chapter 2, Methods). There was no systematic variation in successional stage between the three bay transects; most of the sampled stations were dominated by successional stage I or I/II (Table 11).

The RPD depth did not vary in a systematic manner with habitat type. However, a strong relationship was detected between RPD depth and macrofaunal biomass. For each habitat type, low biomass occurred at areas with shallow RPD depths (Figure 36). This relationship held over a relatively large range of RPD depths and biomass. The lone exception to this relationship occurred at a Lower Bay station in the disposal area habitat. One of the two Lower Bay stations in this habitat had an unusually low biomass, accounting for this discrepancy.

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[1] W. C. Isphording, 1989, unpublished report to US Army Engineer District, Mobile; Mobile, AL.

Upper Bay. No systematic variation in sediment type occurred across the habitats sampled (flats, disposal areas, and channel areas). Deposits of fine sand were observed at the disposal area and channel stations west of the navigation channel and at one of the two channel stations east of the channel. Surface relief was low in the flat habitat and tended to be higher and more variable at the channel stations and in the disposal area west of the navigation channel (Table 11). The RPD depth did not vary with habitat in a predictable manner (Figure 35). However, there was some indication of a west-east trend; the RPD depth became shallower and less variable moving from west to east on the transect.

Stage I was the predominant successional stage across this transect (Table 11), although Stage II/III transition communities did occur at one station in the channel habitat. Sediment profiling imagery indicated an abundance of surface-living, tube-building polychaetes at three stations east of the channel (Table 11). This agrees with the benthic grab data, which indicated that *Mediomastus* sp. was the dominant species at these sites.

Middle Bay. No significant variation in sediment type across the Middle Bay transect was evident in the sediment profiling imagery (Table 11). Areas of fine sand were identified at two of the sampled stations; these sites corresponded to areas of low penetration depth. Surface relief was uniformly low and relatively stable across this transect (Table 11). The RPD depth was shallow at all Middle Bay stations and did not vary with habitat type or west-east direction (Figure 35). Successional stage II was the most prevalent stage identified at these stations, although there was some indication of the presence of Stage III communities at stations sampled in the disposal area (Table 11).

Lower Bay. The predominant sediment type at all stations in the Lower Bay transect was silt; fine sand and clay sediments were identified at only one site. Surface relief was very variable across the Lower Bay stations, but did not vary systematically with habitat type or east-west direction (Table 11). The pattern in RPD depth was very similar to that of surface relief; no trends were notable, and values were maximal at the disposal area stations west of the navigation channel (Figure 35). The most prevalent successional stage identified at the Lower Bay stations was Stage II (Table 11). Stage II/III transition communities were identified at all stations except those sampled in the flats habitat. Fauna were more frequently observed in the sediment profile images for the Lower Bay than those for the Upper and Middle Bay, corroborating the faunal density data discussed above.

4 Discussion

Impacts of Open-Water Disposal

Hydraulic disposal of maintenance material involves large volumes of sediments. Results of the present study indicate that deposition of these sediments does entail short-term consequences for the fate of benthic communities in the historically used in-bay disposal areas. Sediment profiling imagery documented widespread presence of a dredged material overburden throughout the disposal area following passage of a discharge pipe. Although sample size was small, the benthic grab data showed significant reduction in benthic community parameters at disturbed stations.

The data also indicated, however, that the dredged material overburden resulting from hydraulically pumped material was relatively thin, generally less than 15 cm thick at short distances from the point of discharge. Figure 16 depicts a "typical" overburden of approximately 5 cm, seen in the sediment profiling survey. Lateral spread of the material at the study site appeared to be to the west, possibly in response to wind-driven water circulation on the July 1988 sampling dates. The unconsolidated state of the dredged material, in conjunction with the prevailing dispersive forces in this shallow estuary, would appear to ensure an effective thin-layer overburden.

In the short term, responses of benthos to open-water disposal in Mobile Bay should be ameliorated by the tendency of the overburden to rapidly become thinner due to lateral spread of the finite volume of dredged material and winnowing of fine sediment fractions by natural transport processes. For example, on the first day of the discharge point sediment profiling survey, the dredged material overburden at the station closest to the pipeline terminus was at least 20 cm thick. On the next day, after the pipeline had been moved northward, the overburden at the same site had thinned to less than 9 cm. These factors may allow enhanced recovery of the benthos by vertical migration through thin overburdens, particularly with increasing distance from the discharge point. However, dispersion of the unconsolidated material also ensures that the areal extent of bottom disturbance is greater than would be the case with discharge of coarse or cohesive materials. During this study, no movement of the dredged material east of the discharge point was detected, either during active disposal or in the follow-up surveys.

On the second-day survey, deposits of dredged material up to 11 cm thick were detected at the westernmost station, approximately 750 m from the discharge point. Therefore, the western extent of dredged material cannot be determined from these data. However, a reasonable estimate of spread would be an additional 750 m. This estimate should be considered conservative based on the evidence from the September sediment profiling survey, which included additional western stations. This survey revealed no evidence of dredged material beyond 500 m from the original discharge point. Using 1,500 m as an estimate of the lateral extent of bottom disturbance, and factoring in the average rate of advance of a maintenance dredging operation, an estimate of the total area of bottom disturbance at a given time can be calculated.

In a study of hydraulic aspects of maintenance dredging operations in Mobile Bay (performed concurrently with the present study), Trawle, Johnson, and McComas (report in preparation) used numerical modeling techniques to predict suspended sediment dispersion and sediment deposition from a pipeline discharge (see Appendix D). Field collections of suspended sediment concentration samples were used to calibrate the model runs simulating discharge from pipelines with the discharge either downturned or horizontal without a baffle plate (in water depths of 3.4 and 0.9 m, respectively).

Deposition from the downturned pipeline discharge (model runs assumed a discharge duration of 1 hr) resulted in dredged material overburdens with a maximum thickness of 0.6 ft, which extended up to 700 ft from the point of discharge. Horizontal discharges resulted in overburdens with a maximum thickness of 0.5 ft and a lateral extent of 1,050 ft. Although the model runs did not examine cumulative deposition based on rates of movement of the discharge point, these results tend to corroborate the estimates of significant sediment deposition derived from the SPI data.

The total surface area of Mobile Bay is approximately 102,800 ha. If an area of 24,880 ha is removed from this total (representing delta shallow-water habitats, coarse bottom shoreline habitats, oyster reefs, channels, and Gaillard Island), the open-water bottom habitats of Mobile Bay encompass approximately 77,920 ha. These estimates are based on planimetric measurements of bottom habitats using a recent sediment map prepared by Isphording (Appendix C) to derive a description of the Mobile Bay sedimentary regime.

The length of the main Mobile Bay navigation channel, from its intersection with the Gulf Intracoastal Waterway to the docking facilities in Mobile, is approximately 44 km. Given a 1,500-m swath of disturbed bottom on each side of the channel, a total of approximately 13,200 ha would receive direct disturbance by maintenance dredging operation over the course of 11 months (average duration of recent maintenance dredging operations). If the worst-case scenario of complete loss of ecological functions in disturbed habitats is assumed, 16.9 percent of available open-water habitats would be impacted.

Partitioning Mobile Bay into upper, middle, and lower reaches (roughly corresponding to oligo-, meso-, and polyhaline zones), would change the estimate somewhat because of the disproportionate distribution of area and channel reach among these categories. For the purposes of taking planimetric measurements, the boundary between the Upper and Middle Bays was arbitrarily delineated as a straight line connecting the entrance to the Theodore ship channel on the western shore and Point Clear on the eastern shore. Likewise, an arbitrary boundary between the Middle and Lower Bays was established as a straight line running due east from Alabama Port on the western shore to a point just south of Weeks Bay on the eastern shore.

Based on these boundaries, the Upper Bay, constituting the smallest open-water area, has 17.08 km of channel and about 28,280 ha of areal coverage, of which approximately 18,200 ha is open-water habitat. About 5,124 ha, or 28.2 percent, of the Upper Bay open-water bottoms would be disturbed. Of 27,455 ha of the Middle Bay open-water habitat (total coverage is approximately 34,330 ha with a channel length of 17.73 km), about 5,319 ha, or 19.4 percent, would be disturbed. Of 32,265 ha of the Lower Bay open-water bottom (total coverage approximately 40,190 ha with a channel length of 9.19 km), about 2,757 ha, or 8.6 percent, would be disturbed.

Because these estimates are not adjusted for spatial and temporal factors that affect the absolute magnitude of disturbance, they should be considered as the high-end points of the range of potential bottom disturbance. For example, on average the pipeline discharge location is moved about 1,065 m ahead each time the dredge has advanced to the limit of the available pipe. The "footprint" of the dredged material overburden would therefore tend to be a series of temporary mounds and not necessarily a continuous blanket along the bottom.

Because the recovery process of the benthos in Mobile Bay has been documented to take as little as several weeks or up to 6 months (US Army Corps of Engineers (USACE) 1987, Clarke et al. 1990), depending on the time of year of disturbance and other factors, the percentage of total available habitat lost at any given time to bay ecosystem functions would be considerably less than the estimates given above. The average maintenance dredging operation progresses at a rate of approximately 4 km per month (i.e., assuming an 11-month project for the 44 km of navigation channel).

Applying a conservative estimate of a 3-month recovery period for benthos at any given location, the disturbed bottoms adjacent to 12 km of channel could be affected at any point in time. Thus, 3,600 ha, or 4.6 percent, of the total available open-water bottom habitat could potentially be disrupted to various degrees at any point in time. For sections of the channel dredged during periods of peak benthic recruitment (i.e., a relatively short recovery period), the relative percentage of impacted bay bottom habitat would effectively be reduced. For example, a 1-month recovery period would entail disturbance of 1,200 ha at any point in time, or 1.5 percent of the available open-water habitat.

These estimates also discount the high probability that, during a substantial part of the recovery period, conditions in the disposal areas represent an enhancement in terms of prey availability. As Rhoads and Germano (1986) reported, prey items in recovering benthic systems are small, highly abundant, and concentrated at the sediment surface. These would appear to be ideal foraging conditions for feeding by juvenile demersal fishes and shellfishes that inhabit Mobile Bay.

Inference of Cumulative Impacts from Bay-Wide Benthic Conditions

Densities of the total macroinvertebrate community in this study were within the range of densities reported in the literature for mud substrates in estuaries bordering the Gulf of Mexico. Flint and Younk (1983) reported densities ranging from 389 to 18,889 individuals m^{-2} in Corpus Christi Bay. Gaston, Lee, and Nasci (1988) reported an average density of 1,279 m^{-2} for the macrobenthic community in Calcasieu Lake, Louisiana. In Apalachicola Bay, Florida, Mahoney and Livingston (1982) reported an average density of 2,655 m^{-2} for the benthic community. Lackey et al. (1973) found densities of the benthic community to range from 45 to 1,080 m^{-2} in the upper and middle portions of Mobile Bay. Because of differences in sieve size, the densities from Vittor's (1973) study in Mobile Bay are not directly comparable. Vittor (1978) found densities to range from 1,871 to 8,428 m^{-2} in the extreme upper portion of the bay near Garrows Bend. Vittor (1979) found densities to range from 228 to 6,056 m^{-2} just off Dauphin Island. USACE (1987) noted densities ranging from 112 to 8,820 m^{-2} in June 1987.

Estuaries in this region appear to be characterized by a large degree of temporal as well as spatial variability in benthic densities (Gaston and Nasci 1988). Unlike more northern systems, densities of benthic organisms in southeastern estuaries are typically maximal during the winter and early spring; minimal densities most often occur during the summer months (Flint 1985). The Marine Environmental Sciences Consortium (MESC) (1983) conducted a study to assess the potential impact of a ship channel extension on the west side of middle Mobile Bay. They observed a seasonal low in the summer, and abundance peaks in fall and early spring.

The Upper to Lower Bay patterns in total macrofaunal density, biomass, species diversity, and number of taxa followed those expected on the basis of the salinity gradient. High densities of relatively few species characterized the oligohaline portions of the bay sampled on the Upper Bay transect. The mesohaline portion of the bay, represented by the Middle Bay transect, was characterized by intermediate diversities, an intermediate number of taxa, and low densities. Faunal densities, number of taxa, and species diversity were maximal for the more marine Lower Bay stations.

To place the transects occupied in this study into a salinity regime framework, reference can be made to several recent studies by Raney et al. (1989a,b). These hydrographic modeling studies examined the short-term effects of tidal variation, riverflow, and wind fields on the pattern of flow vectors and salinity distribution in Mobile Bay. Based on results of numerical model runs (two-dimensional, depth-averaged, finite-difference), salinities across the Upper Bay transect ranged from 0 to 5 ppt (during high-riverflow periods) to 5 to 10 ppt (during low-riverflow periods). Salinities across the Middle Bay transect ranged from 5 to 15 ppt during both high and low riverflows, except in the vicinity of the channel where salinities were as high as 20 ppt during periods of low riverflow. Likewise, across the Lower Bay transect, salinities ranged from 10 to 20 ppt during high riverflow and from 15 to 25 ppt during low riverflow.

The results of the cluster analysis corroborated the implication of salinity as a dominant factor regulating benthic community structure; the sampled stations generally clustered in accordance with bay transect. Exceptions included the channel stations from the Upper Bay transect and the station sampled in Bon Secour Bay on the Lower Bay transect. Because of their low densities, these stations clustered with stations from the Middle Bay transect.

The overriding control of the salinity regime on benthos distribution and abundance has been repeatedly recognized (Tenore 1972, Flint and Kalke 1985, Gaston and Nasci 1988); typically, abundance, biomass, and the number of species increase with increasing salinity. Our results lend additional support to this generality.

Flint and Kalke (1985), in their report on the benthos of Corpus Christi Bay, observed an increase in the number of taxa downbay, yet total abundance decreased. This exception was due to the restricted salinity range at the sampled stations; mean salinity ranged from 22.5 ppt at their upper station, to 28.2 ppt at their middle station, to 31.3 ppt at their lower station.

Working in the Calcasieu Lake system, Gaston and Nasci (1988) observed a maximum density of 2,652 m^{-2} in the middle portion of the estuary; mean annual salinity in this region was 5.6 ppt. Gaston, Lee, and

Nasci (1988), working in just the lake portion of the estuary, noted highest densities in the more northern section. Densities in this area averaged 1,737 m^{-2}, and mean annual salinity was 11.4 ppt. The mean numbers of taxa during this 2-year study were 14 in the upper lake area and 11 in the southern portion. Unpublished data collected by the Alabama Coastal Area Board (CAB) in Mobile Bay also indicated an increase in species richness from north to south. However, this study, conducted over the course of a year, found the highest densities of macroinvertebrates to be associated with those stations most influenced by river discharge.

Data collected for the series of localized studies conducted by Vittor (1978, 1979) indicated an increase in the number of species in the lower versus the upper portion of the bay and diversities that ranged from 0.45 to 1.56. USACE (1987) noted that diversity ranged from 0.5 to 3.98 for stations sampled on the east side of the Middle Bay.

Upper to Lower Bay patterns in biomass were masked by the inclusion of shell weight for molluscan species. Considering only nonmolluscan biomass, maximal values were observed for the Lower Bay stations; the Middle and Upper Bay stations were similar with respect to total biomass.

Literature-based comparisons of biomass values are difficult, as few researchers report wet weight values. However, biomass values for this study appear to be low in comparison to those of other studies in southeastern estuaries. In their 2.5-year study in Corpus Christi Bay, Flint and Kalke (1985) observed an annual mean of 49 g m^{-2} at their riverine station, 86.4 g m^{-2} at their middle bay station, and 25.5 g m^{-2} at the most oceanic station. They noted, however, that biomass ranged from 0.4 g m^{-2} in summer periods to a maximum of 151.8 g m^{-2} during winter and spring at their upper bay station. The annual range for their middle and lower bay stations was 0.05 to 157.0 g m^{-2} and 15.4 (October) to 47.1 g m^{-2} (January), respectively. The pattern at their middle bay station was not seasonal and was linked to the presence of the enteropneust *Schizocardium*, a deep-living, bioturbating species. The presence of this species increased the amount of oxic living space for the benthos, resulting in higher benthic density and biomass.

Community biomass during the June 1987 USACE study in the Fowl River area ranged approximately 10-fold, from 0.5 to slightly less than 5.0 g m^{-2}. The low biomass values observed in this study were most likely the result of sampling during the summer when biomass is expected to be at a minimum and the dominance of the benthic community by shallow-dwelling, early-successional stage species.

Based on our review of existing information, benthos in Mobile Bay show little evidence of different taxonomic composition and community structure than that reported for other Gulf estuaries. Although comprehensive comparisons cannot be drawn, those differences that do exist can be accounted for by factors not linked to dredging and disposal impacts (e.g., biogeographic and abiotic conditions).

Interhabitat Comparisons

The premise for examining bay-wide benthic conditions is that cumulative effects of repeated open-water disposal events over the span of decades should be apparent in the benthic communities that currently occupy Mobile Bay. Subtle differences in total densities were noted between habitat types within transects; densities in the disposal areas were generally higher than those in the channel and bay-flat habitats. These differences, however, were not statistically significant. No pattern in the differences of species diversity or number of taxa between habitat types was recognized. Faunal biomass was significantly different between habitats; channels were characterized by lower biomass than bay-flat or disposal area habitats. The differences were most pronounced for the Upper Bay transect. These results can be explained largely by the physical presence of the navigation channel and its effects on circulation, and do not appear to be strongly linked to open-water disposal.

Flint and Younk (1983) compared the sedimentary conditions and the benthic community at a channel station (15 m deep) and a shoal station (<3.5 m deep). The shoal station had coarser sediment, a higher diversity (3.76 versus 2.96), and more species (55.5 versus 21.6) than the channel station. Additionally, Fling and Younk (1983) noted that, although densities at the channel station were lower than at the channel station, shoal densities fluctuated more.

As stated above, taxonomic composition of the Mobile Bay benthic community was similar to that of many Southeastern estuaries. The benthos was dominated by polychaetes, both numerically and with respect to the number of taxa; molluscs were second in importance. Arthropods and echinoderms were collected in abundance only from the more marine Lower Bay stations. Gaston, Lee, and Nasci (1988) noted that polychaetes in Lake Calcasieu comprised 71 percent of the community (by number); molluscs, 8 percent; and amphipods, 10 percent. The CAB data set indicated that seasonal patterns in community density were driven primarily by changes in the densities of polychaetes; exceptions occurred when there was a large recruitment of juvenile molluscs.

Trends in taxonomic composition between habitat types were noted for molluscs and arthropods. In general, molluscs were uncommon at channel stations, and arthropods were most abundant at the disposal area stations. Sediment deposition and current winnowing in the disposal areas appear to result in a slightly coarser substrate for this habitat (Table 11); this may be the preferred habitat of the dominant cumacean and amphipod species. Flint and Younk (1983) noted an decreased abundance of molluscs (primarily

Mulinia lateralis) at the channel relative to the shoal station. Lackey et al. (1973) conducted pre- and post-dredging assessments of the benthic community in Mobile Bay. These researchers noted fewer organisms in the disposal areas and reported that this trend was most notable for bivalves. Interestingly, they noted that polychaetes were eliminated from the disposal area immediately after disposal.

In this study, the numerically dominant species in the Mobile Bay system was the polychaete *Mediomastus* sp. *Mediomastus* sp. was most abundant in the Upper Bay stations; its abundance was minimal in the Middle Bay. Densities ranged from 973 to 400 to 728 m^{-2} for the Upper, Middle, and Lower Bay, respectively. *Mediomastus* sp. is a commonly encountered species in Mobile Bay (USACE 1982, 1987; MESC 1983) and southeastern estuaries. Dardeau (1988), in reviewing the CAB data, noted that *Mediomastus* was the most abundant macroinvertebrate in Mobile Bay and averaged densities of 637 m^{-2}. In the CAB study, *Mediomastus* sp. (probably *M. ambiseta*) was most abundant at the oligohaline stations. Large peaks in abundance were noted in spring for the Middle Bay stations. Johnson (1980) noted that *Mediomastus* was a fall-winter dominant in Mobile Bay. Reproductively active adults appear to be present most of the year; however, no reproduction was noted in August. Flint and Younk (1983) found an average density of 1,443 m^{-2} for this species in Corpus Christi Bay; peak densities were noted in late fall.

Mediomastus was also the most abundant species in the Apalachicola Bay system (Mahoney and Livingston 1982). Gaston and Nasci (1988) reported densities ranging from 228 to 2,516 m^{-2} for this species in Calcasieu Lake, Louisiana. A winter peak in densities was noted in this latter study. The numerical importance of this species in benthic communities of southeastern estuaries has been noted repeatedly (see review by Armstrong 1987).

The most abundant molluscs in Mobile Bay were the bivalves *Macoma mitchelli* and *Mulinia lateralis*. *Macoma mitchelli* was collected only from the Upper Bay stations, and *Mulinia lateralis* was collected primarily from the Lower Bay stations. *Mulinia lateralis* is an extremely common estuarine species. In Mobile Bay, Lackey et al. (1973) collected this species at densities ranging from 15 to 44 m^{-2} (midbay), 15 to 118 m^{-2} (upper bay), and 15 to 74 m^{-2} (transect C, upper bay). Dardeau (1988) also noted the numerical importance and ubiquity of this species in Mobile Bay. This species was found throughout the bay, but peaks in density occurred at different times throughout the bay. Total mean density reported was 234 m^{-2}. Densities during the 1982 USACE study in Mississippi Sound ranged from 69 to 172 m^{-2}. Densities in this study ranged from 0 to 398 m^{-2}. Flint and Younk (1983) collected *Mulinia lateralis* at densities of 417 m^{-2} in Corpus Christi Bay. *Mulinia* has been reported as a numerical dominant in many other studies of the benthos in estuaries bordering the Gulf of Mexico (Holland et al. 1975, Livingston 1984, Gaston and Nasci 1988).

The tendency of this species to undergo population irruptions is well known (Kaplan, Welker, and Kraus 1974; Johnson 1980; Luckenbach 1984; Williams, Copeland, and Monroe 1986). Although many of the peaks in abundance appear to be aseasonal in nature, the recruitment period for this species in southeastern estuaries appears to fall in the winter and spring (Holland, Maciolek, and Oppenheimer 1973; Matthews, Marcin, and Clements 1974; Flint and Younk 1983). It is believed that colonization of disturbed habitat is by juveniles (Luckenbach 1984; Williams, Copeland, and Monroe 1986).

Macoma mitchelli is also a common species in southeastern estuaries. Densities in this study ranged from 0 to 161 m^{-2}, being most abundant in the upper estuary. The presence of this species has also been noted in many studies of southeastern estuarine benthos. There is evidence that populations typically peak in the winter (Flint and Younk 1983).

Other polychaete species that were relatively abundant in the Mobile Bay system include *Paraprionspio pinnata*, *Glycinde solitaria*, *Podarkeopsis levifuscina*, *Capitella capitata*, *Paramphinome* sp. B, and *Sigambra tentaculata*. These are all commonly reported members of benthic communities in Mobile Bay (USACE 1987, MESC 1983) and in southeastern estuaries (Holland, Maciolek, and Oppenheimer 1973; Holland et al. 1975; Flint and Younk 1983; Livingston 1984; Gaston and Nasci 1988). *Paraprionspio pinnata* and *Glycinde solitaria* were also listed among the 10 most dominant species observed during the 1982 USACE study. Dardeau (1988) reported densities for these species of 94 to 170 m^{-2} and 8 to 33 m^{-2}, respectively. Relatively stable populations of *P. pinnata* were noted at all sampled stations throughout the year. Mean density reported for this species from the CAB data set was 38 m^{-2}. Johnson (1980) noted the presence of this species year round in his study of the Mobile Bay benthos. Peak recruitment appears to occur in late fall for this species (Flint and Younk 1983). Recolonization by this spionid is believed to occur via the adults that arrive soon after a disturbance and quickly become abundant.

Interestingly, *Pseudoeurythoe ambigua*, a numerically important amphinomid polychaete species in Mobile Bay as indicated in the CAB data set, was not collected in this study. This species is probably a synonym of the numerically abundant *Paramphinome* sp. B from this study.

Glycinde solitaria, a carnivorous polychaete, represented greater than 10 percent of the individuals collected in the CAB study. Total mean density of this species during the CAB study was 17 m^{-2}. Densities in this study ranged from 22 to 66 m^{-2}. Johnson (1980) noted a year-round high abundance of this species in his study.

Capitella capitata was collected only from the upper estuary during this study; densities on that transect averaged 106 m^{-2}. This species is a recognized opportunist and appears to be extremely tolerant of habitat disturbances. Its presence has been noted in other studies of southeastern estuarine benthic communities (Hildebrand and King 1978, Gaston and Nasci 1988); however, it does not appear to be a numerically important component on a year-round basis.

Actiniarians and rhynchocoels were also common taxa in Mobile Bay, but were not identified to the species level because of taxonomic difficulties. The abundance of Rhynchocoela has been noted in previous studies of the benthos of Mobile Bay (USACE 1987, Dardeau 1988). USACE (1982) reported densities of this taxon ranging from 52 to 76 m^{-2}. It is believed that more than six species exist in Mobile Bay, but the taxonomy of these carnivorous organisms requires further study.

Some of the numerically important species in other studies of southeastern estuarine benthos (*Streblospio benedicti*, *Mulinia pontchartrainensis*, *Hobsonia florida*, *Rangia cuneata*, *Cossura delta*, *Heteromastus filiformis*, and *Balanoglossus auranticus*) were numerically important components of the benthic community in Mobile Bay; however, they were typically restricted in their distribution to the Upper or Lower Bay. Flint and Younk (1983) noted that the enteropneust *Balanoglossus auranticus* was extremely seasonal in its abundance in the Corpus Christi system.

Cluster analysis identified five major species groups (Figure 33). The species composition of these groups reflected in large part the salinity gradient in the bay. Group 1 was composed of species reaching their highest abundances in the oligohaline Upper Bay. Seven of the ten species in this group were collected only from the Upper Bay stations. *Macoma mitchelli* and *Rangia cuneata* have been classed as "estuarine endemics" and have clustered together in previous classification studies of estuarine benthos (Schaffner et al. 1987, Diaz 1989). Flint and Kalke (1985) noted that *Streblospio benedicti* and *Heteromastus filiformis* were more abundant in lower salinities in Corpus Christi Bay. Group 5 consisted primarily of species that occurred in relatively high densities and are known to prefer higher salinity habitats. Flint and Younk (1983) recognized *Magelona* sp. and *Sigambra tentaculata* as more oceanic species in their study of the Corpus Christi Bay benthos. Shaffner et al. (1987) noted the co-occurrence of *S. tentaculata*, *G. solitaria*, and *P. pinnata* in their study of the James River estuary. The remaining species groups were generally groups of relatively uncommon and generally euryhaline species. Interestingly, group 4 was composed entirely of filter feeders that appear to prefer disposal areas or sandier areas with some shell hash.

The Mobile Bay benthic community was dominated during this study by ubiquitous, opportunistic species. *Mediomastus* sp., *Paraprionospio pinnata*, and *Mulinia lateralis* were numerically important in the Mobile Bay benthic community and are recognized as euryhaline, typically estuarine species characteristic of early successional stages. *Mediomastus* sp. and *Mulinia lateralis* are known to be able to withstand relatively high levels of physical disturbance. The community structure is one that is very tolerant of salinity fluctuations.

Sediment Profiling Imagery

Results of the sediment profiling bay-wide survey can be used to draw a picture of summer benthic conditions in Mobile Bay. The most striking features of the summer benthic community are the predominance of early successional stages and generally shallow RPD depths encountered throughout the bay. Figures 37-44 exemplify the observed sediment and faunal conditions. These examples are illustrative of features used in the interpretation of SPI images and are not intended to be "typical" of the images within any habitat type.

Successional stage I and II communities dominated the Mobile Bay benthos during this study. It appears that disturbance (natural or anthropogenic in origin) of the benthic habitat is frequent enough that the deeper dwelling, longer lived species do not have the opportunity to establish themselves. The predominance of stage I and II communities in the Middle and Upper Bays was noted in the Clarke et al. (1990) study using SPI. Working in Calcasieu Lake, Gaston and Nasci (1988) also noted that benthic succession rarely proceeded beyond the initial settlement stage.

Apparent RPD depths in Mobile Bay ranged from 0.5 to 3.5 cm. Shallower RPD depths were noted for the Middle Bay area, a result also noted in the Clarke et al. (1990) study. A relationship between apparent RPD depth and faunal biomass was noted for this study. Relationships between levels of bioturbating activities and faunal characteristics such as density or biomass have been noted in previous research (Moore and Scruton 1957; Winston and Anderson 1971; Howard and Frey 1975; Myers 1977a,b; Schaffner et al. 1987).

Flint (as cited in Armstrong 1987) noted that RPD depth was related to biomass and species number in Corpus Christi Bay; seasonally, there appeared to be a small time lag between the deepening of the RPD and the response of the fauna. Although many factors affect the relationship between biomass, apparent RPD, and the level of bioturbating activity, it appears that SPI can be used to obtain a rapid assessment of the degree of physical control of the species composition of a benthic community. Shallow RPD depths appear to be associated with a simple, physically controlled benthic community. In contrast, deeper RPD depths, typically caused by increased activities of bioturbating species, indicate a more complex benthic community in which species interactions may assume a more important role in determining species composition.

The consistent pattern that emerges from examination of the sediment profiling and benthic characterization data in this study is that open-water habitats in Mobile Bay are subject to control by physical forces. Frequent resuspension events of the soft surficial bottom sediments is a consequence of shallow overlying waters and prevailing wind conditions (reviewed in Clarke et al. 1990). These periodic resuspensions prevent progress of benthic succession beyond early stages. Stage III equilibrium communities, such as occur in deep waters of Atlantic coast estuaries, are rarely seen in Mobile Bay. Few patches of bottom habitat remain undisturbed for sufficient durations for these communities to reach maturity. Thus, natural forces repeatedly act to return the bay to a "disturbed" state. Benthos in Mobile Bay reflect these conditions, being typified by opportunistic species with extended recruitment periods.

In a system such as Mobile Bay (i.e., dominated by early benthic successional stages), the benthos can be expected to show high levels of tolerance or susceptibility to impacts depending on the specific type of physical or chemical alteration. Rhoads and Germano (1986) contrast these fundamental differences in tolerances and susceptibilities (Table 12). For example, the potential for food-web contamination in Mobile Bay should be considered high due to the predominance of fine sediments and frequent resuspension events. However, contamination of sediments involved in historical maintenance dredging operations has not been found to be significant. Mobile Bay sediments may represent a sink for many nutrients as a result of the general restriction of bioturbation to the surficial sediment layers. Although no detailed studies of nutrient exchange have been documented for Mobile Bay, a safe assumption would be that the exchange rate is low. It would be unlikely that dredging and disposal operations, either conducted on a routine basis or abandoned entirely, would result in a change in the factors that drive nutrient exchange in the bay.

As noted by Rhoads and Germano (1986), systems such as Mobile Bay have a high potential for bottom hypoxia due to the accumulation of labile detritus. Hypoxic events have been observed periodically in Mobile Bay for several centuries, predating the advent of large-scale dredging projects. No documented studies have been found which suggest or substantiate a linkage between open-water disposal of dredged material and the frequency or severity of hypoxia in Mobile Bay.

There is little evidence that benthic communities in Mobile Bay have been affected by open-water disposal practices other than for temporary, short-term reductions in localized populations. Open-water disposal of unconsolidated dredged material in Mobile Bay and similar shallow, soft-bottom estuaries involves physical disturbance analogous in many respects to storms. Within several hundred meters of the points of discharge, the benthos are potentially subject to acute impacts by burial under highly viscous dredged material. At greater distances the overburdens, either by direct transport along the sediment-water interface or by resuspension and sedimentation elsewhere, should produce thin veneers of sediment that do not exceed natural rates of sedimentation. Ample evidence exists that Mobile Bay benthos are highly adapted to this type of disturbance.

The magnitude of these limited spatial and temporal impacts on the benthos in an ecosystem context appear to be minimal. Unfortunately, the importance of the "loss," albeit temporary, of open-water habitat to secondary production as a consequence of disposal cannot be evaluated with confidence at this time. For example, it would be desirable to quantify the dependence of fisheries resources on benthic secondary production so that open-water disposal can be placed in a meaningful perspective. However, almost no data suitable for quantitative estimation of secondary production in Mobile Bay, or any other Gulf coast estuary, are available. Biomass and population level growth data, both required on a seasonal basis, are seldom incorporated into monitoring programs.

Diaz and Schaffner (1990) estimated differential production rates for benthic habitats in the Chesapeake Bay. They compared mean annual productivity (grams carbon/m^2/year) for mud, sand, and mixed substrates among tidal freshwater, oligohaline, low- and high-mesohaline, polyhaline, and euhaline habitats. Mud substrates, the category most similar to Mobile Bay, were most productive in euhaline (marine) areas of the bay, moderately productive in oligohaline and low-mesohaline areas, and least productive in high-mesohaline, polyhaline, and particularly the tidal freshwater areas. Production in euhaline habitats was distributed rather equally among many taxa, whereas production in most of the remaining habitats was dominated by relatively few taxa.

Diaz and Schaffner (1990) estimated the total benthic production needed to support the maximum sustained yield (MSY) of important benthic feeding fishery resources. Assuming that ecological efficiency (fish prey consumption/fish production ratio) of the major Chesapeake Bay benthic consumers (blue crabs, spot, croaker, white perch, and flounder) was in the 17 to 22 percent range, Diaz and Schaffner (1990) calculated that 12,200 to 15,900 metric tons of benthic organic carbon was required to support a MSY of these resources, and an additional 3,270 metric tons was required to maintain a MSY for oyster, hard clam, and soft clam (benthic herbivore) commercial harvests. To support maximum fishery yields of all commercial and recreational resources, they calculated that benthic production of up to 27,550 metric tons would be required. Their estimate of total benthic production in the bay system (194,000 metric tons carbon) was found to be seven times greater than the maximal consumption requirement.

The magnitude of benthic production in an estuarine system is subject to a multitude of factors. Diaz and Schaffner (1990) emphasize the importance of relationships between physical and biological factors that regulate production through effects on growth, size distribution, life span, fecundity, and reproductive success. Therefore, in the absence of comparable information on Mobile Bay benthic production, extrapolations cannot be made between the Chesapeake Bay and Mobile Bay estuarine systems with respect to total fisheries yield and benthic production. However, it is unlikely, given the available evidence, that benthic production limits yields of fishery resources in Mobile Bay. Blue crabs, spot, croaker, flounder, and oyster consumer populations are common to both estuaries. Benthic production in Mobile Bay, characterized by frequent physical disturbances of bottom sediments, opportunistic benthic assemblages, and relatively high water temperatures, should be higher than systems characterized by undisturbed equilibrium communities and low water temperatures (Odum

1969; Wolff, Sandee, and deWolf 1977; Rhoads, McCall, and Yingst 1978).

In terms of open-water soft-bottom habitat function, a <2- to 10-percent reduction in available habitat would not appear to be critical for fishery resource support. A priority need with regard to future assessment of the absolute effects of open-water disposal, in comparison with other uses of the estuary, is for studies designed to quantify secondary production across habitat types in Mobile Bay and other Gulf estuaries.

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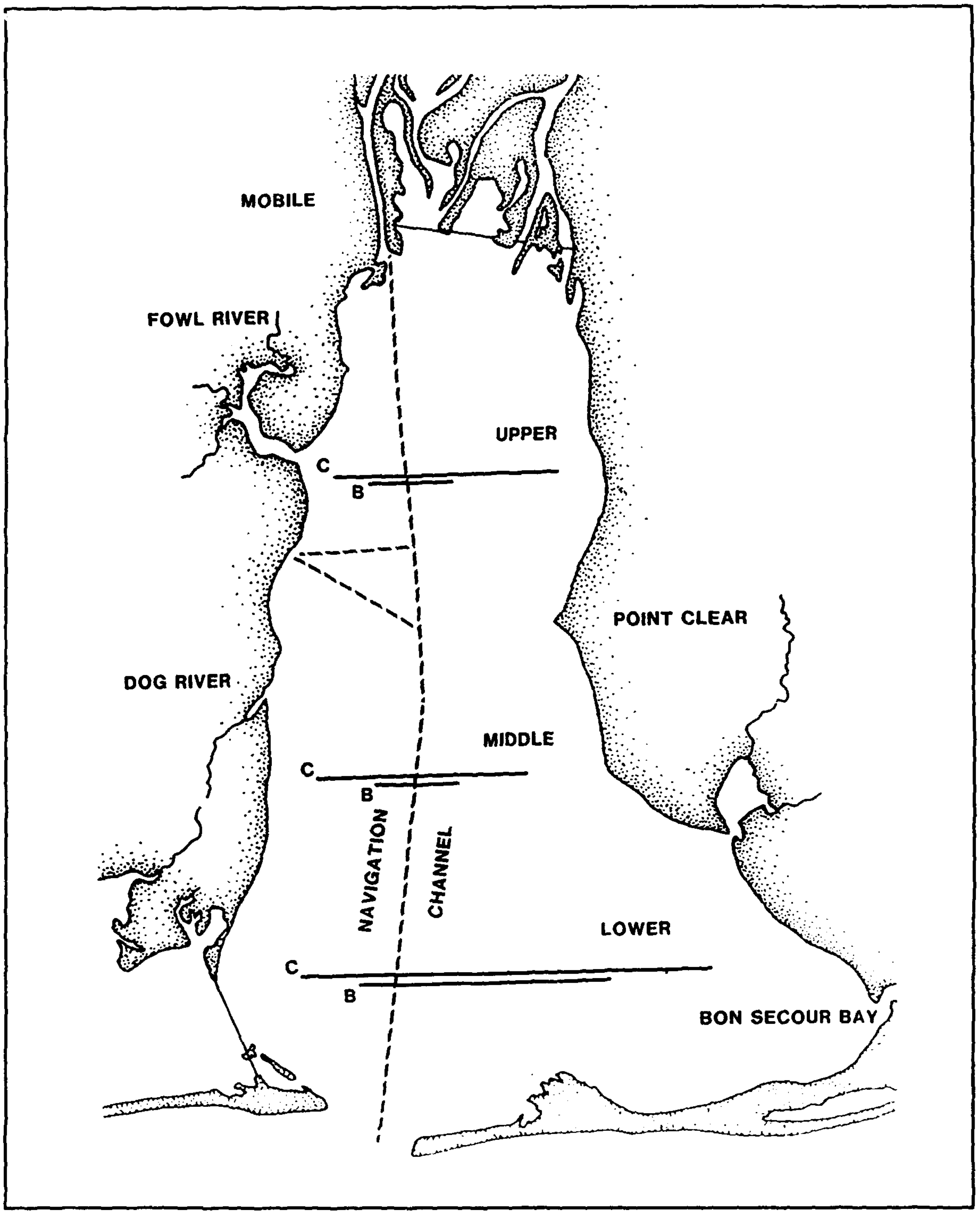

Figure 1. Map of Mobile Bay, Alabama, showing approximate locations of sediment profiling camera (C) and benthic grab (B) transects used in this study

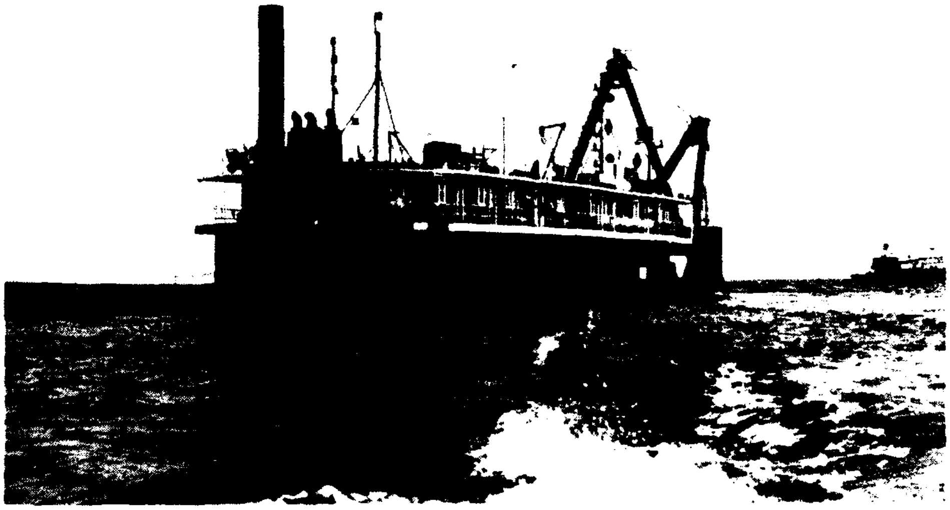

Figure 2. Hydraulic dredge *Louisiana* in the main Mobile Bay navigation channel during maintenance dredging operations

Figure 3. Configuration of pipeline terminus in place during the study

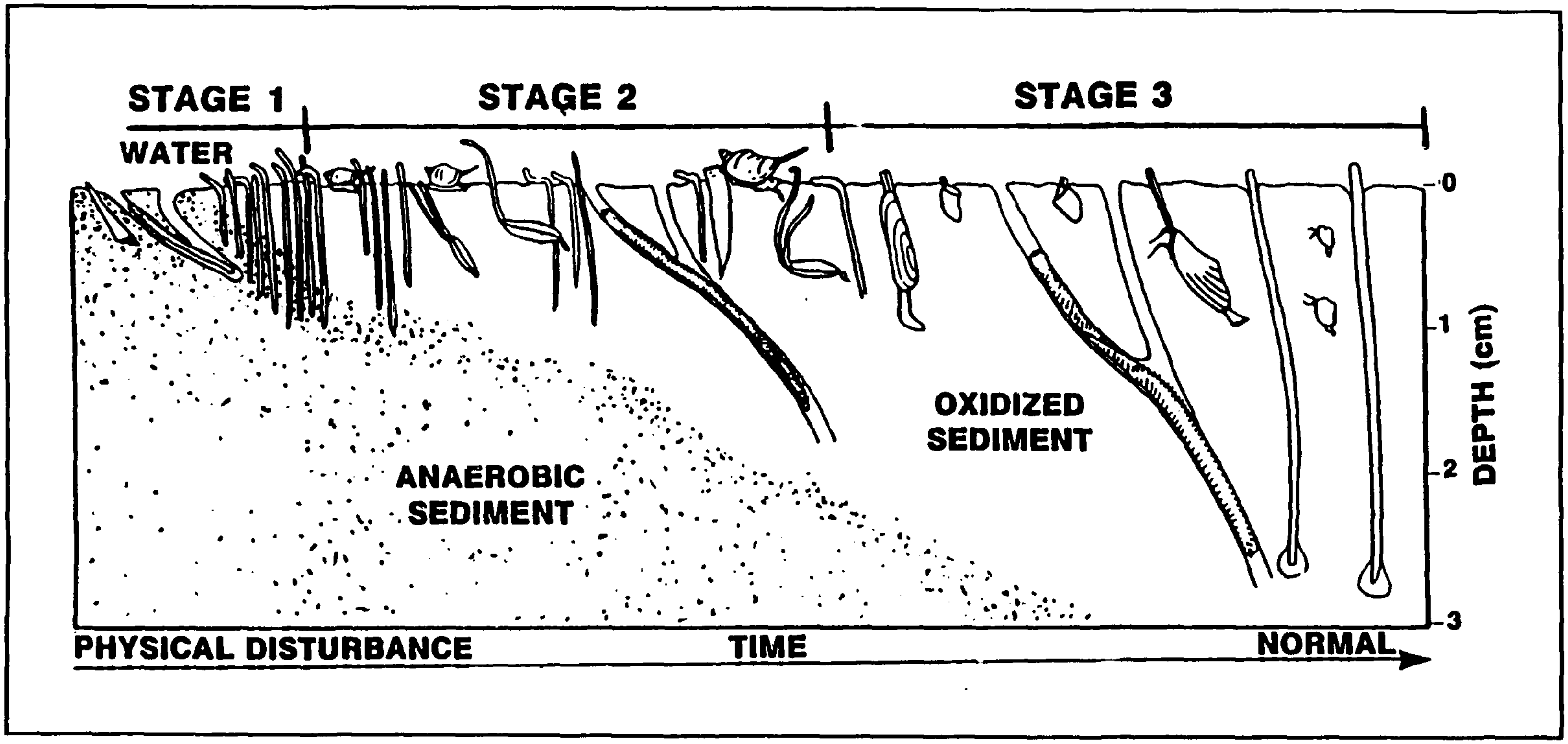

Figure 4. Diagrammatic representation of benthic infaunal succession following physical disturbance of the sediment column (adapted from Rhoads, McCall, and Yingst 1978)

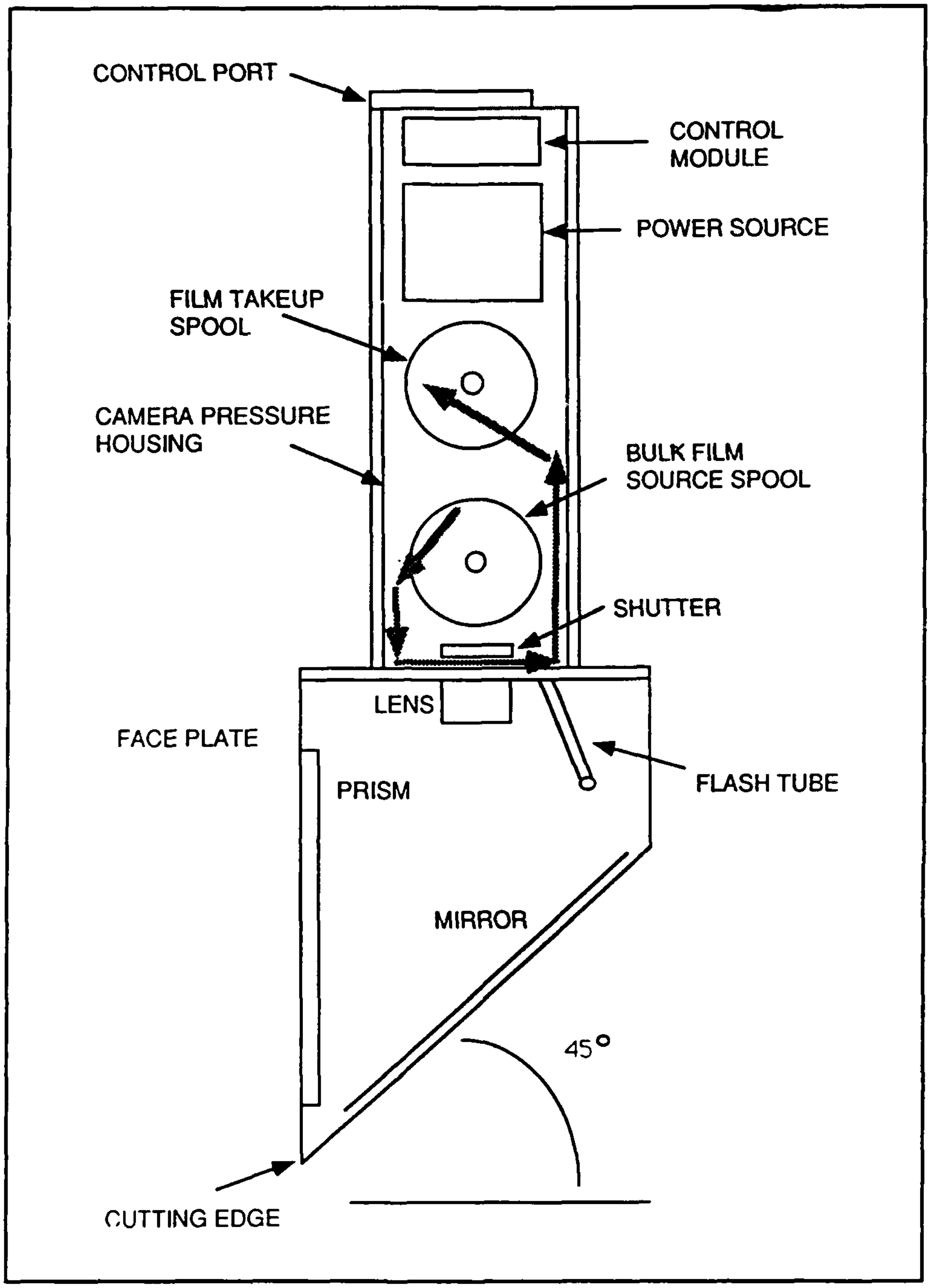

Figure 5. **Schematic diagram of Hulcher sediment profiling camera internal components**

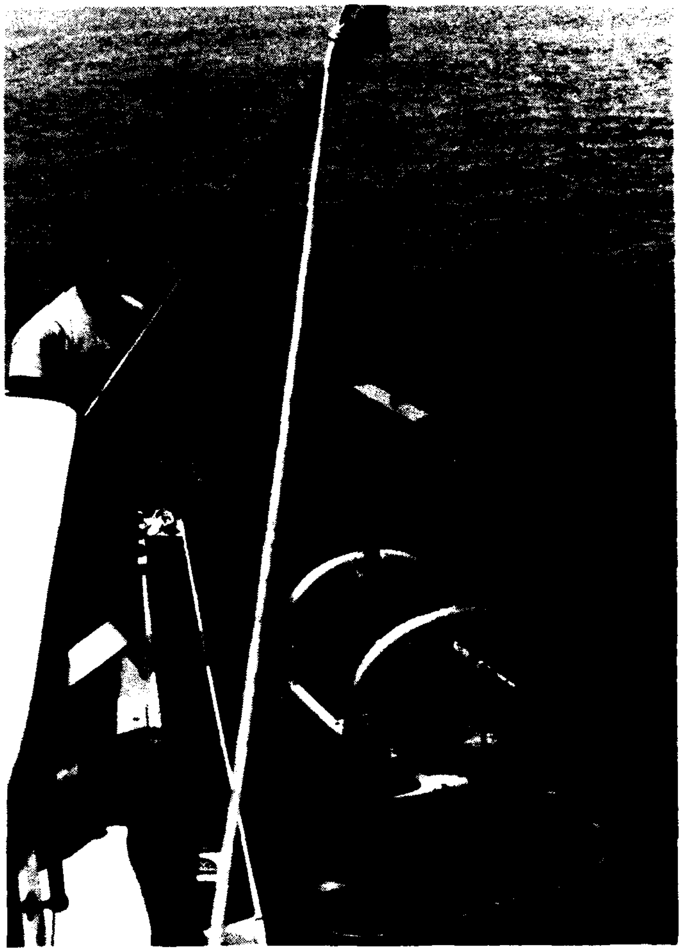

Figure 6. Hulcher sediment profiling camera and support frame at the water surface during deployment in the present study

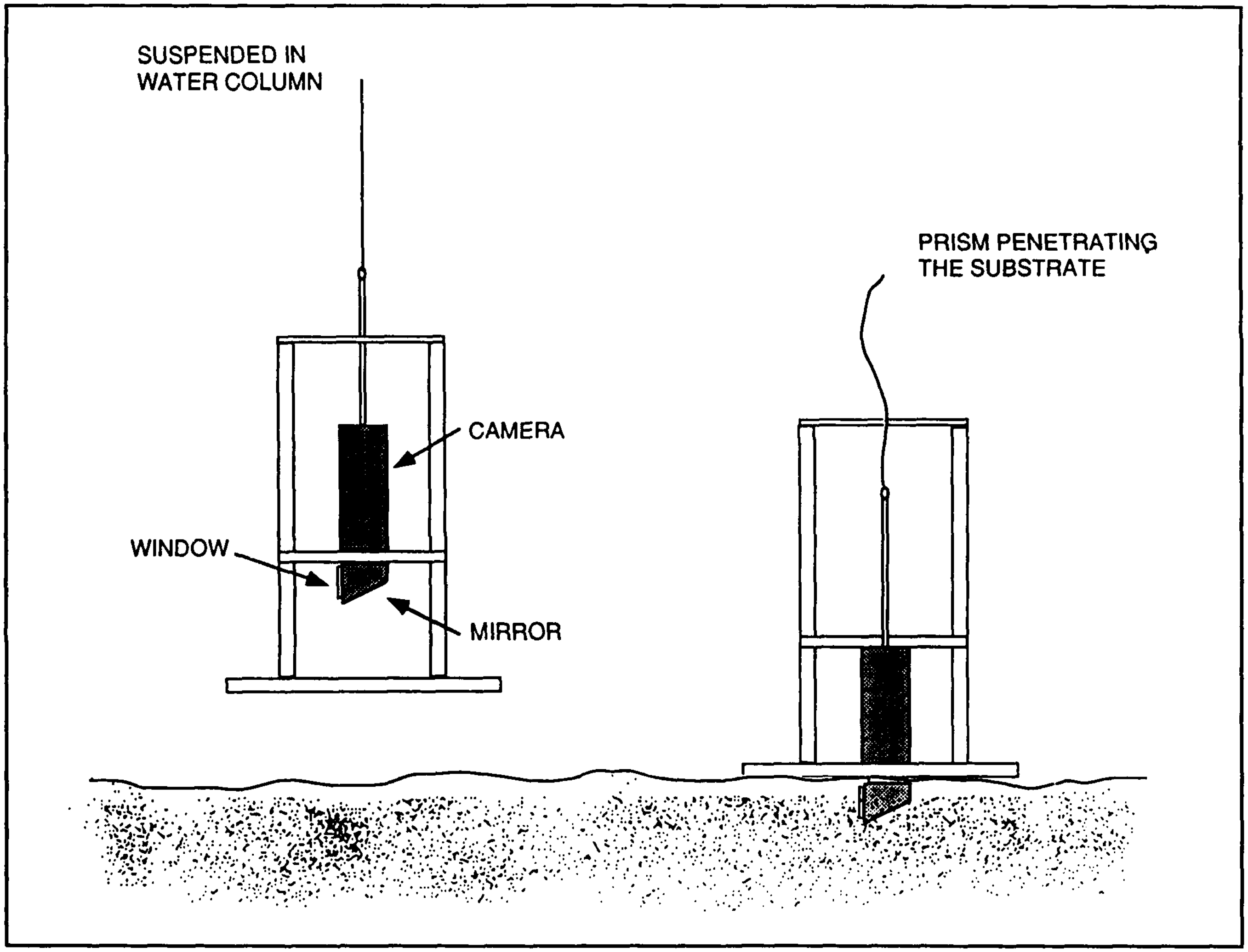

Figure 7. Deployment of sediment profiling camera system

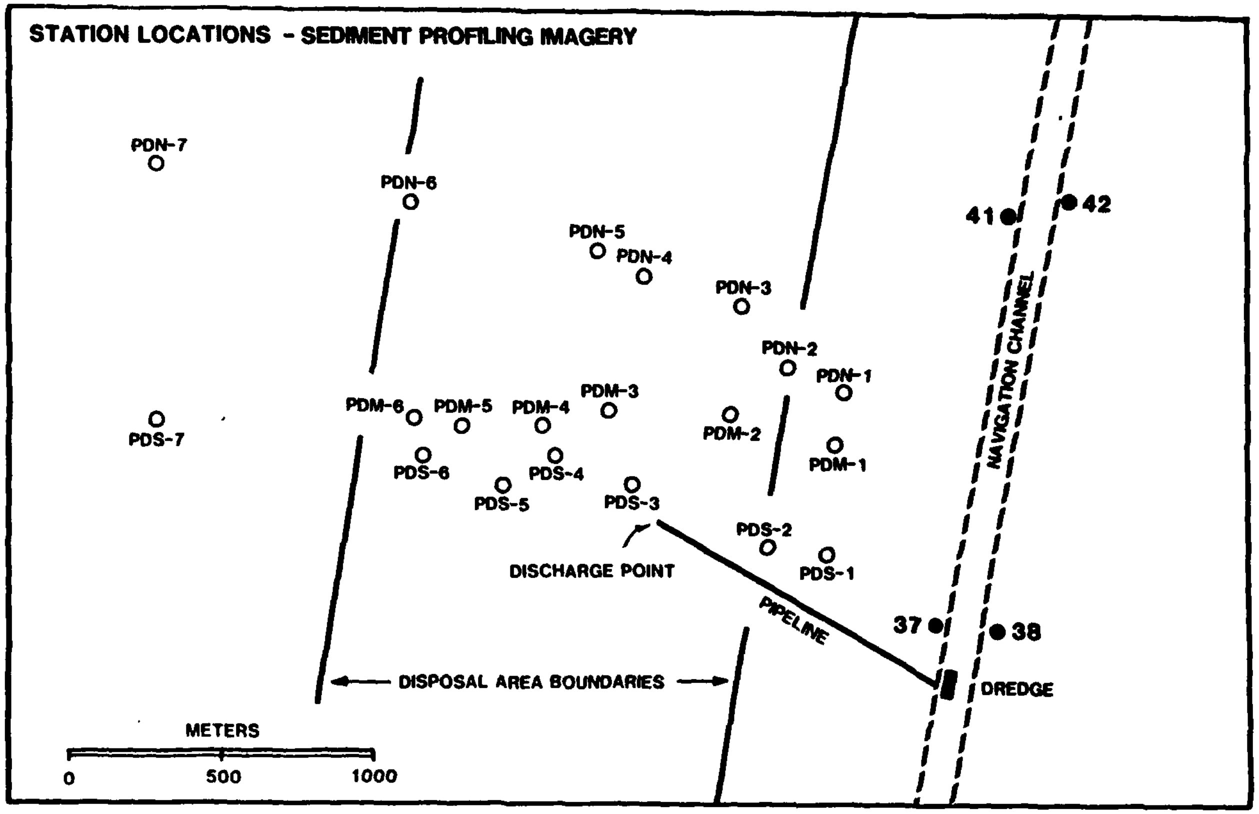

Figure 8. Station locations for sediment profiling camera surveys. Stations PDS-, PDM-, and PDN-1 through 6 were occupied in front of the northward-progressing dredge and pipeline on 8 July 1988. Stations along transects PDN and PDS, with the additional stations PDN-7 and PDS-7, were revisited in September and December 1988, and again in June of 1989

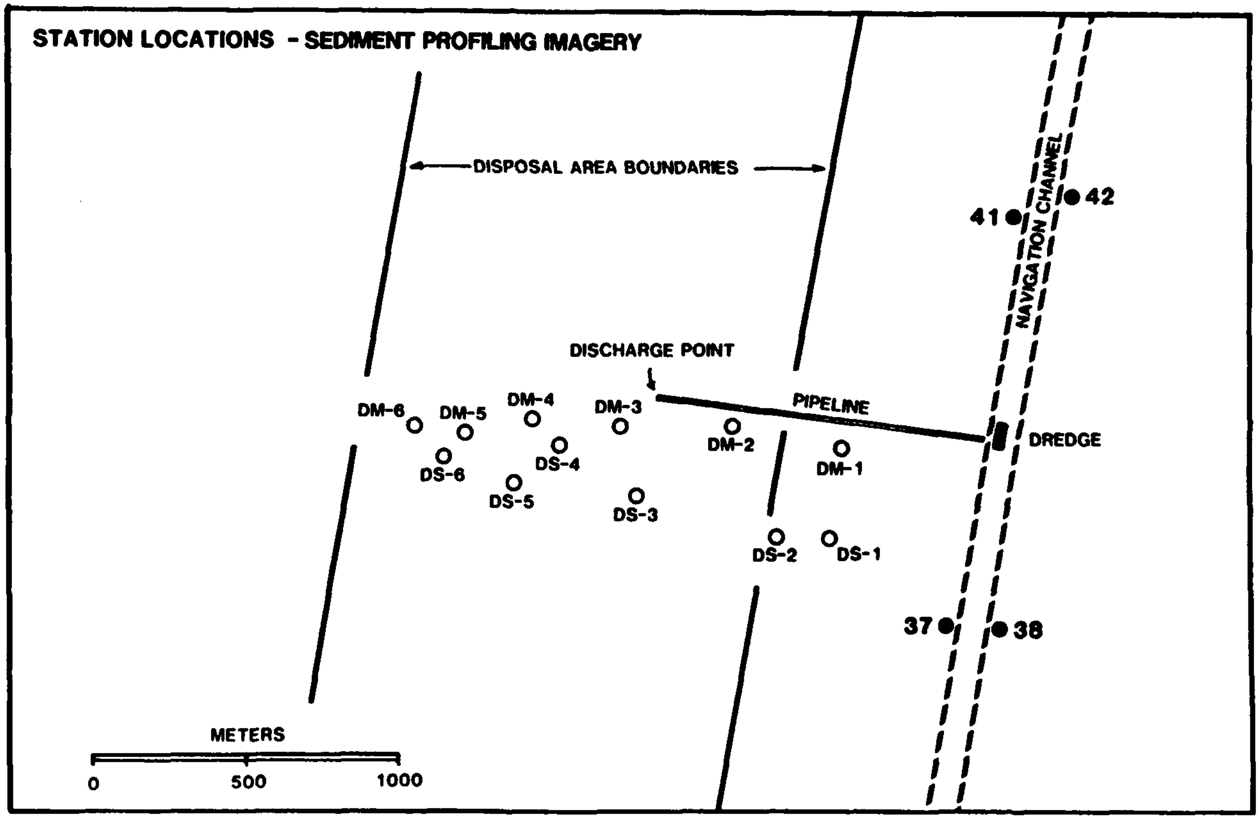

Figure 9. Station locations for sediment profiling camera survey on 9 July 1988. These stations were situated to the south of the northwardly progressing pipeline

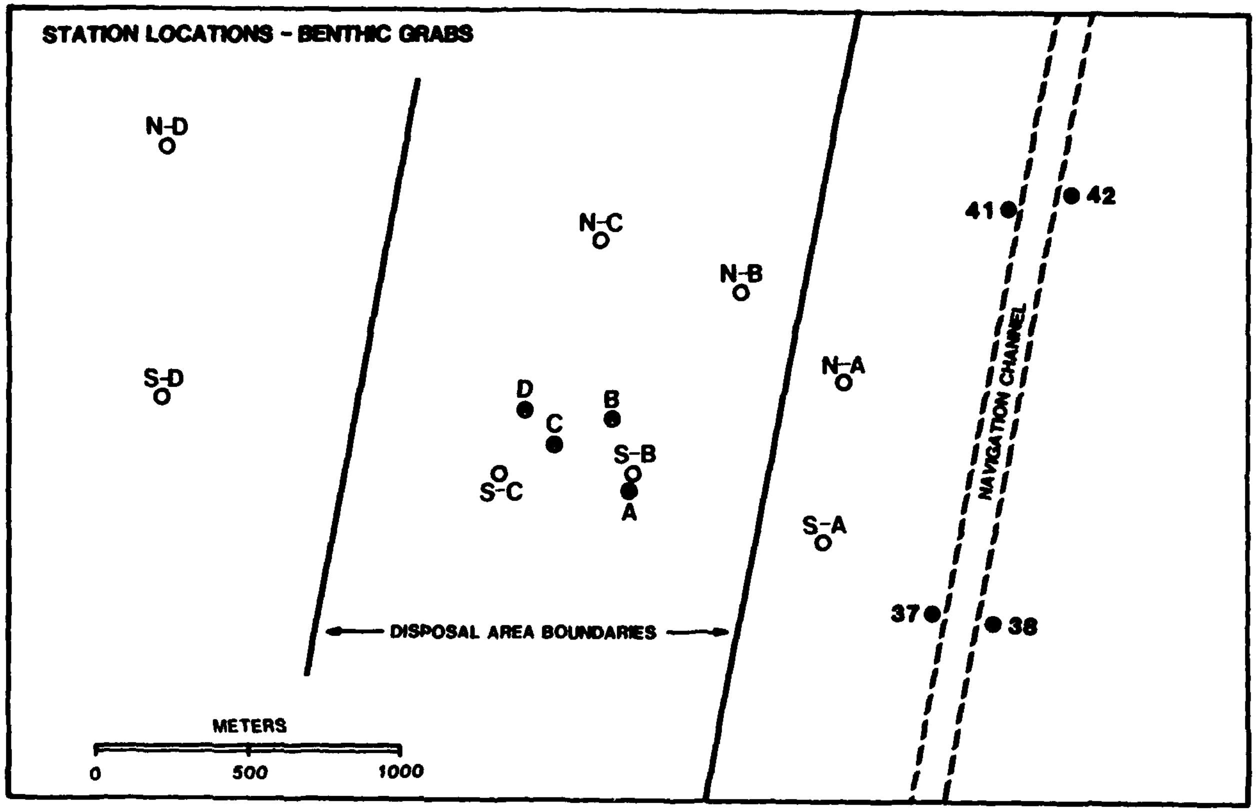

Figure 10. Station locations for benthic grab samples. Stations A, B, C, and D were occupied in July 1988. Stations N- and S-A through D were sampled in June 1989

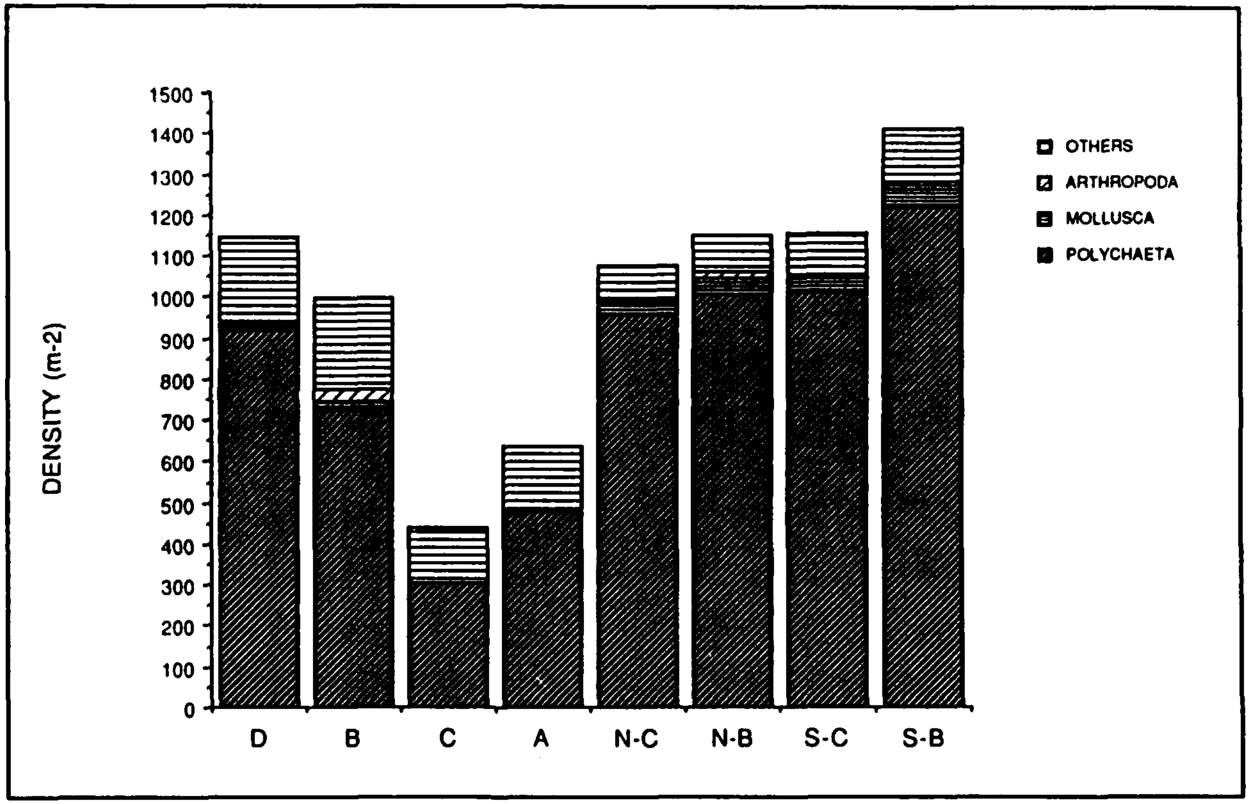

Figure 11. Densities (individuals m^{-2}) of major taxonomic categories at stations sampled within the disposal site boundaries in 1988 (stations A, B, C, and D) and 1989 (N-C, N-B, S-C, and S-B)

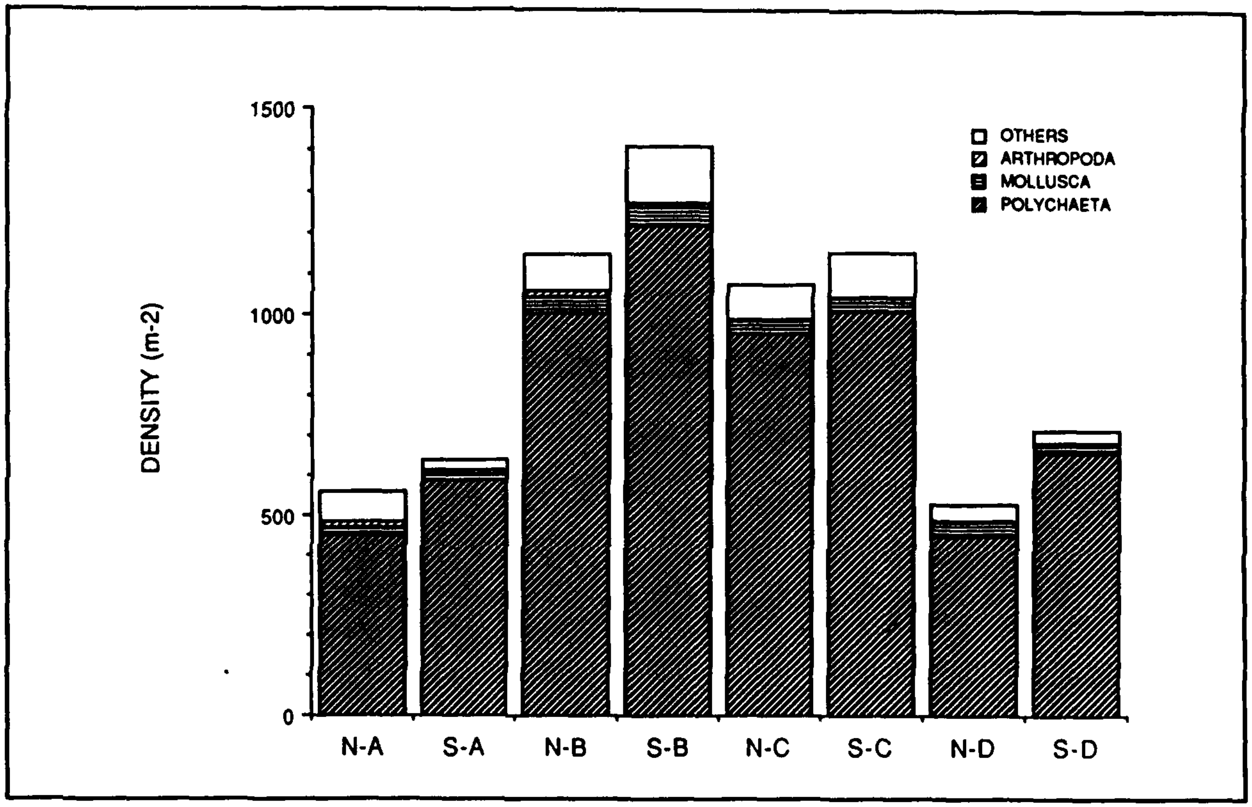

Figure 12. **Densities (individuals m^{-2}) of major taxonomic categories at stations sampled within the disposal site boundaries in July 1989 (N-B, N-C, S-B, and S-C) as compared to bottoms adjacent to the navigation channel (N-A and S-A) and shallow flat stations (N-D and S-D)**

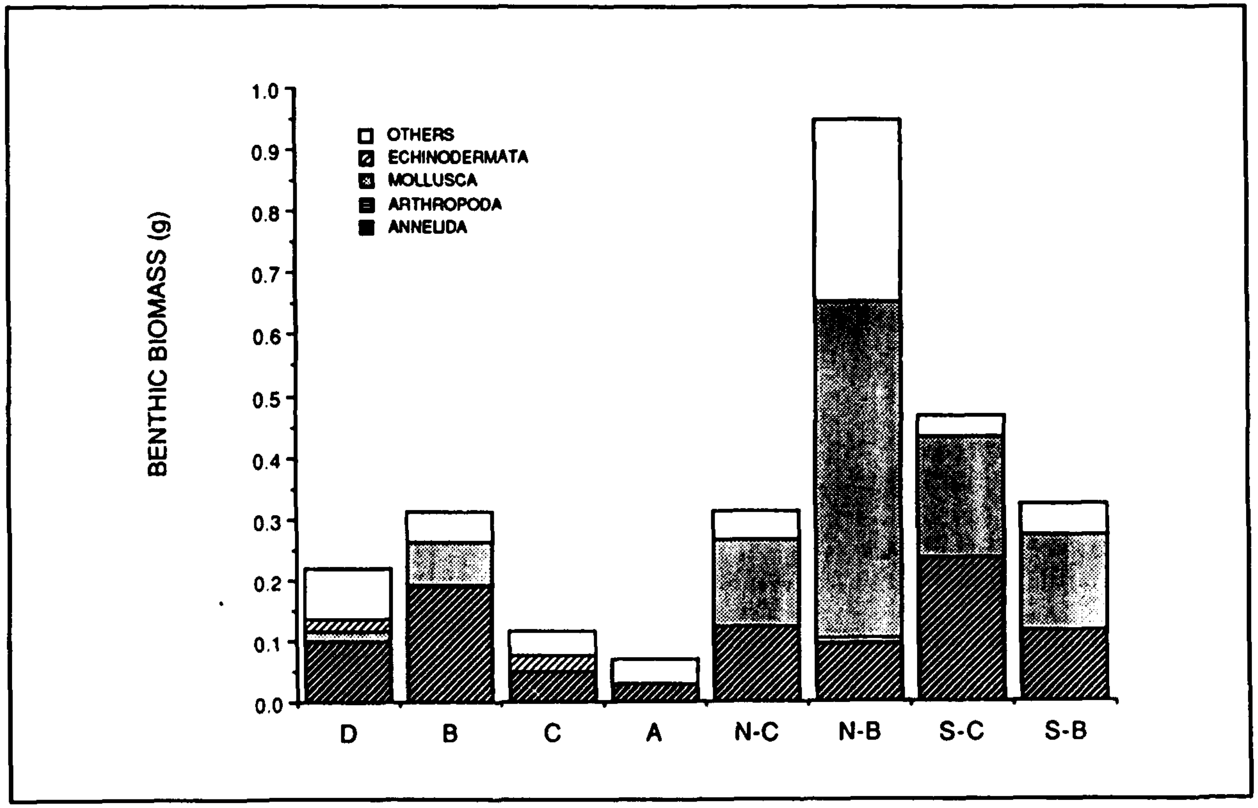

Figure 13. Benthic biomass (g m^{-2}) of major taxonomic categories at pipeline discharge stations sampled within the disposal site boundaries in June 1988 (A, B, C, and D) and July 1989 (N-C, N-B, S-C, and S-B)

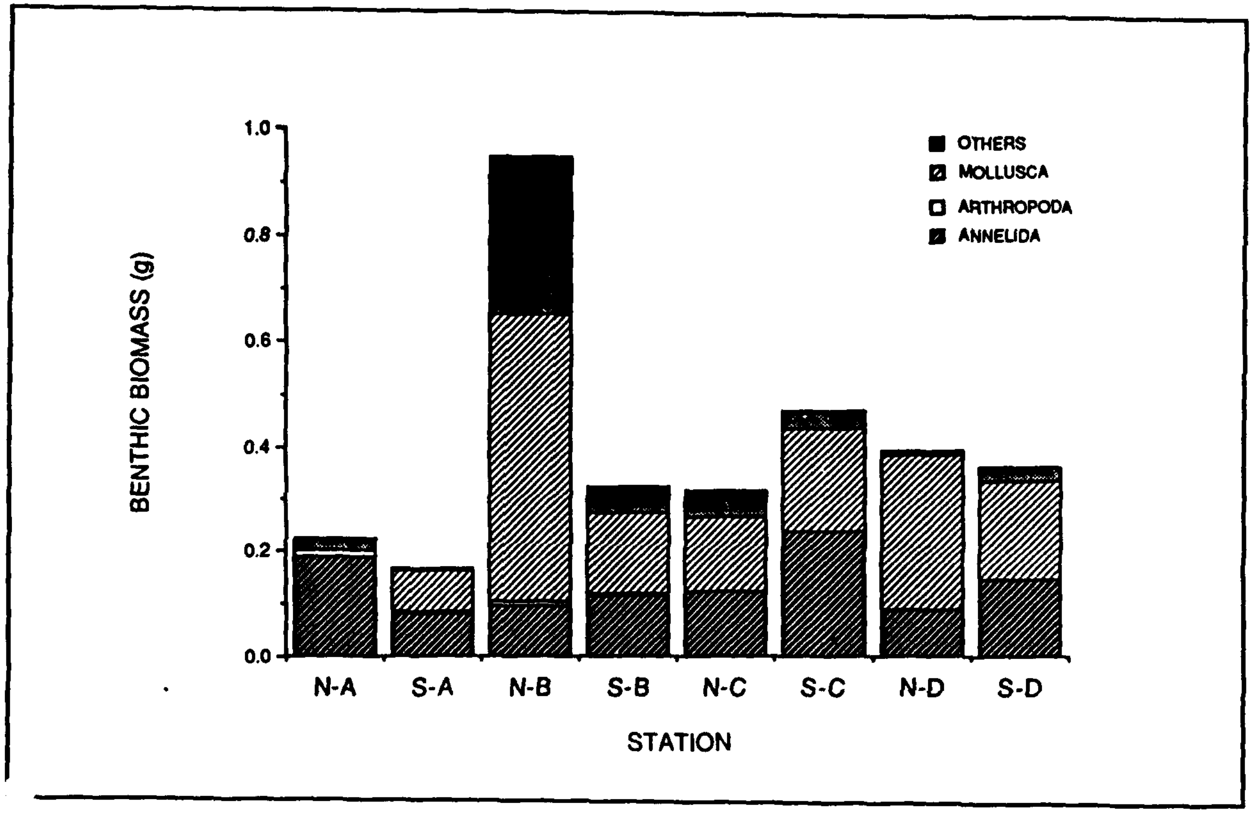

Figure 14. Benthic biomass (g m^{-2}) of major taxonomic categories at pipeline discharge stations sampled within the disposal site boundaries in July 1989 (N-B, N-C, S-B, and S-C) as compared to bottoms adjacent to the navigation channel (N-A and S-A) and shallow flat stations (N-D and S-D)

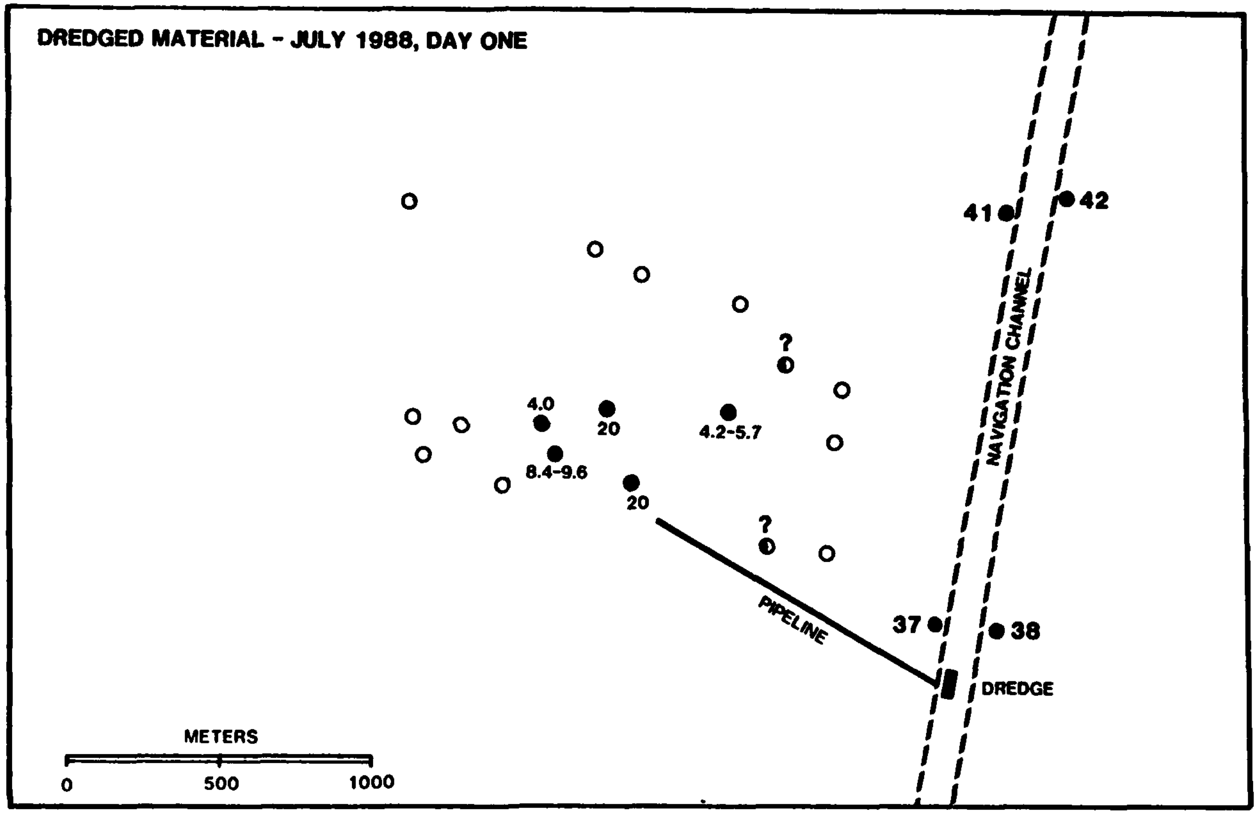

Figure 15. Dredged material overburden thickness (cm) at sediment profiling camera stations surveyed on 8 July 1988. Ranges indicate maximum and minimum overburden thickness among replicate images at a station. Open circles represent stations at which no dredged material was detected. Question marks signify the possible presence of dredged material

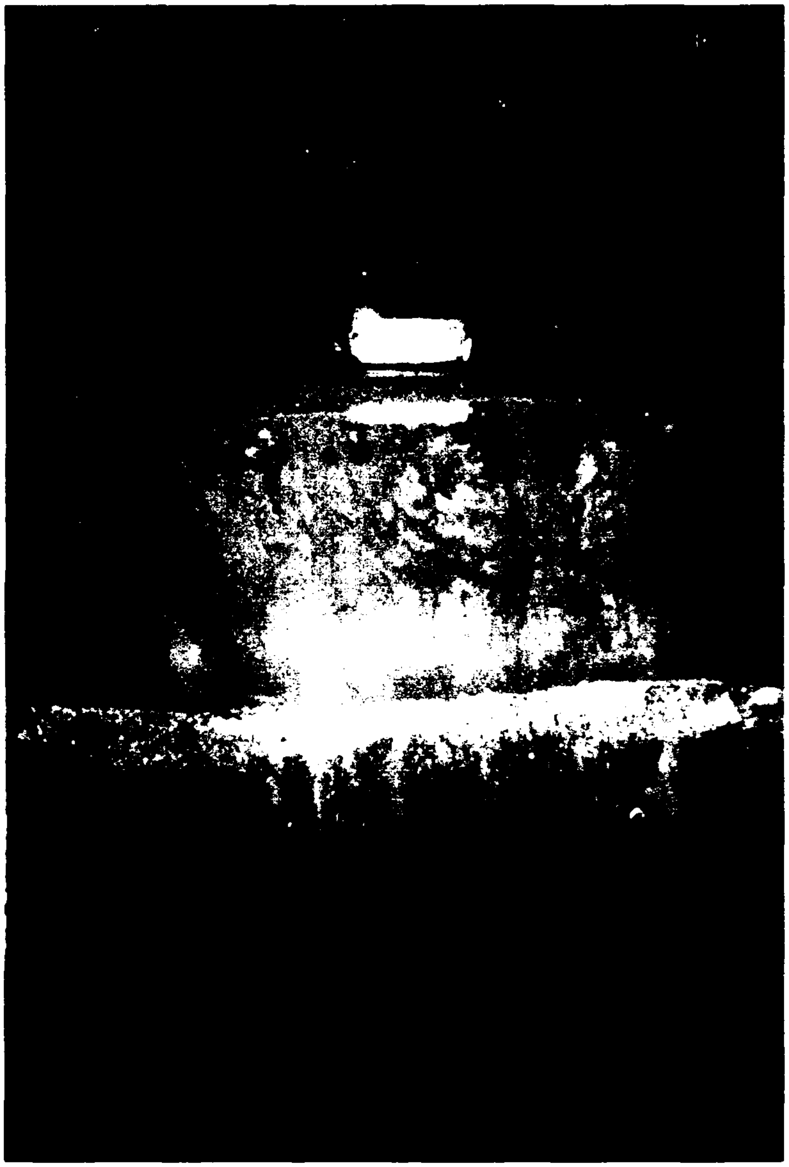

Figure 16. Example sediment profiling image, showing the presence of newly deposited dredged material. The original sediment surface is visible as the slightly curved layer of light-colored sediment transversing the image slightly below the midline. The highly viscous overburden is approximately 7 cm thick in this image. Actual dimensions of the image are 20 cm on the vertical axis and 15 cm on the horizontal axis. A watch used to track image date and time is seen in the upper right corner. The white and black bars just above the center of the image are artifacts due to a reflection of the strobe within the camera prism

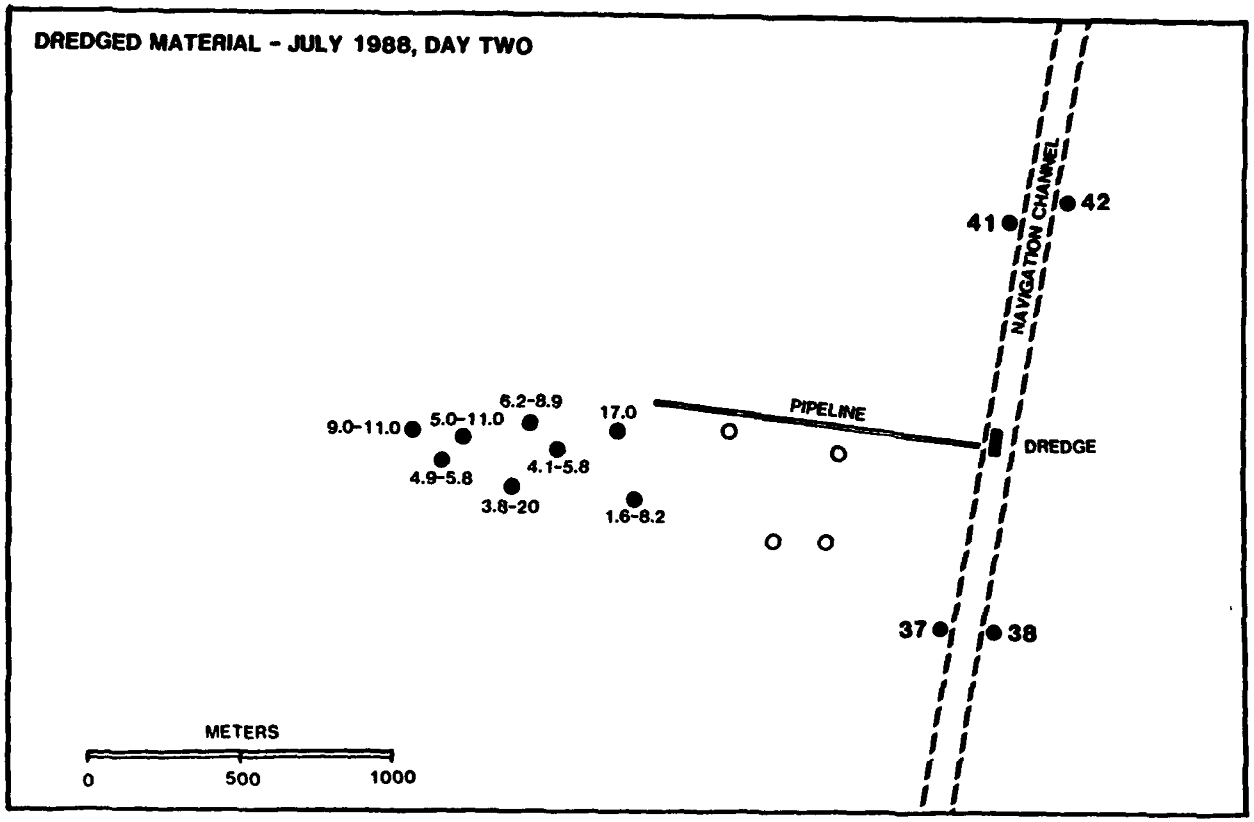

Figure 17. Dredged material overburden thickness (cm) at sediment profiling camera stations surveyed on 9 July 1988. Ranges indicate maximum and minimum overburden thickness among replicate images at a station. Open circles represent stations at which no dredged material was detected.

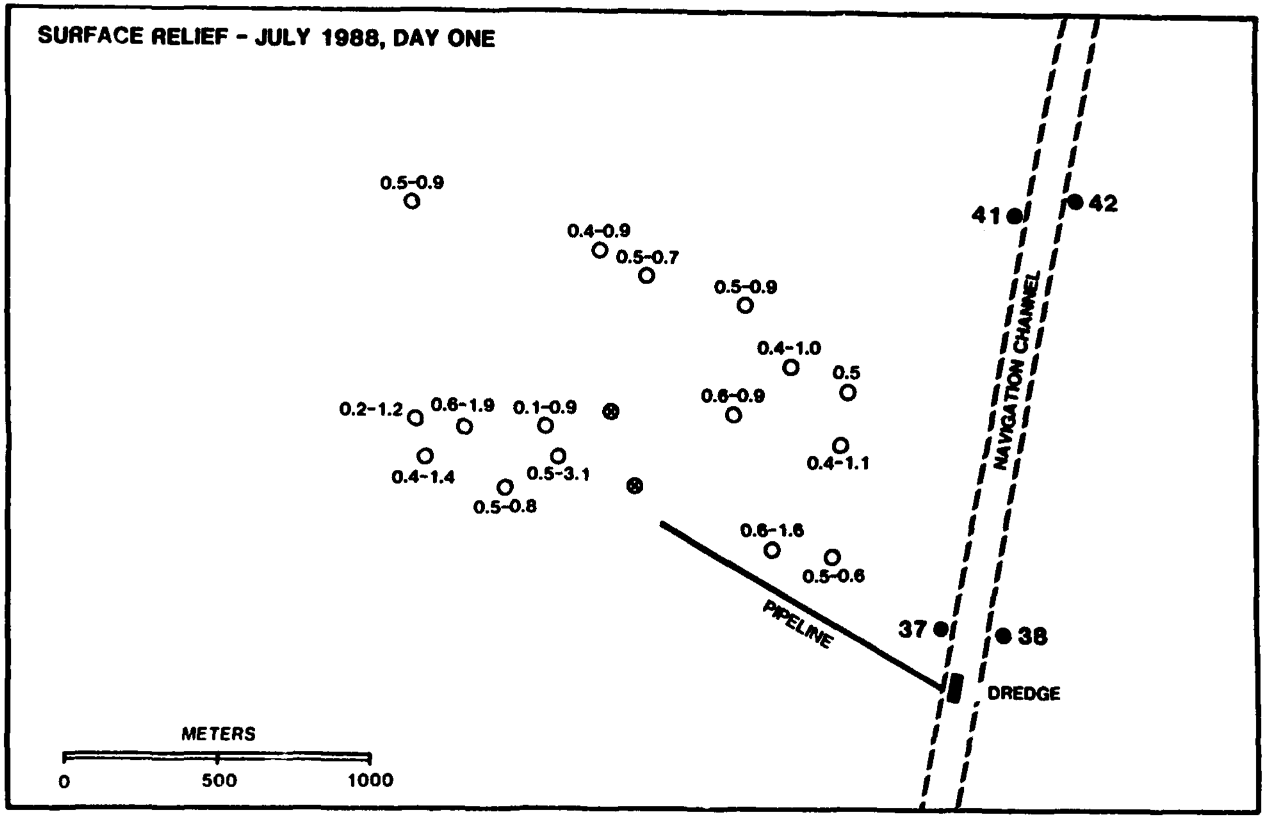

Figure 18. Surface relief (cm) at the sediment-water interface (July 1988, day 1) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

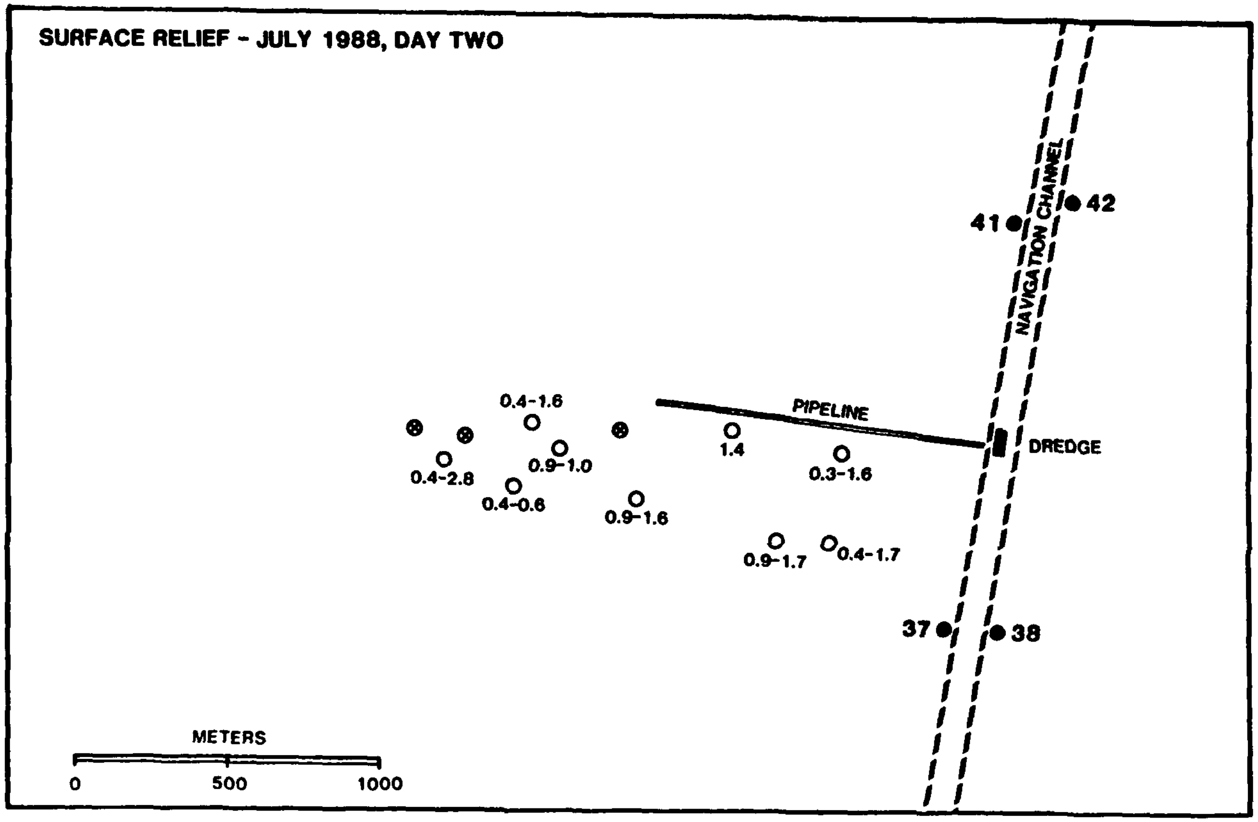

Figure 19. Surface relief (cm) at the sediment-water interface (July 1988, day 3) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

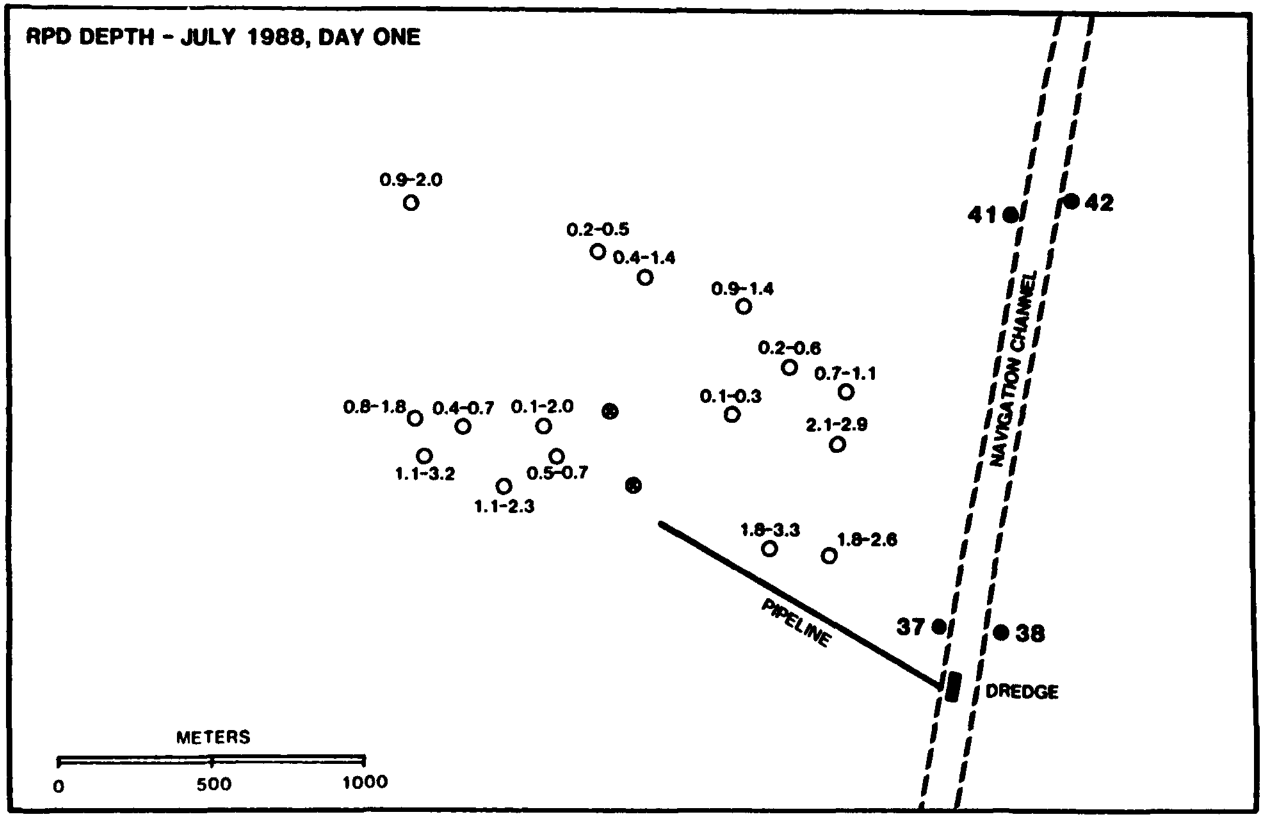

Figure 20. Depth (cm) of the RPD in sediments (July 1988, day 1) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

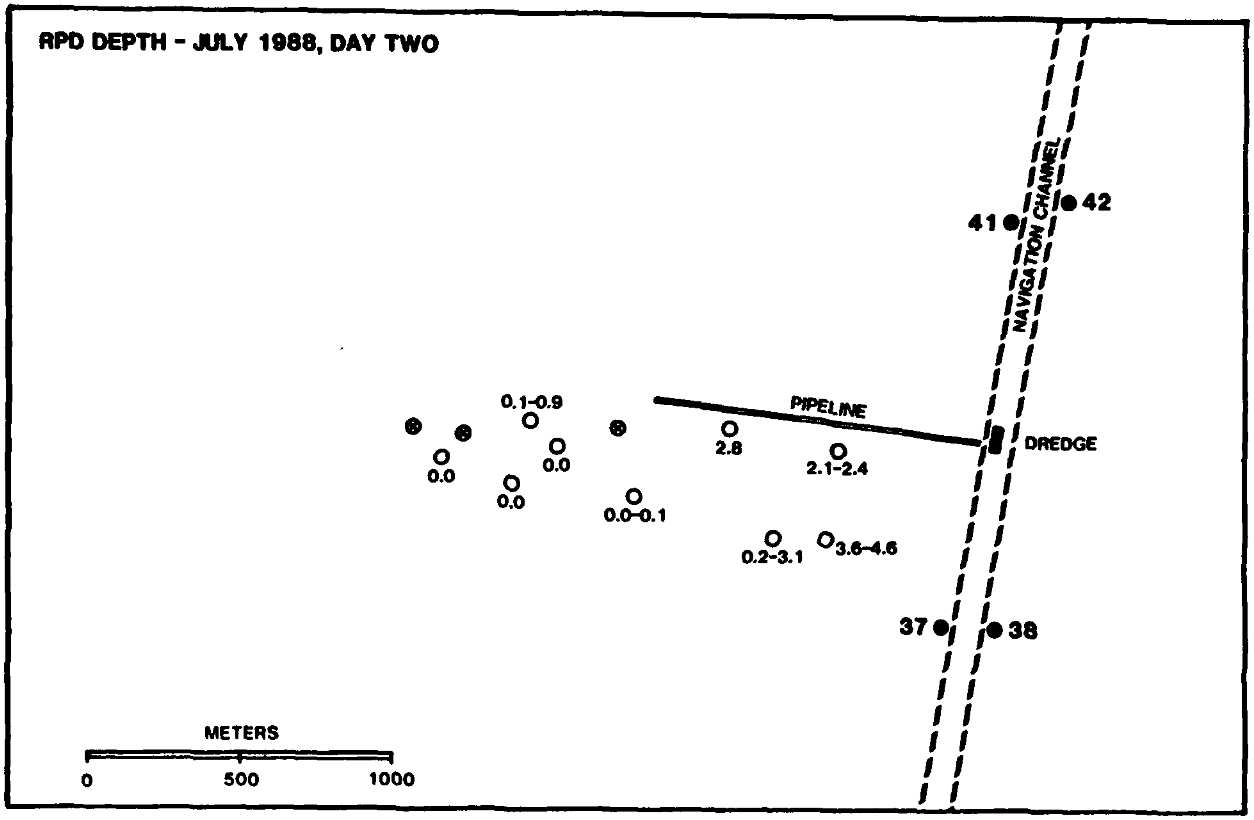

Figure 21. Depth (cm) of the RPD in sediments (July 1988, day 2) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

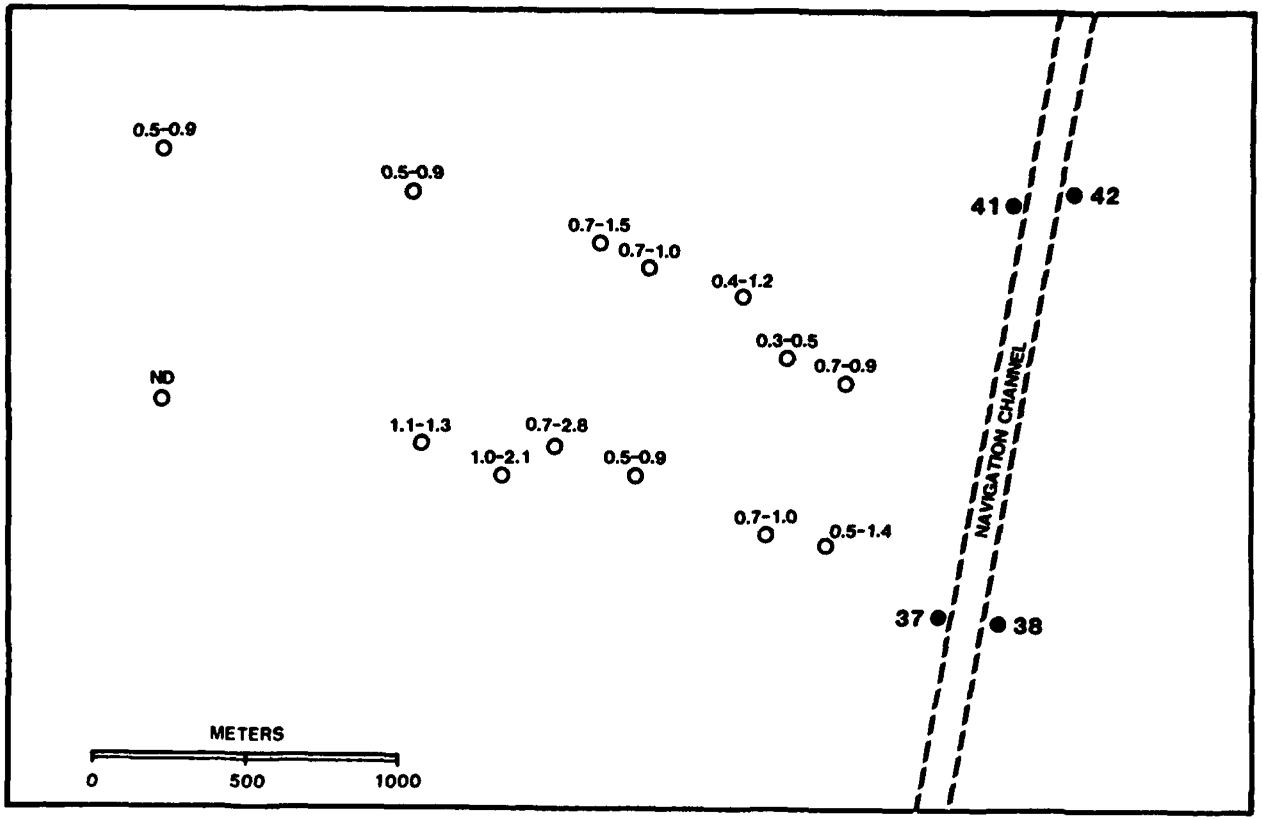

Figure 22. Depth (cm) of the RPD in sediments (September 1988) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate *variability among replicate images. Crossed circles indicate overpenetration of the* camera into the substrate

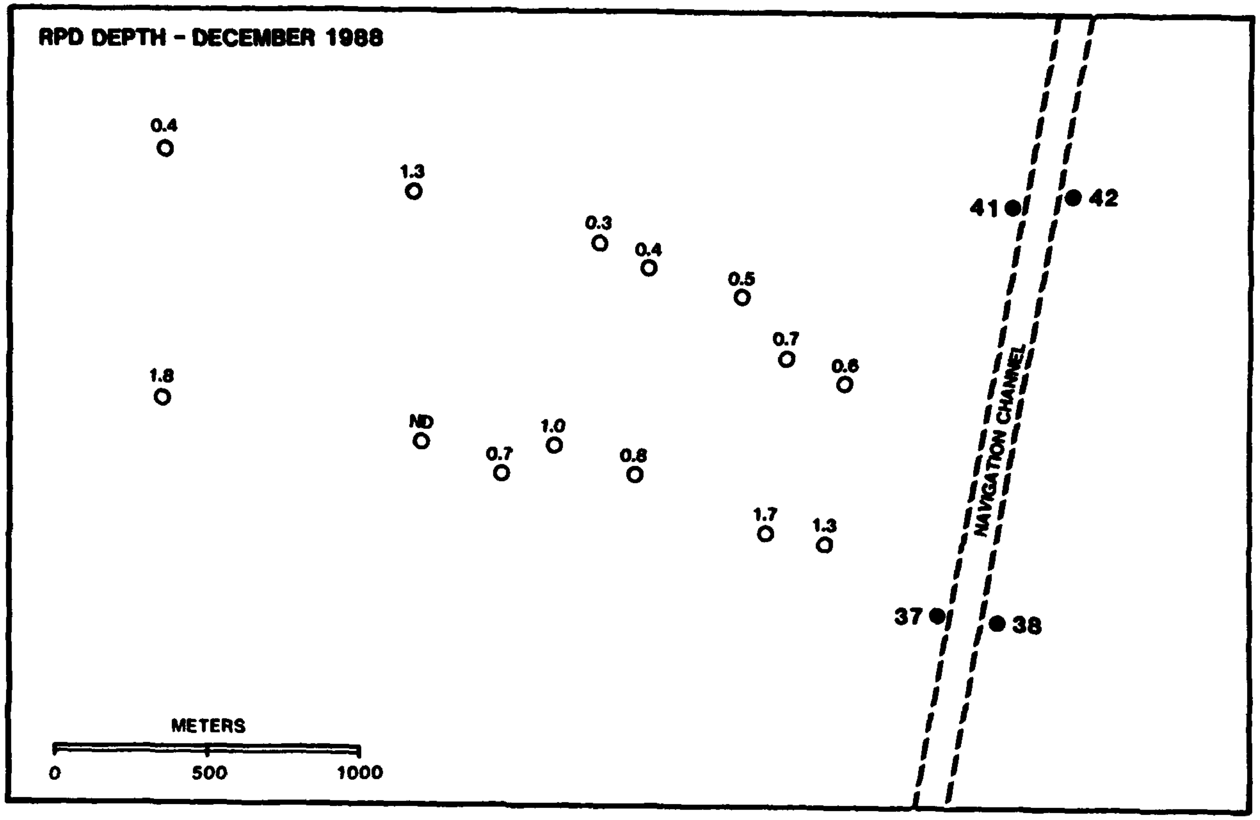

Figure 23. Depth (cm) of the RPD in sediments (December 1988) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

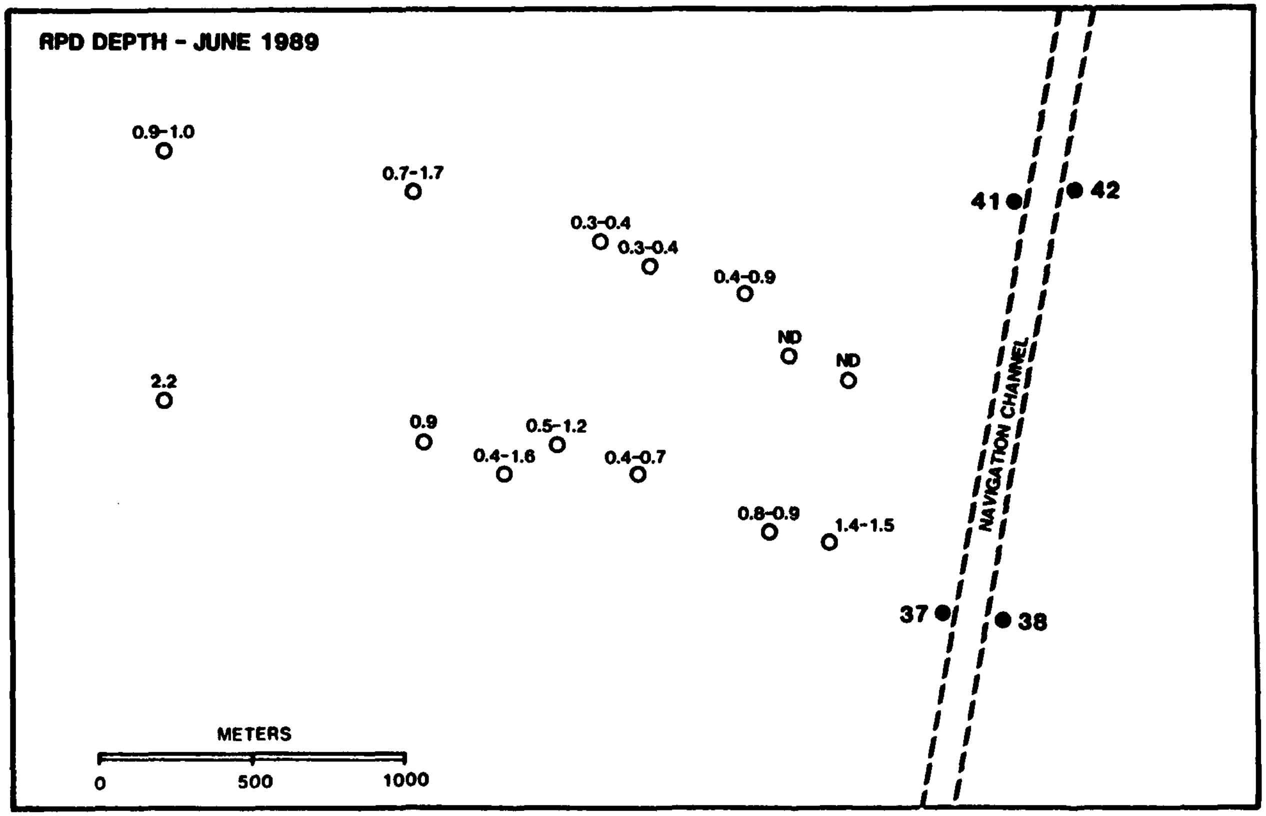

Figure 24. Depth (cm) of the RPD in sediments (June 1989) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Station locations indicated by open circles. Multiple values denoted at a station indicate variability among replicate images. Crossed circles indicate overpenetration of the camera into the substrate

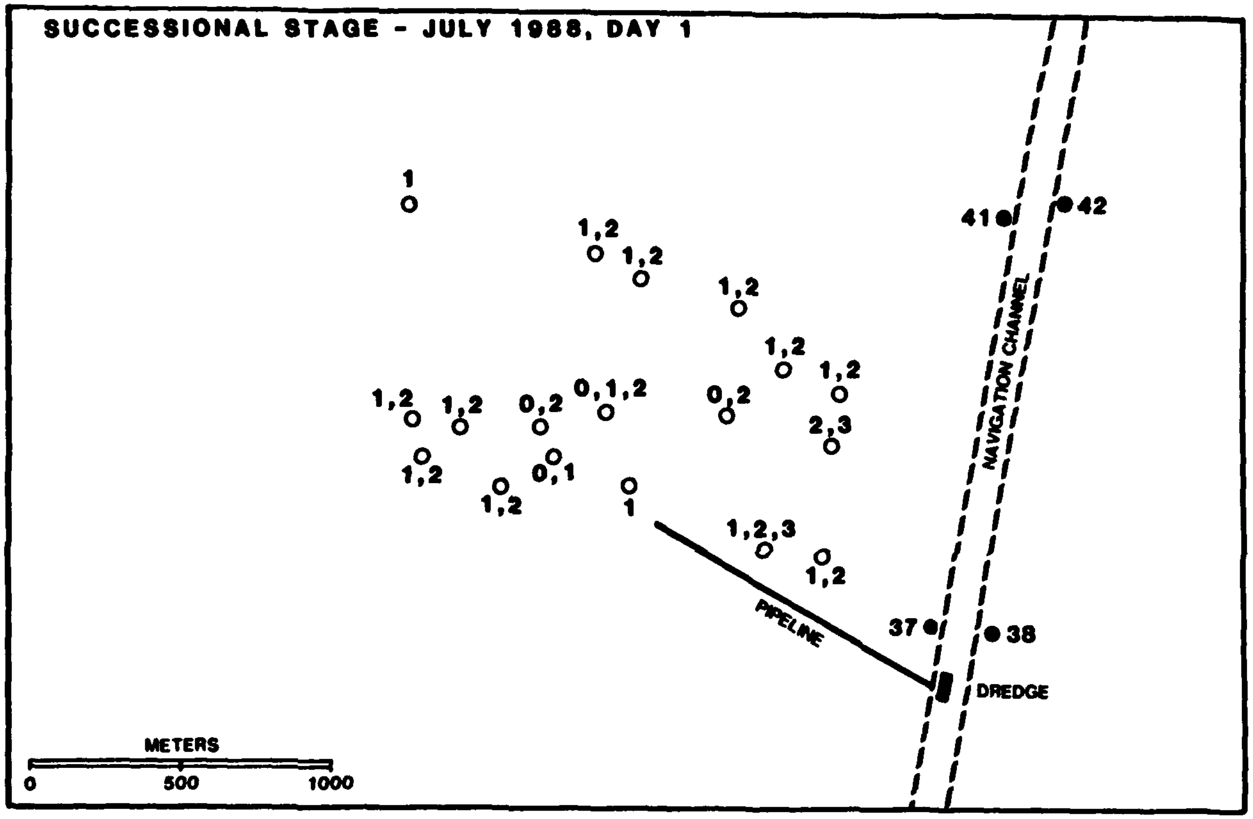

Figure 25. Successional stage of benthic communities (July 1988, day 1) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Multiple stages denoted at a station indicate variability among replicate images or the presence of transition community features

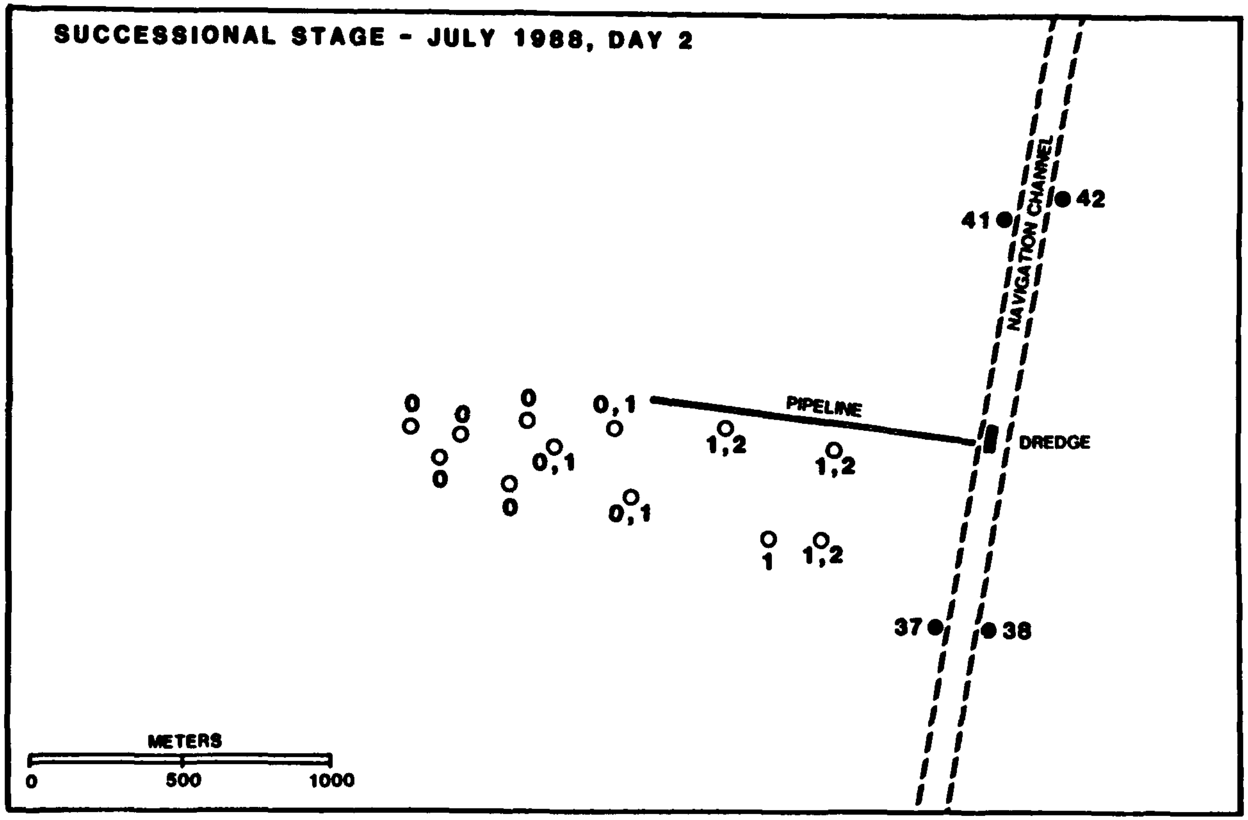

Figure 26. Successional stage of benthic communities (July 1988, day 2) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Multiple stages denoted at a station indicate variability among replicate images or the presence of transition community features

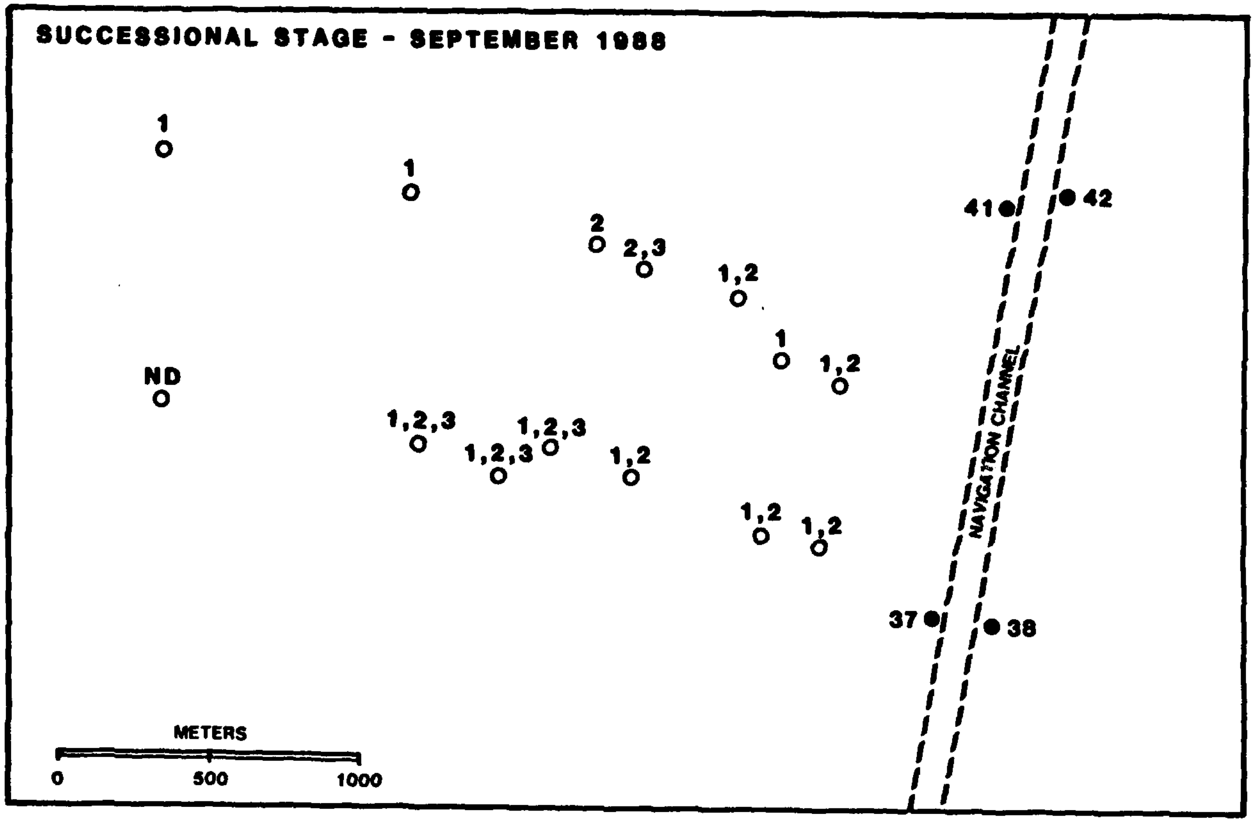

Figure 27. Successional stage of benthic communities (September 1988) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Multiple stages denoted at a station indicate variability among replicate images or the presence of transition community features (ND = no data)

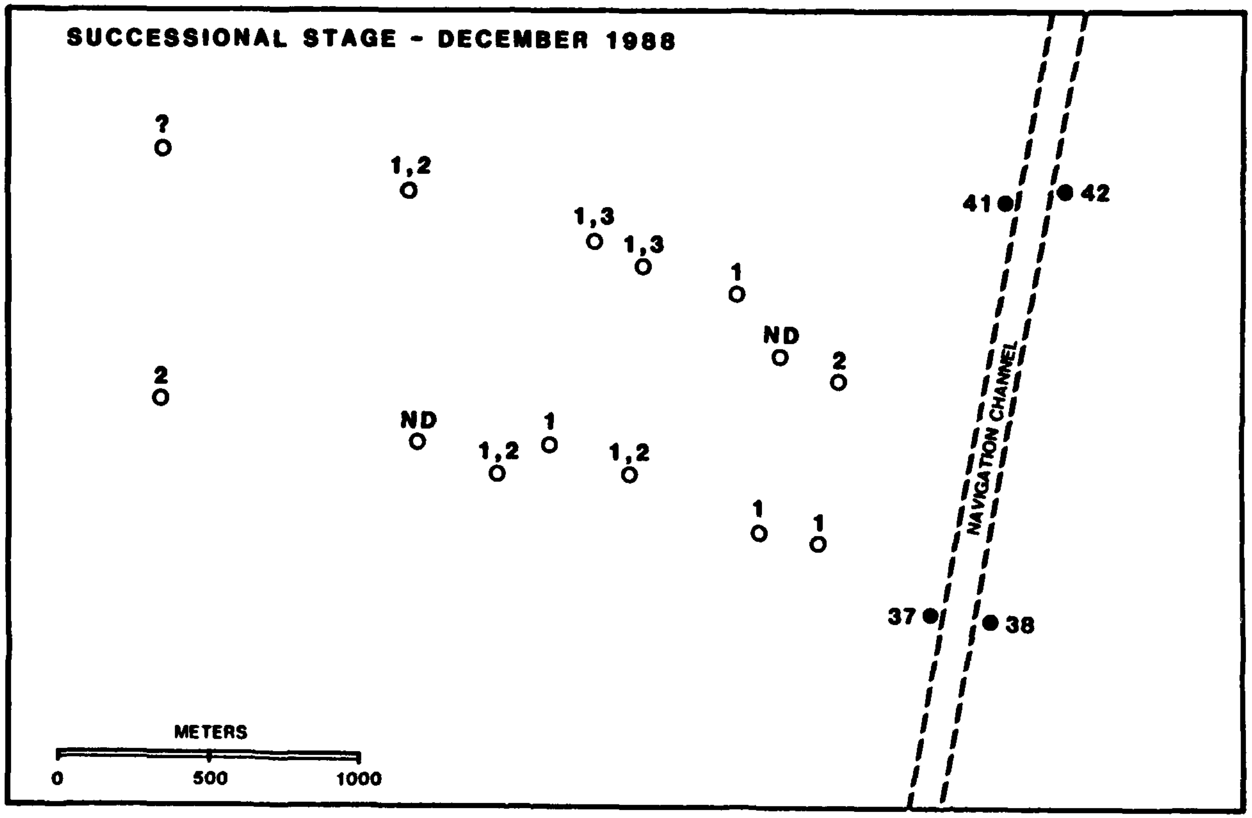

Figure 28. Successional stage of benthic communities (December 1988) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Multiple stages denoted at a station indicate variability among replicate images or the presence of transition community features (ND = no data, ? = indeterminate)

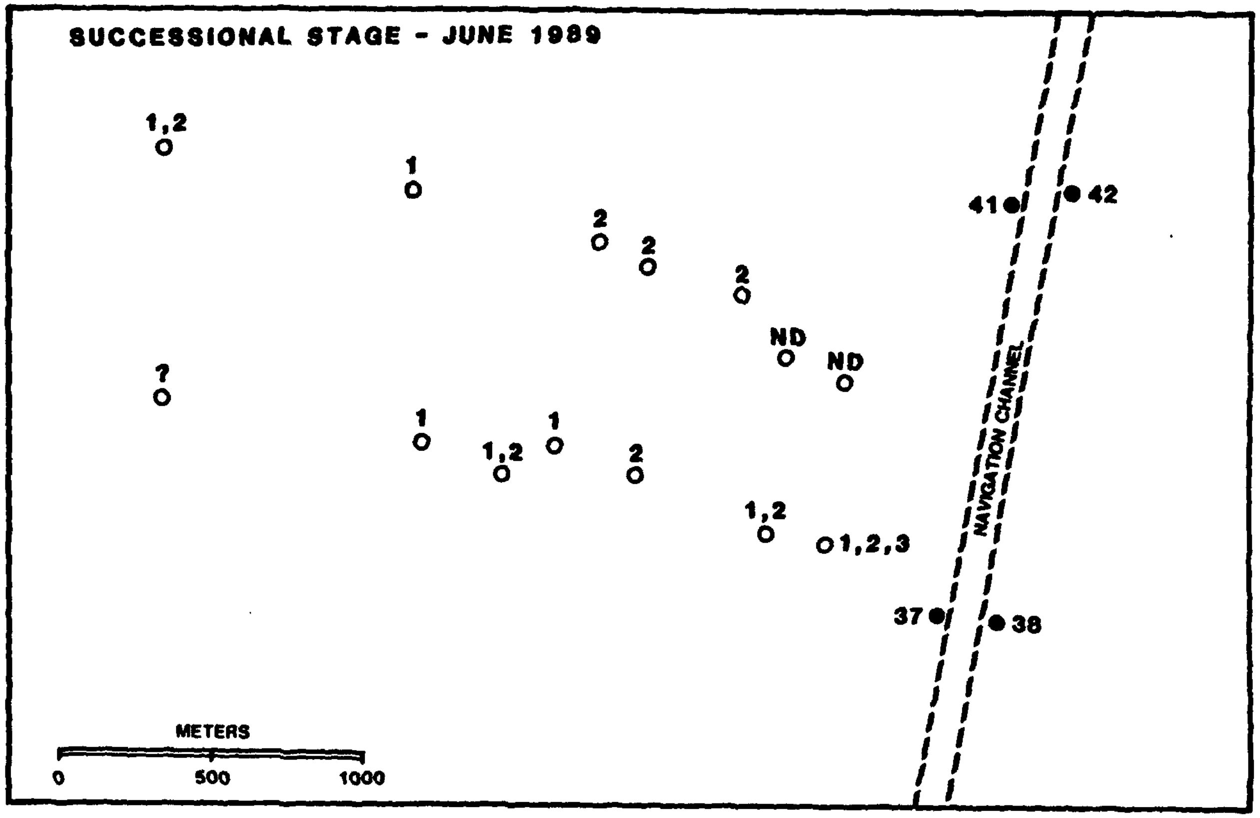

Figure 29. Successional stage of benthic communities (June 1989) in the vicinity of a dredged material pipeline discharge as determined by sediment profiling imagery. Multiple stages denoted at a station indicate variability among replicate images or the presence of transition community features (ND = no data, ? = indeterminate)

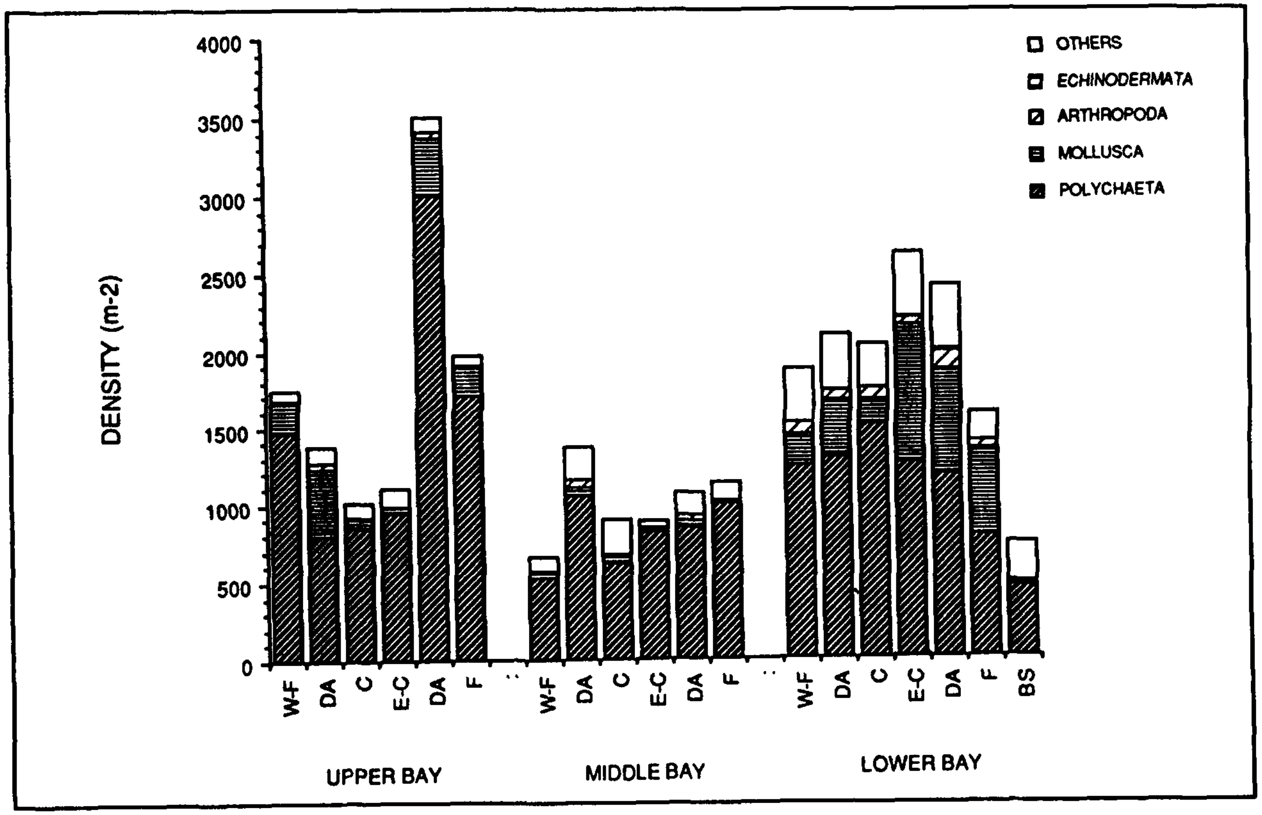

Figure 30. Densities (individuals m^{-2}) of major taxonomic groups for Petersen grab samples taken in Mobile Bay during summer months of 1988. Each transect is partitioned into shallow flat (F), disposal area (DA), and bottoms adjacent to channel (C) habitats on the western (W) and eastern (E) sides of the main navigation channel

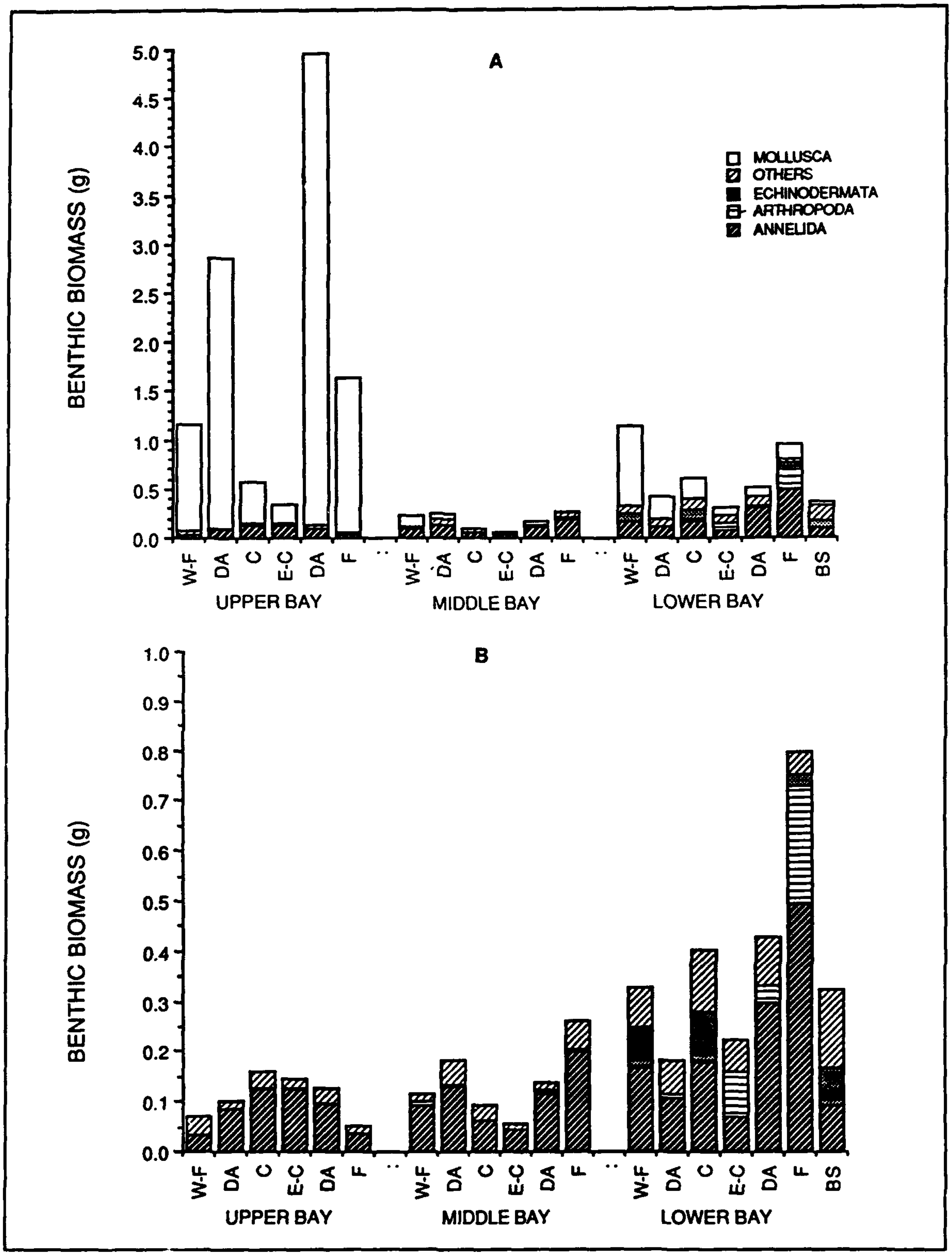

Figure 31. Distribution of benthic biomass (wet weights) among major taxonomic categories in the upper, middle, and lower portions of Mobile Bay during the summer months of 1988. Graph A depicts total biomass, whereas Graph B depicts biomass for all taxonomic groups except molluscs

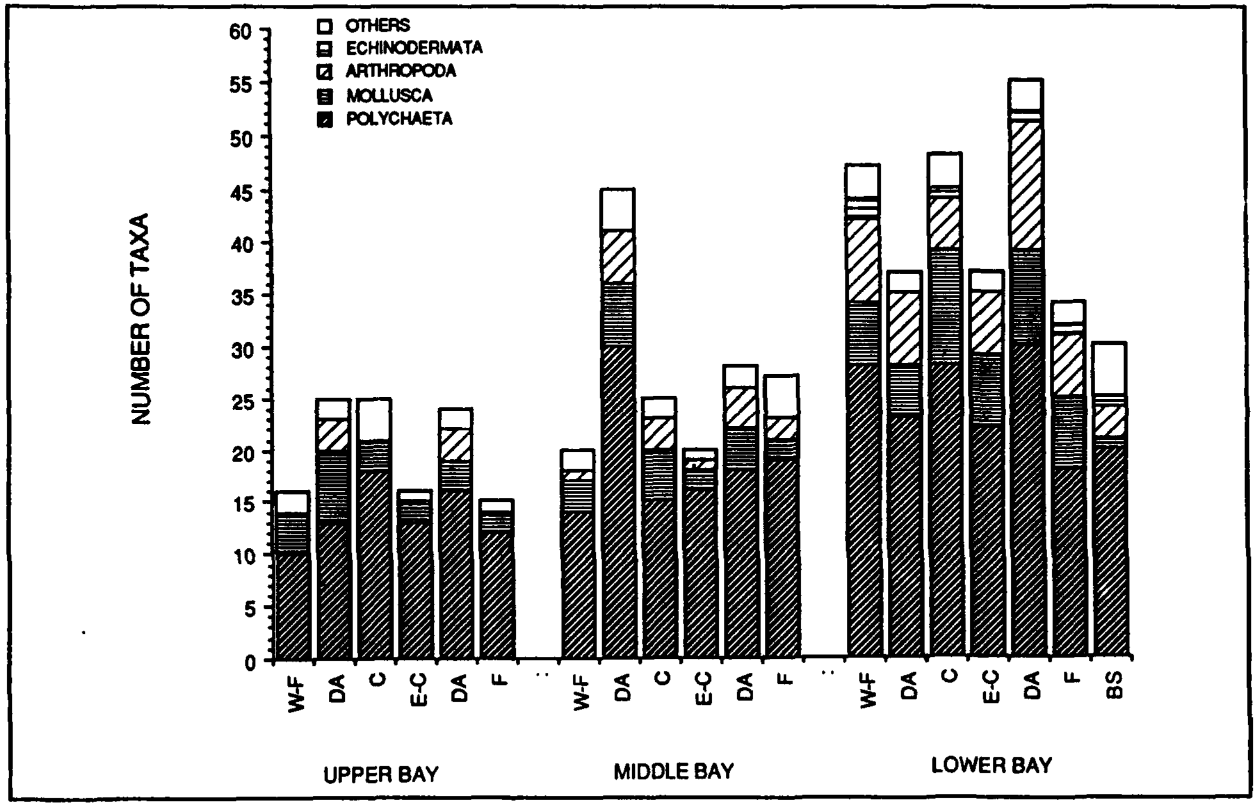

Figure 32. Taxonomic composition of Petersen grab samples taken on transects in the upper, middle, and lower portions of Mobile Bay in the summer months of 1988. Each transect is partitioned into shallow flat (F), disposal area (DA), and bottoms adjacent to channel (C) habitats on the western (W) and eastern (E) sides of the main navigation channel

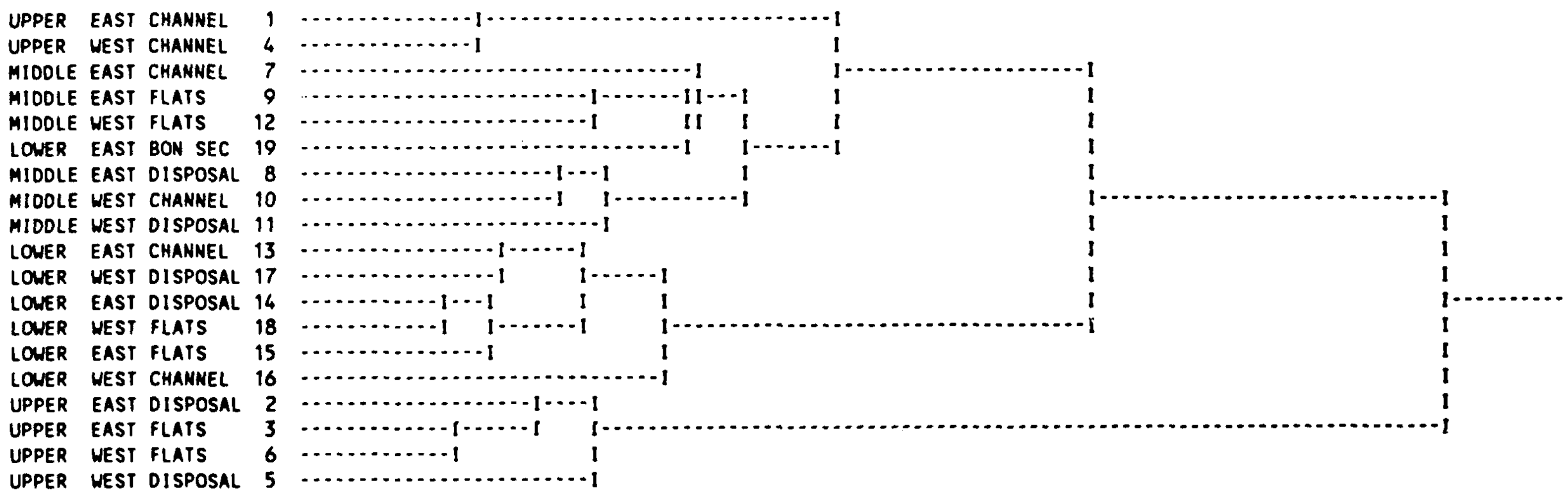

Figure 33. Dendrogram of benthic samples taken on transects through the upper, middle, and lower portions of the Mobile Bay estuary. East and west refer to location with respect to the main navigation channel. Flats, disposal, and channel refer to open-water shallow flat, disposal area, and bottom adjacent to the navigation channel habitats, respectively. Data were log-transformed and sorted with a flexible clustering technique (beta = -0.25)

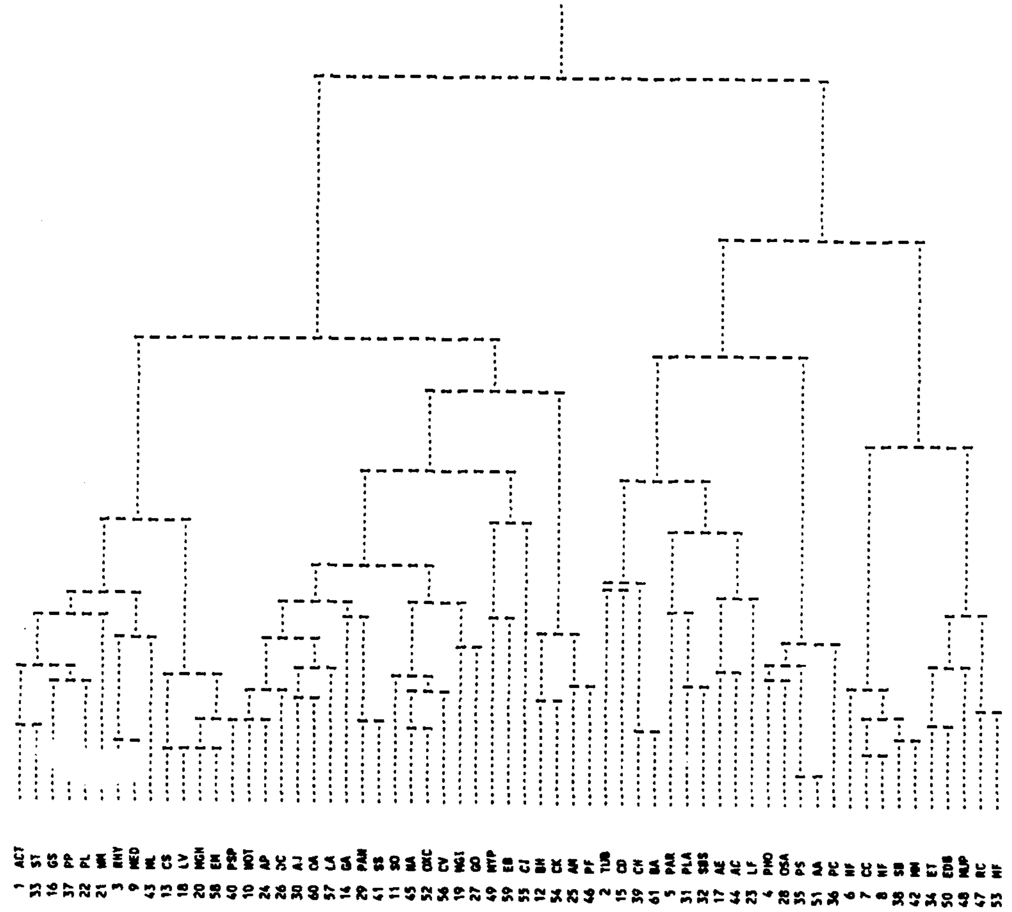

Figure 34. Dendrogram of taxonomic associations of benthic grab data collected in Mobile Bay, Alabama. A flexible sorting strategy (beta = -0.25) was used on log-transformed abundance data. The Bray-Curtis similarity coefficient was used as a resemblance measure

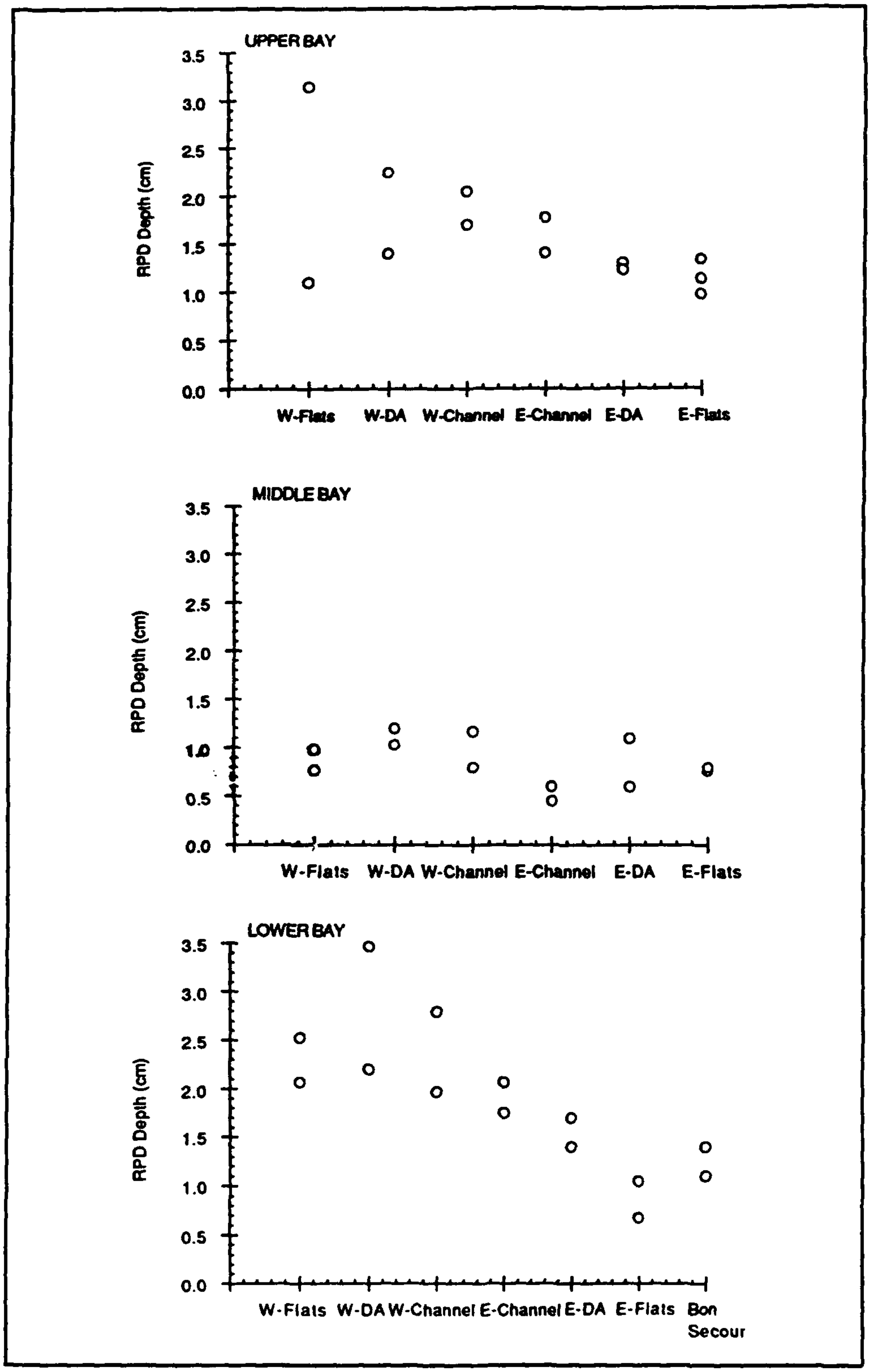

Figure 35. Depth of the RPD in the upper, middle, and lower portions of Mobile Bay during the summer months of 1988. Stations run form west to east on the x-axis. Habitat types include shallow flats, disposal areas (DA), and bottoms adjacent to the main navigation channel

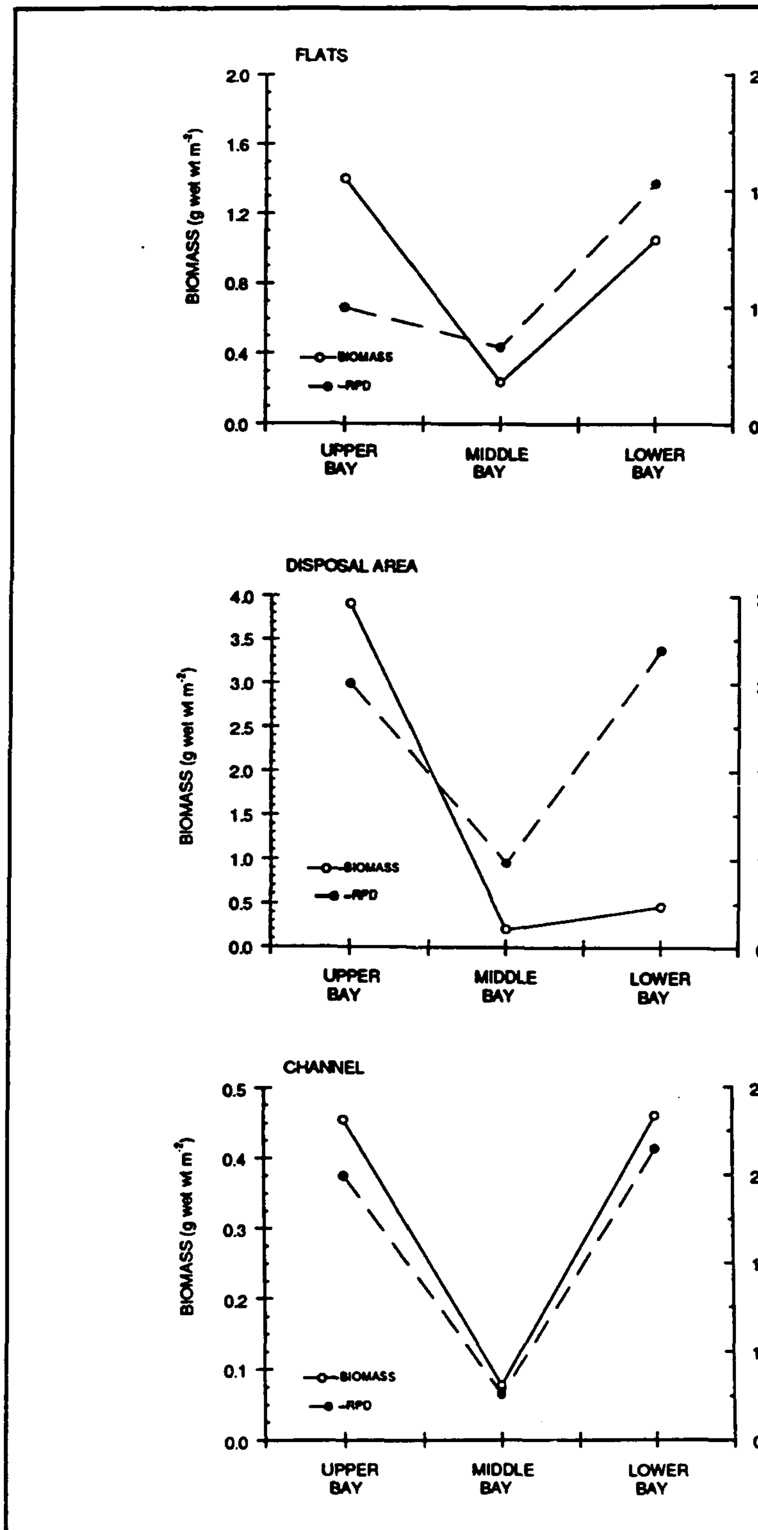

Figure 36. Plots of the relationship between depth of the RPD and total benthic biomass in the upper, middle, and lower portions of Mobile Bay during the summer months of 1988. Separate relationships are shown for shallow flats, disposal areas, and bottoms adjacent to the main navigation channel

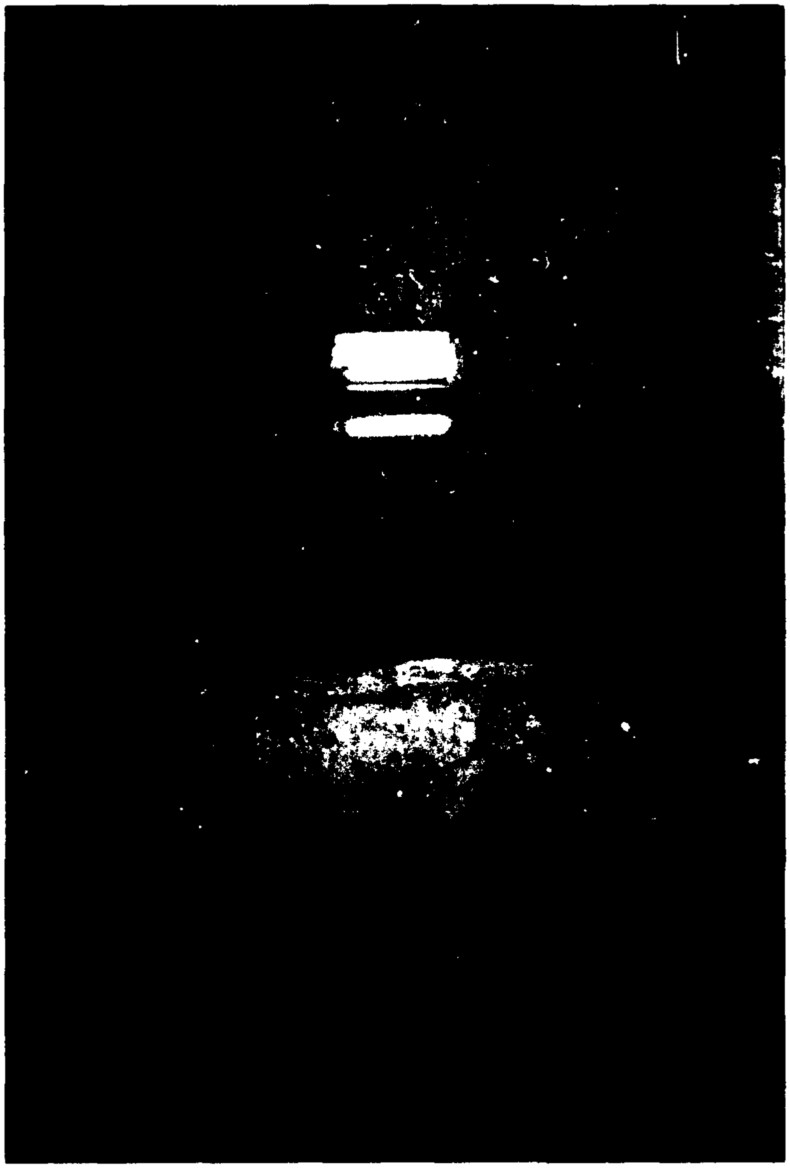

Figure 37. Sediment profile image taken in the disposal area on the eastern side of the main Mobile Bay navigation channel on the Upper Bay transect (station UT E(1300)). Silty sediments with some shell hash; penetration depth 9 cm; RPD depth 1.3 cm; even surface with small mounds and fecal pellets present; tubes at surface; worm at 5 cm; three small oxic feeding voids present. Interpreted to be a successional stage I/III benthic community

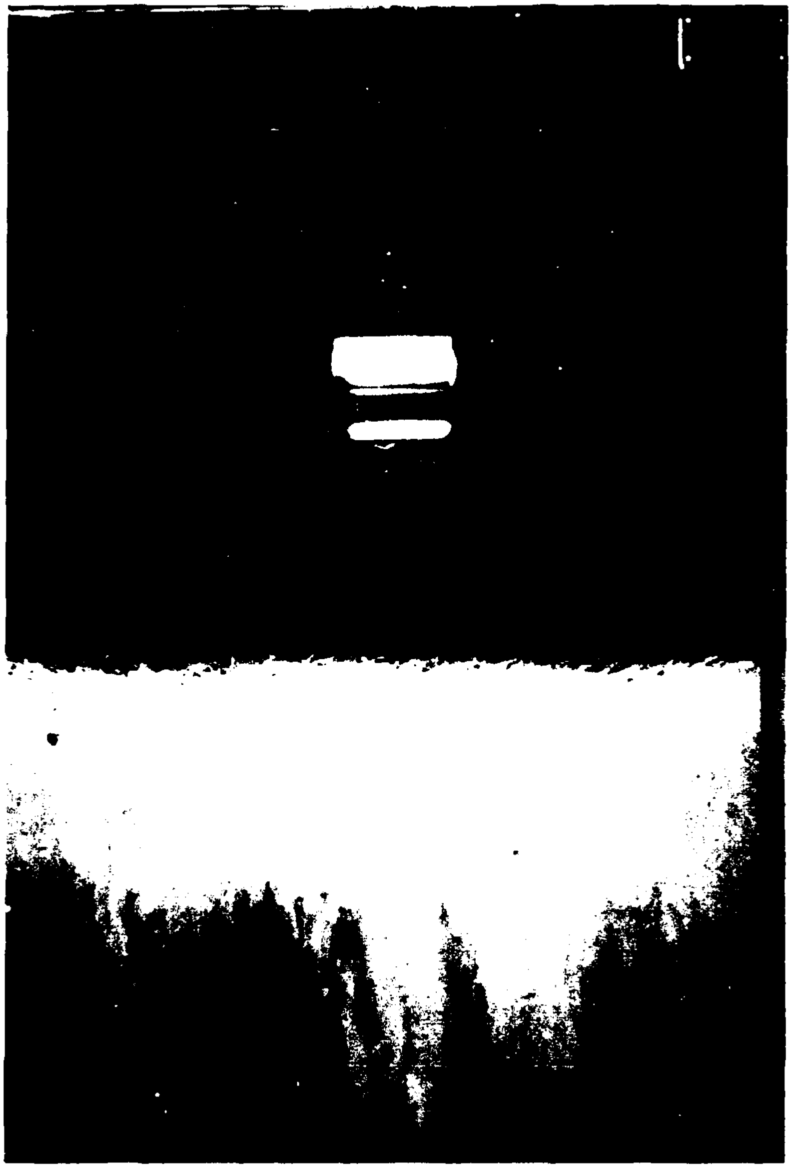

Figure 38. Sediment profile image taken in the shallow flats east of the main Mobile Bay navigation channel on the Upper Bay transect (station UT E(8870)). Silty sediments; penetration depth 11 cm; RPD depth 0.8 cm; surface even with dense tube mat; one small oxic feeding void present. Indicative of a transitional stage I/II benthic community

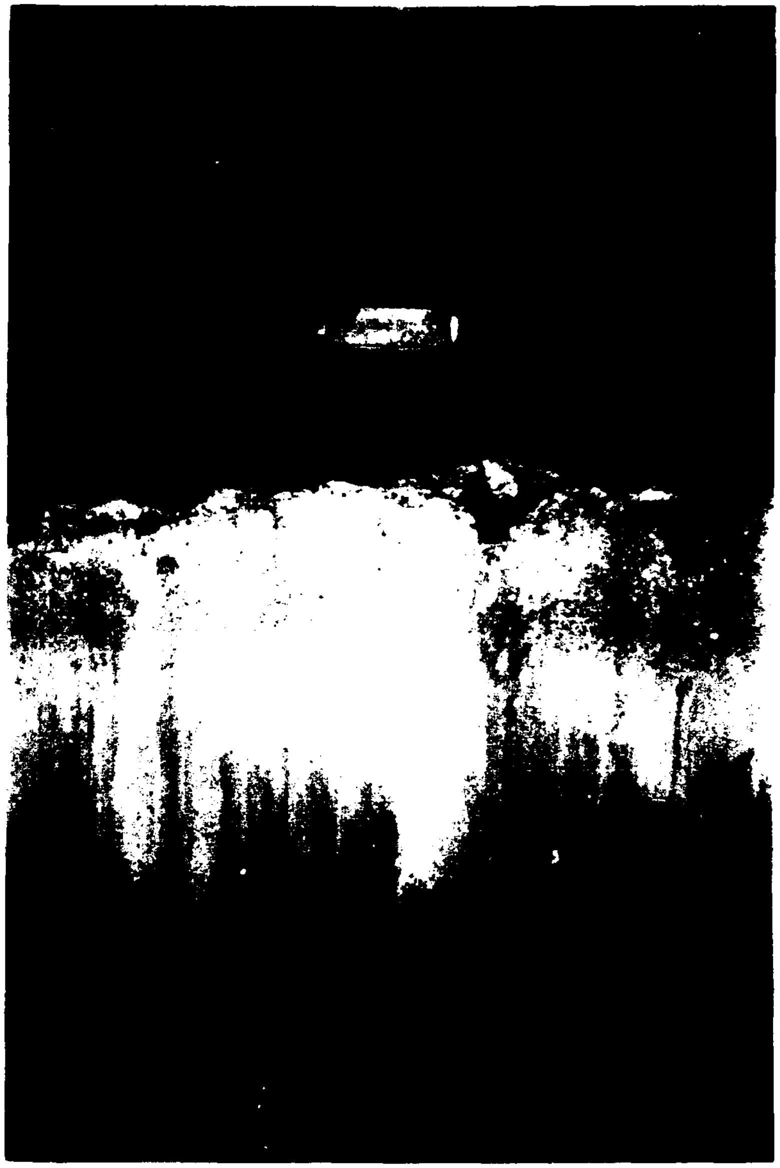

Figure 39. Sediment profile image taken in the shallow flats west of the main Mobile Bay navigation channel on the Middle Bay transect (station MT W(2300)). Silty sediments; penetration depth 13 cm; RPD depth 0.8 cm; uneven surface with some physical disturbance evident; few tubes; sediment layer at 12 cm; feeding voids absent. Successional stage II benthic community

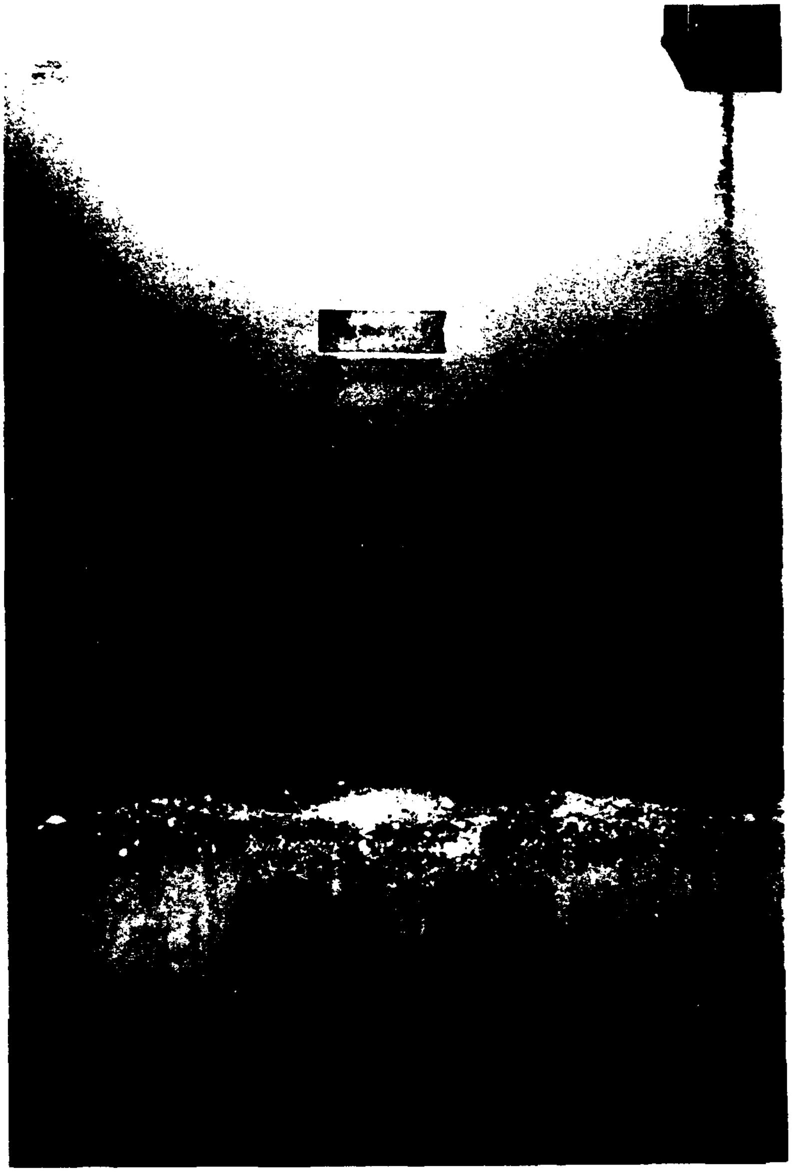

Figure 40. Sediment profiling image taken in the disposal area on the west side of the main Mobile Bay navigation channel on the Middle Bay transect (station MT W(1300)). Fine sand mixed with silt and some shell hash; penetration depth 7 cm; RPD depth 0.7 cm; bed form present; some tubes at surface; one feeding void and three burrows present. Benthic community in successional stage II/III transition

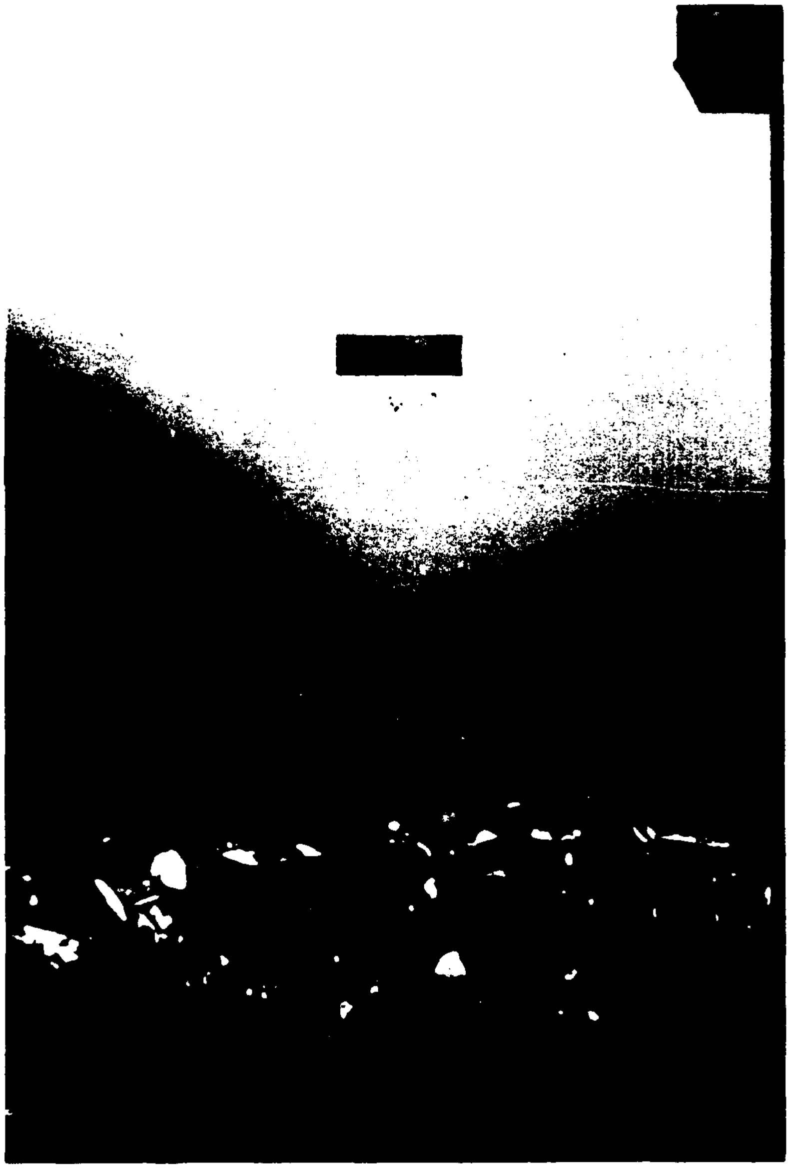

Figure 41. Sediment profiling image taken adjacent to the west side of the main Mobile Bay navigation channel on the Middle Bay transect (station MT W(650)). Clay sediments with shell hash; penetration depth 7 cm; RPD depth 0.4 cm; uneven surface with mound; many voids and one burrow. Benthic community successional stage II

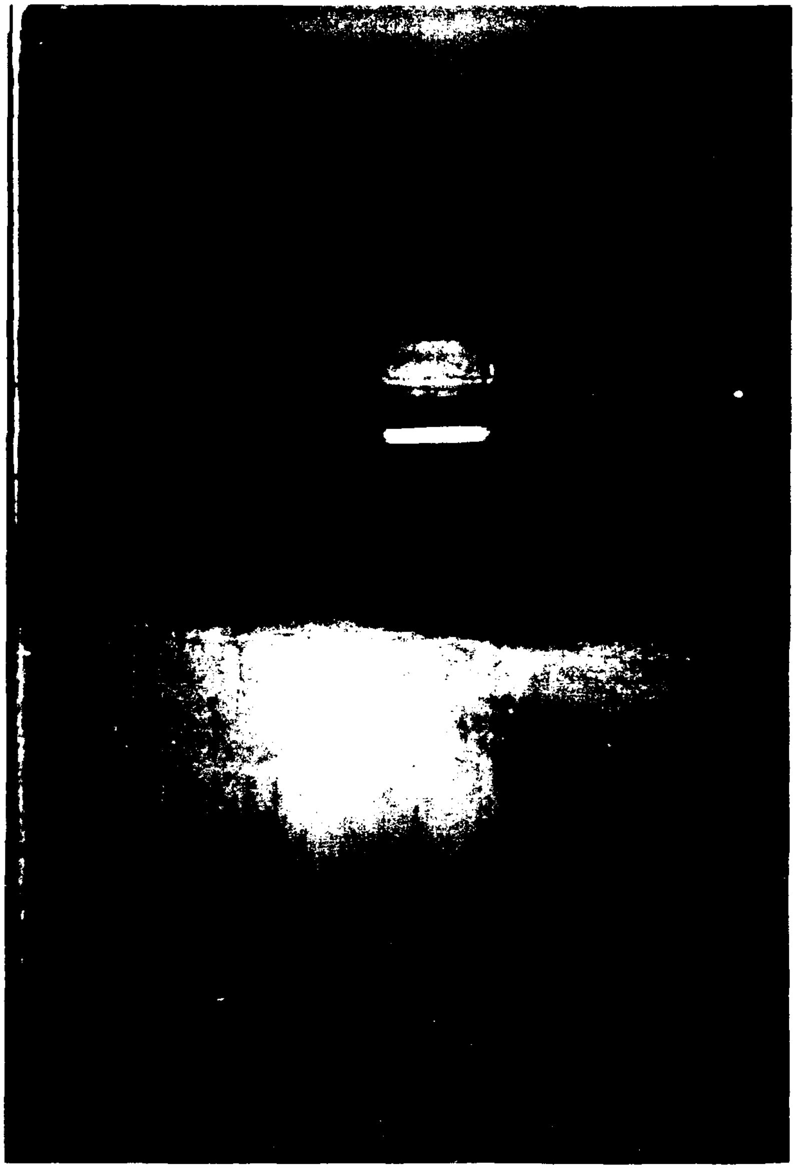

Figure 42. Sediment profiling image taken adjacent to the east side of the main Mobile Bay navigation channel on the Middle Bay transect (station MT E(650)). Silty sediments; penetration depth 12 cm; RPD depth 0.6 cm; even surface with some feeding pits; two oxic voids present. Benthic community successional stage II

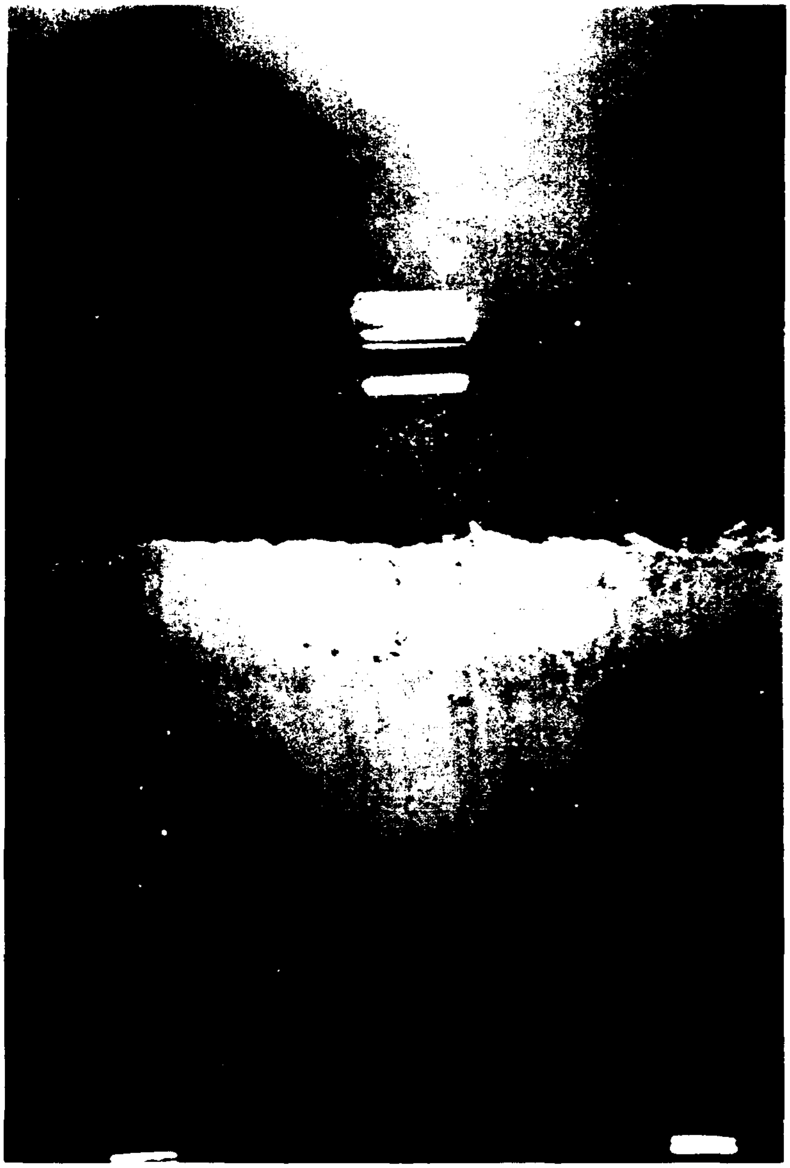

Figure 43. Sediment profiling image taken in the shallow flats on the western side of the main Mobile Bay navigation channel on the Lower Bay transect (station LT W(5800). Silty sediments; penetration depth 12 cm; RPD depth 2.6 cm; even surface with oxic clasts; few tubes; one oxic void and two burrows present. Benthic community successional stage II/III

Figure 44. Sediment profiling image taken in the disposal area on the western side of the main Mobile Bay navigation channel on the Lower Bay transect (station LT W(1300)). Fine sands mixed with silt and some shell hash; penetration depth 20 cm; RPD depth 2.9 cm; uneven surface with mounds; worm in void at 17 cm; few tubes at surface; several large oxic feeding voids present. Benthic community successional stage II/III

Table 1
Types of Data Derived from Sediment Profiling Images and Relevance of Each to Benthic Community Characterizations

Measurement	Method	Information Gained
Depth of penetration	Average of maximum and minimum distance from sediment surface to bottom of prism window	Indicator of degree of sediment compaction
Surface relief	Maximum minus minimum depth of penetration	Indicator of small-scale bed roughness
Depth of apparent RPD layer	Area of oxic layer divided by width of prism window	Indicator of dissolved oxygen conditions in the sediment and bottom waters and the degree of biogenic activity in muddy sediments
Color contrast of apparent RPD	Contrast between oxic and anoxic layers is determined from density slicing of the digitized image	Establishes the RPD boundary. Degree of boundary convolution indicates the dominance of physical or biological processes
Area of anoxic sediment	Area determined from conversion of pixel number below boundary between oxic and anoxic layers	Indicator of processes controlling RPD dynamics when combined with measurement of area of oxic layer
Area of oxic sediment	Total area of image minus area of anoxic layer	Indicator of processes controlling RPD dynamics when combined with measurement of area of anoxic layer
Sediment grain size	Determined from comparison of image to images of known grain size	Provides modal estimate of grain size and sediment layering
Voids	Number counted, depth from surface measured, area determined	Oxic voids indicative of deep-living fauna
Other inclusions (methane bubbles, mud clasts, shells, etc.)	Number counted, depth from surface measured, area determined	Indicate certain physical and biological processes
Burrows	Number counted, area delineated	Indicative of deep-living infauna. Area provides a rough estimate of faunal density
Surface features (tubes, epifauna, mud clasts, shells, pelletized layer)	Number counted, species determined, qualitative estimate of coverage depth and area determined	Indicative of recent biological and physical processes
Dredged material	Thickness above original sediment surface measured and area delineated	Provides quantitative measure for relating impacts to the benthos of a disposal project
Successional stage	Interpretation of key image features listed above	Measure of biological community development

Table 2
Diversity Indices for Petersen Grab Samples[1]

Station	H'	J'	D
A	1.52	0.58	2.48
B	2.21	0.66	4.74
C	1.55	0.60	2.45
D	1.46	0.51	2.91
N-A	2.06	0.71	3.60
N-B	1.86	0.59	4.23
N-C	1.11	0.39	2.98
N-D	2.16	0.73	3.86
S-A	1.75	0.61	3.50
S-B	1.38	0.43	4.25
S-C	1.48	0.47	4.04
S-D	1.61	0.57	3.22

[1] Collected in the vicinity of a dredged material pipeline in Mobile Bay during the summer months of 1988.

Table 3
Image Analysis Summary Data for Sediment Profile Images from Pipeline Discharge Point Stations of the Mobile Bay Maintenance Dredging Study, July 1988 (Day 1)

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
				Layers[2]	Type[2]		Tubes	Fauna	Voids	Burrows			
DS1	1-3	15	1.8	@ 12 cm	SI	E						I?	Dark grey over light grey
	2-3	12	2.6		SI	E	Many		1-O		8.8	II	Tubes <1 x 2 mm
	3-3	11	2.4		SI	E	Many	WR @ 7 cm				II	Tubes < x 2 mm
DS2	1-3	10	3.3	DM?	SI	E,M	Many					I/II	Many light grey clasts @ 7 cm
	2-3	8	2.6		SI	E,M	Many					I/II	
	3-2	8	1.8		SI	U,P	Many		1-O	1 lg.	0.1	II/III	Active burrow
DS3	1-3			DM	SI	OVRP		WR @ 7 cm				I?	Orig. interface @ 10 cm, traces of aerobic sediment, DM very fluid
	2-3			DM	SI	OVRP						?	Same as DS3 1-3
	3-3			DM	SI	OVRP						?	Same as DS3 1-3
DS4	1-3	8	0.7	DM/SH	CL/SI	U						0/I?	DM very fluid, shell layer @ 7 cm, aerobic sediment at original interface
	3-3	9	0.5	DM/SH	SI	E						0/I?	Same as DS4 1-3

(Continued) *(Sheet 1 of 4)*

[1] Station location code: DS = Disposal South, DM = Disposal Middle, DN = Disposal North.
[2] Sediment type: DM = dredged material, SH = shell hash, SI = silt, CL = clay.
[3] Surface and subsurface features: E = even, M = mound, U = uneven, P = pi, OVRP = overpenetrated, CO = oxic clast, CA = anoxic clast, SH = shell hash; many = >24, some = 7-24, few = 1-6, WR = worm, O = oxic, A = anoxic.
[4] Benthic successional stage: 0 = azoic, I = early successional stage, II = transitional stage, III = late successional stage.

Table 3 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
DS5	1-3	9	1.4	@ 7 cm	SI	E,M	Many					I	Tubes <1 x 2 mm, dark grey over light grey
	2-3	8	2.3	@ 7 cm	SI	E,P	Many					I/II	Same as DS5 1-3
	3-3	9	1.1	@ 7 cm	SI	E,M,CO	Many					I	Same as DS5 1-3
DS6	1-3	10	1.1		SI	U,P,CA	Some	WR @ 7 cm	1-O		6.5	II	Tubes <1 x 2 mm
	2-3	10	2.5		SI	E,M	Many					I	Tubes <1 x 2 mm
	1-3	11	3.2		SI	E,M	Many		1-A		10.1	I	Tubes <1 x 2 to 4 mm
DM1	1-1	13	2.3		SI	E,P	Some		4-O	1 lg., 2 sm.	8.8, 9.2	II/III	Anaerobic sediment at surface
	2-3	12	2.9		SI	E	Few			4 sm.		II	Tubes <1 x 2 mm
	3-3	11	2.1		SI	E,CA	Few	WR @ 10 cm		4 sm.		II	Anaerobic sediment at surface
DM2	1-2	14	0.1	DM	SI	E		WR @ 10 cm				0/II?	5 cm DM over original interface, aerobic sediment under DM
	2-1	13	0.1	DM	SI	E		WR @ 3 cm?				0/II?	Same as DM2 1-2
	3-3	13	0.3	DM	SI	E		WR @ 8 cm				0/II?	Same as DM2 1-2
DM3	1-3			DM	SI	OVRP		WR @ 5, 3 cm	1-O, 1-A			0/II?	Original interface @ 10 cm, aerobic sediment under DM
	2-1			DM	SI	OVRP			1-O			0/I?	Same as DM3 1-3
	3-3			DM	SI	OVRP			2-A			?	Same as DM3 1-3
DM4	1-3	12	0.1	DM	SI	E		WR @ 7 cm	1-O		1.6	0/II?	DM very fluid, aerobic sediment under DM
	2-2	9	2.0	SH @ 7 cm	SI	E,CA	Some	2 WR @ 3 cm	1-A		0.1	II	
	3-3	7	0.8		SI	E,M,P	Some	WR @ 6 cm			10.1	II	

(Continued)

(Sheet 2 of 4)

Table 3 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
DM5	1-2	9	0.5		SI	U,P	Some		1-A			I	Tubes <1 x 3 to 4 mm
	2-3	10	0.4	@ 8 cm	SI	U,P	Many	2 WR @ 3 cm	1-A	1 sm.	10.1	I/II	Dark grey over light grey
	3-3	10	0.7	@ 8 cm	SI	U,P	Many			1 sm.		I	Dark grey over light grey
DM6	1-3	9	0.8	@ 8 cm	SI	E,P	Some	WR @ 4, 6 cm		1 sm.	0.8	II	Dark grey over light grey
	2-2	10	1.8	@ 8 cm	SI	E	Many		1-A		7.8	I/II	Same as DM6 1-3
	3-2	10	1.4	@ 8 cm	SI	U,P	Many	2 WR @ 4 cm				I/II	Same as DM6 1-3
DN1	1-3	10	1.1		SI	E		WR @ 3 cm				I?	
	2-3	9	0.8		SI	E	Some		1-O, 1-A	3 sm.	1.9, 7.3	I/II	
	3-2	8	0.7		SI	E	Many		2-O	6 sm.		I/II	Tubes <1 x 3 to 4 mm
DN2	1-2	8	0.2	DM?	SI	E,P	Many	WR @ 4 cm		1 sm.	2.5	I/II	Tubes <1 x 3 to 4 mm, many light grey clasts, same as DS2 1-3
	2-2	8	0.6	DM?	SI	E	Many	WR @ 2 cm	1-O	7 sm.	1.8	I/II	Tubes <1 x 3 to 4 mm, same as DN2 1-3
	3-3	7	0.2	DM?	SI	E, SH	Many			2 sm.	3.7	I/II	Same as DN2 1-3
DN3	1-3	9	0.9		SI	U,P	Many	WR @ 7 cm		4 sm.		I/II	Tubes <1 x 2 mm
	2-3	9	0.9		SI	U,P	Some					I	Tubes <1 x 2 mm
	3-3	9	1.4		SI	U,P	Many	WR @ 5, 7 cm				I/II	Tubes <1 x 2 to 4 mm

(Continued)

(Sheet 3 of 4)

Table 3 (Concluded)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
DN4	1-3	9	1.4		SI	E	Some	WR @ 6 cm	1-O	4 sm.	6.0	II	Same as DN2 1-3
	2-3	10	0.9		SI	E	Some		1-O	4 sm.	7.1	I/II	Same as DN2 1-3
	3-3	10	0.4		SI	E	Some		1-O	8 sm.	5.0	I/II	Same as DN2 1-3
DN5	1-3	11	0.5		SI	E,M	Some		2-O	6 sm.		I/II	Brittle star arms
	2-3	11	0.5		SI	E	Few			4 sm.		I/II	Same as DN2 1-3
	3-3	11	0.2		SI	E	Few	WR @ 1 cm	2-O	4 sm.	4.9	I/II	Same as DN2 1-3
DN6	1-3	12	2.0		SI	E,P	Many					I?	Same as DN2 1-3
	2-3	11	1.1		SI	E,M	Many					I	Similar to DN2 1-3
	3-2	11	0.9		SI	E,M	Few					I	Similar to DN2 1-3

(Sheet 4 of 4)

Table 4
Image Analysis Summary Data for Sediment Profile Images from Pipeline Discharge Point Stations of the Mobile Bay Maintenance Dredging Study, July 1988 (Day 2)[1]

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
				Layers[2]	Type[2]		Tubes	Fauna	Voids	Burrows			
DS1	1-3	13	4.6	DM?	SI	E,M	Few					II?	
	3-3	12	3.6	DM?	SI	U,M,P	Many		1-A		4.6	I/II	
DS2	2-3	15	0.2	DM	SI	D						?	
	3-2	14	3.1	DM	SI	U	Some					I?	
DS3	1-3	16	0.0	DM	SI	E		WR @ 10, 14 cm				0/I	10 cm DM over original interface
	2-3			DM	SI	OVRP			1-A			?	DM very fluid, original interface @ 8 cm
	3-3	10	0.1	DM	SI	U			6-1, 1-O			0/I	2 to 3 cm DM, very fluid
DS4	1-1	13	0.0	DM	SI	E			1-A			0	8 cm DM, very fluid
	3-2	8?	0.0	DM	SI	U?		WR @ 5 cm				0/I	3 to 4 cm DM, very fluid
DS5	1-3	9?	0.0	DM	SI	E?						0	3 to 4 cm DM, very fluid
	2-3	8?	0.0	DM	SI	U?						0	2 to 3 cm DM, very fluid
	3-3		0.0	DM	SI	OVRP			1-O			0	DM very fluid

(Continued)

[1] Station location code: DS = Disposal South, DM = Disposal Middle.
[2] Sediment type: DM = dredged material, SH = shell hash, SI = silt.
[3] Surface and subsurface features: E = even, M = mound, U = uneven, P = pit, D = disturbed, OVRP = overpenetrated, B = bed form, CA = anoxic clast, CO = oxic clast, SH = shell hash; many = >24, some = 7-24, few = 1-6, WR = worm, O = oxic, A = anoxic.
[4] Benthic successional stage: 0 = azoic, I = early successional stage, II = transitional stage, III = late successional stage.

Table 4 (Concluded)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
DS6	1-3	15	0.0	DM	SI	U						0	4 to 5 cm DM, aerobic sediment present @ original interface
	2-3	16	0.0	DM	SI	E						0	6 cm DM, same as DS6 1-3
	3-3	16	0.0	DM	SI	U						0	6 cm DM, same as DS6 1-3
DM1	1-3	12	2.1		SI	E,M	Many					I/II	Tubes <1 × 2 mm
	3-2	11	2.4		SI	U,B?	Some					I/II	Tubes <1 × 8 to 10 mm
DM2	1-2	13	2.8		SI	B	Some					I/II	Tubes 1 × 5 mm
DM3	1-2	>22		DM	SI	OVRP		WR @ 18 cm				0/I	Original interface @ 17 cm, DM very fluid
DM4	1-2	9?	0.1	DM	SI	U?						0	DM very fluid, interface @ 9 cm
	2-3	9?	0.9	DM	SI	U?						0	DM very fluid, interface @ 9 cm
	3-3	6?	0.4	DM	SI	U?						0	DM very fluid, interface @ 6 cm
DM5	1-3	>22		DM	SI	OVRP		WR @ 2 cm				0	DM very fluid, interface @ 5 cm
	2-2	>22		DM	SI	OVRP						0	DM very fluid, interface @ 5 cm
	3-2	>22		DM	SI	OVRP						0	DM very fluid, interface @ 11 cm
DM6	1-3	>22		DM	SI	OVRP						0	DM very fluid, interface @ 11 cm
	2-2	>22		DM, SH @21	SI	OVRP						0	DM very fluid, interface @ 11 cm
	3-2	>22		DM	SI	OVRP						0	DM very fluid, interface @ 9 cm

Table 5
Image Analysis Summary Data for Sediment Profile Images from Pipeline Discharge Point Stations of the Mobile Bay Maintenance Dredging Study, September 1988

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
				Layers[2]	Type[2]		Tubes	Fauna	Voids	Burrows			
PS1	1-3	13	1.3	@ 11 cm	SI	U,B?			2-O		1.7, 3.1	II	Light grey layer
	2-3	10	0.5		SI	E,CA,CO						I?	
	3-3	13	1.4		SI	E	Few		2-O		5.8, 6.7	II	
PS2	1-3	9	0.9		SI	B,CA?	Few		2-A			I/II	
	2-3	11	1.0		SI	E,CO						I?	Light grey clumps @ 4 cm
	3-3	9	0.7	@ 6 cm	SI	U,P,B?	Few					I	Light grey over dark grey
PS3	1-3	13	0.9	?	SI	E	Some		4-O	5	9.0	I/II	Uniform dark grey, reworked
	2-3	15	0.5	?	SI	U			2-O			I	Uniform dark grey, fish
	3-3	13	0.7	?	SI	U,P	Some	WR @ 21 cm	4-O	2	5.9, 6.8, 9.3, 9.8	I/II	Light grey clay clumps, reworked
PS4	1-3	16	2.8	?	SI	E			3-O	6	8.6, 10.6, 11.2	II	Uniform dark grey, reworked
	2-3	16	0.7	?	SI	U,P	Few	2 WR @ 12 cm	5-O	5	7.4, 9.5, 10.8, 10.9, 12.8	I/II	Uniform dark grey, reworked
	3-3	17	1.9	?	SI	U,CO, CA			3-O	9	10.6, 11.0	II/III	Very reworked

(Continued)

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[1] Station location code: PS = Postdisposal South, PN = Postdisposal North.

[2] Sediment type: SI = silt, CL = clay.

[3] Surface and subsurface features: E = even, U = uneven, B = bed form, P = pit, CO = oxic clast, CA = anoxic clast, D = disturbed, SH = shell hash; many = >24, some = 7-24, few = 1-6, WR = worm, O = oxic, A = anoxic.

[4] Benthic successional stage: I = early successional stage, II = transitional stage, III = late successional stage.

Table 5 (Concluded)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
PS5	1-3	18	1.0	?	SI	E,CA			3-O	6	11.3	II	Reworked, same as PS3, PS4
	2-3	18	2.1	?	SI	U,P			2-O	5	9.4, 9.6	II/III	Reworked, same as PS3, PS4
	3-3	18	1.8	?	SI	E	Some	WR @ 15 cm	2-O	3		I/III	Same as PS3, PS4
PS6	1-3	12	1.1		SI	U					3.2	I?	Light grey layer @ 11 cm
	2-3	14	1.3		SI	U,CO,CA			3-O		6.3, 6.7	II	Light grey layer @ 12 cm
	3-3	14	1.2		SI	U,CO,CA		WR @ 12 cm	2-O		2.6	II/III	Light grey layer @ 11 cm
PN1	1-3	11	0.9		SI	U,P	Few		2-O		2.7, 9.0	I/II	
	2-3	10	0.7		SI	E						I?	
	3-3	12	0.8		SI	E	WR @ 10 cm					II	
PN2	1-3	6	0.5	?	CL	E,P,SH						I?	Light grey layer @ 3 cm
	2-3	3	0.3	?	CL	E,SH	Some					I?	Light grey clay
	3-3	7	0.3		SI/CL	E,SH	Many		1-O			I	
PN3	1-3	13	0.4	?	SI	D,U		WR @ 5 cm	2-O		7.5, 9.1	I/II	
	2-3	12	0.5	?	SI	U						I?	2 cm very dark grey over dark grey
	3-3	13	1.2	?	SI	D,U,CA, CO		WR @ 7 cm				II	
PN4	1-3	18	1.0	?	SI	E		3-O	8			II/III	Reworked
	2-3	17	0.7	?	SI	U	WR @ 15, 17 cm	3-O	8		2.8, 2.8	II/III	Reworked
	3-3	19	1.0	?	SI	E	WR @ 5, 17 cm	4-O	8			II/III	Reworked

Table 6
Image Analysis Summary Data for Sediment Profile Images from Pipeline Discharge Point Stations of the Mobile Bay Maintenance Dredging Study, December 1988

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment Type[2]	Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
						Tubes	Fauna	Voids	Burrows			
S1	1-3	16	1.3	SI	E						I?	
S2	1-2	12	1.7	SI	E						I?	
S3	1-3	13	0.8	SI	E,SH	Some		2-O	9	7.9, 11.6	I/II	Reworked DM
S4	3-3	13	1.0	SI	E	Some					I	
S5	3-2	15	0.7	SI	U,CO,CA	Few		6-O	3	7.3, 9.4, 9.5, 9.7, 9.9, 10.9	I/II	Reworked DM
S7	1-3	8	1.8	SI	E,M				1		II	
N1	1-3	11	0.6	SI	E		WR @ 9 cm				II	
N3	3-3	13	0.7	SI	E	Some		1-A		11.3	I	
N4	1-3	17	0.5	SI	E,M	Some	WR @ 16 cm	2-O	8	15.0, 15.3	I/III	Reworked DM
N5	1-3	19	0.4	SI	E	Few?	WR @ 4 cm		7		I/III	
	3-3	13	0.3	SI	U,D	Few	2 WR @ 11 cm	3-O	8	7.4, 8.9, 10.4	I/III	Reworked DM
N6	3-3	12	1.3	SI	E	Few			3		I/II	
N7	1-3	8	0.4	SI	E,CO						?	

[1] Station location code: S = south; N = north.

[2] Sediment type: SI = silt.

[3] *Surface and subsurface features:* E = even, M = mound, U = uneven, D = disturbed, CO = oxic clast, CA = anoxic clast, SH = shell hash; some = 7-24, few = 1-6, WR = worm, O = oxic, A = anoxic.

[4] Benthic successional stage: I = early successional stage, II = transitional stage, III = late successional stage.

Table 7
Image Analysis Summary Data for Sediment Profile Images from Pipeline Discharge Point Stations of the Mobile Bay Maintenance Dredging Study, June 1989

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment Type[2]	Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
						Tubes	Fauna	Voids	Burrows			
PS1	1-3	14	1.4	SI	E,P						I?	
	2-3	14	1.4	SI	U	Few		1-O		3.2, 3.7	II	
	3-3	15	1.5	SI	U,P	Few		2-O	1	5.8, 6.7	III	
PS2	2-3	12	0.9	SI	E,M	Few	WR @ 5, 6 cm		1		II	
	3-3	10	0.9	SI	U,M	Some					I	
PS3	1-3	12	0.4	SI	E	Some		1-O	2	9.0	II	Reworked DM
	3-3	11	0.7	SI	U,P	Some	WR @ 2 cm	1-A	2	9.0	II	Reworked DM
	4-3	11	0.5	SI	E,M	Few		1-O	5		II	Reworked DM
PS4	1-3	15	1.2	SI	E						I?	Reworked DM
	2-3	13	0.5	SI	E,M	Few		1-A		6.9	I	Reworked DM
	3-3	13	1.1	SI	E ,CO						I?	Reworked DM
PS5	1-3	15	0.4	SI	E,CO		WR @ 1 cm	1-O		11.3	II	
	2-3	13	1.6	SI	E						I?	
PS6	4-3	13	0.9	SI	E,M	Few	WR @ 4 cm				I	
PS7	4-3	12	2.2	SI	D						I?	
PN7	1-3	10	0.9	SI	M	Some	WR @ 6 cm				II	
	3-3	9	1.0	SI	E,M	Few					I	

(Continued)

[1] Station location code: PS = Postdisposal South, PN = Postdisposal North.

[2] Sediment type: SI = silt.

[3] Surface and subsurface features: E = even, M = mound, U = uneven, P = pit, D = disturbed, CO = oxic clast, some = 7-24, few = 1-6, WR = worm, B = bed form, O = oxic, A = anoxic.

[4] Benthic successional stage: I = early successional stage, II = transitional stage, III = late successional stage.

Table 7 (Concluded)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment Type	Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
						Tubes	Fauna	Voids	Burrows			
PN6	1-2	12	1.7	SI	D						I?	
	3-3	11	0.7	SI	E						I?	
PN5	1-3	17	0.4	SI	U	Some	WR @ 3 cm	1-O	3	6.6	II	Reworked DM
	2-3	13	0.4	SI	U	Some		2-O	4		II	Reworked DM
	3-3	16	0.3	SI	U,P	Some	WR @ 14 cm		5		II	Reworked DM
PN4	1-2	14	0.4	SI	E,M	Some			3		II	Reworked DM
	2-2	12	0.4	SI	E,P	Some		2-O	9	2.2, 2.8	II	Reworked DM
	3-2	14	0.3	SI	E	Some	WR @ 4 cm		6		II	Reworked DM
PN3	1-3	10	0.9	SI	B?,M	Some			3		II	Reworked DM
	2-3	10	0.7	SI	U	Some			2		II	Reworked DM
	3-3	13	0.4	SI	B?,M	Some	WR @ 2 cm				II	Reworked DM

Table 8
Diversity Indices for Petersen Grab Samples Collected on Transects in Upper, Middle, and Lower Portions of Mobile Bay, Summer 1988

Location/Station	H'	J'	D
Upper Bay			
West - flats	1.59	0.57	2.40
West - disposal area	2.40	0.75	3.98
West - channel	2.03	0.63	4.21
East - channel	1.79	0.65	2.59
East - disposal area	1.69	0.53	3.31
East - flats	1.14	0.42	2.19
Middle Bay			
West - flats	2.28	0.76	3.58
West - disposal area	2.61	0.69	7.31
West - channel	2.06	0.64	4.29
East - channel	2.02	0.67	3.41
East - disposal area	1.89	0.57	4.69
East - flats	2.09	0.63	4.47
Lower Bay			
West - flats	2.39	0.62	7.27
West - disposal area	1.91	0.53	5.59
West - channel	2.50	0.65	7.34
East - channel	1.91	0.53	5.40
East - disposal area	2.46	0.61	8.21
East - flats	2.43	0.69	5.36
East - Bon Secour	2.72	0.80	5.40

Table 9
Species Groups Determined by Cluster Analysis of Petersen Grab Data Collected in Mobile Bay, Summer 1988

Group 1

- *Heteromastus filiformis*
- *Capitella capitata*
- *Hobsonia florida*
- *Streblospio benedicti*
- *Macoma mitchelli*
- *Eteone lactea*
- *Edotea* sp. B
- *Mulinia pontchartrainensis*
- *Rangia cuneata*
- *Monoculodes* sp. F

Group 2

- *Notomastus*
- *Ancistrosyllis papillosa*
- *Diopatra cuprea*
- *Ancistrosyllis jonesi*
- *Ogyrides alphaerostris*
- *Leucon americanus*
- *Glycera americana*
- *Paraonidae*
- *Sternapsis scutata*
- *Spiochaetopterus oculatus*
- *Nassarius acutus*
- *Oxyurostylis* sp. C
- *Cyclasis varians*
- *Magelona* sp. I
- *Galathowenia oculata*
- *Bhawania heteroseta*
- *Corophium* sp. K
- *Armandia maculata*
- *Periploma fragile*
- *Mysella planulata*
- *Eudorella* sp. B
- *Corophium* sp. I

Group 3

- *Turbellaria*
- *Cossura delta*
- *Carazziella hobsonae*
- *Balanoglossus aurantiacus*
- *Paramphiome* sp. B
- *Parandalia* sp. A
- *Sigambra bassi*
- *Asychis elongatus*
- *Acteocina canciculata*
- *Leitoscoloplos fragilis*

Group 4

- *Phoronis*
- *Polydora cornuta*
- *Polydora socialis*
- *Ampelisca abdita*
- *Owenia* sp. A

Group 5

- *Actinaria*
- *Sigambra tentaculata*
- *Glycinde solitaria*
- *Paraprionospio pinnata*
- *Podarkeopsis levifuscina*
- *Nereis micromma*
- *Rhyncocoela*
- *Mediomastus*
- *Mulinia lateralis*
- *Cossura soyeri*
- *Lumbrineris verrilli*
- *Magelona* sp. H
- *Eudorella monodon*
- *Prionospio*

Table 10
Relative Abundances of Dominant Benthic Taxa in Petersen Grab Samples Taken in Mobile Bay, Summer 1988

	Upper Bay			Middle Bay			Lower Bay		
Species	Flats	Disposal Area	Channel	Flats	Disposal Area	Channel	Flats	Disposal Area	Channel
Polychaetes									
Capitella capitata	■	■		A	A	A	A	A	A
Glycinde solitaria			■	■	■	■	■	■	■
Mediomastus sp.	■	■	■		■	■	■	■	■
Paramphinome sp. B		A	■					A	A
Paraprionspio pinnata	A	A	■	■	■	■	■	■	■
Podarkeospis levifuscina	A	A	■	■	■	■			■
Signambra tentaculata				■	■	■	■		
Molluscs									
Macoma mitchelli	■		■		A	A	A	A	A
Mulinia lateralis	A	A	A	A		■			
Other									
Actiniaria	A			■	■	■	■	■	
Rhynchocoela	■	■	■	■	■		■		
Composite no. of individuals	1,114	1,465	632	536	737	531	1,030	1,347	1,388

Legend

>40%	■
10-40%	
5-10%	■
1-5%	■
<1%	
A	Absent

Table 11
Image Analysis Summary Data for Sediment Profile Images from Bay-Wide Transect Stations of the Mobile Bay Maintenance Dredging Study

Station[1]	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface[3]	Subsurface Features[3]				Void Depth cm	Successional Stage[4]	Comments
				Layers[2]	Type[2]		Tubes	Fauna	Voids	Burrows			
UT-W3550	1-2	12	1.4		SI	U,P,M						I	
	3-1	9	1.0		SI	U,P,M		WR @ 3, 5 cm				I	
	4-1	7	0.9		SI	E,P			I-A			I	
UT-W2300	1-2	19	4.9		SI	U,M	Few?					II?	Deep RPD
	2-5	16	1.4		SI	U,M			4-A		7.5, 7.6, 9.3, 10.9	I	
UT-W1300	1-5	12	1.5	@ 6 cm	FS/SI	B,SH						I	Grey over greenish grey
	2-5	7	1.2	@ 6 cm	FS/SI	B?,SH			2-O		4.4	I/II	Grey over greenish grey
	3-5	6	1.5		SI	U,M,SH	Few?		3-O, 1-A		3.8, 4.6, 4.8, 5.0	II	
UT-W1000	1-5	7	2.9		FS	B,SH						I?	
	2-5	2	1.6		FS	B						I?	

(Continued) *(Sheet 1 of 8)*

[1] Transect/station designation: UT = upper transect, MT = middle transect, LT = lower transect, W = west of navigation channel, E = east of navigation channel (distances in meters).

[2] Sediment type: SH = shell hash, SI = silt, CL = clay, FS = fine sand.

[3] Surface and subsurface features: E = even, U = uneven, M = mound, B = bed form, P = pit, D = disturbed, FP = fecal pellets, Mat = tube mat, CO = oxic clast, CA = anoxic clast, SH = shell hash; many = >24, some = 7-24, few = 1-6, WR = worm, O = oxic, A = anoxic.

[4] Benthic successional stage: I = early successional stage, II = transitional stage, III = late successional stage.

Table 11 (Continued)

Station	Repli-cate	Pene-tration Depth cm	RPD Depth cm	Sediment		Surface Inter-face	Subsurface Features				Void Depth cm	Succes-sional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
UT-WO650	1-5	8	2.6	@ 4 cm	FS/CL	B,SH						I?	Light grey clay layer
	2-5	7	1.5	@ 4 cm	FS/CL	B,SH	Few		1-O		4.8	II	Light grey clay layer
UT-WO250	2-5	20	1.6		SI	E,CA	Some	WR @ 5 cm	3-O		10.5, 15.1 17.0, 17.8	II	
	3-5	12	1.8		SI	U	Few		1-O		10.4	II	
UT-EO250	1-4	13	1.3		SI	B		WR @ 2 cm	1-O		10.4	II	
	2-3	14	1.5		SI	M						I	
UT-EO650	1-3	16	2.0		FS/SI	B	Some		3-O		8.2, 8.4	II/III	Thin sand layer?
	2-3	16	2.2		FS/SI	B?	Few		1-O		6.1	II/III	
	4-4	18	1.1		FS/SI	B?,SH	Few					II	
UT-E1000	2-2	8	1.2		SI	E,SH,FP			1-A		5.7	I	
	3-3	8	1.3		SI	U,P,FP	Some		1-O		4.7	I/II	
	4-3	9	1.4		SI	E,P	Many		1-O		2.4	I/II	
UT-E1300	1-2	9	1.3		SI	E,M,SH, FP	Many	WR @ 5 cm	3-O		3.3, 4.9, 7.8	I/III	
	2-3	9	1.1		SI	E,M,P, SH, FP	Many	WR @ 7 cm				I/II	
	3-3	9	1.3		SI	E,M,SH, FP	Many		2-O			I/II	

(Continued)

(Sheet 2 of 8)

Table 11 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage[4]	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
UT-E1300 (Cont.)	2-3R	12	1.2		SI	D,CO,CA	Many		6-O		2.5, 4.0, 4.1, 4.3, 4.4, 5.0, 6.1	I/II	
UT-E2300	2-2	11	1.9		SI	B?,SH	Many					I	
	4-2	12	1.1		SI	E,P,SH	Many	1-0			6.8	I/II	
	5-3	13	1.0		SI	E	Many	1-0			7.6	I/II	
UT-E5800	1-2	14	1.2		SI/SH	E,CA,SH	Some	WR @ 5 cm				II	Light grey over dark grey
	2-3	14	1.2		SI/SH	E,P	Many	WR @ 4 cm				I/II	Light grey over dark grey
	3-3	11	1.0		SI/SH	E	Many					I	Light grey over dark grey
UT-E8870	1-2	11	1.0		SI	E	Mat	WR @ 4 cm	1-A		6.6	I/II	Tubes up to 1 x 6 mm
	2-3	11	0.8		SI	E	Mat		1-O		8.1	I/II	Tubes up to 1 x 6 mm
	3-3	11	1.1		SI	E	Mat					I	Tubes up to 1 x 6 mm
MT-W5800	1-4	7	0.9		FS/SI	B						I?	Bed forms with 6-cm wavelength
	2-4	7	0.8		FS/SI	B?,CA		WR @ 3 cm				II	
	3-3	8	0.6		SI	B?	Few		1-O		5.9	II	

(Continued)

(Sheet 3 of 8)

Table 11 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
MT-W2300	2-4	10	1.6		SI	U						I?	
	3-4	13	0.8	@ 12 cm	SI	U,D?	Few					II	Dark grey over light grey
	2-2	12	0.8		SI	U,CA	Few	WR @ 11 cm	2-O		6.4, 8.9	II	
	3-3	12	0.7		SI	U,CA, CO		WR @ 3 cm	3-O		2.3, 7.8, 9.5	II	
MT-W1300	1-4	6	1.0		FS/CL	B,SH	Some		1-O	1	3.3	II/III	
	2-4	9	1.4		FS/CL	B,M	Some		1-O	4	4.7	II/III	
	3-3	7	0.7		FS/SI	B,SH	Some		1-O	3	5.4	II/III	
MT-W1000	1-4	6	0.3		FS/SI	E,M,SH			1-O		1.0, 1.8, 1.9	I/II	Dark grey SI with thin veneer
	1-3	14	2.2		SI	E,CA			1-O		7.9	I/II	2 cm light brown over dark grey
	2-3	16	1.5		SI	D,CA,CO			1-O	2	13.3	II/III	2 cm light brown over dark grey
	3-3	16	0.8		SI	D,CA,CO			1-O	5	13.5	II	Same as UT-W1100 1-3
MT-W0650	2-4	7	0.4		CL	U,SH,M			7-O	1	2.6, 3.2, 3.5, 4.4, 4.6, 4.7, 4.9, 5.0	II	

(Continued)

Table 11 (Continued)

Station	Repli-cate	Pene-tration Depth cm	RPD Depth cm	Sediment		Surface Inter-face	Subsurface Features				Void Depth cm	Succes-sional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
MT-W0850 (Cont.)	1-3	9	1.0	@ 6 cm	SI	D,CA,SH						I?	Dark grey over light grey
	2-2	9	1.0	@ 6 cm	SI	U,P,M	Some					II?	Dark grey over light grey
MT-W0250	1-3	10	1.2		SI	E	Few					II?	
	3-3	8	1.0		SI	E,M	Some		1-A		4.6	I/II	
	5-3	9	1.3		SI	U,P	Some		1-O		1.8	I/II	
MT-E0250	1-1	19	0.4		SI	U,P	Few	WR @ 1 cm	1-O		14.6	I/II	
	2-3	18	0.8		SI	U,P	Some		2-O		13.7, 14.6	II	
	3-3	17	0.6		SI	U,P	Some		1-O		12.6	II	
MT-E0650	1-3	14	0.3		SI	U,P,M	Some		2-O		10.9	I/II	
	3-3	12	0.6		SI	E,P	Some		2-O		7.3, 8.3	II	
MT-E1000	1-2	9	0.4		SI	B?	Some		3-O		1.5, 7.4	I/II	No sand
	1-4R	13	0.8		SI	D,CA, CO,SH			2-O		1.5	I?	
MT-E1300	1-3	17	1.2	@ 15 cm	SI	D,CA, CO			1-A	3		II/III	Dark grey over light grey
	2-3	16	1.4		SI	D,CA, CO			2-O	4	8.6, 13.1	II/III	
	3-2	16	0.7		SI	E,P	Few			4		II	
MT-E2300	1-3	11	1.2		SI	U,P,M	Few		1-O			I/II	
	2-3	10	0.4		SI	U,P,M	Few			1		II	
	3-3	9	0.7		SI	E	Few			1		II	

(Continued)

(Sheet 5 of 8)

Table 11 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
MT-E5800	1-3	11	0.6		SI	U,CA	Few			1		II	
	2-3	12	1.0		SI	U,M,CA	Some					I	
LT-W5800	1-3	17	2.9		SI	E,CA,CO		WR @ 13 cm	2-O	1	10.6, 10.9	III	
	2-3	12	2.6		SI	E,CO	Few		1-O	2	5.0	II/III	
	2-3	13	1.5		SI	D,CA, CO	Few		3-O	1	10.9	II/III	
	1-4R	17	3.1		SI	U,M			1-A		10.3	II?	
LT-W2300	1-2	17	2.6		SI	U,P	Few	WR @ 13 cm				II/III	
	2-2	15	1.3		SI	U,P,SH	Few					II	
	3-3	14	2.3		SI	U,M	Few					II	
LT-W1300	1-3	15	2.1		FS/SI	U,M,SH	Few		2-O, 2-A		5.1, 6.2, 6.8, 13.4	II	
	2-3	14	2.2		FS/SI	U,P,SH			2-O	1	8.2	II/III	
	3-3	20	2.9		FS/SI	U,M,SH	Few	WR @ 17 cm	4-O		9.3, 15.0, 16.5, 17.0, 19.8	II/III	
	2-3R	17	1.6		SI	E,P,SH	Some		1-O		9.8	II	
LT-W1000	1-3	17	1.9		SI/CL	U,P,SH	Few	WR @ 4 cm	1-O		6.3	II/III	
	2-3	18	3.9		SI	U,P,SH		WR @ 4 cm				II	Some camera disturbance

(Continued)

(Sheet 6 of 8)

Table 11 (Continued)

Station	Replicate	Penetration Depth cm	RPD Depth cm	Sediment		Surface Interface	Subsurface Features				Void Depth cm	Successional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
LT-W1000 (Cont.)	3-3	18	4.6		SI/CL	U,P,SH			4-O		3.4, 10.8, 13.1, 14.8	II/III?	Some camera disturbance
LT-W0650	1-3	10	3.2		SI/CL	U,M,P, SH	Few					II?	Black particles at surface
	2-3	8	1.7		SI	U,M,P, SH	Few	WR @ 4 cm				II	Black particles at surface
	3-3	7	1.0		FS?/ SI	B,SH			1-A		3.9	I	Black particles at surface
LT-W0250	1-1	20	2.7		SI	E	Few		1-O		16.8	II	
	2-3	21	3.0		SI	U,P	Few	WR @ 16 cm	1-O		8.1	II/III	
	3-2	20	2.7		SI	E,CA						II?	
LT-E0250	1-3	16	1.9		SI	E,P	Some		1-A		6.0	II	
	2-1	15	1.5		SI	U,P,CA	Some					II	
	3-3	15	2.5		SI	E	Some	WR @ 10 cm	4-A, 1-O		9.5, 10.8, 11.2, 12.4	II/III	
	1-3R	17	1.1		SI	U,M,CA	Few		3-O		4.5, 5.3	II	*Diopatra* tube
LT-E0650	1-2	13	2.1		SI	E,M,P	Some	WR @ 9,4 cm	1-O		4.2	II/III	
	2-3	13	2.3		SI	U,P	Some		1-A		8.0	II	
	3-3	13	1.8		SI	E,P	Some		2-A		3.3, 10.9	II	

(Continued)

(Sheet 7 of 8)

Table 11 (Concluded)

Station	Repli-cate	Pene-tration Depth cm	RPD Depth cm	Sediment		Surface Inter-face	Subsurface Features				Void Depth cm	Succes-sional Stage	Comments
				Layers	Type		Tubes	Fauna	Voids	Burrows			
LT-E1000	1-2	14	2.2		SI	E,P	Few			1		II	
	2-2	14	1.4		SI	B?	Some					II	
	3-3	13	1.5		SI	B?	Some					II	
LT-E1300	1-3	12	1.6		SI	E	Few					II	
	2-3	12	1.3		SI	E,M	Some					II	
	3-2	12	1.0		SI	E	Few		1-O		3.2, 9.3	II	
	1-3R	16	1.7		SI	U,P	Some	WR @ 9 cm				II/III	
LT-E2300	1-3	10	0.6		SI	E,P						I?	
	2-2	11	1.4		SI	U,M,P						I?	
	3-3	11	1.2		SI	U,M,P, SH						I?	
	1-3R	17	1.0		SI	U,P,SH	Few		1-A		12.7	I	
LT-E5800	1-3	5	0.4		SI	U,M	Some					I	
	2-3	6	0.7		SI	E,M,P	Few					I	
	3-3	7	0.9		SI	U,P	Some					I	
	1-2R	7	0.7		SI	B						I?	
LT-E11700	3-3	7	0.7		SI	D,SH			3-O	1	2.6, 3.3, 4.1	I/II	
LT-E17300	1-3	9	2.1		SI	U,CA						I?	
	2-3	12	1.1		SI	D,CO			1-O	1	5.4	II?	

(Sheet 8 of 8)

Table 12
Attributes of Benthic Communities Associated with Early and Late Successional Stages (Adapted from Rhoads and Germano 1986)

Attribute	Successional Stage	
	Early (Stage I)	Late (Stage III)
Secondary production	High potential for r-selected taxa.	Lower potential for K-selected taxa.
Prey availability	High, as prey are concentrated near the surface.	Lower, as infauna are deep burrowing, except for siphon grazing.
Potential for food-web contamination	Highest for suspended or recently sedimented particulates. Body burdens may be low as a consequence of short mean life spans.	Highest for deeply buried contaminants. Longer mean life spans may lead to significant body burdens.
Nutrient recycling	Limited to solutes in upper 3 cm of sediment column.	Solutes exchanged to sediment depths of 20 cm or greater.
Potential for bottom water hypoxia	High, due to accumulation of labile detritus.	Low, labile detritus recycled.

Appendix A
Loran C Coordinates for Pipeline Discharge Stations

STATION	SAMPLING DATES	W	Y	SAMPLING*
S1	Day 1; 12,26,52 weeks post	12774.6	47121.1	C,B (52 weeks post)
S2	Day 1; 12,26,52 weeks post	12773.1	47121.1	C
S3	Day 1; 12,26,52 weeks post	12770.5	47121.5	C,B (52 weeks post)
S4	Day 1; 12,26,52 weeks post	12768.9	47121.6	C
S5	Day 1; 12,26,52 weeks post	12767.5	47121.4	C,B (52 weeks post)
S6	Day 1; 12,26,52 weeks post	12765.8	47121.5	C
S7	12,26,52 weeks post	12760.0	47121.5	C,B (52 weeks post)
M1	Day 1	12774.8	47122.0	C
M2	Day 1	12772.5	47122.1	C
M3	Day 1	12769.9	47122.0	C
M4	Day 1	12768.4	47121.8	C
M5	Day 1	12766.7	47121.7	C
M6	Day 1	12765.6	47121.7	C
N1	Day 1; 12,26,52 weeks post	12775.0	47122.4	C,B (52 weeks post)
N2	Day 1; 12,26,52 weeks post	12773.8	47122.5	C
N3	Day 1; 12,26,52 weeks post	12772.6	47122.8	C,B (52 weeks post)
N4	Day 1; 12,26,52 weeks post	12770.7	47123.0	C
N5	Day 1; 12,26,52 weeks post	12769.6	47123.1	C,B (52 weeks post)
N6	Day 1; 12,26,52 weeks post	12765.5	47123.3	C
N7	12,26,52 weeks post	12760.0	47123.3	C,B (52 weeks post)
PS1	Day 2	12774.8	47121.2	C
PS2	Day 2	12773.2	47121.1	C
PS3	Day 2	12770.6	47121.5	C,B
PS4	Day 2	12768.9	47121.7	C,B
PS5	Day 2	12767.6	47121.4	C
PS6	Day 2	12766.1	47121.5	C
PM1	Day 2	12775.0	47121.9	C
PM2	Day 2	12772.4	47122.0	C
PM3	Day 2	12770.0	47121.8	C,B
PM4	Day 2	12768.2	47121.7	C,B
PM5	Day 2	12766.6	47121.6	C
PM6	Day 2	12765.5	47121.6	C
Pipeline discharge location, day 1		12771.0	47121.4	

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* C = sediment profiling camera photography, B = benthic grabs

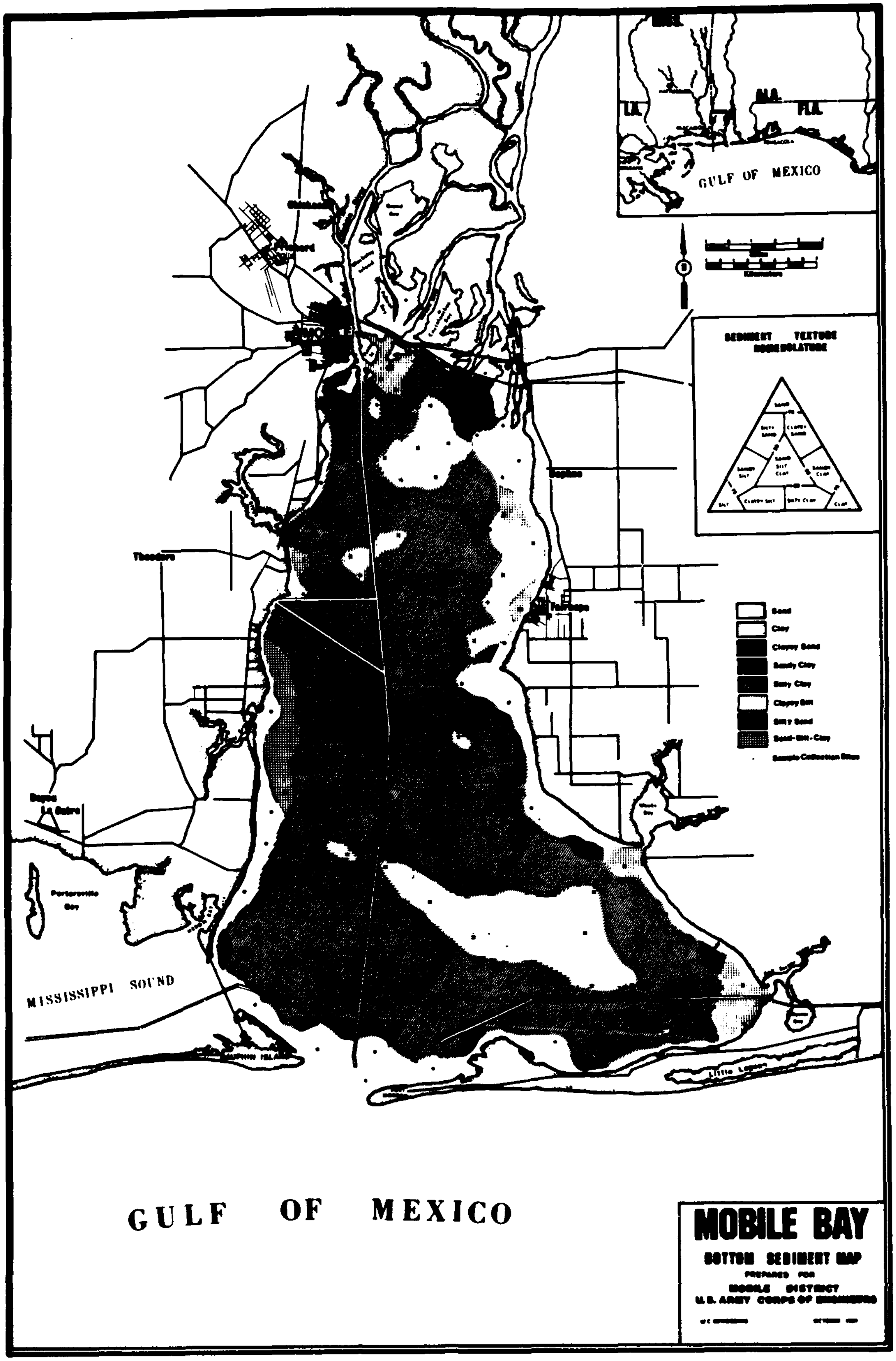
Appendix B
Loran C Coordinates for Transect Stations

TRANSECT	STATION	W	Y	SAMPLING*
UPPER BAY	W3550	12757.6	47161.2	C
	W2300	12766.2	47161.5	B,C
	W1300	12773.6	47161.8	C
	W1000	12775.0	47161.9	B,C
	W650	12776.8	47161.9	C
	W250	12779.7	47162.0	B,C
	E250	12783.4	47162.2	B,C
	E650	12786.0	47162.4	C
	E1000	12787.4	47162.4	B,C
	E1300	12788.8	47162.4	C
	E2300	12796.6	47162.6	B,C
	E5800	12820.0	47163.7	C
	E8870	12840.0	47164.3	C
MIDDLE BAY	W5800	12743.6	47126.6	C
	W2300	12766.2	47127.5	B,C
	W1300	12773.7	47127.5	C
	W1000	12775.0	47127.8	B,C
	W650	12776.0	47127.8	C
	W250	12779.4	47127.9	B,C
	E250	12782.9	47128.0	B,C
	E650	12786.0	47128.0	C
	E1000	12787.4	47128.0	B,C
	E1300	12788.6	47128.1	C
	E2300	12796.4	47128.4	B,C
	E5800	12820.0	47129.2	C
LOWER BAY	W5800	12730.9	47101.9	B
	W2300	12753.2	47103.0	B,C
	W1300	12760.4	47102.6	B
	W1000	12761.6	47102.7	B,C
	W650	12763.2	47102.8	C
	W250	12766.4	47102.8	B,C
	E250	12770.4	47102.9	B,C
	E650	12773.4	47103.0	C
	E1000	12774.6	47103.0	B,C
	E1300	12775.8	47103.0	C
	E2300	12783.6	47103.2	B,C
	E5800	12805.8	47103.7	C
	E11700	12843.0	47104.4	B,C
	E17300	12880.0	47104.9	C

NOTE: Stations are designated as W (west of the navigation channel) or E (east of the navigation channel) followed by a numerical value approximating the distance from the channel in meters.

* B = benthic grabs, C = sediment profiling camera photography

Appendix C
Mobile Bay Sediment Map


MISS.
LA.
ALA.
FLA.
GULF OF MEXICO
SEDIMENT TEXTURE NOMENCLATURE
SAND
SILTY SAND
CLAYEY SAND
SANDY SILT
SAND SILT CLAY
SANDY CLAY
SILT
CLAYEY SILT
SILTY CLAY
CLAY
Chickasaw
Prichard
MOBILE
Daphne
Theodore
Fairhope
Bayou La Batre
Portersville Bay
Weeks Bay
MISSISSIPPI SOUND
DAUPHIN ISLAND
Little Lagoon
Sand
Clay
Clayey Sand
Sandy Clay
Silty Clay
Clayey Silt
Silty Sand
Sand-Silt-Clay
Sample Collection Sites
GULF OF MEXICO
MOBILE BAY
BOTTOM SEDIMENT MAP
PREPARED FOR
MOBILE DISTRICT
U.S. ARMY CORPS OF ENGINEERS

Appendix D
Numerical Modeling and Field Calibration Studies of Open-Water Disposal of Maintenance Dredging Material in Mobile Bay[1]

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[1] This appendix was prepared by M. J. Trawle, B. H. Johnson, and D. N. McComas of the Hydraulics Laboratory, WES.

Introduction

Background

Mobile Bay is a pear-shaped estuary extending about 30 miles from the Gulf of Mexico to Mobile Harbor at the mouth of the Mobile River. In 1988 Congress authorized the deepening and widening of the navigation channel to Mobile Harbor from 40 by 400 ft to 55 by 550 ft. The first phase of action would deepen the channel to 45 ft and leave the width unchanged. In the past, the dredged material from maintenance operations along the Mobile Bay reach of the project has been disposed in adjacent open-water disposal areas along both sides of the channel.

Scope

To determine the disposal pattern of maintenance material disposed in open-water sites adjacent to the navigation channel, the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) conducted field collection efforts at three locations in Mobile Bay. In June 1988 and February 1989, HL personnel collected data in the vicinity of disposal plumes resulting from channel maintenance operations. This report presents each of the data sets collected and an analysis of the sediment dispersal patterns for a typical maintenance operation.

The first survey was conducted on 4 June 1988 and consisted of one data collection effort, hereafter referred to as Test 1. The second survey was conducted on 16-17 June 1988 and consisted of four data collection efforts, hereafter referred to as Tests 2-5. The third survey was conducted on 14-15 February 1989 and consisted of two data collection efforts, hereafter referred to as Tests 6 and 7. The approximate locations of each of these surveys are shown in Figure D1.

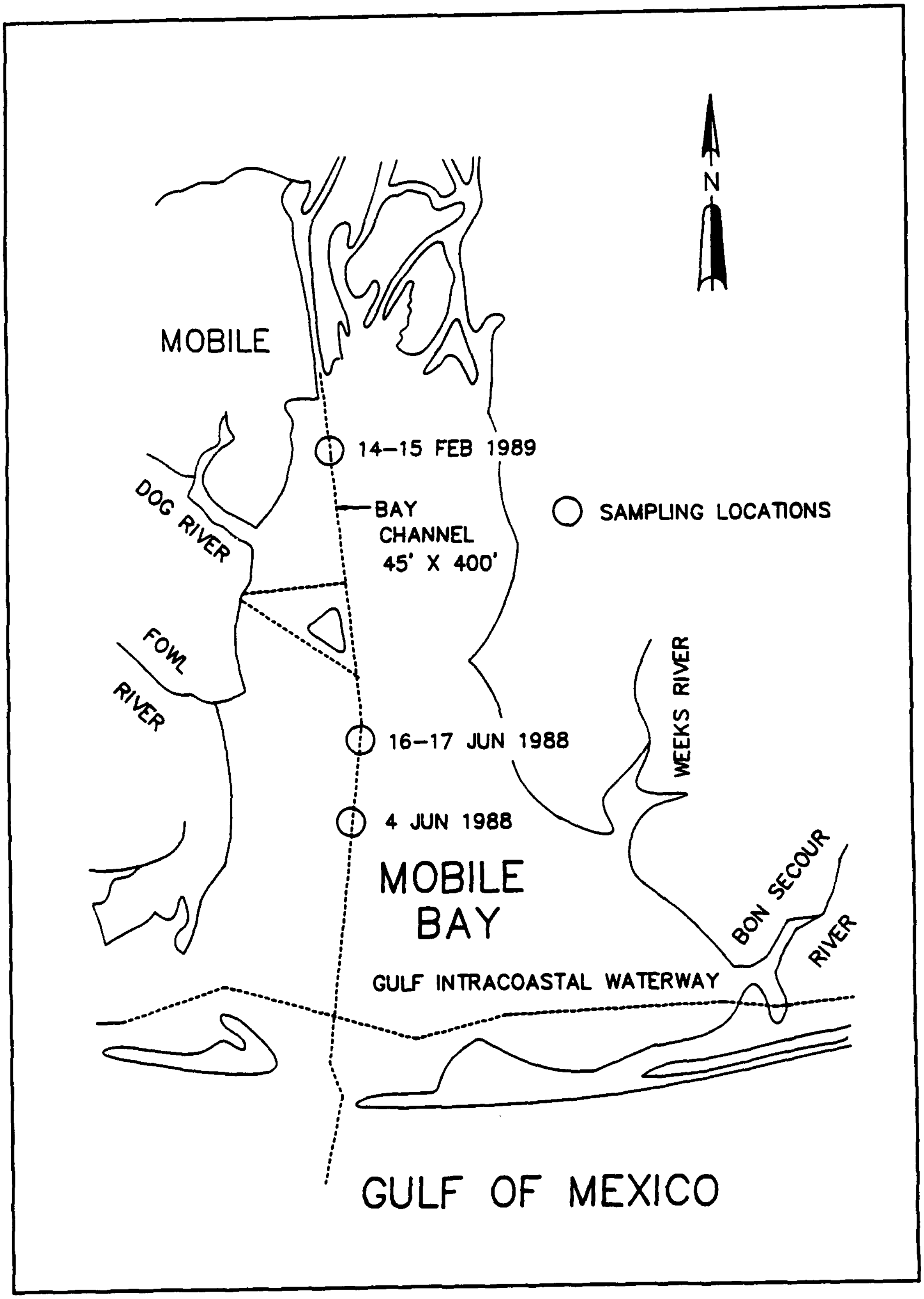

Figure D1. Survey locations

Equipment and Measurements

For all surveys, three boats were deployed—two for obtaining suspended sediment samples and one for monitoring wind speed and water currents.

Current Speed and Direction

The boat that monitored wind and current conditions was equipped to deploy current meters over the side. Collapsible aluminum frames were used to support the equipment, and wenches with 1/8-in. wire rope were used to raise and lower the velocity and direction equipment. An indicator on the winch displayed the depth of the instruments below the water surface. A Gurley model 665 vertical axis cup-type impeller velocity meter with direct velocity readout was used to measure the current speeds. These meters have a threshold speed of less than 0.2 fps and an accuracy of ±0.2 fps for velocities less than 1.0 fps. Current directions were monitored with a magnetic directional indicator mounted above the velocity meter on a solid suspension bar. This entire assembly is connected to a streamlined lead weight that holds the sensors in a vertical position and orients them in the direction of flow. The signal cables from each instrument are raised and lowered with the equipment and connect to the display units located on the deck of the boat.

Wind Speed and Direction

Wind conditions at the time of each survey were recorded using a Weathermaster model 132 hand-held anemometer. The directions of the prevailing winds were determined from the compass heading of the anemometer giving the highest speed indication. Maximum wind speeds and directions were recorded several times throughout each survey.

Suspended Sediment Concentrations

At most stations water samples for subsequent analysis of suspended sediment concentrations were obtained manually by pumping the sample from the assigned depth to the surface collection point. The pumping system consisted of 1/4-in. inside diameter plastic tubing and a 12-v pump to pump the sample through the tubing to the deck of the boat, where each sample was then collected in individual 8-oz plastic bottles and labeled with test number, depth, position, and time. The pumps and tubing were flushed for approximately 1 min at each depth before collecting the sample.

At selected stations, samples were taken automatically during each survey, using ISCO model 2799 automatic water samplers. A typical field installation of these samplers in Mobile Bay is shown in Figure D2. These devices operate from a 12-v battery power source. Samples were collected in 24 plastic bottles located inside the sampler. These samplers are fully programmable for obtaining any volume of sample desired up to the maximum size of the bottle, for obtaining composite or integrated samples, for setting different intervals between samples, and for setting the time to begin the sampling routine. When the sampling period is complete, the sample bottles are replaced with empty bottles to begin a new sampling program.

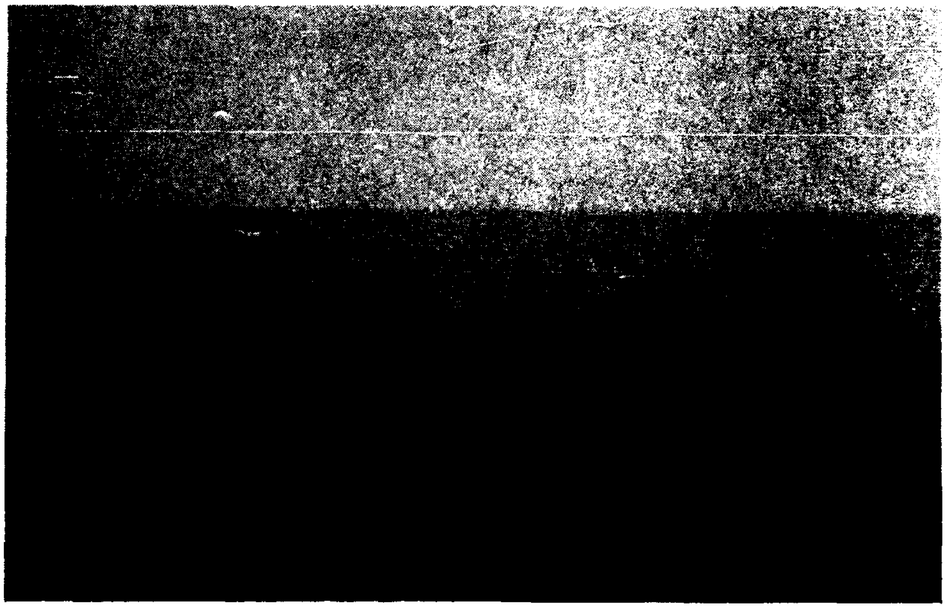

Figure D2. Typical field deployment of ISCO samplers near discharge pipe (16 June 1988)

Dredged Material Discharge

For each survey, the disposal pipe discharge was provided by the captain of the pipeline dredge doing the maintenance dredging. The discharge sediment concentration was determined by analysis of samples collected at the end of the discharge pipe.

Field Surveys

4 June 1988 Survey

General

On 4 June, the pipeline dredge *Louisiana* was working the navigation channel in the vicinity of channel marker 37. The dredging location is shown in Figure D1. The dredged material was discharged about 1,000 ft west of the navigation channel. The discharge line was moved periodically (every hour or two) as the dredge worked up the channel.

The discharge line ended with a downward angled (approximately 30 deg from horizontal) pipe section (Figure D3). The discharge jet exited the pipe about 3 ft below the water surface in the downward direction. The captain of the dredge reported the pipeline velocity at about 21 fps. The inside diameter of the discharge line was 25 in., resulting in a discharge

Figure D3. Downward-angled discharge used in 4 June and 16-17 June 1988 surveys of about 72 cfs. The pipeline sediment transport was calculated at 1,053 tons/hr by using the pipeline discharge of 72 cfs and a discharge concentration of 130,000 mg/L. (This production rate was assumed to be representative for Tests 1 through 5.) The 130,000 mg/L value was considered a good average flow concentration based on the limited samples collected at the end of the discharge pipe.

The station locations for the 4 June survey are shown in Figure D4. One test was conducted during flood tide, hereafter referred to as Test 1.

Four ISCO automatic samplers were set in line with the end of the pipeline in the flood direction. ISCO sampler No. 1 (Station 1) was located about 10 ft from the end of the discharge point; ISCO 2 (Station 2) was about 80 ft from ISCO 1 in the flood direction; ISCO 3 (Station 3) was 60 ft farther out; and ISCO 4 (Station 4) was 80 ft farther out (Figure D3). The remaining stations (Stations 5-11), where samples were collected manually, are shown in Figure D4.

Test 1

The ISCO samplers were deployed at about 8 a.m. (CST). The test was initiated at 8:39 a.m. (CST). Test 1 conditions were flood tide, from 220 deg, with no wind and calm water. Current velocity was measured at 0.5 fps. Water depth in the vicinity of the discharge averaged about 11 ft. Test 1 conditions and suspended sediment concentration measurements are given in Tables D1 and D2, respectively.

16-77 June 1988 Survey

On 16 and 17 June, the pipeline dredge *Louisiana* dredged the Mobile Harbor ship channel between markers 45 and 46. This dredging location is shown in Figure D1. The dredged material was discharged approximately 1,000 ft west of the navigation channel. The discharge line was moved periodically (every hour or two) as the dredge worked up the channel.

As was the case with the 4 June survey, the discharge line ended with a downward angled (approximately 30 deg from horizontal) pipe section. The discharge jet exited the pipe about 3 ft below the water surface in the downward direction. The captain of the dredge *Louisiana* estimated the pipeline velocity at about 21 fps. The inside diameter of the discharge line was 25 in., resulting in the discharge of about 72 cfs.

The station locations for the June 16-17 survey are shown in Figure D5. Actually, four separate tests were conducted over the 2-day period. Tests 2, 3, and 4 were conducted on the 16 June, and Test 5 on 17 June. Tests 2 and 5 were conducted during flood tide, and Tests 3 and 4 during ebb tide.

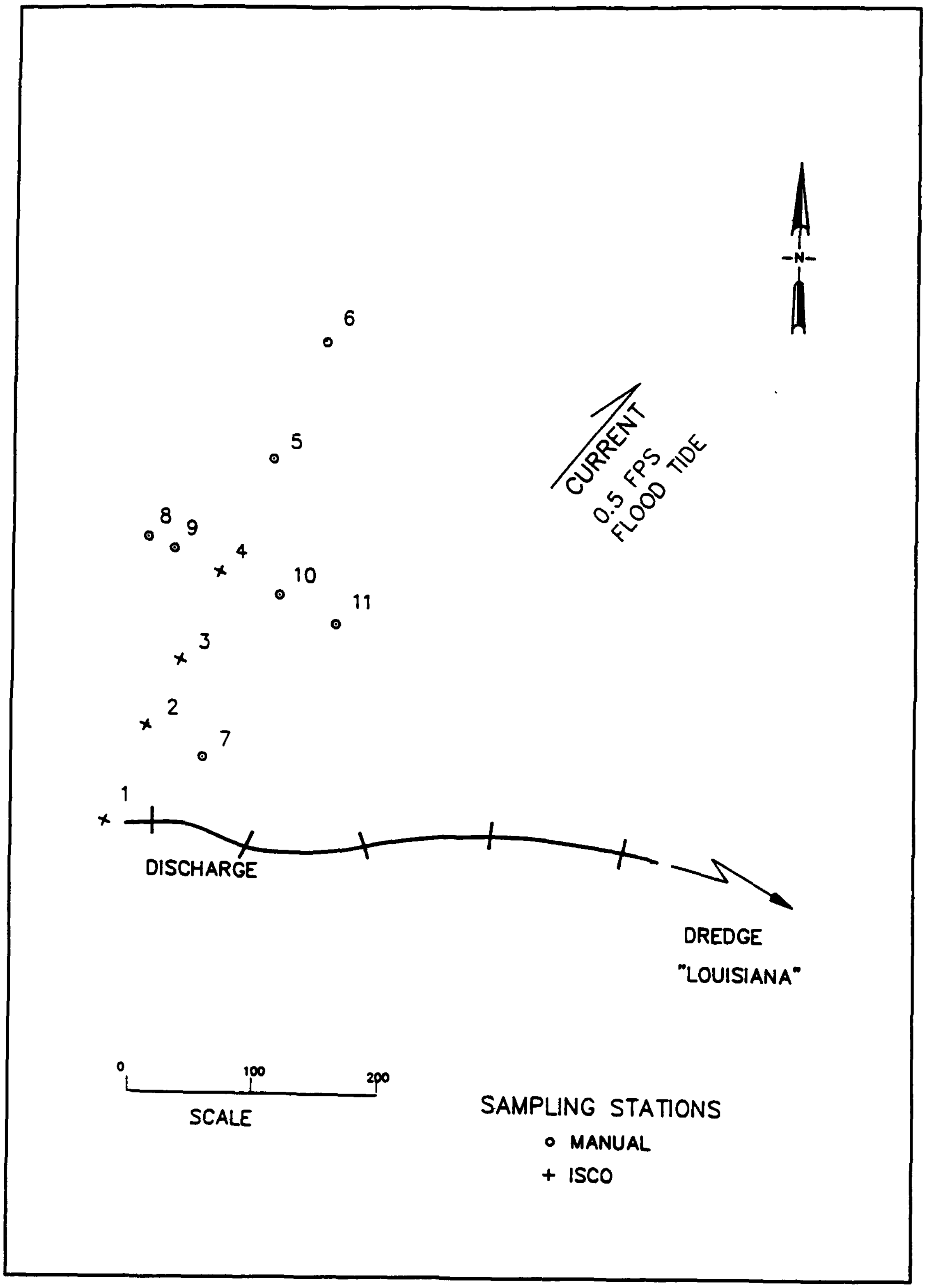

Figure D4. Station locations for 4 June 1988 survey (Test 1)

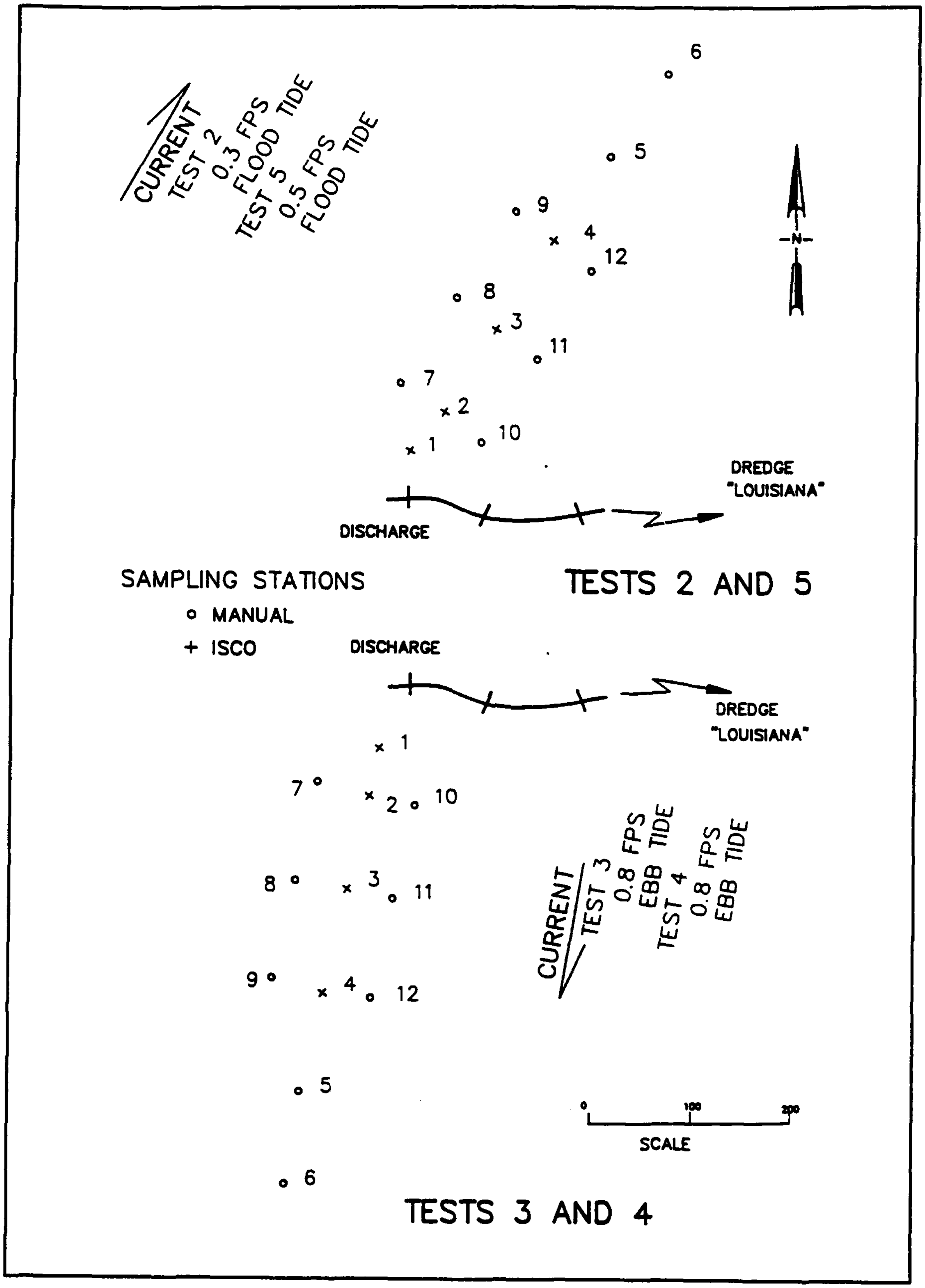

Figure D5. Station locations for 16-17 June 1988 survey

For the flood tide tests (2 and 5), the stations were established north of the discharge pipe; for the ebb tide tests (3 and 4), the stations were oriented south of the discharge pipe.

The samples were taken in the same manner for all four tests. Four ISCO automatic samplers were set in line with the end of the pipeline according to the current direction. The ISCO sampler No. 1 (Station 1) was set 50 ft from the discharge point, ISCO 2 (Station 2) was 50 ft farther, ISCO 3 (Station 3) was 100 ft farther, and ISCO 4 (Station 4) was 100 ft farther. These samplers collected a total of 24 samples approximately 3 ft above the bay bottom at set time intervals. Station 5 was 100 ft beyond Station 4 on the same line. Station 6 was 100 ft beyond Station 5 on the same line. Stations 5 and 6 were manual collection locations. Stations 7, 8, and 9 were 50 ft to the right of the corresponding ISCO stations; Stations 10, 11, and 12 were 50 ft to the left, looking downcurrent. These offset stations were also manual collection locations. For all manual stations, water samples were taken once at each of three depths: 3 ft off the bottom, middepth, and 3 ft below the surface. Also, a detailed profile was taken at Station 3 (ISCO 3) with samples collected manually, once per test, at 6-in. intervals over the water column.

Test 2

The ISCO samplers were deployed at 10 a.m. (CST). Test 2 conditions were flood tide, from 210 deg, with no wind and calm water. ISCO's samplers 1, 2, and 3 were set on a 2-min sample interval, while ISCO 4 was on a 3-min interval. All four ISCO samplers started within a 10-min period. The surface samples at Stations 10, 11, and 12 were collected at 0.5 ft below the surface. At Stations 7, 8, and 9, "surface" samples were collected 3 ft below the surface. At 9:30 a.m. (CST), background samples were collected upcurrent from the dredge pipeline, in 11 ft of water, at depths of 3 and 8 ft below the water surface. Another sample was collected at the discharge point under the water surface. The visible plume was about 60 ft across and 120 ft long, at about a 60-deg angle from the line of ISCO samplers. An aerial photograph of the visible plume during Test 2 is shown as Figure D6. Test 2 conditions and suspended sediment concentration measurements are reported in Tables D3 and D4, respectively.

Test 3

The ISCO samples were started at 2:20 p.m. (CST), with a sampling interval of 3 min. Test 3 conditions were ebb tide, from 10 deg. The Bay was choppy, causing difficulty in setting the suction heads from the ISCO samplers at the selected distance (3 ft) from the bottom. The test ended at 3:20 p.m., when the dredge began moving the discharge line. The ISCO 2 collected only one sample because a crimp had developed in the suction line but escaped detection during the test. A sample of the discharge material was taken from an above-surface leak near the end of the pipeline.

Figure D6. Aerial photograph of discharge from 1,000 ft during Test 2, 16 June 1988

Throughout the test, this leak appeared and disappeared, and varied from muddy-black to relatively clear. The sample was collected when the flow through the pipeline seemed strong and of average color. The sample collection layout was the same as for Test 2. Test 3 conditions and suspended sediment concentrations are given in Tables D5 and D6, respectively.

Test 4

The ISCO samplers were started at 5:15 p.m. (CST), with a sample interval of 3 min. Test 4 conditions were ebb tide from 10 deg. The water continued to be choppy. The only change in the sampling layout from Test 3 was that Station 8 was located 25 ft from Station 3 rather than 50 ft. Test 4 conditions and suspended sediment concentration measurements are provided in Tables D7 and D8, respectively.

Test 5

Test 5 was conducted on 17 June 1988 during flood tide. The current was coming from 200 deg. The sampling interval for the ISCO samplers was 3 min. Samplers 1, 2, and 4 were started at 7:20 a.m. (CST). ISCO 4 was started at 7:48 a.m. (CST). Also, a sample was collected from the leak in the discharge line. Test 5 conditions and suspended sediment concentrations are reported in Tables D9 and D10, respectively.

14-15 February Survey

On 14 and 15 February 1989, the pipeline dredge *Alaska* was working at channel marker 73, near the Arlington Harbor channel. The end of the discharge line was horizontal and above the water surface with no splash plate. The captain of the dredge reported the dredging production rate at about 5,000 to 5,500 cu yd of in situ material per hour. Assuming that the in situ material weighed about 90 lb/cu yd, which is typical for maintenance material of the type being dredged, the production rate in tons per hour was 3,050. The end of the discharge line was located east of the navigation channel in water only about 3 ft deep. Conditions were generally calm over the 2 days during the surveys. Two tests were conducted, one on the first day (Test 6) and one on the second (Test 7). Both tests were conducted during flood tide.

Test 6 - flood tide

On 14 February, initial observations were made of the discharge area to determine the best locations for sampling stations. The current direction was about 220 deg from the north (flooding) with a magnitude of 0.6 fps. Directly upstream from the end of the discharge pipe, a ridge of sediment had developed that was approximately 30 ft in length. The visible plume did not follow the direction of the bay current, but was oriented more along a direction of 200 deg from the north. The sampling stations were set using the 200-deg orientation, as shown in Figure D7. The ISCO samplers were programmed to begin sampling at 11:50 a.m. (CST), with samples collected at 3-min intervals 1.5 ft from the bottom. A sample of the discharge from the end of the pipe was obtained during the test. At Stations 4 through 10, samples were collected twice during the 72-min test period. Since the water depths were generally only about 3 ft, samples were collected at depths of 1 ft below the surface and 1 ft above the bottom. It should be noted that it was extremely difficult to accurately determine the bottom because of the soft texture of the upper layer of bottom material.

During the sampling period, the visible surface plume was shifting constantly to the east and had a meandering appearance. Sampling was completed at 12:45 p.m. (CST), and the ISCO samplers were retrieved. A

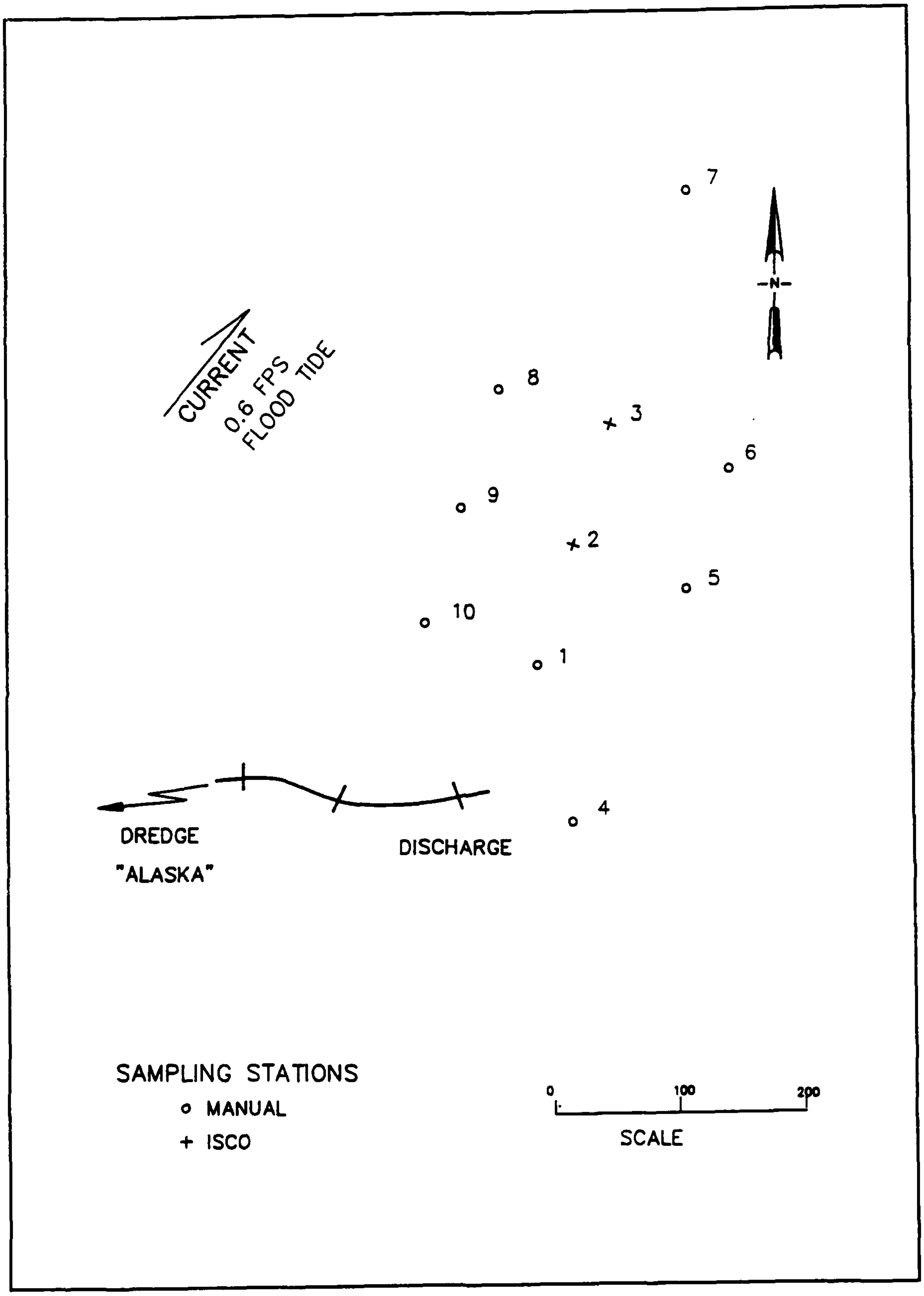

Figure D7. Station locations for 14 February 1988 survey (Test 6) wind measurement at this time indicated wind at 8 mph from the south-southeast (170 deg). Test 6 conditions and suspended sediment concentrations are provided in Tables D11 and 12, respectively.

Test 7 - flood tide

On 15 February, test setup began just after the dredge personnel completed moving the discharge line to a new location. Current velocity measurements began at 9:15 a.m. (CST) to determine magnitude and direction for proper placement of the sampling stations. Unlike the previous test, no ridge of sediment was visible at the end of the discharge pipe, since the pipeline had just been moved to its new location. Water depths in the vicinity of the discharge were generally found to be only 3 ft. The current direction was 230 deg from north at a magnitude of 0.3 fps (flooding). The sampling stations were oriented as shown in Figure D8. A sample of the pipe discharge was obtained prior to starting the test. The ISCO samplers were programmed to begin sampling at 10 a.m. (CST) and to collect samples at 3-min intervals, 1.5 ft from the bottom.

During the test, the visible surface plume did not appear to be moving in the general direction of the sampling stations, but maintained a general direction in line with the discharge pipe. By the end of the test, current velocity had increased to about 0.6 fps in the flood direction. This increase in current velocity appeared to have little or no effect on the visible plume orientation, as it continued to be positioned in line with the discharge pipe. Also, the plume continued to exhibit a meandering pattern. After completing the designed sampling program (Stations 1-10), additional samples were collected at Stations 11-28, within the limits of the visible surface plume. The locations of these additional stations are shown in Figure D9. The additional sampling was completed at 11:15 a.m. (CST). A wind measurement taken at this time indicated wind velocity of 8.5 mph from the south (180 deg). Test 7 conditions and suspended sediment concentrations are reported in Tables D13 and D14, respectively.

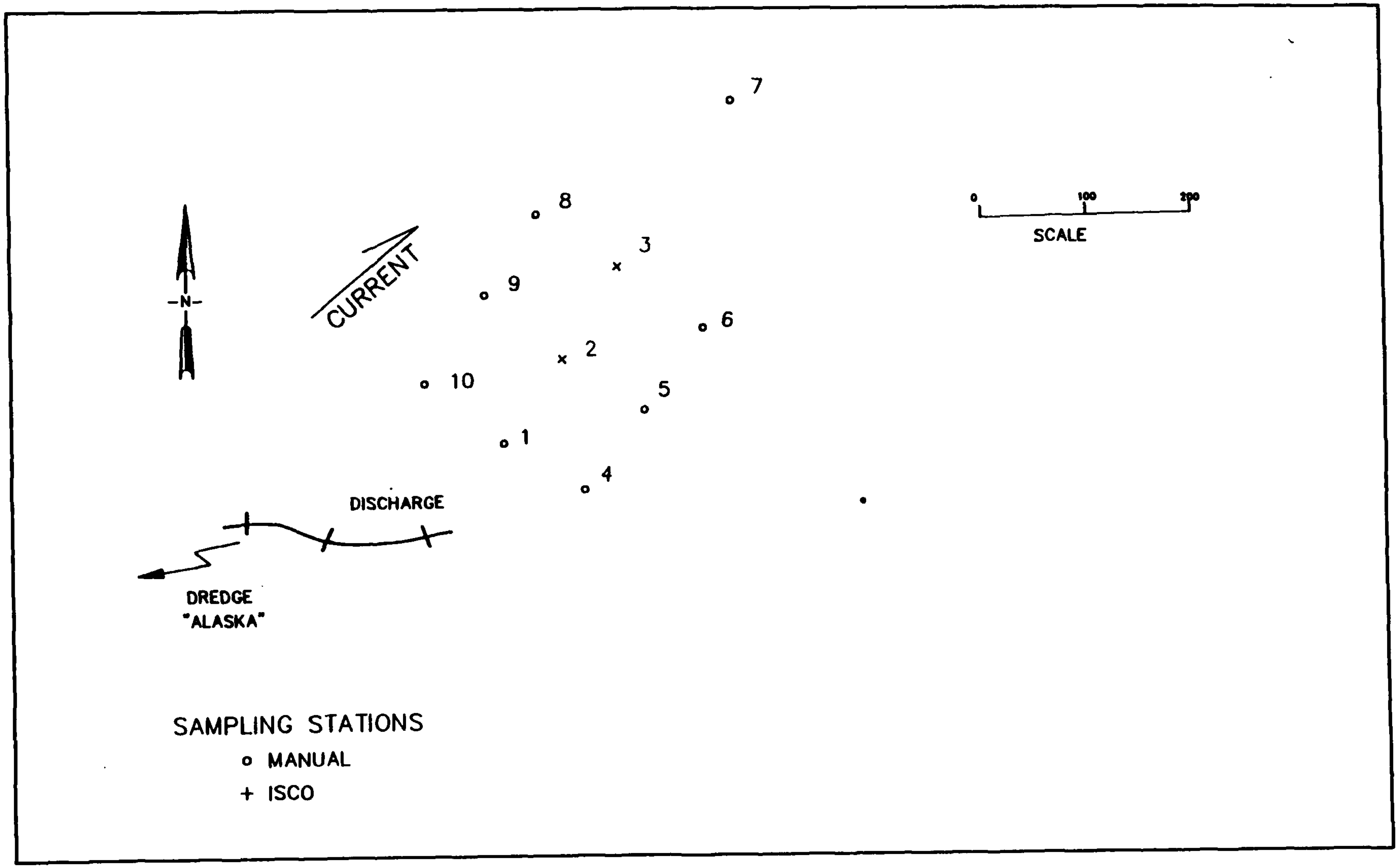

Figure D8. Initial station locations for 15 February 1989 survey (Test 7)

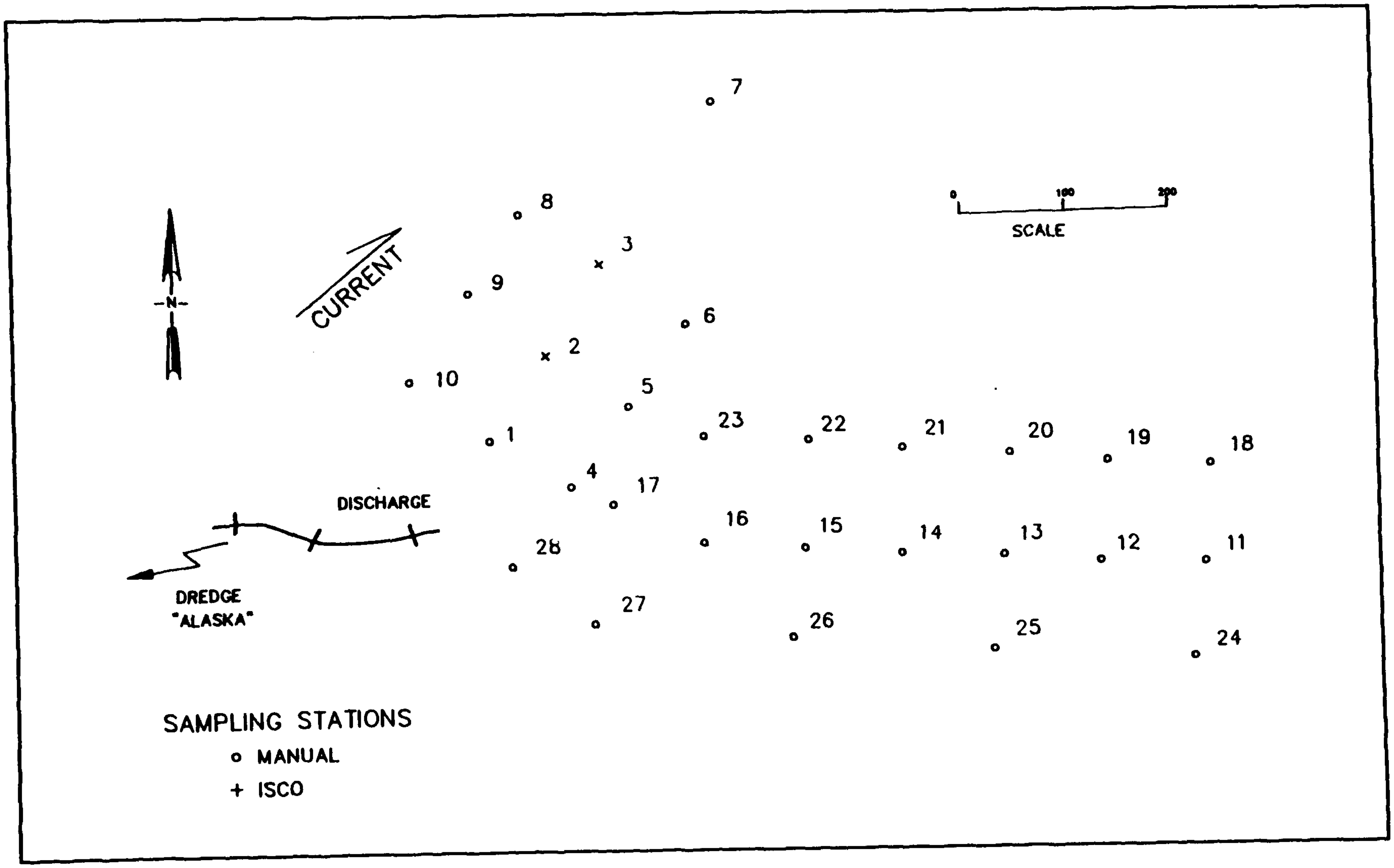

Figure D9. Final station locations for 15 February 1989 survey (Test 7)

Discussion of Field Results

Test 1

This initial test demonstrated the effectiveness of the downward-angled discharge pipe in placing the dredged material on the bay bottom in 10 to 12 ft of water with relatively little sediment in the water column. Observations indicated that a fluid mud bottom was created by the disposal operation and spread in a radial fashion from the discharge point. Collected samples indicated a sharp suspended sediment concentration interface near the bottom, within 1 ft. With this type of discharge configuration, the tidal current had little or no effect on the disposal pattern of the material.

Tests 2-5

These tests provided further evidence of the effectiveness of the downward-angled discharge pipe in placing the dredged material on the bay bottom in 10 to 12 ft of water and minimizing the amount of suspended sediment. Measurements in the upper water column at all stations indicated little or no sediment above background concentrations. Tidal currents seemed to have little or no effect on the pattern of disposal or deposition.

Overall Downward-Angled Discharge Results

The water depth for the sampling stations in Tests 1 through 5 ranged from 10 to 12 ft. If one ignores the stations located within 150 ft of the discharge point, the average suspended sediment concentration of all measurements made within 3 ft of the bottom was about 8,900 mg/L. However, the average of all measurements made above that was only about 20 mg/L. These average concentrations emphasize the effectiveness of the downward-angled discharge in placing the dredged material on the bottom as a "fluid mud" in a pancake fashion. From the standpoint of short-term fate, very little material is moved away from the discharge site by tidal currents.

Tests 6 and 7

These tests were conducted in the upper bay in only 3 ft of water. Unlike the previous tests, the discharge line was horizontal at the water surface without a splash plate. The suspended sediment measurements again demonstrated the existence of a fluid mud layer at the bay bottom, and mound-building during the disposal operation was observed. Measurements in the water column indicated much more sediment in the water column than in previous tests, which was probably due to both the type of discharge and the shallowness of the bay in the disposal area.

Overall Horizontal Discharge Without Splash Plate Results

The water depth for the sampling stations in Tests 6 and 7 ranged from 2.5 to 3.5 ft. If one ignores the stations located within 150 ft of the discharge point, the average suspended sediment concentration of all measurements made within 1.5 ft of the bottom was about 56,000 mg/L. The average of all measurements made above 1.5 ft from the bottom was about 1,750 mg/L. From these results it is concluded that, in shallow water only a few feet deep with the horizontal discharge and no splash plate, tidal currents can be only a limited factor in the initial dispersal of a portion of the dredged material discharge. However, during and immediately after disposal, most of the material is found on the bottom in the vicinity of the discharge point.

Disposal Model Tests

Numerical Model

The model used to simulate the short-term fate of disposed material is DIFCD. A detailed description of the model is given in Johnson (1990).[1]

Test Conditions

Model simulations were conducted to be representative of the dredge *Louisiana* discharge (field tests 6 and 7). Model conditions for each run are given in the tabulation below.

Run No.	Water Depth, ft	Current Velocity, fps	Time Simulated, min	Production Rate tons/hr
1	11	0.3	60	1,053
2	11	0.5	60	1,053
3	11	0.7	60	1,053
4	3	0.3	60	3,050
5	3	0.5	60	3,050
6	3	0.7	60	3,050

For all the above runs, the sediment was clay-silt, with at settling velocity of 0.0013 fps. The sediment voids ratio was set at 4.0 for all runs.

Deposit thickness (TH) is determined by the following equation:

$$TH = \frac{1 + VR}{AREA} \times VOL$$

---

[1] See References at the end of the main text.

where

VR = voids ratio (4.0)
AREA = grid cell size (150 × 150 sq ft)
VOL = solids volume, cu ft

Model Results

Deposition patterns after 60 min of pipeline discharge at a single location for the six model runs are shown in Figures D10 and D11.

Deposition pattern characteristics for each of the six runs are summarized in the following tabulation.

Run No.	Length of Mound, ft (0.05-ft Contour)	Width of Mound, ft (0.05-ft Contour)	Maximum Thickness of Mound, ft
1	570	475	0.65
2	700	375	0.62
3	700	385	0.62
4	900	730	0.44
5	950	700	0.56
6	1,050	670	0.44

In all runs, approximately 90 percent of the discharged material had deposited by the end of the 60-min simulation.

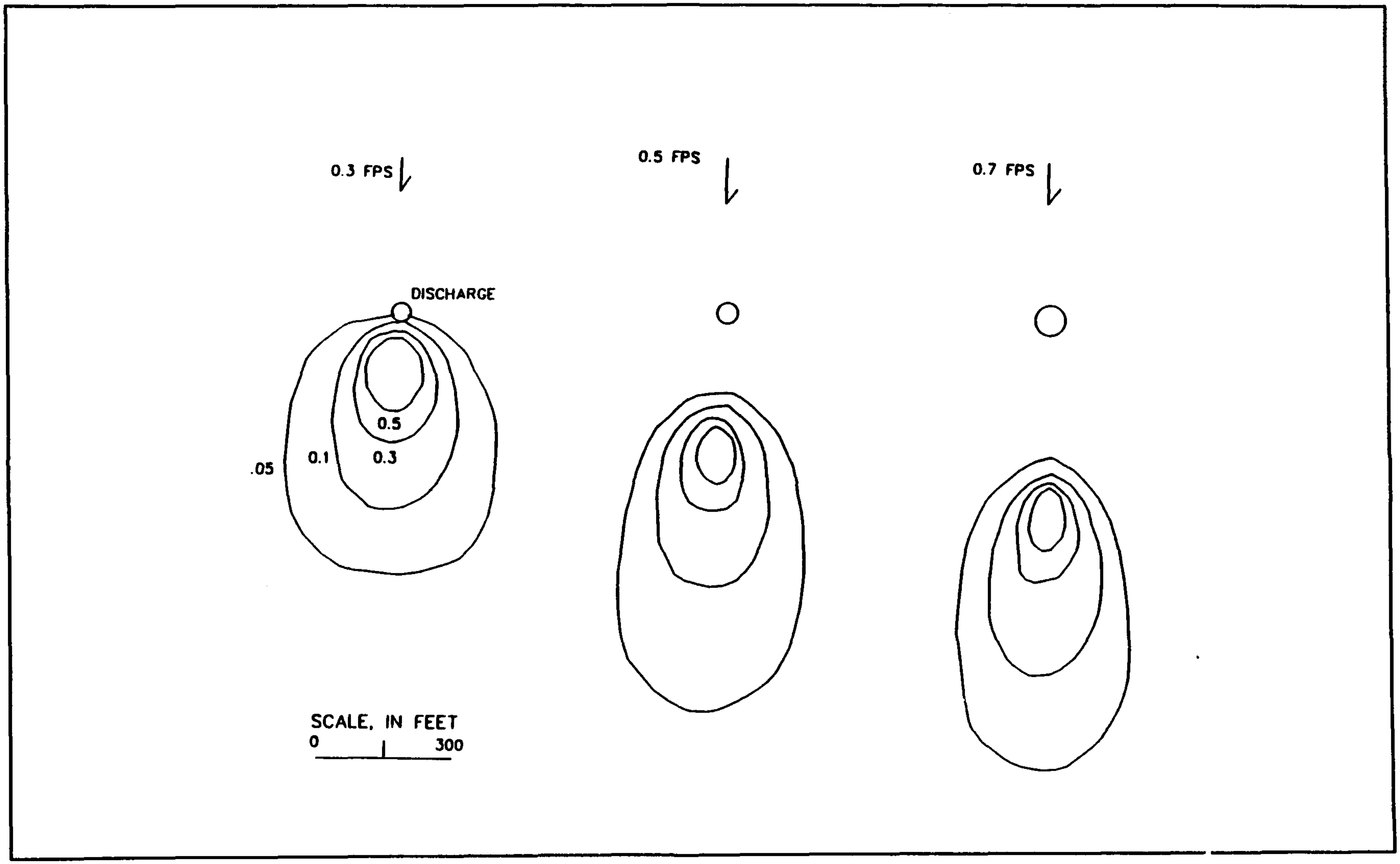

Figure D10. Thickness of deposition (in feet) for model runs 1 to 3

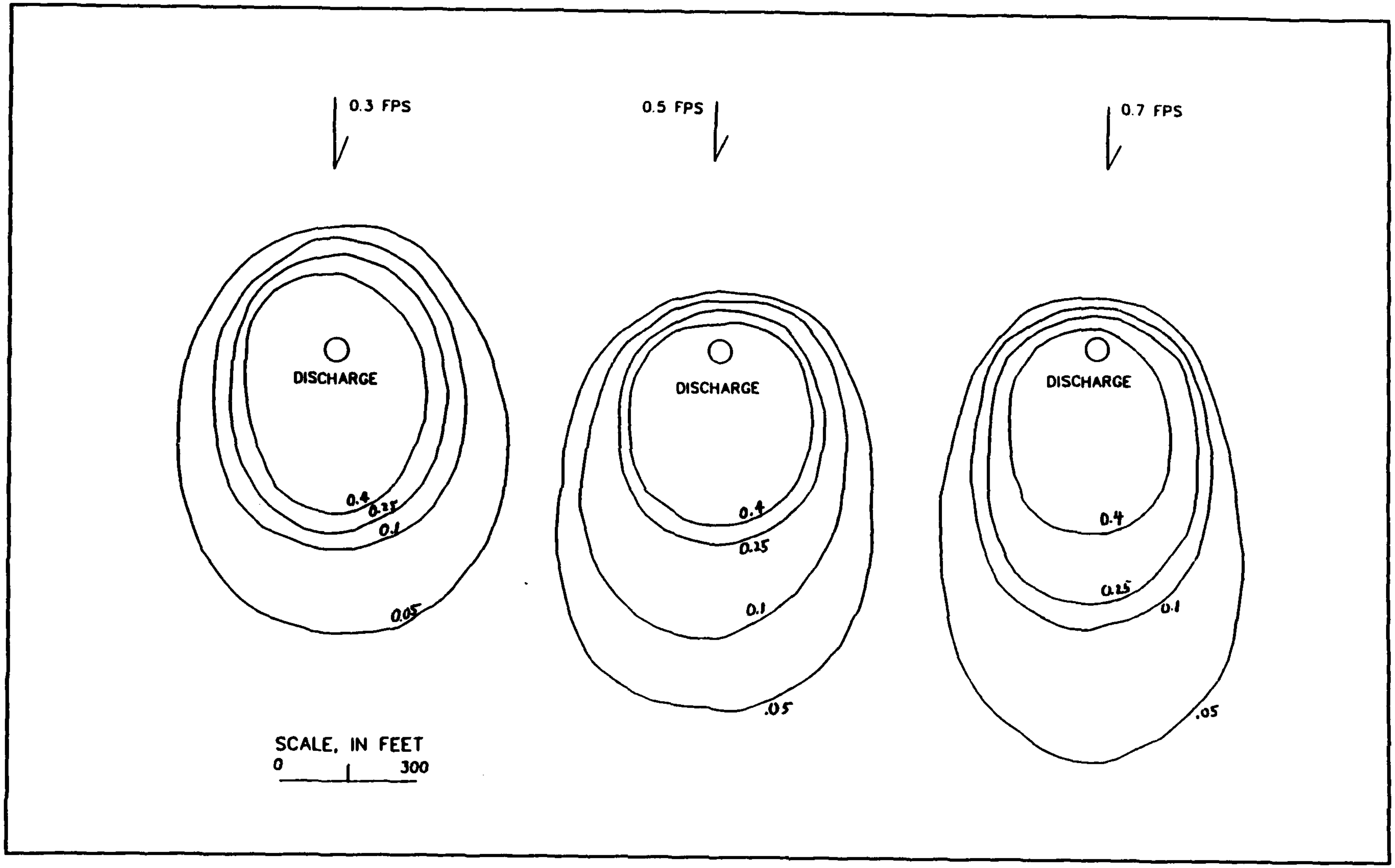

Figure D11. Thickness of deposition (in feet) for model runs 4 to 6

Summary

Downward-Angled Discharge

The field monitoring of the downward-angled discharge in 11-ft-deep water indicated that the disposed material was placed near bottom with only a small fraction of material suspended in the upper water column. Material was effectively placed on the bottom in a pancake fashion in the discharge vicinity. Very little material was moved away from the site by tidal currents.

The equivalent numerical disposal model runs in 11-ft-deep water predicted that a pipeline discharge continuing for 1 hr would create a pancake mound with a maximum thickness of about 0.6 ft, ranging in length from about 570 to 700 ft and in width from about 375 to 475 ft.

Horizontal Discharge

The field monitoring of the horizontal discharge in 3-ft-deep water indicated that, beyond 150 ft from the discharge point, average lower water column suspended sediment concentrations averaged about 56,000 mg/L. The average upper water column suspended sediment concentrations, including those within 150 ft of the discharge point, averaged only about 1,800 mg/L. Tidal currents played only a limited role in the initial dispersal of the disposed material. Most of the discharged material quickly moved to near-bottom in the vicinity of the discharge point.

The equivalent numerical disposal model runs predicted that a pipeline discharge continuing for 1 hr would create a pancake mound with a maximum thickness of about 0.5 ft, ranging in length from about 900 ft to 1,050 ft and in width from about 670 to 730 ft.

Table D1
Test 1 Conditions

Date of Test: 4 June 1988
Start Time: 8:30 a.m. (CST)
End Time: 10:00 a.m. (CST)

Wind Speed: Calm
Wind Direction: NA

Wave Conditions: Calm

Current Speed: 0.5 fps
Current Direction: from 220 deg (flood tide)

Pipeline Flow Rate: 72 cfs
Pipeline Sediment Concentration: 130,000 mg/L
Pipeline Sediment Discharge: 1,053 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
1	ISCO	11	8
2	ISCO	11	8
3	ISCO	11	8
4	ISCO/Manual	11	8/1
5	Manual	11	4,8
6	Manual	11	4,8
7	Manual	11	2,4,8
8	Manual	11	2,4,8
9	Manual	11	10,11
10	Manual	11	10,11
11	Manual	11	10,11
BG-A	Manual	40	4,8,12
BG-B	Manual	11	4,8

Table D2
Suspended Sediment Concentrations (mg/L), Test 1, 4 June 1988

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
1	11.0	8.0	ISCO	8
				10
				3
				37
				24
				13
				68
				21
				17
				29
				20
				31
				14
				16
				15
				10
				14
				12
				31
				23
				22
2	11.0	8.0	ISCO	238
				1,230
				414
				252
				198
				134
				112
				206
				1,888
				374
				112
				114
				110
				120
				138
				126
				98
				172
				102
3	11.0	8.0	ISCO	31
				39
				24
				69
				35
				32
				36
				34
				39
				39
				42
				53
				61
				48
				50

(Continued)

Table D2 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
3 (Cont.)	11.0	8.0	ISCO	49 50 50 53 50 55 66
4	11.0	1.0	Manual	5 4 6 10 5 5 10 7 7 43 39 56 53 59 67 40 54 47
5	11.0	4.0	Manual	40
		8.0		86
6	11.0	4.0	Manual	43
		8.0		77
7	11.0	2.0	Manual	11
		4.0		10
		4.0		36
		8.0		146
8	11.0	10.0	Manual	136
		10.5		5,380
9	11.0	10.0	Manual	209
		10.5		8,240
10	11.0	10.0	Manual	268
		10.5		40,200
11	11.0	10.0	Manual	120
		10.5		10,120
BG-A	40.0	4.0	Manual	8
		8.0		17
		12.0		13
BG-B	11.0	4.0	Manual	6
		8.0		71
Discharge (at pipe leak)	--	--	--	138,800
Discharge (at end of pipe)	--	--	--	60,900

Table D3
Test 2 Conditions

Date of Test: 16 June 1988
Start Time: 9:30 a.m. (CST)
End Time: 11:00 a.m. (CST)

Wind Speed: Calm
Wind Direction: NA

Wave Conditions: Calm

Current Speed: 0.3 fps
Current Direction: from 210 deg (flood tide)

Pipeline Flow Rate: 72 cfs
Pipeline Sediment Concentration: 130,000 mg/L
Pipeline Sediment Discharge: 1,053 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
1	ISCO	12	8
2	ISCO	12	9
3	Manual	12	10,11
4	ISCO	12	9
5	Manual	12	3,6,9
6	Manual	12	3,6,9
7	Manual	12	3,6,8
8	Manual	12	3,6,9
9	Manual	12	3,6,9
10	Manual	12	3,6,9
11	Manual	12	3,6,9
12	Manual	12	3,6,9

Table D4
Suspended Sediment Concentrations (mg/L), Test 2, 16 June 1988

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
1	11.4	8.4	ISCO	31
				15
				11
				13
				10
				14
				8
				8
				8
				13
				9
				43
				14
				14
				16
				56
				254
				89
				31
				29
				10
2	11.5	8.5	ISCO	164,680
				164,600
				162,160
				160,870
				160,720
				157,260
				156,160
				154,360
				153,230
				152,040
				154,270
				157,650
				160,070
3	11.5	11.0	Manual	101,834
		10.5		67,527
		10.0		30,366
		9.5		19,960
4	11.5	8.5	ISCO	160
				210
				140
				350
				290
				370
				180
				210
				560
				320
				420
				480
				640
				640
				680
				660

(Continued)

Table D4 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
4 (Cont.)	11.5	8.5	ISCO	480
				440
				460
				450
5	11.5	3.0	Manual	23
		6.0		28
		8.5		103
6	11.5	3.0	Manual	8
		6.0		21
		8.5		34
7	11.0	3.0	Manual	16
		5.5		28
		8.0		294
8	11.5	3.0	Manual	12
		6.0		15
		8.5		406
9	11.5	3.0	Manual	16
		6.0		12
		8.5		72
10	11.5	3.0	Manual	14
		6.0		16
		8.5		232
11	11.5	3.0	Manual	11
		6.0		49
		8.5		147
12	11.5	3.0	Manual	8
		6.0		19
		8.5		96
BG	11.0	3.0	Manual	10
		8.0		138

Table D5
Test 3 Conditions

Date of Test: 16 June 1988
Start Time: 2:20 p.m. (CST)
End Time: 3:20 p.m. (CST)

Wind Speed:
Wind Direction:

Wave Conditions: Choppy

Current Speed: 0.8 fps
Current Direction: from 10 deg (ebb tide)

Pipeline Flow Rate: 72 cfs
Pipeline Sediment Concentration: 130,000 mg/L
Pipeline Sediment Discharge: 1,053 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
1	ISCO	12	9
3	ISCO/Manual	12	9/1,2,4,6,8,9,10,11
4	ISCO	12	9
5	Manual	10	3,5,7
7	Manual	10	5,7,9
8	Manual	11	3,6,8
9	Manual	10	3,5,7
10	Manual	12	3,6,11
11	Manual	12	3,6,11

Table D6
Suspended Sediment Concentrations (mg/L), Test 3, 16 June 1988

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
1	11.5	8.5	ISCO	5,076
				47,887
				48,293
				39,269
				41,548
				44,759
				37,029
				48,128
				30,323
				24,452
				12,819
				18,118
				22,199
				20,819
				16,439
3	11.5	8.5	ISCO	5,870
				19,080
				18,430
				2,570
				122
				85
				111
				108
				321
				157
				127
				120
				97
				94
				93
				124
				84
		1.0	Manual	8
		2.0		6
		4.0		20
		6.0		38
		7.5		224
		8.0		103
		8.5		275
		9.0		1,026
		9.5		34,527
		10.0		34,611
		10.5		11,146
		11.0		50,811
				78,312
4	11.5	8.5	ISCO	270
				3,980
				7,230
				6,080
				10,070
				5,350
				8,550
				7,570
				2,710
				13,080
				8,270

(Continued)

Table D6 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
4 (Cont.)	11.5	8.5	ISCO	12,440 7,900 2,060 10,860 21,390 12,120 13,490 2,630 5,430 3,980
5	10.0	3.0	Manual	11
		5.0		20
		7.0		27
7	10.0	5.0	Manual	35
		7.0		18
		9.0		16
8	11.0	3.0	Manual	9
		5.5		28
		8.0		165
9	10.0	3.0	Manual	11
		5.0		12
		7.0		44
10	11.5	3.0	Manual	9
		5.5		15
		11.0		207
11	11.5	3.0	Manual	6
		5.5		66
		11.0		82
12	11.5	3.0	Manual	9
		3.0		2
		5.5		26
		11.0		92

Table D7
Test 4 Conditions

Date of Test: 16 June 1988
Start Time: 5:15 p.m. (CST)
End Time: 6:15 p.m. (CST)

Wind Speed:
Wind Direction:

Wave Conditions: Choppy

Current Speed: 0.8 fps
Current Direction: from 10 deg (ebb tide)

Pipeline Flow Rate: 72 cfs
Pipeline Sediment Concentration: 130,000 mg/L
Pipeline Sediment Discharge: 1,053 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
2	ISCO	12	9
3	ISCO/Manual	12	9/1,2,4,6,9,10,11
4	ISCO	12	9
5	Manual	10	3,5,7
6	Manual	11	3,6,8
7	Manual	10	3,5,7
8	Manual	11	3,6,8
9	Manual	10	3,6,8
10	Manual	12	3,6,9
11	Manual	12	3,6,9
12	Manual	12	6,9

Table D8
Suspended Sediment Concentrations (mg/L), Test 4, 16 June 1988

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
2	11.5	8.5	ISCO	123
				150
				177
				127
				81
				55
				56
				33
				20
				22
				16
				40
				19
				35
				21
				14
				18
				13
				22
				28
				42
				43
				65
3	11.5	8.5	ISCO	39
				38
				56
				33
				35
				65
				65
				76
				54
				37
				14
				21
				17
				24
				23
				26
				19
				17
				26
3	11.5	8.5	ISCO	11
				12
				39
				20
				30
		10.5	Manual	11,310
		8.0		24
		2.0		8
		4.0		9
		6.0		32
		8.5		156
		1.0		8
		9.0		238

(Continued)

Table D8 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
3 (Cont.)	11.5	9.5	Manual	302
		10.0		521
4	11.5	8.5	ISCO	10,080
				16,910
				310
				524
				1,543
				542
				626
				1,250
				2,250
				3,970
				3,400
				3,060
				8,190
				8,070
				3,830
				3,420
				4,080
				8,260
				5,910
				1,390
				3,380
				1,170
				5,670
				14,570
5	10.0	3.0	Manual	5
		5.0		13
		7.0		19
6	11.0	3.0	Manual	1
		5.5		5
		8.0		14
7	10.0	3.0	Manual	11
		5.0		38
		7.0		45
8	11.0	3.0	Manual	6
		5.5		6
		8.0		82
9	10.0	3.0	Manual	16
		5.5		10
		8.0		94
10	11.5	3.0	Manual	12
		5.5		16
		8.5		12
11	11.5	3.0	Manual	11
		5.5		21
		8.5		26
12	11.5	5.5	Manual	10
		8.5		22

Table D9
Test 5 Conditions

Date of Test: 17 June 1988
Start Time: 7:20 a.m. (CST)
End Time: 9:00 a.m. (CST)

Wind Speed:
Wind Direction:

Wave Conditions: Calm

Current Speed: 0.5 fps
Current Direction: from 200 deg (flood tide)

Pipeline Flow Rate: 72 cfs
Pipeline Sediment Concentration: 130,000 mg/L
Pipeline Sediment Discharge: 1,053 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
2	ISCO	12	9
3	ISCO/Manual	12	9/1,2,4,6,9,10
4	ISCO	12	9
7	Manual	10	3,5,7
8	Manual	11	3,6,8
9	Manual	10	3,5,7
10	Manual	12	3,6,9
11	Manual	12	3,6,9
12	Manual	12	3,6,9

Table D10
Suspended Sediment Concentrations (mg/L), Test 5, 17 June 1988

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
2	11.5	8.5	ISCO	54
				56
				105
				52
				44
				48
				50
				69
				71
				44
				35
				41
				82
				36
				43
				39
				37
				37
				42
				45
				59
				59
				45
				53
3	11.5	8.5	ISCO	29
				27
				26
				21
				24
				28
				27
				29
				32
				32
				48
				40
				39
				24
				28
				30
				30
				35
				31
				22
				27
		1.0	Manual	8
		2.0		9
		4.0		11
		6.0		9
		8.0		76
		8.5		32
		9.0		74
		9.3		122

(Continued)

Table D10 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
4	11.5	8.5	ISCO	39,100 29,460 37,240 31,230 33,270 12,480 33,010 43,970 21,950 22,660 27,180 61,470 53,090 25,810 34,190 49,090 54,980 38,190 48,270 75,910 62,080
7	10.0	3.0 5.0 7.0	Manual	8 54 505
8	11.0	3.0 5.5 8.0	Manual	8 9 87
9	10.0	3.0 5.0 7.0	Manual	5 7 147
10	11.5	3.0 5.5 8.5	Manual	13 26 105
11	11.5	3.0 5.5 8.5	Manual	3 13 41
12	11.5	3.0 5.5 8.5	Manual	5 25 16

Table D11
Test 6 Conditions

Date of Test:	14 February 1989
Start Time:	11:50 a.m. (CST)
End Time:	1:10 p.m. (CST)
Wind Speed:	
Wind Direction:	
Wave Conditions:	
Current Speed:	0.6 fps
Current Direction:	from 220 deg (flood tide)
Pipeline Flow Rate:	
Pipeline Sediment Concentration:	
Pipeline Sediment Discharge:	3,050 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
1	Manual	3	1,2
2	ISCO	3	2
3	ISCO	3	2
4	Manual	3	1,2
5	Manual	3	1,2,3
6	Manual	3	1,2,3
7	Manual	4	1,2,3
8	Manual	4	1,2,3
9	Manual	3	1,2
10	Manual	3	1,2
BG	Manual	5	1,2,3,4

Table D12
Suspended Sediment Concentrations (mg/L), Test 6, 14 February 1989

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
1	3.0	1.0	Manual	308
				264
				192
				340
				268
				212
				256
				172
				124
				132
				160
				168
				192
				228
				352
				448
				284
				340
				252
				292
				484
				468
				256
				300
				288
		2.0		68,500
				29,400
				32,000
				40,820
				45,000
				55,300
				56,800
				52,600
				60,400
				62,800
				60,400
				47,700
				53,800
				55,700
				60,000
				76,300
				71,800
				49,800
				70,400
				44,100
				48,900
				50,900
				60,500
				60,500
				60,100
2	3.0	2.0	ISCO	26,940
				30,880
				23,280
				14,200
				6,620
				17,460
				11,460

(Continued) *(Sheet 1 of 3)*

Table D12 (Continued)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
2 (Cont.)	3.0	2.0	ISCO	5,500
				6,180
				6,640
				9,580
				6,380
				5,200
				5,520
				22,560
				20,900
				26,500
				31,560
				16,560
				9,460
				17,340
				13,600
				16,780
				10,700
3	3.0	2.0	ISCO	3,560
				12,200
				10,140
				29,460
				15,640
				14,280
				7,820
				3,100
				2,100
				3,160
				1,240
				3,520
				5,560
				2,680
				1,180
				280
				11,640
				8,380
				18,400
				22,420
				12,160
				16,620
				29,340
				27,380
4	3.0	1.0	Manual	11,700
				6,800
		2.0		23,340
				21,360
5	3.0	1.0	Manual	856
				128
		1.5		12,720
				32,600
		2.5		172,700
				131,800
6	3.0	1.0	Manual	84
		1.5		2,800
		2.0		19,100
		2.5		27,700

(Continued) *(Sheet 2 of 3)*

Table D12 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
7 (Cont.)	3.5	1.0	Manual	80
				100
		2.0		32,200
				50,000
		2.5		183,000
8	3.5	1.0	Manual	66
				360
		2.0		692
				45,000
		3.0		113,400
				116,400
9	3.0	1.0	Manual	112
				216
		2.0		89,200
				20,700
10	2.5	0.5	Manual	160
		1.0		188
		1.5		16,900
		2.0		28,200
BG	5.0	1.0	Manual	60
		2.0		186
		2.5		222
				54
				180
				90
		3.0		202
				56
				118
		3.5		78
		4.0		56
				54
				70
Dredge line	--	--	--	65,300
End of pipe	--	--	--	338,500
				337,000

(Sheet 3 of 3)

Table D13
Test 7 Conditions

Date of Test: 15 February 1989
Start Time: 9:15 a.m. (CST)
End Time: 10:45 a.m. (CST)

Wind Speed: 8 mph
Wind Direction: from 180 deg

Current Speed: 0.3 - 0.6 fps
Current Direction: from 230 deg (flood tide)

Pipeline Flow Rate:
Pipeline Sediment Concentration:
Pipeline Sediment Discharge: 3,050 tons/hr

Station	Type	Water Depth, ft	Sample Depth, ft
1	Manual	3	1,2
2	ISCO	3	2
3	ISCO	3	2
4	Manual	3	1,2
5	Manual	3	1,2
6	Manual	2	1
7	Manual	3	1,2
8	Manual	3	1,2
9	Manual	3	1,2
10	Manual	3	1,2
11	Manual	4	1,2,3
12	Manual	4	1,2,3
13	Manual	4	1,2,3
14	Manual	4	1,2,3
15	Manual	3	1,2
16	Manual	3	1
17	Manual	3	1,2
18	Manual	4	1,2,3
19	Manual	4	1,2,3
20	Manual	4	1,2,3
21	Manual	3	1,2
22	Manual	3	1,2
23	Manual	3	1,2
24	Manual	3	1,2

(Continued)

Table D13 (Concluded)

Station	Type	Water Depth, ft	Sample Depth, ft
25	Manual	3	1,2
26	Manual	3	1,2
28	Manual	4	1,2,3
28	Manual	3	1,2
BG	Manual		

Table D14
Suspended Sediment Concentrations (mg/L), Test 7, 15 February 1989

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
1	3.0	1.0	Manual	104
				78
				112
				212
				204
				212
				256
				336
				316
				340
				340
				332
				384
				348
				468
				340
				340
				476
				312
				276
				348
				268
				500
				292
				384
		2.0		64,600
				10,200
				108
				7,260
				4,780
				240
				1.620
				3,160
				9,700
				26,200
				2,320
				404
				4,740
				11,760
				22.160
				20,800
				12,680
				42,200
				18,760
				15,700
				48,120
				32,640
				28,780
				548
				484
2	3.0	2.0	ISCO	69,500
				64,100
				59,400
				48,600
				53,300
				69,100
				74,400
				63,600
				69,100
				63,900

(Continued) *(Sheet 1 of 4)*

Table D14 (Continued)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
2 (Cont.)	3.0	2.0	ISCO	62,100
				75,200
				58,900
				71,200
				72,800
				67,900
				76,500
				61,000
				64,400
				77,300
				72,100
				76,800
				83,100
				75,300
3	3.0	2.0	ISCO	2,768
				10,116
				5,440
				688
				164
				13,780
				6,220
				3,260
				14,180
				6,980
				1,440
				14,160
				3,440
				716
				3,000
				5,060
				15,320
				4,080
				548
				10,380
				22.560
				686
				3,440
				17,360
4	3.0	1.0	Manual	9,820
		2.0		23.400
5	2.5	1.0	Manual	700
				592
		2.0		57,100
				5,580
6	2.0	1.0	Manual	5,320
				8,100
7	2.5	1.0	Manual	244
				424
		2.0		23,380
				70,900

(Continued) *(Sheet 2 of 4)*

Table D14 (Continued)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
8	3.0	1.0	Manual	144
				1,260
		2.0		3,140
				19,600
9	3.0	1.0	Manual	1,320
				248
		2.0		6,960
				296
10	3.0	1.0	Manual	276
				412
		2.0		404
				192
11	3.5	1.0	Manual	80
		2.0		37,200
		3.0		188,500
12	3.5	1.0	Manual	1,033
		2.0		91,900
		3.0		181,300
13	3.5	1.0	Manual	4,166
		2.0		9,233
		3.0		186,600
14	3.5	1.0	Manual	2,533
		2.0		46,300
		3.0		144,700
15	3.0	1.0	Manual	1,933
		2.0		38,840
16	3.0	1.0	Manual	9,600
17	3.0	1.0	Manual	4,433
		2.0		3,600
18	3.5	1.0	Manual	2,633
		2.0		40,400
		3.0		161,300
19	3.5	1.0	Manual	1,500
		2.0		41,300
		3.0		138,400
20	3.5	1.0	Manual	580
		2.0		4,100
		3.0		29,230
21	3.0	1.0	Manual	1,980
		2.0		4,000
22	3.0	1.0	Manual	3,900
		2.0		25,400
23	3.0	1.0	Manual	4,140
		2.0		5,960
24	3.0	1.0	Manual	960
		2.0		49,900

(Continued) *(Sheet 3 of 4)*

Table D14 (Concluded)

Station No.	Water Depth, ft	Sample Depth, ft	Sample Type	Concentration, mg/L
25	3.0	1.0 2.0	Manual	980 45,300
26	3.0	1.0 2.0	Manual	1,220 2,660
27	4.0	1.0 2.0 3.0	Manual	640 1,760 12,600
28	3.0	1.0 2.0	Manual	1,320 2,660
BG (Channel marker 67)	--	--	--	440

(Sheet 4 of 4)

Waterways Experiment Station Cataloging-in-Publication Data

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