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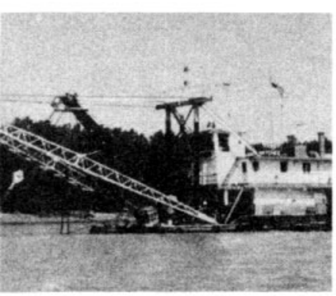

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SELECTED TOOLS AND TECHNIQUES FOR PHYSICAL AND BIOLOGICAL MONITORING OF AQUATIC DREDGED MATERIAL DISPOSAL SITES

by

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Monitoring of aquatic dredged material disposal sites may require a variety of physical and biological tools and techniques. Chemical monitoring tools and techniques are not discussed in this report since this document does not address chemically unsuitable material. In the tiered approach discussed in the companion report ("Guidelines for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites"), the lower level tiers may examine primarily physical changes at a site. Changes in physical environment, such as mounding, can result in a navigation hazard or lead to changes in the biological community (e.g., burial), which necessitates biological monitoring. Design of a monitoring program must consider what equipment to use and at what spatial and temporal frequency to sample. These factors will be determined by the level of information required for the questions being addressed, given present technical, monetary, regulatory, and political considerations.

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19. ABSTRACT (Continued).

Physical monitoring tools. Physical monitoring tools can be broadly classified into several groups. Navigation and positioning equipment, though not actually monitoring tools, are primary among these. The effectiveness of all physical and biological sampling depends upon knowing the location of a sample relative to the disposal site. A variety of equipment types are available for locating a sample. Generally, more precise locationing requires more complex and expensive systems.

Equipment that measures bathymetry and ocean bottom configuration with acoustic energy is a second group. A third group of physical instruments consists of those that directly sample sediment. These range from grab samplers, which one person can operate to retrieve a small surface sample, to large vibracores that return a core (up to 40 ft (12 m) long) through a disposal site.

A fourth group of tools for physical monitoring includes those instruments that return data on site conditions remotely through the use of photography. These instruments, such as the sediment-profiling camera or video cameras attached to remotely operated underwater vehicles, have had success in helping to delineate outer fringes of disposal material, where necessary within a site.

In situ measurements of engineering properties of mounds, such as density, sediment size, pore pressure, settlement rates, and shear strength, are possible with a fifth group of tools. Waves and current meters form the last group of tools that may be useful in physical monitoring. They are used to measure the driving forces for sediment transport.

Biological monitoring tools. Fish and shellfish are generally the animals of the greatest socioeconomic importance to individuals and agencies. However, obtaining quantitative information about a given species or assemblage presents more of a problem with mobile organisms such as fish and shellfish. Most sampling devices are selective in terms of size and, often, species, causing a bias in the resulting estimates of density, species diversity, or biomass. Considerable difficulty is often faced in obtaining replicate data, due to the variability in dispersion of individuals and their mobility. This results in great variability in both time and space.

Sampling of nektonic organisms (fishes, shrimps, and crabs) is most commonly accomplished through the use of nets or traps of various types. The choice of sampling device(s) for monitoring depends on the type(s) of organism(s) of interest.

Benthic infauna (particularly macrobenthos) and submergent vegetation are regarded as good indicators of environmental quality because of their sedentary nature and thus their susceptibility to physical and chemical alterations. In addition, they can be sampled more quantitatively and efficiently. Grab samplers and box corers are the tools of choice for quantitative sampling of sessile epifauna and infauna (to the depth excavated by the sampler).

PREFACE

These guidelines were prepared as part of the Dredging Operations Technical Support (DOTS) Program at the US Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The DOTS Program is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), through the Dredging Division. The DOTS is managed by the WES Environmental Laboratory (EL) through the Environmental Effects of Dredging Programs (EEDP). Dr. Robert M. Engler was Program Manager for the EEDP; Mr. Thomas R. Patin was the DOTS Program Manager. Mr. Joseph Wilson was the HQUSACE Technical Monitor.

The report was prepared by Dr. Thomas J. Fredette, Mr. David A. Nelson, Ms. Tina Miller-Way, Mr. Jeffery A. Adair, and Ms. Virginia A. Sotler of the Coastal Ecology Group (CEG), Environmental Resources Division (ERD), EL, and by Messrs. James E. Clausner, Edward B. Hands, and Fred J. Anders of the Coastal Structures and Evaluation Branch (CD-S), Engineering Development Division (CD), Coastal Engineering Research Center (CERC). Dr. Thomas W. Richardson, CD; Mr. Hands, CD-S; Mr. Edward J. Pullen, CEG; and Mr. Nelson, CEG, served as technical reviewers for the draft report. Dr. Mark W. LaSalle, CEG, edited and provided information for biological portions of the report. The report was edited for publication by Ms. Jessica S. Ruff of WES Information Technology Laboratory.

The CEG personnel worked under the direct supervision of Mr. Edward J. Pullen, Chief, CEG, and under the general supervision of Dr. Conrad J. Kirby, Chief, ERD, and Dr. John Harrison, Chief, EL. The CD-S personnel worked under the direct supervision of Ms. Joan Pope, Chief, CD-S, and under the general supervision of Dr. Thomas J. Richardson, Chief, CD, and Dr. James R. Houston, Chief, CERC.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

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

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

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	2.54	centimetres
knots (international)	0.5144444	metres per second
miles (US nautical)	1.852	kilometres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
tons (2,000 pounds, mass)	907.1847	kilograms

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

SELECTED TOOLS AND TECHNIQUES FOR PHYSICAL AND BIOLOGICAL MONITORING OF AQUATIC DREDGED MATERIAL DISPOSAL SITES

PART I: INTRODUCTION

1. Monitoring of aquatic dredged material disposal sites may require a variety of physical and biological tools and techniques. Chemical monitoring is not discussed since this document does not address sites where chemically unsuitable material is placed. In the tiered approach discussed in Fredette et al. (1990), the lower level tiers may examine primarily physical changes at a site. Changes in physical environment, such as mounding, can result in a navigation hazard or lead to changes in the biological community (e.g. burial), which necessitates biological monitoring. Design of a monitoring program must consider what equipment to use and at what spatial and temporal frequency to sample. These factors will be determined by the level of information required for the questions being addressed, given present technical, monetary, regulatory, and political considerations.

2. This report describes selected tools and techniques used for biological and physical monitoring of aquatic dredged material disposal sites. A wide variety of tools are discussed, ranging from those that are routinely used in monitoring to those that are occasionally used for special cases or research purposes. For most monitoring programs, only a very limited number of tools described in this report will be needed. The selection of tools to use will be dictated by the site-specific questions to be answered. Within this report a brief description of each tool and its intended use is presented, along with an evaluation of its usefulness for routine or extraordinary monitoring. Past examples of use, approximate instrument costs, ease of data interpretation, and instrument attributes and limitations are discussed. Examples of tool selection for different monitoring levels are briefly presented here and in Fredette et al. (1990).

Physical Monitoring Tools

3. Physical monitoring tools can be broadly classified into several groups. Navigation and positioning equipment, though not actually monitoring tools, are primary among these. The effectiveness of all physical and

biological sampling depends upon knowing the location of a sample relative to the disposal site. A variety of equipment types are available for locating a sample. Generally, more precise locationing requires more complex and expensive systems. Accuracies from ±1,500 ft* to ±0.1 ft are presently available. Accurate, low-cost satellite positioning may be readily available in the near future.

4. Equipment that measures bathymetry and ocean bottom configuration with acoustic energy comprises the second group. Fathometers (depth sounders) are most commonly used for bathymetry and can give elevations accurate to ±0.6 ft when corrections are applied for water-level and boat-level variations. Side-scan sonar has been used to map aerial distribution of sediment and surface bed forms for determining direction of sediment motion. Subbottom profilers have been used to examine internal mound and seafloor features.

5. A third group of physical instruments consists of those that directly sample sediment. Surface samples and cores can be collected with a variety of instruments. These range from grab samplers, which one person can operate to retrieve a small surface sample, to large vibracores that return up to a 40-ft-long core through a disposal site. Usually, sands are the most difficult to penetrate, thus limiting tool selection.

6. A fourth group of tools for physical monitoring includes those instruments that return data on site conditions remotely. Included are airborne imaging systems and those on or within the seafloor. Instruments such as the sediment-profiling camera, or video cameras attached to remotely operated underwater vehicles, have proven useful in delineating the outer fringes of disposal material, where necessary within a site.

7. A collection of tools are available for measuring various engineering properties of disposal mounds in situ. Approximate sediment size, density, pore pressure, shear strength, settlement rates, etc., can be measured with these devices. Some of these are diver-operated, while others can be deployed from a ship.

8. Waves and current meters form the last group of tools that may be useful in physical monitoring. They are used to measure the driving forces for sediment transport. These instruments are costly to purchase and

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

maintain. Records over long periods of time are difficult to obtain due to natural equipment failure and accidental destruction by fishing boats.

9. Spatial and temporal sampling intensity is generally low for tier 1 monitoring. As the tier level increases, frequency of sampling also increases. This applies to biological monitoring as well. Most sampling plans establish a regular or modified grid over the disposal study site for sample collection to ensure complete site coverage. Grid spacing, size, and shape depend on tier level, site conditions, and available resources. Tier 1 grids are typically widely spaced, with a few sampling points covering the minimal area of anticipated impact. With increasing tiers, grid spacing is reduced, sampling frequency is increased spatially and temporally, and the grid area may be increased. Temporal sampling frequency is highly dependent on the anticipated level of impact and on temporal variability of the physical and biological site characteristics.

Biological Monitoring Tools

Fish and shellfish sampling

10. Fish and shellfish are generally the animals of the greatest socioeconomic importance to individuals and agencies. However, obtaining quantitative information about a given species or assemblage presents more of a problem with mobile organisms such as fish and shellfish. Most sampling devices are selective in terms of size and, often, species, causing a bias in the resulting estimates of density, species diversity, or biomass. Considerable difficulty is often faced in obtaining replicate data, due to the variability in dispersion of individuals and their mobility. This results in great variability in both time and space. The combination of variability in abundance of fish and shellfish species and the variation in sampling equipment and methods makes comparisons of data from various sources imprecise over large areas.

11. Sampling of nektonic organisms (fishes, shrimps, and crabs) is most commonly accomplished through the use of nets or traps of various types. Nets generally collect a greater diversity of organisms than do traps. Traps are usually designed to attract and capture a particular species (e.g., crab pots). The choice of sampling device(s) for monitoring depends on the type(s) of organism(s) of interest. Nets are either passive or active collectors of organisms. Passive nets are set in stationary positions, collecting organisms

that become entangled (e.g., anchored gill net, hoop net, and fyke net) or entrapped within the confines of the netted area (e.g., fish traps) and may require extended deployment, in-place, and recovery periods. Active nets (e.g., otter trawls and purse seines) are towed through the water and produce more immediate results.

Benthic infauna and
<u>submergent vegetation</u>

12. Benthic infauna (particularly macrobenthos) and submergent vegetation are regarded as good indicators of environmental quality because of their sedentary nature and thus their susceptibility to physical and chemical alterations. Because their sedentary existence requires a tolerance of short-term variation in environmental conditions, they reflect long-term integral conditions. In addition, they can be sampled more quantitatively and efficiently. However, some disadvantages of macrobenthos as indicator species, when compared to fish, are that they have less life history information available, are more difficult to identify, and may not be as socially relevant (this may not hold true for certain macroinvertebrates deemed of importance to human beings, such as oysters and clams).

13. Benthic sampling devices come in a wide variety of designs and sizes. Many were developed and used on a regional basis and as a consequence are little known outside their respective areas. However, certain commonly used samplers have had widespread application.

14. A number of trawls and dredges have been designed and used as qualitative samplers of epifaunal and infaunal organisms in a variety of habitats, particularly in water deeper than 10 m (e.g., epibenthic sleds). These devices are best used for the purpose of general description of the assemblages present (species presence/absence). These devices are highly selective and are limited to collecting epifauna and shallow infauna, thereby providing little information on infauna at sediment depths greater than a few centimetres.

15. Grab samplers and box corers are the tools of choice for quantitative sampling of sessile epifauna and infauna (to the depth excavated by the sampler). Some of the more commonly used grabs include the Petersen, van Veen, Ponar, Ekman, and Smith-McIntyre grabs. These samplers all basically operate as mechanical scoops that, when triggered, remove a semicircular parcel of the bottom substrate. Typically, these samplers collect material representing 0.02 to 0.5 sq m of surface area and penetrate to sediment depths

ranging from 5 to 20 cm. Vertical sectioning, which is generally more quantitative than a basic grab, is also possible with certain instruments, such as the Reineck and Gray-O'Hara box corers.

PART II: PHYSICAL MONITORING TOOLS AND TECHNIQUES

16. Physical monitoring is the core of any dredged material disposal site monitoring program. Biological effects are the direct result of physical actions of the dredged material on the biological community, such as burial, change in grain size or composition of the bottom sediments, and increased turbidity. Consequently, the initial stage of any tiered monitoring program often is primarily a physical monitoring program. Physical monitoring is also used to determine whether the purely physical effects of dredged material disposal are escalating into problems. Physical monitoring of dredged material disposal sites can provide input to a number of basic questions:

- a. Where are the disposal sediments located, and what is the spatial extent of the deposit?
- b. What volume of disposal sediments is in the site?
- c. Is the disposal material stable or mobile?
- d. If the disposal material is moving, how fast, in what directions, and in what quantities? Is it moving outside the designated site boundaries?
- e. If the disposal sediments are stationary, how much longer can the site be used?

17. The design of the physical portion of a monitoring program can attempt to address any and all of these questions. However, some will be more important than others for a specific site. Initial assumptions, past experience, and results of the site designation investigation, managerial needs, and regulatory requirements will help shape the initial physical monitoring program.

18. Equipment for disposal site physical monitoring can be presented in several groups. Navigation and positioning equipment forms an essential group, since the effectiveness of other equipment depends in part on knowing its location. A second group of equipment consists of depth sounders, side-scan sonar, subbottom profilers, and other acoustic imaging devices, which are discussed in subsequent sections of the text. Sediment sampling equipment forms a third group; a subsequent section is devoted to sediment cores. Bottom photography, the sediment-profiling camera, and other remote sensing tools are then described, followed by a discussion of guidelines for determining the engineering properties of disposal sediments. The last tools discussed are current meters and drogues. A section on frequency of monitoring and a summary of physical monitoring tools and techniques complete Part II.

19. Throughout the discussion it will be emphasized that certain tools have broad application to a variety of monitoring projects, while others are very specific to particular site problems and not generally useful at all sites. The broadly focused instruments have been and will be routinely used at disposal sites, but the narrowly focused instruments are used only for special monitoring applications.

Navigation and Positioning

20. All forms of monitoring data (physical, biological, and chemical) are useless without adequate positioning. The two basic forms of positioning and navigation systems generally used in coastal regions, Loran-C and short-range microwave, are both electronic systems. Optical systems, based on lasers, can potentially be used in nearshore monitoring applications. The new Navstar Global Positioning System (GPS) is a navigation and positioning system that uses satellites. The GPS will probably replace Loran-C in the next few years. The majority of the information in this section is based on a report by Tetra Tech (1986).

21. Loran-C is a defacto standard on virtually all working vessels over 25 ft long. The accuracy of the system (discussed in more detail below) is sufficient for many navigation applications, and Loran-C receivers are relatively inexpensive ($1,000 to $2,000 in 1986). The Coast Guard operates the Loran-C network, which uses pulsed low-frequency (90 to 110 kHz) radio waves. Loran-C receivers match cycles to measure time differences between the master and coded secondary signals. The microsecond differences in arrival time are displayed and can be recorded at any point in time and/or plotted on special Loran-C latticed charts as lines of position.

22. The range and accuracy of Loran-C are due to the operating characteristics of the system. The low frequency and long baseline distances between the master and slave stations (1,150 miles or more) allow Loran-C to provide position information out to 1,380 miles with reasonable accuracy. Effective range at a specific location is a function of transmitter power, receiver sensitivity, interference levels, and signal path losses.

23. The absolute accuracy of a positioning system is the ability of the system to correctly define the actual position of an object. For Loran-C, the absolute accuracy varies from 600 to 1,500 ft. Repeatable accuracy is the ability of a given method or system to return the user to the same position

time after time. The repeatable accuracy of Loran-C varies from 50 to 300 ft. The ranges of both the absolute and repeatable accuracy for Loran-C are primarily a function of the vessel's location within a given coverage area (Tetra Tech 1986). Other factors include time and spatial variations in the Loran-C signals, anomalies associated with land/water interfaces, and large structures, such as bridges and tall buildings. Noise and interference from internal sources (e.g., ship engines, other electronics) and outside sources (e.g., US Navy radar and communications) can range from occasionally causing minor problems to making Loran-C virtually useless. Before making the decision to use Loran-C for a monitoring program, one should check with the District's survey branch or local Coast Guard office. They should be able to provide guidance on the accuracies and potential interference problems associated with Loran-C use in a particular area.

24. Short-range microwave positioning systems (e.g., the Motorola Mini Ranger or the Del Norte Trisponder) represent the second navigation and positioning system commonly used in coastal waters. Microwave positioning systems operate by erecting two remote transponders at known locations onshore and placing the master receiver-transmitter system on the vessel. By measuring the round-trip time of the signals from each of the transponders, distance from each transponder to the vessel is calculated, giving a position circle. The location of the vessel is determined as the intersection point of the two position circles. Short-range microwave systems are limited to radio line-of-sight, or maximum ranges of 16 to 25 miles depending on the system and antenna height. Positioning accuracy varies from ±3 to 10 ft depending on the system and conditions.

25. Although they provide high accuracy, short-range microwave systems have a number of limitations. The shore stations have to be set up on known points, which often means that surveying will be required to locate these points. In remote areas, this can be a significant problem. Shore stations are powered electrically by 110-V house current or 12-V automobile batteries and consist of a small electronics box and antenna placed on a surveying tripod. If the stations are unmanned, they are very vulnerable to vandalism. Shore stations have to be set up and removed each day. The electromagnetic signals are subject to interference in industrial areas or in the vicinity of radar-intensive military bases. Finally, microwave systems are expensive, $40,000 to $100,000 (1989). For occasional use, renting/contracting may be more cost effective than purchasing a unit.

26. At disposal sites where repeated monitoring trips are anticipated, tandem use of a microwave station and Loran-C on the first trip may provide long-term cost savings. Absolute accuracy of Loran-C is low, but repeatability is moderate (50 to 300 ft). If microwave positioning is used on the first trip and Loran-C coordinates are noted for each sampling site, then on repeat trips Loran-C alone could be used, saving the cost and time of a microwave instrument.

27. Reliable radar positioning systems have recently become available, although to date their use is not widespread. Accuracy of these systems is comparable to microwave instruments; however, powered shore stations are not required. Locations of shoreline landmarks are surveyed prior to a mission. Landmark locations are recorded relative to a coordinate system. As the radar sweeps the area, it recognizes the presurveyed points and measures the distance and angle to compute the position, even at surveys speeds in excess of 28 knots.

28. Laser-based electronic distance and angle measurement survey instruments, also known as total stations, could be used for positioning in nearshore monitoring programs. Total stations combine a laser-based distance measuring device with a theodolite, microprocessor, rechargeable power supply, and interchangeable solid-state memory. When optically aimed at a reflecting prism assembly mounted on the monitoring vessel, the instrument calculates, records, and stores the x and y coordinates of the vessel. Total stations that will track a prism mounted on a vessel are available. Position data can be recorded as frequently as every second. Most systems provide an interface that allows the information to be dumped directly to a computer or remotely transmitted using a modem. Total stations provide very high positioning accuracies, on the order of 0.1 ft at 1 mile, but are limited to maximum ranges of 2.5 miles or less under ideal conditions.

29. For nearshore monitoring, such as nearshore berm disposal, the single-station aspect of total stations is attractive. Setup and calibration are minimized, and logistics are much simpler than with a multistation system. The system can be used for vessel positioning and monitoring with a single radio link. Tracking stations are fully automated, requiring little operator time once set up. These stations are significantly more expensive, $75,000 and up (1989), than conventional total stations, $15,000 to $30,000 (1989).

30. Navstar GPS is a second-generation satellite navigation system now being developed by the Department of Defense (DoD). When all 18 satellites

have been launched, precise, continuous, worldwide, all-weather, three-dimensional (x,y,z) navigation and positioning will be provided for land, sea, and air applications (Tetra Tech 1986). Less than 10 satellites were in orbit in 1989, providing limited hours of coverage for two- and three-dimensional work. A sufficient number of satellites to support continuous two-dimensional work should be available by 1990, and continuous three-dimensional coverage (elevation in addition to x and y coordinates) is projected for 1992.

31. The system consists of the satellites, a master, land-based control station, several monitoring stations, and small receivers (Tetra Tech 1986). Signals received from the satellites are demodulated, time-correlated, and processed to obtain position information. The satellites transmit two frequencies, one for civilian applications (C/A code) and one for military applications (P code). In addition to being more accurate, the P code also allows better position information at high speeds (for planes and missiles) and is more resistant to jamming. Originally, it was planned that two-dimensional position data from the C/A code would have accuracies of about 300 ft, while the more precise P code data would have a two-dimensional accuracy of 30 ft. However, recent advances in signal acquisition and data processing have vastly improved the accuracy available using the C/A code data. Simultaneous tracking of multiple satellites, operating in a differential mode using two receivers, and various numerical techniques (e.g., integrated Doppler) have proven that two-dimensional accuracies of 6 ft or less are possible for platforms moving at velocities comparable to those of survey vessels (Ashjee 1985).

32. While the DoD is considering degrading the C/A code to reduce accuracy, the advances made to date indicate that GPS-based systems will soon replace Loran-C and will probably also make microwave positioning systems nearly obsolete. One disadvantage of these systems is the postprocessing required to obtain accurate locations. The cost of simple GPS receivers that will replace Loran-C receivers is expected to be less than $1,000, while receivers with accuracies comparable to microwave positioning will probably be in the same price range as current microwave positioning equipment.

33. Under special circumstances, unusually deep water (greater than 200 ft) and high currents and/or wind forces on the sampling vessel, the position of the sampling instrument relative to the vessel can become important. Under these conditions, the potential exists for the sampling instrument to be from several tens of feet or more away from the horizontal position of the ship. For most monitoring applications, this is not critical. However, for

capping operations in deep water where accurate positioning of the sampler is required, an acoustic position system can be used to more accurately determine sampler location. Wire line indicators can also be used, but they assume a straight line to the sampler, an assumption that is less likely to be valid as depth and currents increase.

34. Acoustic positioning systems consist of a transponder mounted on the ship, a transponder on the sampling device, and one or more reference transponders mounted on the seafloor. By computing the travel time and time differences between each of the transponders, the position of the sampler relative to the ship and/or bottom reference transponders can be determined. Such systems are readily available, but are expensive, $50,000 and up depending on the sophistication of the system used. Ultrashort baseline systems (single bottom transponder and one transponder on the ship) can provide accuracies on the order of ±10 to 20 ft, depending on depth. Short and long baseline systems (multiple transponders on the ship and bottom) can potentially provide accuracies in the ±3- to 6-ft range, but at much higher costs (Milne 1986).

35. For limited monitoring programs (lowest tier, large area, limited expected impacts), Loran-C may provide sufficient accuracy. This is particularly true when the repeatable accuracy is considered. It may be possible to use microwave positioning initially in conjunction with Loran-C. Once the correct Loran-C coordinates have been established, Loran-C's repeatable accuracy (e.g., 50 to 300 ft) may suffice for some applications. At the present time, short-range microwave positioning systems are the choice for most monitoring programs. They provide sufficient accuracy for any monitoring program. However, microwave systems have a number of limitations, including high cost, susceptibility of shore stations to vandalism, longer setup times, potential difficulty in locating acceptable shore station sites, and limited range. Some of these limitations are overcome by radar positioning systems. Tracking total stations are potentially useful in very nearshore monitoring programs. Once set up, they are easy to use and highly accurate. However, they are expensive and restricted to within 2.5 miles of shore. There is no question that GPS will replace Loran-C and microwave positioning for many future applications.

Bathymetry

36. Probably the most basic measurement of a disposal site is bathymetry. In practice, this measurement is generally performed routinely in all monitoring levels. The casual observer might assume that disposal of tens of thousands up to millions of cubic yards of material would leave a measurable mound on the bottom. While some sites are naturally dispersive, the fact that no measurable differences between before and after bathymetric surveys are detected at a disposal mound does not always mean that the material has left the site. The authorized disposal area may be so large and the disposal pattern sufficiently spread out as to not show a measurable mounding of material. For example, 1 million cubic yards of sediment deposited evenly over a circle 1 mile in radius would raise the seafloor by an average of less than 3 in., which is below the level of detection of most bathymetric survey devices.

37. For most applications, bathymetric surveys are the primary tool for determining where the material has been placed and how much of it remains on site. Bathymetric surveys require microwave positioning accuracy or better for almost all cases. Other standard, high-quality survey equipment and techniques are also needed, including a survey-quality depth sounder (200 kHz or higher frequency, narrow beam), tide and squat (change in draft with vessel speed) corrections, and a bar check (speed of sound correction). Even with all these accuracy-improving techniques, the maximum accuracy on repetitive surveys through time is estimated to be ±0.7 ft (Morton, Stewart, and Germano 1984). The best accuracy of an individual depth sounder measurement is estimated at ±0.2 ft, with typical accuracies of 0.3 to 0.7 ft (Clausner, Birkemeier, and Clarke 1986). Such uncertainties should be taken into account when calculating volume changes over time. Morton, Stewart, and Germano (1984) discuss calculating percent errors in volume change measurements. Survey-quality fathometers are available in most District survey offices. The current (1989) cost of a new system begins at approximately $15,000.

38. The concept of nearshore placement is attractive due to the potential benefits of reducing haul distances and/or providing sand for beach nourishment. In nearshore placement sites, a total station and sea sled may be used as an alternative bathymetric surveying system. The sea sled is towed over the dredged material disposal site (self-propelled, remote-controlled sea sleds are currently being developed), and the total station is used to measure the x,y,z position of a prism mounted atop a mast attached to the sled.

Results from this survey are very accurate (±0.1 ft in x and y, and ±0.5 ft in z); however, the technique is limited to nearshore zones (less than 2.5 miles offshore) and to water depths less than the height of the sled mast (maximum approximately -40 ft). (See Clausner, Birkemeier, and Clarke (1986) for a more detailed description of the equipment and procedures.)

39. A critical item when using hydrographic surveys to monitor disposal sites is the horizontal spacing and extent of the survey grid. A wide range of grid coverage has been used, from a two-transect cross over a 1.6- by 1.6-nautical mile square at the Wilmington Harbor, North Carolina, offshore dredged material disposal site, to 200-ft spacing of parallel transects over a 0.7- by 1.2-nautical mile area at the Dam Neck disposal site, down to 80-ft spacing between parallel transects over 0.5- by 0.5-nautical mile sites in Long Island Sound as part of the DAMOS (Disposal Area Monitoring System) Program. The complexity of the survey effort should be responsive to the questions being posed. If the bathymetric survey is being done to verify whether significant mounds have developed, or other changes in bathymetry have occurred, then a minimal effort with a few transects may be adequate. Conversely, if the survey's purpose is to make an accurate measurement of the volume of material contained in a mound, then 100- to 200-ft spacing between the survey lines is probably required. Parallel survey lines at the appropriate spacing are preferred over a grid pattern, since a grid pattern requires more ship time to complete. Spacing will be a function of the size of the area, and a trade-off between accuracy and cost. When attempting to estimate volume of contaminated material, or the thickness of a sand cap over contaminated material, distances between survey lines of 50 to 80 ft are required.

40. Bathymetric surveys should extend beyond the area of interest to include areas "not affected" by the disposal operation. Initially, the survey boundaries should be 100 to 200 percent longer than the site itself. For large sites (greater than 2 miles on a side), this figure can be reduced to between 50 and 100 percent. As time passes, the area surveyed can be reduced if no changes are seen, or expanded in a specific direction if movement is indicated. Controlled dumping at precise coordinates or at marker buoys may reduce the required survey area to only a fraction of the total site area.

41. Development of a disposal site bathymetric map may take days to months. Processing rates for bathymetric data often depend on the degree of automation used, size of the area, density of data, and the type of data

presentation desired. Bathymetric information can be presented in a number of forms, such as charts with depths, contour charts, cross sections, and various types of three-dimensional charts. Probably the most effective methods of presentation for showing information on dredged material disposal sites are cross sections (Figure 1) and contours of difference in elevations before and after disposal (Figure 2). Although the three-dimensional displays usually do not present quantitative results, they can give the reader a good visual impression of the disposal area's bathymetry (Figure 3).

42. Several computer-integrated sounding systems permit the collection of continuous bathymetric data over a wide swath to both sides of the vessel path (Asbey and Zielman 1985). Swath surveying systems can be divided into those with wide transducer arrays and those with scanning or rotating transducers. Floating (wide) transducer arrays can be towed or pushed ahead of a boat. Where the equipment is to be mounted on a dedicated vessel, it may be convenient to mount the arrays on retractable beams (Figure 4). The signal from each transducer is recorded separately. In the other type of swath surveying, transducers scan from side to side. In both, the data can be integrated by onboard computers into various formats much easier to interpret than conventional profile traces.

43. As mentioned above, a scanning sonar uses the same principles as a conventional depth sounder, but adds a rotating head to produce continuous bathymetric cross sections (Figure 5) perpendicular to the vessel track. Depending on angular rotation and range, this system can produce a bathymetric cross section every 4 to 9 sec. These high-resolution systems (500 kHz or 1 MHz) are limited to ranges of 130 ft both horizontally and vertically and are often used in pairs to prevent the boat hull from blocking a portion of the signal. The major limitation of this system is its sensitivity to vessel motion, making it suitable only for work during calm conditions.

44. In swath systems, the spreading and overlapping of beams from adjacent transducers will limit the application of these systems to shallower disposal sites. Swath systems also cost much more than conventional equipment, and may have difficulty operating effectively in rough seas. The extra cost may be partially balanced by eliminating lengthy and costly data reduction, but the real difference lies in the comprehensive coverage made available. While swath instruments may not be appropriate for regular use, especially in lower tiers of monitoring because of the cost and physical limitations, they may have special applications. For instance, where it is imperative to

determine if any material has been misplaced outside of authorized disposal boundaries or to identify any thin areas in a capping operation, the extra expense of swath surveying may be justified.

45. In special cases, stationary survey devices may be necessary. These instruments have limited spatial coverage but can provide detailed temporal bathymetric data. Depth of disturbance rods are similar to other conventional reference rods that are driven into the bottom to allow measurement of erosion and accretion. The difference is the washer or washers used to define the layer of active sediment movement (Greenwood and Hale 1980). Washers placed on the surface move down the rods as the surface sediments are moved by currents. By measuring the difference between the sediment surface and the depth of the washer below the sediment surface over a specific time period, the depth of the active surface layer can be estimated. This diver-intensive tool is useful only when investigating a limited area.

46. Sonar altimeters are produced by Datasonics, Inc. These small depth sounders are mounted on pipes several feet above the bottom and make measurements of the height of the bottom accurate to the nearest centimetre. They can also measure total depth, along with salinity and temperature. Altimeters require diver installation. New weather-proof units are available; these are self contained and self recording, and accept up to 16 channels for multiple-data entry from remote locations. Altimeters could be useful in special cases to continuously monitor fluctuations in seafloor or disposal mound elevations.

47. Repetitive bathymetric surveys are usually the most fundamental measurement in a monitoring program. However, often they are an expensive portion of the monitoring program and can be difficult to schedule. Consequently, it is most cost effective to schedule other monitoring activities to coincide with the bathymetric survey. Recently, Fathometers that will return sediment information along with bathymetric data have become available. Rough classes of sediment can be distinguished at the same time bathymetry is measured. The additional cost over a conventional Fathometer may be justified in special cases where disposal sediments are markedly different from native disposal site sediments. This information could aid in distinguishing the aerial extent of the disposal material.

Side-Scan Sonar

48. Surface characteristics of the seafloor can be mapped using side-scan sonar. This information is not generally required for basic site monitoring; however, if postdepositional sediment motion is suspected or if it is important to map the thin outer fringe of a disposal mound, this tool can be useful. Side-scan sonars use acoustic energy projected laterally from a pair of transducers housed in a towed "fish." The received signal is transmitted through the tow cable to the shipboard recorder, which processes the signal and prints the record. The resulting image of the bottom is roughly similar to a continuous, oblique aerial photograph. However, the physics of underwater acoustics are sufficiently different from optics in the atmosphere that interpretation of side-scan sonar records requires training and experience. Side-scan sonars usually operate at one of two frequencies, 100 or 500 kHz. The lower frequency has greater range but provides less detail than the higher frequency.

49. Under proper conditions, a 500-kHz system can distinguish differences in grain size. For example, in Figure 6, moderately graded 0.25- and 0.13-mm sands are easily separated. However, in most cases, only broad sediment classes can be distinguished. The spacing and orientation of sand ripples are also clearly recorded. Because ripples form more readily in sands than silts, and are usually larger for a coarser sand size, discrimination between disposed and natural sediments may be further enhanced.

50. If bed form or grain size differences are substantial, a 100-kHz system may be preferred for its wider coverage, even at the expense of lost detail. The lower frequency system typically covers 600 to 1,200 ft in a single scan as compared to 300 ft for the 500-kHz system. Both frequencies should be available onboard when surveying unfamiliar areas.

51. Overlapping coverage obtained with closely spaced survey lines, as in Figure 7, allows precise and continuous mapping of the edges of disposal deposits. Side-scan sonar delineates the edge of disposal deposits more accurately than standard bathymetric surveys, provided the released and natural sediments have distinct backscatter characteristics. This requirement should not severely restrict use, as native and disposal materials often differ significantly in grain size. Even if the grain sizes and reflection characteristics of the native and disposed material are similar, the differences in bed forms can be observed on a side-scan sonar record. To increase the

probability of observing differences in bed forms of native and disposal sediments, side-scan sonar surveys should be conducted as soon as possible after disposal. Deep water and less active environmental forces increase the allowable time interval between disposal and survey.

52. Individual side-scan sonar records can be pieced together to make a mosaic of the area. The heavy lines on each scan of Figure 7 indicate distinct contacts between the high- and low-backscatter regions. Note that these contacts, which were identified on each scan separately, match longitudinally when composed in the map view.

53. The low-backscatter region along the base of the predisposal survey is typical of silty bottoms. The same low-backscatter region can be seen in the postdisposal survey 5 months later (Figure 7). Reappearance of the same boundary on both surveys and the close match from one scan to the next within each survey demonstrate accurate positioning.

54. A new low-backscatter area at the center of the postdisposal survey delineates the major disposal deposit. Outlying low-backscatter patches represent shallow pools of the finest disposal material, which spread away from the central deposit.

55. At the edge of the major disposal deposit and in outlying patches, the disposal material thins to a surface film. Bathymetry should be run in conjunction with side-scan to determine where deposits are thick enough to warrant attention. These areal techniques supplement and strengthen one another. Fortunately bathymetric, side-scan, and subbottom surveys (discussed in the following section) can be run simultaneously from the same boat. Sediment samples collected at the same time are useful for ground truthing the side-scan record.

56. Unless a great deal of sonar work is planned, contracting of the side-scan surveys is the most efficient method (cost savings on equipment and trained personnel). The 1989 cost of side-scan equipment and technician rental is approximately $1,000 per day. As stated above, both 100- and 500-kHz side-scan sonars should be available when surveying an unfamiliar site. The greater range of the 100-kHz system is preferred; however, the higher resolution of the 500-kHz system may be required when native and disposal sediments have similar grain sizes. Recently developed side-scan sonars can provide simultaneous 500-kHz images over the first 150 to 300 ft of swath and 100-kHz images over the outer 300 to 600 ft. The grid spacing and overlap between the tracks, if any, will be function of the purpose of the survey.

Complete coverage with 30 to 50 percent overlap should be required only for contaminated material or to check coverage of capping operations. Relatively few tracks with no overlap may be needed to verify whether a stable deposit has started to spread. A discrete track spacing of three times the swath width is recommended.

Subbottom Profiles

57. The principles of subbottom seismic profiling are fundamentally the same as in acoustic depth sounding. Subbottom seismics employ a lower frequency, higher power signal to penetrate the seafloor. The signal is reflected from interfaces between sediment layers of different acoustical impedance. Subbottom seismics originally were developed to search for deep petroleum traps. In contrast, the value of this tool for disposal monitoring is in its high precision and shallow penetration, which enable it to detect layering within and just below disposal deposits. Medium-power, high-resolution subbottom equipment on the order of 25 to 50 J and 3.5 to 14 kHz best suits this type of application.

58. Subbottom profilers should be restricted to monitoring programs that require knowledge of the disposal mound stratigraphy. The configuration of sediment layers within the disposal deposit can indicate characteristics such as degrees and uniformity of compaction, while the shape of the predisposal bottom may indicate subsidence of the underlying seafloor. Such settling, if unidentified, could be mistakenly interpreted as a loss of dredged material from the disposal site.

59. The volume of hauled material usually exceeds excavated volumes at dredging sites because water is added during the dredging process. Comparisons indicated volume increases from 7 to 36 percent clamshell dredging of freshly accumulated material.* As a rough guide, similar volumes could be lost as compaction expels pore water from a disposal mound.

60. Subsidence beneath disposal mounds has yet to be fully documented, but depressions of the original seafloor are evident under disposal mounds near Savannah, GA, and at New London, CT. These examples show the need for

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* J. F. Tavolaro. 1987. "Sediment Budget Study for Clamshell Dredging and Disposal Activities" (unpublished), US Army Engineer District, New York, New York, NY.

predisposal surveys and geotechnical data to determine whether such depressions are caused by the weight of the overlying deposits or whether they existed before deposition. Sediment coring or more detailed seismic work may predisposal surveys and geotechnical data to determine whether such be needed to establish which explanation is most likely.

61. Subbottom surveys with appropriate equipment and geotechnical measurements of the disposal mound are needed to confirm the extent to which compaction and subsidence contribute to apparent losses of material from disposal mounds. The geophysical surveys now routinely conducted during archaeological (cultural resource) evaluation of potential disposal sites in the United States have the potential to provide data on conditions prior to disposal. Geotechnical techniques are discussed in a later section of this report.

62. Coarse sand and gravel are often difficult to penetrate with conventional subbottom profilers, resulting in poor records. However, recently developed instruments are specifically aimed at overcoming sand and gravel substrate problems, although often at a loss of resolution. This type of instrument may be useful in an area of known coarse sand/gravel near the seafloor surface.

63. Traditional profilers usually can return information only about changes in stratigraphy. However, the Naval Ocean Research Development Activity (NORDA) laboratories are currently experimenting with modified systems that will determine the acoustic impedance with depth of each 1.5-ft-thick layer of sediment. From this information, one can estimate the seafloor substrate. Commercial systems could be available in future years. This system could substantially reduce the present cost of obtaining sediment data.

64. Since subbottom surveys are usually performed in conjunction with bathymetric and/or side-scan sonar surveys, spacing and grid dimensions are usually the same as those used for the other surveys. The maximum information derived from subbottom surveys will occur where a substantial amount (2 ft or more) of cohesive (silt and clay) disposal material exists in the disposal mound. Subbottom information can also be used to check on the thickness of a protective cap, but this information should be verified with results from sediment cores. Subbottom profiling requires expensive equipment, trained operators, and someone trained in interpretation. One can expect to pay $600 per day (1989) if this work is contracted to a geophysical firm. This price would include the equipment and trained operator. The cost of a

subbottom profile combined with a side-scan survey can be less than the sum of individual costs since often one operator can handle both systems.

Sediment Samples

65. In specific cases, knowledge of sediment characteristics may be useful to support data collected at advanced monitoring levels. Sediment samples are needed primarily to aid in discriminating between disposed and native seafloor materials. Grain size characteristics of bottom sediments may also help to predict when and where the disposal materials might move during storms. Samples of seafloor materials may also be required to aid in interpreting the results of biological or chemical analysis.

66. Acoustic monitoring techniques, bathymetry, side-scan sonar, and subbottom profiles survey essentially the entire study area, or at least provide continuous coverage along a track line. Obtaining seafloor material is the first of the physical monitoring tasks requiring a discrete sampling plan. The chosen plan will depend on prior knowledge of spatial variability; the degree of difference between native and disposed materials; the proximity of disposal to critical zones such as marine sanctuaries, shellfish beds, or beaches; and cost constraints.

67. Systematic sampling on a grid offers some practical advantages when sampling from a boat. If actual placement of dredged material differs somewhat from that anticipated, information loss is minimized by the uniform, widespread coverage. The regularity of a uniform grid also tends to reduce positioning blunders while sampling. A stratified grid, however, offers greater advantage where the area of potential impacts far exceeds the area of immediate disposal. Stratifying the sampling plan allows a concentration of samples to characterize the disposal material and track it in the direction of anticipated movement. Combined with widespread coverage at lower sampling densities farther away, the stratified sampling plan usually provides the most information for a cost-constrained effort.

68. Because monitoring interests focus on movement of material, and thus changes in bottom characteristics, it is desirable to have a predisposal sample at the exact site of each postdisposal sample. However, since the method of disposal may not be fully specified in the bid documents, the general configuration and location of the future deposit may not be entirely predictable. The greater the uncertainty, the more extensive the predisposal

sampling has to be in order to provide an adequate level of reference. With later knowledge of the variability of native seafloor materials, their difference from the disposal material, and the exact shape and location of the disposal deposit, the number of samples may be reduced on subsequent surveys.

69. Sediment sampling densities used in past studies have varied widely depending on the specific project. High densities were used to sample sites used for contaminated sediments (Figure 8), while densities as low as one or two per square mile have been used at sites where sand was placed on sand. Continental Shelf Associates (1986) used the sampling plan shown in Figure 9 to monitor a disposal site off Tampa Bay, Florida.

70. It will be useful in devising particular sampling plans to keep the dual function of grab samples in mind. Search sampling, in conjunction with areal surveys (bathymetry or side-scan sonar), is intended to identify the boundary between disposed and native sediments. Purposeful sampling is intended to provide good estimates of typical characteristics of disposal and native material as they exist at particular times on the bottom. Both types of information are needed to predict and track sediment movements.

71. A variety of tools can be used to provide samples for laboratory determination of pertinent sediment properties. The sediment characteristics of importance in predicting if and where sediment will move include particle size, shape, and composition. Permeability, porosity, and cohesiveness, which can be influenced by biological activity, are of secondary importance. Characteristics of importance for distinguishing between native and disposal materials again include particle size, shape, and composition plus color. Heavy mineral content, roundness, microscopic surface textures, grain shape analysis, and microfaunal analysis are examples of sediment tests that have potential use in special cases.

72. Of the aforementioned properties, grain size is the most important, and often the only item of routine concern. To the extent that shape and particle density of dredged material do not vary widely, the criterion for estimating initiation of motion by currents (threshold velocity) is a simple function of grain size for sand-sized sediments. The effects of redeposition, bioturbation, organic content, and compaction on threshold velocities are discussed by Young and Southard (1978).

73. Sand size almost always decreases regularly from the beach toward deeper water. This seaward fining trend often ends at a depth of about 30 ft, where silty sands abruptly meet coarse, poorly sorted offshore material.

Explanations of this pattern are controversial, but observations of it are widespread. Since dredged material is often fine grained and deposited beyond the 30-ft contour, grain size alone may be sufficient to identify the disposal deposit. The Dam Neck disposal site is an example of this distinction. Data gathered using the sampling plan shown in Figure 10 revealed that disposal material in the center of the sample grid is finer grained than on the surrounding seafloor.

74. The sampling plan at the Dam Neck disposal site (Figure 10) also illustrates a stratified sampling plan that concentrated on the disposal mound. This 900-sq ft sampling grid was supplemented with three additional samples near the center of the disposal mound. Concentrating an even greater number of samples at the center would have improved identification of the deposit and clarified how storms modified its surface texture.

75. Sampling plans must also consider adjacent critical areas and the need for reference areas. Selecting reference areas that are exposed to the same sediment redistribution forces, yet clearly beyond the effect of disposal, may be difficult. Furthermore, monitoring of such areas may add significant cost to the overall effort. However, without such references, it may be impossible to ascribe any observed change to the disposal, as opposed to some other event that occurred in the same time period. Reference areas also compensate for the lack of predisposal site characterization.

76. When planning the number and location of sampling stations, consideration should be given to the fact that selective sorting by grain size will already have occurred before the disposal operations cease. Coarser grains will be concentrated toward the center or locus of deposition. The finer materials will be deposited farther from the center. This separation can be referred to as radial sorting (Figure 11). It should be noted that actual sorting will be more chaotic than as stylized in this figure (Hands and Deloach 1984).

77. Long-term reworking of the bottom by waves and currents will tend to further reinforce the radial pattern because finer grained fractions tend to be winnowed from the mound peak and accumulate toward the deposit base on the leeward flank.

78. Sediment traps offer the potential for measuring sediment transport rates at disposal mounds. A new design (Figure 12) incorporates a vertical array of streamers that capture the moving sediment with minimal disturbance of the flow. This new trap has provided valuable field data on alongshore

transport in the surf zone (Kraus and Dean 1987) and is currently being modified for deployment in deeper waters where it could be retrieved after storms to quantify bed and suspended load transport.

79. One disadvantage of available sediment traps is that they must be installed and serviced by divers at frequent intervals, making long-term observation impractical. The potential to provide short-term data during extreme conditions (e.g., storms) could make the sediment trap valuable for uses such as estimating the longevity of protective caps.

80. The most regularly used instrument for sampling seafloor sediments is the grab sampler, of which a variety of types exist. The grab sampler is discussed in more detail in Part III (section, Benthic Sampling Devices), since benthic fauna are often sampled using this device. Most types consist of a pair of spring-loaded jaws that, when tripped, excavate a semicircular sample from the seafloor. Grab samplers are inexpensive, reliable, and easy to use. However, they return only disturbed surface samples. Undisturbed samples or sampling at greater depth requires some type of coring device.

Sediment Cores

81. In cases where more intensive monitoring is required, the use of sediment cores may be necessary. Cores allow retrieval and examination of the layered sequence of material in the disposal pile. The vertical structure of the deposit indicates the depth to which the material has been reworked by bottom currents and by benthic organisms. Storms may mobilize a layer of material without creating any poststorm change in bathymetry. The thickness of the upper disturbed layer is important to the understanding and prediction of long-term sorting and stability. It is particularly important in the development of guidelines on design of capping procedures. Capping may be useful to isolate pollutants from the biological environment or simply to retain finer grained, more mobile sediments.

82. The distinction of material from different disposal operations is evident in the cores shown in Figure 13. The upper deposits represent recent maintenance dredging material. The coarser layers below represent a much earlier deepening project than dredged coarser sands.

83. The identification of the upper, active layer of reworking is enhanced by x-radiography of the cores. The disturbance of fine disposal

lamination by organisms and bottom currents shown in Figure 14 took place in just a few months.

84. Where cores are long enough, the entire depositional history can be captured to identify compaction, chemical migration, etc. The buried predisposal seafloor can be seen in Figure 14 beneath the thinner edge of recently disposed material. Depending on the information required, the buried sediments may be taken to the laboratory for determination of grain size, carbonate content, organic content, microfaunal identification, visual and enhanced x-radiograph stratigraphic analysis, age dating, or many engineering tests. Microfaunal identification, visual and enhanced x-radiograph stratigraphic analysis, and age dating are generally reserved for research on disposal operations (e.g., capping contaminated material). Measurement of engineering properties will often be necessary only for capping operations or where consolidation must be measured for accurate mass balance determination.

85. Depending on the lengths of cores required and working conditions at the disposal site, the cost of coring varies drastically. Field methods may be as simple as dropping gravity cores from small boats or hand insertion and underwater sealing by divers. Small impact and vibratory cores have also been adapted as diver-operated tools. Precise location and minimum sediment disturbance are two advantages realized with divers, but site conditions limit their usefulness. Longer cores can be obtained under less restricted conditions with surface-deployed devices.

86. Short gravity cores can be taken from almost any boat with a boom. These corers weigh up to 250 lb and typically provide 3- to 6-ft-long cores in soft, fine-grained materials. To recover cores with lengths greater than 10 ft, a piston must be used to reduce the friction inside the core barrel. Free-falling gravity and piston cores can penetrate sand only to depths of 1 ft, if at all. Consequently, vibratory devices are normally used to obtain cores in sand. The vibratory unit is lowered to the seafloor to obtain 20-ft cores, although 40-ft vibracores are possible. Usually, longer cores are obtained in steps. The upper section can be done conventionally down to resistance. Then, a second longer core barrel is jetted to that depth and vibrated farther to obtain the lower section. With this staged technique, the largest disposal mound could be cored, making it unnecessary to consider the even more expensive drilling techniques.

87. The reader may consult Bouma (1969), Tirey (1972), Lee and Clausner (1979), and the references they cite for additional information on larger

coring devices. The light-weight vibratory corer was designed for small boats, up to about 50 ft, which are typically used for offshore sand inventory surveys (Fuller and Meisburger 1982). Diver-operated corers have been developed at the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), as expedient means of sampling a few sites for research purposes.

88. Coring to provide samples for geotechnical properties can require special corers, and places special emphasis on the handling of cores. Short gravity cores are usually acceptable. However, when the length-to-diameter ratio exceeds 10:1 to 20:1 (27- to 54-in. length for standard 2.68-in. inside diameter gravity cores), a piston corer or larger diameter gravity corer is required to reduce sediment disturbance to an acceptable level. See Hvorslev (1949) and Lee and Clausner (1979) for more details on taking engineering-quality cores.

89. A possible solution to obtaining high-quality cores can be the use of a box corer (Figure 15). These devices take short (up to 24-in.-long) large-volume cores (typically 0.28, 0.67, or 2.78 sq ft). The large sample can be subsampled with short core tubes to provide very high-quality samples. The large volume is also very useful for biological sampling.

90. Most cores are used to determine index properties, grain size distribution, color, composition, etc. Consequently, disturbance of the core between the time it is taken and analyzed is often not a major concern. However, in order to preserve layering, the cores should be stored vertically and should not be subjected to excessive vibration. Cores that are to be tested for engineering properties need more careful storage and transport. The cores should be stored vertically, preferably in a rack. If the bottom temperature was below 50° F, or if the cores will be subjected to high temperatures for long periods of time onboard ship, the cores should be refrigerated. They must never be frozen, because expansion of the ice destroys the soil fabric. Cores that have been exposed to high temperature are somewhat degraded, but frozen cores are useless for evaluating engineering properties. They should be protected from vibration, both onboard ship and during transport to the laboratory.

91. Guidance for planning larger scale data collection, where long cores in sand are needed, is outlined by Prins (1980). A coring platform, tug, positioning and coring equipment, and personnel would cost on the order of $1,000 to $1,500 per core (1989) depending on number of cores and working

conditions. Recovery of 6 to 10 cores per day would not be unusual. In uncompacted disposal deposits, coring is easier and quicker than for the natural seafloor.

Remote Sensing Techniques

92. Several types of remote sensing tools are available to assist with site data collection efforts. The various tools can be distinguished based on the platforms from which the site is viewed. Bottom photography and photography of and within the seafloor form one group of tools. A second group consists of a variety of airborne imaging systems, such as aerial photography, satellite imagery, laser depth sounding systems, multispectral scanners, and electromagnetic profilers.

93. Photography and underwater video with cameras lowered from the surface or mounted on remotely operated vehicles (ROV's) can add to our understanding of bottom conditions. Video cameras attached to ROV's have been used in a few cases to map the contact between disposal and native materials and to examine bed forms. Although relatively inexpensive, this procedure is limited to areas of good visibility (usually not the case in the vicinity of disposal sites). Exact positioning of the camera and determination of the scale of bed forms for quantitative measurements are difficult with this type of system.

94. Of the many photographic systems available, one that is gaining acceptance is the sediment-profiling camera. For physical monitoring of disposal sites, use of this tool is still limited. However, the growing acceptance of the sediment-profiling camera as a reconnaissance tool for biological sampling will mean increased use as a physical monitoring tool. This unique camera provides physical data about the sediments, and a significant amount of biological information. A brief discussion of the camera's physical monitoring aspects is presented here. More information can be found in Part III.

95. The camera provides a vertical view of the sediment-water interface. It is mounted in a frame that is lowered to the seafloor (Figure 16). Once on the bottom, a viewing prism penetrates the upper layer of sediment, and an image is recorded on film. Figure 17 shows a vertical slice through disposal material. Disposed sediment boundaries with the seawater above and the predisposal seafloor below are indicated. In addition to measuring depth of surface sediment layers up to a maximum penetration depth of 18 cm, the

photographic image can also be analyzed for surface roughness and approximate grain size. By comparison with a set of standards, mean grain size and sorting can be estimated for material as small as coarse silt.

96. Recent additions to the system include a computer image analysis for rapid interpretation of a wide range of physical/chemical as well as biological variables (Rhoads and Germano 1982). Typically, 100 images, 3 per station, can be obtained in a 8-hr day. The updated version interprets 20 parameters and has been used to detect dredged material spread on the seafloor, various changes with time, and the thickness of capping material placed over polluted sediments (Germano 1983). The available data include the following parameters:

a. Physical/chemical.
   (1) Grain size.
   (2) Total prism penetration depth.
   (3) Sediment surface relief.
   (4) Mud clasts (number, size, oxidized or reduced).
   (5) Redox area.
   (6) Redox contrast.
   (7) Relict redox boundaries.
   (8) Methane gas vesicles (number, size, depth).
   (9) Other comments.

b. Biological.
   (1) Epifauna (number of taxa).
   (2) Tube density (centimetres).
   (3) Tube types (number of taxa).
   (4) Pelletal layer (thickness).
   (5) Microbial aggregations.
   (6) Infauna (number of taxa).
   (7) Feeding voids (number, depth).
   (8) Faunal dominants (epifauna/infauna mixed).
   (9) Apparent species richness.
   (10) Successional stage.
   (11) Other comments.

97. The 7-in. prism depth is a limiting factor in measuring thicknesses of accumulation and of reworking by physical forces and/or biological activity. The frame will sink by various amounts in soft disposal material. Coarse or compacted sands are difficult to penetrate. A video option may

allow controlled positioning with real-time adjustments from an onboard monitor. Sediment motion, heights, and rates of ripple migration are examples of the measurements that could be recorded on video tape to improve monitoring of disposal mounds.

98. Sediment-profiling camera stations have typically been arranged in the pattern shown in Figure 18, with spacing of 300 to 1,200 ft. Denser spacings are generally used in the center with wider spacing at the edges to define the boundary of the disposal mound or cap thickness. Distances between points of less than 400 ft are probably needed only with contaminated sediments or small disposal mounds. The typical cost for a sediment-profiling imagery survey is about $700 per day (not including boat time). Depending on time and distance between stations, approximately 50 stations, 3 replicates each, can be accomplished in a 8-hr day. When sampling in water depths of 30 to 40 ft, three replicates can be taken in less than 5 min (excluding time between stations). Analysis costs from $30 to $50 per image, depending on the quantity processed.

99. Airborne remote sensing techniques can be used in two ways for monitoring open-water dredged material disposal sites. The first application is to use aerial photography and/or satellite imagery to detect shoaling in shallow water. The second application is to measure water depths using lasers, passive scanners, or electromagnetic sensors. Remote sensing has a number of other applications for monitoring dredging activities, particularly in monitoring plumes. Because these applications are not directly related to these guidelines, they will not be discussed here. The reader is directed to a recent report from the Cold Regions Research and Engineering Laboratory (McKim et al. 1985) for a discussion of remote sensing applications for dredging.

100. Aerial photography has been used to detect shoals in shallow water. Should nearshore disposal become an acceptable method for nourishing beaches, storing sand, or reducing dredging costs, aerial photography could be an effective monitoring tool. Aerial photography is generally inexpensive, and two-dimensional data collection is rapid. The Remote Sensing Applications Guide (US Army Corps of Engineers 1979) describes the best combinations of film type, camera, elevation, platform, etc., to achieve optimum results.

101. Using satellites to detect shoals is a potential application of remove sensing technology. Acquisition of images of the entire coast at least once a month makes satellite imagery a very promising tool, if sufficient

detail of the shoals can be resolved. The recently launched French Probatoire d'Observation de la Terre (SPOT) satellite has higher resolution (30 ft in panchromatic and 60 ft in the multispectral bands) than previous satellites. Hopes are that the capability for resolution of such small areas will provide enough detail for useful shoal observations. Initial indications are that the ability to detect shoals is limited to shallow water less than 10 ft deep. At present (1989), SPOT images cost approximately $2,500 each. This can be inexpensive compared to other field techniques if sufficient information can be retrieved from the image.

102. The ability to use remote sensing for bathymetric measurements offers the greatest potential monitoring benefits. Present state-of-the-art depth sounding systems are slow and relatively expensive. Aircraft-mounted laser depth-sounding systems (LIDAR's) have been used for the past 10 years with varying degrees of success. The speed of the survey and the immunity to surface forces are obvious potential advantages of an aircraft-mounted system.

103. Present limitations include poor penetration in turbid coastal waters and navigation problems. While LIDAR's have been able to measure bathymetry down to 70 ft in clear water, typical penetration in coastal waters is 16 to 40 ft depending on turbidity (McKim et al. 1985). Present precision is ±1 ft. Navigation is a problem due to the speed of the aircraft. The Naval Ocean Research Development Activity (NORDA) hopes to have a LIDAR operating in a Navy P-3 aircraft soon (Hickman et al. 1986). The US Army Corps of Engineers is initiating development of a helicopter-mounted LIDAR, which is expected to be tested in the early 1990's. It is hoped that the slower speed of the helicopter will improve navigation to the accuracy needed for some Corps bathymetric surveying applications.

104. The NORDA is also developing a passive multispectral scanner and an electromagnetic profiler. The multispectral scanner is limited to daylight operation. It can produce an enormous amount of data. For example, from an altitude of 1,500 ft, the system gives 100-percent area coverage of the bottom in 66 ft of water with a 3- by 3-ft pixel size. A prototype multispectral scanner was scheduled for completion in 1988. The electromagnetic profiler has the advantage of not being an optical system, and therefore is not affected by water turbidity, sun glint, bottom vegetation, etc. In initial tests, the system could measure water depths to 66 ft with an accuracy of ±1 ft. A prototype was scheduled for 1989.

Engineering Properties of Disposal Sediments

105. Recent research has indicated that determining the engineering properties of fine-grained disposal sediment can be valuable. However, at present, these geotechnical measurements are reserved for advanced tiers within monitoring programs or for special cases. The increase in water content and the disturbance of the structure of fine-grained sediments during the dredging and disposal operation often increase their volume significantly and reduce compressive strength (Demars et al. 1984a, b; Morton, Stewart, and Germano 1984; Science Applications, Inc. 1985). Consolidation and density data are needed to compute the volume of disposal deposits when checking the mass balance of the disposal materials. The strength of the disposal sediments is needed to determine their stability for cap placement and resistance to erosion. This section gives a brief description of some instruments that can be used to test geotechnical properties in place. For additional background information on marine soil mechanics, see US Army Engineer Waterways Experiment Station (1972) or US Army Corps of Engineers (1981).

106. Under the DAMOS Program, a nuclear density probe (Figure 19) was used to measure in situ density values of native and disposed sediments. This instrument uses a gamma ray source and measures the amount of backscatter to determine density. The results were inconclusive (Science Applications, Inc. 1985), but additional research is being carried out.

107. A pore pressure probe that can be lowered to the seafloor has been developed by NORDA. Intramound pore pressures can be related to sediment compaction and volume loss. The degree of consolidation also affects the stability of the deposit. The higher the pore pressure, the more material is supported by pore water, reducing grain-to-grain contact and increasing the chance of slope failure.

108. Settlement plates were used in the Duwamish Waterway Capping Demonstration Project (Truitt 1986) to evaluate consolidation of the disposal mound. The tiered settlement plates that were used were constructed of marine plywood and steel support plates with central pipe risers and were held in place with screw anchors (Figure 20). The settlement plates were installed and monitored by divers. The plates showed that 75 percent of the settlement took place within the first week after placement.

109. Vane shear devices have been developed for use underwater (Figure 21). These devices measure the shear strength of the material, which can

be related to slope stability and erosion potential. Cone penetrometers are also becoming popular instruments to measure soil properties. Minicone penetrometers, designed for offshore use, have recently come on the market. With a small crane, they can be deployed on the seafloor to obtain sediment information (sediment type, compaction, stratigraphy, etc.) to depths of 60 ft. Most cone penetrometers work on the principle of comparing resistance at the cone tip to resistance along the sleeve. The quality of the data and ease of use make these instruments an economical alternative to coring in many cases.

110. Two varieties of sea sleds have recently been used in monitoring work to assist in the mapping of disposal site boundaries. The Continuous Seafloor Sediment Sampler consists of three subcomponents: a sediment sampler that agitates the seafloor and returns a sample to the vessel while being towed at 3 to 5 knots, a shipboard processor that prepares the sample for analysis, and x-ray fluorescence instrumentation to carry out the elemental analysis of samples. Up to two samples per minute can be collected, and multielement analysis can be completed within minutes of arriving on the ship. The Gamma Radiation Detection Sled is designed to detect gamma radiation as may be emitted from the surficial seafloor sediments. Four gamma-ray detectors are mounted on the sled; data are transmitted through a cable to the surface vessel. This technique is limited if the dredged sediment is the same as native sediment. Usefulness of these sleds for normal uncontaminated disposal monitoring is limited to mapping the contact between disposal and native material in special cases were less expensive equipment will not work. Presently this system is available only by contract; typical daily rates (1989) are about $3,500 for one sled and three technicians.

Current Meters

111. Current velocity and direction measurements are a portion of almost all site designation studies. Information from these studies is used to predict the potential paths of disposal sediment movement from the site, which should be used in the initial design of the monitoring plan. Sampling should be concentrated in the direction the predicted currents are most likely to move the disposal sediments. Current measurements should be considered as part of the monitoring plan if there is a great deal of uncertainty in the potential direction of sediment movement or if sensitive marine resources are

located in the vicinity of the disposal site. Cost and difficulty in retrieving instruments are limitations to current monitoring.

112. Current measurement can be an expensive portion of a monitoring program. Each instrument can cost from several thousand to tens of thousands of dollars. Deploying the meters usually requires a vessel with the capability to lift 0.5 ton or more for the anchor, or divers to install screw anchors. Some current meters require divers for installation and servicing. Current meters require frequent servicing, both to retrieve data records and to verify that the meters are in place and operating.

113. Frequent checks on the status of current meters are needed because they are highly susceptible to damage or loss from trawling activities. Surface floats marking their location can be an invitation for vandalism of the meters or theft of the marker buoys. Subsurface markers using acoustic releases prevent vandalism and loss of marker buoys, but they significantly add to the cost of the mooring, and are still vulnerable to damage and loss. Current meter locations at a site are often a trade-off between the most desirable location from a hydrodynamic standpoint and the areas most heavily used by fishermen.

114. Physical factors influencing placement of current meters to monitor a disposal site include depth, areal extent, and local bathymetry. Most sites will need from one to four current meters depending on the expected complexity of the current regime. If currents measured in the site designation study are uniform across the site and the site is small with even topography, a single current meter should be sufficient. The location of the meter should be at a safe location the same distance offshore as the center of the site. As site size increases and bathymetry becomes more complex, the number of current meters needed to monitor the site also increases. The decision to use two, three, or four meters placed around the periphery of the site should be made by an oceanographer familiar with the area. Care should be taken not to place a current meter on the edge of the site in line with the expected path of the disposal vessels, since a misplaced disposal could damage the meter. In general, current meters used to monitor dredged material disposal should be positioned as close to the bottom as practical.

115. One factor not yet discussed is the type of current meter to use. Experienced local contractors, universities, and Corps personnel should provide guidance. A detailed discussion of current meter capabilities is beyond the scope of this report, but a few important points will be presented in the

following paragraphs. The degree of experience of the persons working with the instruments probably has more to do with the performance of the current meters than does the type of meter used.

116. Several types of current meters are in common use: impeller, electromagnetic (EM), acoustic, acoustic Doppler, laser Doppler, and inclinometer. Impeller current meters have been in use longer than the other types. They are subject to biofouling and bearing failure (particularly in shallow water with sandy bottoms), limiting their deployment time to several months at most. In warm waters, biofouling can limit operating time to just a few weeks. Impeller current meters can easily be inspected for proper operation. Verification that the impeller is free-spinning is usually all that is needed. Impeller current meters are more easily repaired in the field and more easily calibrated.

117. Although the other current meters operate on different principles, they have several characteristics in common. All of these meters have no moving parts, have very rapid response, can be used as components of real-time systems, and are available as self-contained systems. All can be used to measure at least two velocity components. If a pressure sensor is incorporated into the system, it can be used to measure the directional wave spectrum. Based on reported data, all can perform well in steady flows. It has been reported that the EM meter may not provide accurate data in environments with both a steady and oscillatory flow. Of these systems, only the EM meter has been used extensively in monitoring studies in the United States.

118. Bottom drogues, while not new, offer an inexpensive way to map potential paths by which material may be leaving disposal mounds as a result of currents. The exact relationship of drogue motion, currents, and sediment transport is uncertain. The valuable aspect for disposal monitoring is that recovery of drogues or tracers at a particular site does indicate processes that may be capable of moving sediment from the release site to the recovery site. Work is under way at the CERC to improve understanding of the relationships between a widely used oceanographic drogue, the seabed drifter (Figure 22), and bottom transport.

119. Seabed drifters are usually released in groups of 25 to 500. Acoustic tracking devices that can attach to the drifter are available. However, the cost of these devices is relatively high, and their range is limited. Usually they are recovered when they wash up on the beach or are found in trawling nets. An attached, postpaid self-addressed card asks the finder

to note location and time and mail the card. In addition to helping chart the potential paths of bottom sediment movement, the involvement of the public can provide some inexpensive public relations showing that the Corps is monitoring disposal.

Monitoring Frequency

120. The frequency of monitoring is less difficult to define than the monitoring tools and techniques required, but is still site specific. Typical monitoring intervals are quarterly, semiannually, and annually. Monitoring frequency for low-level tiers will typically be yearly, with increasing frequencies at higher levels. As experience with the site is gained, an initial high frequency of monitoring, say quarterly, may be reduced to semiannually or annually. Long-term monitoring can be at even wider intervals of 18 months to 5 years if no additional material is placed at the site. Obviously, the first postdisposal monitoring effort should occur as soon after the disposal operation is completed as possible. Provisions should also be made to monitor after a significant storm event such as a hurricane. The boundaries of the survey may need to be expanded if significant sediment movement is thought to have taken place. If something less than a 25- to 100-year storm is thought to be a problem, it may be worthwhile to schedule an extra monitoring effort each year or two to be performed as needed.

121. Several other factors can influence monitoring frequency. Fine-grained sediments will compact as excess pore water is released over time. As mentioned earlier, this initial compaction can be incorrectly interpreted as a loss of material if only bathymetry is being used to check volume. Therefore, if bathymetry is the primary tool to check volume, it is important to schedule a second monitoring effort prior to severe weather, say 1 month after the initial monitoring. Then, any volume change measured between the two hydrosurveys can probably be attributed to compaction rather than erosion. It should be noted that a substantial thickness of fine-grained material, at least 6 ft, will be necessary to show a volume change due to compaction that can be reliably measured with a Fathometer. If volume change is important, some combination of subbottom profiles, settlement plates, and measurement of engineering properties should be performed.

122. Poor weather is often a problem during monitoring. This can be significant problem along the northwestern coast of the United States, where

the good-weather window for dredging and monitoring is very limited. Often, dredges will work through the summer until bad weather sets in, not allowing sufficient time to complete a monitoring effort. By the time the weather improves in the spring, it may be impossible to accurately determine postdisposal site conditions. One possible solution may be to schedule monitoring before the disposal operation is 100 percent complete. A monitoring effort after disposal is 80 to 90 percent complete may still provide usable information.

Physical Monitoring Summary

123. It is difficult to present generic physical monitoring programs due to the variety of site characteristics and disposal operation variables. The listing below includes most of the conditions that could affect monitoring programs. Not listed are social and political factors, which may affect the level and cost of the monitoring program more than the variables identified.

- a. Site variables.
  - (1) Depth.
  - (2) Bathymetry (topographic relief).
  - (3) Size (areal extent).
  - (4) Current regime.
  - (5) Wave action.
  - (6) Proximity to sensitive resources.
  - (7) Prior disposal operations.
  - (8) Native bottom sediments.
- b. Operation variables.
  - (1) Character of disposal sediments.
  - (2) Capping requirements (if any).
  - (3) Method of disposal.
  - (4) Amount of material disposed.
  - (5) Duration of disposal operation.
  - (6) Weather.

124. Physical monitoring tools and techniques appropriate for a three-tiered monitoring program are outlined below. Additional examples can be found in Fredette et al. (1990). Not all tools and techniques are required at each tier. For many simple monitoring programs, bathymetry alone, or bathymetry supplemented with limited sediment sampling, is sufficient.

a. Tier 1.

(1) Bathymetry (initial density of coverage site-specific).

(2) Grab or core sediment sampling.

(3) Side-scan sonar.

b. Tier 2.

(1) Bathymetry (increased spatial density).

(2) Cores (increased spatial density).

(3) Side-scan sonar.

(4) Sediment-profiling camera (optional; only for fine-grained disposal material).

(5) Current meters and/or seabed drifters.

c. Tier 3.

(1) Bathymetry (high density).

(2) Cores (high spatial density).

(3) Side-scan sonar.

(4) Subbottom profiler (fine-grained material only).

(5) Sediment-profiling camera (fine-grained disposal material).

(6) Current meters.

(7) Engineering properties (fine-grained material).

125. Characteristics of the major physical monitoring tools are summarized in Table 1.

PART III: BIOLOGICAL MONITORING TOOLS AND TECHNIQUES

126. The range of biological sampling and processing equipment is diverse. Each investigator tends to favor certain pieces of equipment based on his or her experience and training, individual biases, and the equipment's regional availability. Each tool provides a unique set of data with some characteristic range of precision and accuracy, but the ultimate value of the data will be only as good as the preciseness of the question and appropriateness of the sampling design. Typical sampling equipment for biological studies includes various types of corers or grabs for sampling benthos and various types of nets (e.g., trawls) for sampling nekton. Each sampling tool or technique, however, has inherent limitations and biases. Excellent discussions of benthic sampling tools and techniques can be found in Holme and McIntyre (1984). Discussions of sampling methods and equipment for motile fauna such as fish or decapod crustaceans can be found in Lagler (1978) and Nielsen and Johnson (1983).

127. The following paragraphs discuss some of the most commonly used tools and techniques that may be considered when designing a monitoring program. Additionally, a recently developed technique for habitat resource assessment is discussed. The order of discussion follows the logical sequence of steps of a monitoring plan. Tools used for site reconnaissance are discussed in terms of information that can be obtained early in the monitoring effort to effectively determine sample site location and to qualitatively describe dominant biota in the system. Commonly used benthic and nektonic sampling devices are then briefly described, and their limitations are discussed. Lastly, the recently developed Benthic Resources Assessment Technique (BRAT) (Lunz and Kendall 1982, 1984; Clarke and Lunz 1985) is briefly described.

Tools for Site Reconnaissance

128. In an effort to reduce the costs of a monitoring program, preliminary site reconnaissance has become increasingly common. Among the tools currently used to evaluate impacted areas are traditional benthic samplers, sonar devices, and more recently, the sediment-profiling camera. The sediment-profiling camera is a useful and cost-effective site reconnaissance tool because it can rapidly provide qualitative and semiquantitative information

for a number of physical and biological parameters not easily obtained by other means. Both physical and biological information may be subsequently used for sample site selection for a more intense and effective biological sampling program. The usefulness of the sediment-profiling camera for site reconnaissance has been discussed by Rhoads and Germano (1982), Clarke and Lunz (1985), Marine Surveys, Inc. (1985), and Cooper Consultants, Inc. (1986).

129. Since its development in 1971 (see Rhoads and Cande 1971), the sediment profiling camera has undergone extensive modification (Rhoads and Germano 1982, Germano 1983). The design of the system and its use in physical characterization of open-water bottom habitats are discussed in Part II (see paragraphs 94-98). The biological data available from the camera system and the advantages and disadvantages of the system in this context are discussed below.

130. For the collection of biological data, the primary advantage of the sediment-profiling camera is its use as a reconnaissance tool. Information from the camera system enables large areas, such as dredged material disposal mounds, to be mapped, thus allowing for more judicious placement of stations for benthic samples and, in some circumstances, a reduction in the required number of benthic samples. Camera surveys enable delineation of bottom habitats into "strata" based on similarities in physical and biological parameters. This allows sampling stations to be allocated in a statistically desirable randomly stratified manner. It should be emphasized that "ground truthing" by means of traditional benthic surveys is necessary to correctly interpret the images obtained. Bosworth et al. (1980) found that use of the sediment-profiling camera allowed them to reduce the number of grab or dredge samples needed to characterize certain benthic habitats. However, the camera system (as discussed below) is limited with regard to quantitative assessment of the biological community. When quantitative information is required, the camera should not be the sole source of biological information about an area.

131. Images from the sediment-profiling camera (Figure 17) can give the following information which may be used to characterize a benthic habitat: grain size, sediment surface relief, level of redox potential discontinuity, epifauna present in image area, organism tube density and types, thickness of the pelletal layer (accumulations of faunal fecal pellets), microbial aggregations, infauna present in image area, feeding voids, and successional stage (Rhoads and Germano 1982). From this information, one can predict the type of benthic faunal assemblage present, obtain preliminary confirmation of this

prediction, infer the relative abundance of the fauna, and examine animal-sediment relationships. One can also assess the relative importance of bioturbation, biogenic sedimentation, and physically driven reworking of an area, thus permitting inferences regarding pore water chemistry, the degree of mixing between native and deposited material, and the potential fate of deposited material.

132. In contrast to the traditional sampling devices discussed, however, the sediment-profiling camera system cannot provide certain types of information, such as taxonomic composition and quantitative estimates of infaunal diversity, abundance, and biomass. One item of information that the sediment-profiling system does provide that is not provided by traditional sampling devices is in situ animal-sediment relationships. This information allows insight into faunal interactions and the factors that control the benthic community. While the sediment-profiling camera provides qualitative information about the biological environment, it cannot provide a quantitative characterization of the benthic community structure.

133. Similar information, i.e., grain size, epifaunal and infaunal taxonomic composition, abundance and biomass, redox boundary, tube density and types, and microbial composition, can be gained from traditional benthic sampling devices. However, this information is gained at a much higher cost than incurred with the sediment-profiling system due to the necessity for taking large numbers of samples to adequately characterize an area and the sampling/processing time requirements.

134. Use of the sediment-profiling camera as the sole source of biological information about an area is not recommended. This technique has several weaknesses that limit its applicability in certain situations. From a biological context, the primary disadvantage of the technique is that it does not furnish quantitative information on taxonomic composition, species diversity, and abundance and biomass. It is also important to note that successional stage and indices of habitat quality determined from the images are currently based on a model of benthic community succession in response to disturbance, which has not yet been demonstrated to occur consistently in all sediment types at all times.

135. Several other limitations of this tool exist. The penetration depth of the viewing prism is limited to 18 cm. Thus, the image may not reveal the boundary between the native and deposited sediments if the overburden thickness exceeds the limit of camera penetration. Second, contrasting

sediment reflectance is needed to distinguish between native and deposited material of the same grain size. Characterization of recent depositional events is therefore difficult unless the sediment grain sizes are distinct. At present, the system is capable of discriminating grain sizes with a resolution of 0.06 mm. Distinctions between finer silts and clays, while important in determining the fate of deposited material, are not possible. Deployment of the camera system in sandy substrates can be difficult due to the decreased penetration depth of the viewing prism caused by the different sediment properties (e.g., compaction, shear strength) and biological community components (e.g., shell, debris). The usefulness of the system is also lessened in relatively deep waters (>1,000 m), as the time advantage is negated in deployment. However, the system is still an effective reconnaissance tool.

136. The primary advantages of the sediment-profiling camera are cost effectiveness and quick data return. With the camera system, the time required to investigate a given station is reduced and the size of the area that can be covered in a given time period is increased. Use of the sediment-profiling camera also offers the advantages of ease of data collection and speed of data reduction. Data obtained from the camera can be viewed instantaneously on a video monitor and stored as a photographic image. Images are then interpreted with a computer image analysis system allowing as many as 100 images to be analyzed in a day. In contrast, months are often required for the processing and analysis of many benthic samples. An ancillary advantage is the simultaneous collection of physical and biological data. Use of the camera system is not recommended as a sole source of biological information.

Benthic Sampling Devices

Qualitative and semi-quantitative samplers

137. A number of trawls and dredges have been designed and used as qualitative samplers of epifaunal and infaunal organisms in a variety of habitats, particularly deeper water (>10 m). Eleftheriou and Holme (1984) describe and discuss a number of these devices and their use. For the purposes of a disposal monitoring program, these devices might be used for reconnaissance prior to or after disposal has taken place for the purpose of describing the assemblages present (species presence/absence). Because of

their design and use, however, these devices are limited largely to collecting epifauna and shallow infauna, thereby providing little information on infauna at depths greater than a few centimetres.

Quantitative samplers

138. Grab samplers and box corers are the tools of choice for quantitative sampling of epifauna and infauna (to the depth excavated). Some of the more commonly used samplers (Figure 23) are the Petersen grab, the Ponar grab, the van Veen grab, the Smith-McIntyre grab, and the Ekman grab. All of these basically operate as mechanical scoops (rounded bottoms), which remove a quantity of bottom substrate. The entire sample is removed and may be treated individually or pooled with other samples. Typically, these samplers collect material from areas of 0.02 to 0.5 m and penetrate to sediment depths ranging from 5 to 15 cm.

139. Limitations of grab samplers include variation in the quantity of material collected from sample to sample and the inability to subdivide or section the collected material (e.g., vertical sectioning). A number of operational factors also influence the efficiency and reliability (performance) of these devices. Most of these samplers are sensitive to wave action, current conditions, and boat movement, factors that may cause premature closure or incomplete closure at the bottom. These factors may also affect the angle of penetration of the device and, therefore, the quantity of material collected. Collections may also be affected by slack in the attached line, jerking of the trap off the bottom causing poor closure, upward pull or drop of the grab at an oblique angle (due to drift of the vessel from over the grab), and inadequate weight on the sampler (contributing to poor penetration). These factors affect both the area and depth (volume) of the sample; therefore, care must be exercised to minimize variability in sample collection. Sediment type also affects penetration of a device (e.g., poorer penetration in sand versus mud). For these reasons, grab samplers generally work best in sheltered areas or under relatively calm weather and sea conditions.

140. Box samplers or corers are most often used to collect relatively large, undisturbed samples and can effectively sample to greater depths than grab samplers in the substrate. The volume of material collected can be as much as 5 to 10 times that of typical grab samplers. Vertical sectioning is also possible on samples collected with these devices. Two commonly used box samplers include the Reineck box sampler and the Gray-O'Hara box corer (Figure 24). The Gray-O'Hara box corer can be fitted with an internal Plexiglas

liner that allows for easy removal of an intact sample suitable for vertical sectioning (see discussion, paragraphs 156-157). The major benefit of using this type of sampler lies in obtaining quantitative samples of larger areal coverage and to greater depths.

141. The use of these larger devices requires the use of cranes or winches and larger vessels, and is subject to some of the operational problems described above for grab samplers. Smaller, cylindrical, hand-operated corers have been used in shallow water or intertidal situations and can be operated by a diver or from a small boat. See Eleftheriou and Holme (1984) for more complete descriptions of these devices.

142. Suction sampling devices employ the use of water flow to draw the sediment and associated fauna into a collecting device (e.g., a sieve or fine mesh bag). Some designs can be operated remotely from a vessel; the sampler removes a quantity of material predetermined by sampler configuration and mechanics. Simpler devices include the use of an open-ended suction tube operated by a diver who directs removal of material from a given area of bottom. Eleftheriou and Holme (1984) provide descriptions of some of these devices.

Nekton Sampling Devices

143. Sampling of nektonic organisms (fishes, shrimps, and crabs) is most commonly accomplished through the use of nets or traps of various types. Nets generally collect a greater diversity of organisms than do traps, which are usually designed to attract and capture particular species (e.g., crab pots). The choice of a sampling device(s) for survey work depends on the type(s) of organism(s) of interest. Discussed in the following paragraphs is the use of active and passive nets for the collection of pelagic or demersal fishes and shellfishes, as well as traps for the collection of less mobile shellfishes (e.g., crabs). Consult Lagler (1978) and Nielson and Johnson (1983) for more thorough discussions of various fish-collecting techniques.

Nets

144. Nets are either passive or active collectors of organisms. Passive nets are set in a stationary position, collecting organisms that become entangled (e.g., anchored gill nets) or entrapped within the confines of the netted area (e.g., fish traps), and may require extended deployment, in-place,

and recovery periods. Active nets (e.g., otter trawls) are towed through the water and produce more immediate results.

145. In general, nets of all types are semiquantitative at best, given the degree of gear selectivity for the target organisms. Selectivity reflects such factors as net size, configuration, and orientation, as well as avoidance behavior on the part of the species being sought. For use as monitoring tools, passive nets and traps can provide qualitative information about organisms using a given area, but may not be capable of collecting adequate numbers of organisms as would be needed for gut analysis. As with other sampling devices and techniques, the choice of a particular tool should be made in light of the question being asked.

146. Gill nets, trammel nets, hoop nets, and fyke nets are commonly used to collect fishes in fresh water and sheltered estuarine/marine waters. Gill and trammel nets (Figure 25) consist of a sheet of netting (of variable length, depth, and mesh size). Hoop nets and trap nets (Figure 26) consist of netting stretched over a frame to form a rigid tube or box in which fishes are collected. To these boxes are attached outwardly radiating sheets of netting (wings), which guide fishes to the centrally located collecting box. These nets are deployed by means of anchors and/or poles and are oriented in such a fashion to intercept fishes as they move. Fyke nets differ from hoop nets by having an additional sheet of netting extending forward out from the central box, often being several times longer than the length of the rest of the trap. Trap nets have additional sheets of netting deployed along the wings to prevent escape of fishes. These nets are highly selective in the species that are captured and in the efficiency of retaining captured organisms. Mesh size varies depending on the target fish species.

147. Trawls (Figure 27) and purse seines are commonly used to collect large quantities of fish at various depths in the water column. A purse seine consists of a large sheet of netting (weighted at the bottom and with floats at the top) that is deployed in open water in such a fashion as to surround surface-pelagic schools of fishes (especially herrings). The net is closed by pulling in a "purse" line attached through rings along the bottom of the net. The fish entrapped by the net are scooped out of the closed net.

148. Trawls are devices that are pulled through the water column at various depths. Otter trawls are the most commonly employed type, consisting of a winged bag having weights at the bottom and floats at the top. The wings are held apart by the lateral spreading action of boards that extend and

maintain the net in an open fashion. A loosely tied length of "tickler" chain is often attached to the lead line of an otter trawl to drive demersal fishes and invertebrates off the bottom and into the net without having to drag the net directly on the bottom. Beam trawls differ by being attached to a rigid frame. Both types of nets can be pulled at various depths (surface, midwater, bottom) depending on the target fishes or shellfishes. Both types of nets are somewhat less selective than previously described passive nets and will generally capture a wider range of species of fishes and shellfishes. Capture efficiency depends on mesh size and its effect on the speed at which the net can be towed. The slower the towing speed, the more likely that some organisms can avoid or escape the net. Selectivity and bias is still very much a problem with trawls. Some degree of standardization can be achieved by controlling the duration, direction, and speed of towing.

Traps/cages

149. Traps or cages can be used to capture specific target organisms. For example, various species of commercially harvested crabs are captured in baited wire mesh traps. Traps and cages can be used to determine if target species are using a given area.

Benthic Resources Assessment Technique

Background

150. Most monitoring programs collect information to document a change in some parameter such as community composition or diversity. However, these data are not generally useful in evaluating changes in the functional value of the system. The Benthic Resources Assessment Technique (BRAT) is a set of procedures for collecting, analyzing, and tabulating environmental data to estimate the value of a particular location (or a number of different locations) as a foraging area for demersal, bottom-feeding, predatory fishes. The BRAT was developed at the WES with funds from the Corps' Environmental Impact Research Program.

151. The BRAT, as presently configured, can be applied under any circumstances in which the preproject or postproject fishery value of an unvegetated soft (muddy or sandy) bottom is an important issue. The technique has been applied in subtidal estuarine and coastal marine systems (Clarke 1986, Lunz 1986) and is currently being applied on intertidal coastal mud flat habitats as foraging areas for benthos-feeding wading birds. Its potential

utility for habitat evaluations involving other types of unvegetated intertidal, riverine, and lacustrine environments is intuitively logical and theoretically feasible but as yet untried.

152. Optimal foraging theory forms the basis for the BRAT. Simply stated, this theory suggests that a predator will detect, capture, and ingest prey food items according to its genetically endowed ability, and in such a way that the greatest nutritional/caloric benefit is obtained for the smallest expenditure of energy. The concept of optimal foraging offers an especially satisfying explanation for the "plastic" foraging habits of bottom-feeding demersal fishes of US bays, estuaries, adjacent coastal marine waters, and other physically accommodated aquatic systems such as large lakes or rivers. These fishes appear to feed nonselectively, consuming different prey at different locations and during different seasons at the same location.

153. In the BRAT, prey vulnerability is defined by the size of benthic invertebrate food items or particles (determined by wet sieving) in relation to a predator's ability to exploit specific-sized particles or a range of particle sizes; availability is defined by the depth of vulnerable sized particles below the sediment-water interface in relation to a predator's ability to exploit vulnerable particles from different sediment depth zones.

154. In recent applications of the technique to actual Corps field operation conditions in the Chesapeake Bay (Kendall and Lunz 1984), Long Island Sound (Lunz 1986), and Puget Sound (Clarke 1986), vulnerable prey size and the available depth zone are defined using data obtained by an expedient analysis of selected predators' diets.

155. A simplified flowchart depicting the BRAT analysis is presented as Figure 28. The only missing steps are the computer-assisted data reduction and analysis routines, which become a practical necessity when dealing with the large numbers of benthos and fish food habit samples associated with moderate- to large-scale field operations. Each step is briefly outlined below.

Sample collection

156. Information on the benthic assemblages within a given project area is obtained from quantitative benthic samples. A box corer capable of penetrating at least 30 cm into an unconsolidated bottom and having a cross-sectional area of at least 0.06 to 0.07 m is needed. The corer used must be adapted for use with a removable liner that has a removable side. A Gray-O'Hara box corer (Figure 24) has been successfully modified in this

manner for use in sample collection. Care must be taken to ensure that an undisturbed sample is taken. Any sample that does not include at least 30 cm of material or shows signs of being disturbed is discarded. The number of replicate samples taken is determined by the sampling design and statistical considerations but may also be affected by constraints on processing time. Typically, at least four to five samples should be taken in any site (e.g., impacted and reference areas). Location of sampling sites within the project area can be facilitated by the use of reconnaissance techniques (e.g., preliminary grab samples or sediment-profiling camera survey).

157. Upon collection of a sample, the liner is removed from the corer and placed on its side (in a processing box that prevents slumping of the sediment) to facilitate sectioning. The removable side of the liner is removed, and the core is sectioned at 2, 5, 10, and 15 cm from the top of the corer using thin metal blades. The top 0- to 2-cm section is washed through a 0.25-mm-mesh sieve to capture surface-dwelling juvenile stages of benthic organisms. All remaining sections are washed in a 0.5-mm-mesh sieve. All fractions are preserved in 10-percent buffered formalin and stained with Rose Bengal. Organisms from each sample are picked and sorted to major taxonomic categories (e.g., oligochaetes, polychaetes, gastropods, etc.) and temporarily stored in 10-percent formalin. Organisms of each taxonomic category are separated into discrete size classes using a wet-sieving procedure modified from that of Carr and Adams (1973) and Sheridan (1979). Samples are carefully washed through a series of nested sieves (6.35, 3.35, 2, 1, and 0.5 mm, plus 0.063 mm for the 0- to 2-cm section). Fractions from each sieve are transferred to weighing bottles after filtering through a millipore filter apparatus (filter type HA, 0.45 μ). Weight is determined to the nearest 0.01 mg.

158. Fish food habit samples are obtained from demersal bottom-feeding fishes collected in the disposal and reference areas. An otter trawl is commonly used to collect sufficient numbers of specimens from a wide range of size classes. Fish collection is directed by the number and composition of fishes in a given area. Optimally, a minimum of 10 individuals of the following size classes of each target species should be collected: 5 to 9.9 cm, 10 to 14.9 cm, 15 to 19.9 cm, 20 to 24.9 cm, 25 to 29.9 cm, and greater than 30 cm. It is recognized, however, that it is not always possible to obtain individuals from all size classes or for each species, given the seasonal variability in habitat utilization by different species and different size

classes. Each specimen collected is classified, measured, and assigned to a given size class. Stomach contents are then removed, and the pooled stomach contents sample for each species-specific size class is preserved in 10-percent buffered formalin and stained with Rose Bengal. Each sample is picked, sorted, size-sieved, and biomassed in the same manner described for benthic samples.

Data analysis

159. Application of the BRAT requires the integration of information from the previously described benthic and fish collections from a given project area. Size selection information obtained from fish stomach analyses is plotted for each size class (Figure 29). This procedure is repeated for each predator collected, and the combined matrix of prey size distributions versus predator species/size classes is analyzed using cluster analysis. The output generated from these analyses objectively classifies the fish size classes into groups based on similarities in prey size distribution patterns.

160. Determination of the available depth zone or maximum feeding depth in the sediments used by a specific demersal predator is accomplished by comparing prey size distribution patterns in a predator's diet with size-class patterns in the benthic community.

161. A more objective method of determining the available depth zone involves the use of a measurement of feeding selectivity such as the Electivity Index (Ivlev 1961). This index is computed by the formula

$$E = \frac{(r_i - P_i)}{(r_i \pm P_i)} \qquad (1)$$

where

r_i = relative value (biomass, number, volume, etc.) of the prey (food) component in the stomach of the predator

P_i = relative value of the prey component in the environment

Each successive vertical fraction is examined by this procedure, and the available depth zone is identified as that cumulative fraction with the highest positive Electivity Index.

PART IV: STATISTICAL CONSIDERATIONS FOR MONITORING PROGRAMS

162. Considerations for the design of a monitoring program include such items as location of sampling stations, selection of appropriate reference areas, number of samples (replicates), sampling frequency, and the correct application of appropriate statistical models. Choice of an appropriate statistical model that rigorously and adequately tests relevant hypotheses is an especially important aspect of sampling design. Each of the above-mentioned items is discussed below. For a more detailed discussion of sampling design and testing, consult Green (1979).

Sample Site Selection

163. The choice of sample-site location must consider factors relative to characterization of the impacted area as well as an adequate reference area. Site reconnaissance techniques, as previously discussed under both physical and biological sampling techniques, can provide adequate information for locating areas within which samples can be taken (e.g., exact location of the disposal mound). The information provided by these techniques can also allow for the designation of strata (e.g., various thicknesses of dredged material) within the impacted area, if desired. The choice of an adequate reference area is also very important and must be made carefully to avoid any influence from the dredged material site. The reference area should be representative of predisposal conditions at the disposal site (e.g., similar sediment type, water depth), so that changes from this baseline condition and ongoing changes can be evaluated.

Number of Samples and Sampling Frequency

164. Any statistical consideration of the data collected requires that replicate samples within each site (impacted and reference) or strata therein be collected to obtain a measure of variability (e.g., standard deviation) in the data. In fact, many of the commonly used parametric tests center on comparison of the variability in the data between sets of data. In general, the necessary number of samples is proportional to the heterogeneity in the variable being measured. The frequency of sampling will depend on the objectives of the study. The following discussion on sample number and frequency of

sampling is taken from Engineer Manual 1110-2-1204, "Environmental Engineering for Coastal Shore Protection" (US Army Corps of Engineers 1988).

165. At a minimum, three replicate samples are required to calculate standard deviation. Decisions about the number of replicates beyond this level largely depend on heterogeneity in the physical factors being measured or the dispersion pattern displayed by the organisms being sampled (e.g., random, aggregated, uniform). In the case of biological sampling, a rapid method for determining the number of samples necessary is to calculate the cumulative mean of a few samples obtained in a pilot survey. A cumulative mean (or running average) consists of taking the average of samples 1 and 2; then of samples 1, 2, and 3; then of samples 1, 2, 3, and 4 (and so on), until all samples have been included. If the results are displayed (Figure 30), the plot of mean values will stabilize as more and more samples are included. In a population with a random distribution (when the variability is fairly low), the mean stabilizes quickly. In the aggregated distribution pattern, the cumulative mean value never stops fluctuating, although as can be seen in Figure 30, after about 15 samples the data begin to stabilize. In the illustrated examples, 8 to 10 samples would be minimally adequate to describe the randomly distributed population, whereas at least 15 to 20 samples would be required for the aggregated population.

166. A more sophisticated technique for estimating the number of samples is described by Green (1979). A preliminary or pilot survey is taken from the population, and individual counts are made from each collection to calculate the sample mean and standard deviation. The following formula is then used:

$$\bar{X} \pm t_{1-(1/2)\alpha} \frac{s}{\sqrt{n}} \quad (2)$$

where

$\bar{X}$ = sample mean

t = t statistic

α = significance level

s = standard deviation

n = number of samples

In the following example, assume that an investigator wishes to estimate the mean density of a species in a population within 10 percent of the actual number and with a 1-in-20 chance of being wrong (0.95-percent confidence limits). The t value is unknown and is a function of $n - 1$ degrees of freedom; however, for large sample sizes, t is a weak function of n and is approximately 2. If t can be estimated, the formula can be solved for n.

167. An additional factor that will serve to limit the number of samples is financial resources. For example, the number of samples upon which bioassays can be performed is determined by the ratio of available dollars and the cost per sample:

$$\text{Maximum number of samples} = \frac{\text{Dollars available}}{\text{Cost per sample}}$$

This approach will provide one method of estimating the number of samples that can be collected and analyzed. However, should the calculated number of samples not be sufficient to establish an adequate sampling program (i.e., the number of samples is insufficient to allow replicate sampling at all locations), one of the following options will have to be considered. The first option is to reduce the replicate sampling at each station. This will allow the distribution of a parameter within the project area to be determined, but variability at a single sampling station location could not be calculated. The second option is to maintain replicate sampling but reduce the number of sampling stations. This will result in the project area being less well defined, but sampling variability can be calculated.

168. The considerations of these two options should be based on project-specific goals. If the first option is used (more stations but fewer replicates), the results will provide a better indication of distribution patterns in the project area, but it will be difficult to compare individual stations. On the other hand, if the second option is used (fewer stations but more replicates), the results will provide a better indication of variability at a given station and will improve comparison between sampling stations. However, the project area will be less well defined. A third option is, of course, to increase the financial resources available for sample analysis. This will increase the number of samples that can be collected and analyzed to establish an adequate sampling program.

169. It is suggested that consideration be given to collecting samples (stations and numbers) in excess of the number determined by the above process. The samples do not have to be analyzed and may even be discarded later without analysis. Should sample analysis indicate abnormal results, it is easier and ultimately less expensive to analyze additional samples on hand rather than to remobilize a field crew. Also, the additional and potentially confounding variable of different sampling times is avoided with this approach.

Statistical Design

170. A statistical design must be developed that will detect differences resulting from the project, in this case, the disposal of dredged material. A statement of exactly what will be measured, as well as what kind of change will be looked for, is a necessary first step in producing a statistically valid design. Other changes will be detected as well, so the statistical design must account for a range of variability, and the appropriate variables to measure must be selected. Historically, impact studies have tested the null hypothesis of "no change" against the alternative of "any detectable change of any kind, which will be assumed to be a change for the worse unless someone (else) proves it otherwise" (Green 1984). A more efficient approach, given sufficient knowledge of the system, is to specify the magnitude of the effect to be detected. Specifying the direction of the change is also necessary, since not all change is for the worse. The test for significance of change due to impact must be tested against an appropriate error term (i.e., a predetermined threshold) (Green 1984).

171. Monitoring programs collect data that are either analyzed quantitatively to test specific hypotheses or summarized and displayed to illustrate differences in a qualitative way. Because of the inherent difference in the two approaches, data analysis techniques fall into two categories: exploratory and confirmatory (Tukey 1977). Exploratory techniques such as graphs, ordination, principal components analysis, and classification analysis "are attempts to reveal patterns and regularities in the data--to suggest hypotheses and potentially fruitful further studies" (Stewart-Oaten, Murdoch, and Parker 1986). Exploratory techniques are generally used when the study area is poorly known, or more often to detect patterns in very large data sets. Confirmatory techniques such as the analysis of variance (ANOVA), t-test,

difference models, and nonparametric techniques are procedures that test specific hypotheses.

172. Historically, impact studies have used techniques in the confirmatory category (Stewart-Oaten, Murdoch, and Parker 1986). Confirmatory techniques are preferred over exploratory techniques because they can provide tests of specific questions of interest, and they can do so with a specified degree of confidence. Parametric procedures are generally more powerful than their nonparametric counterparts; both, however, provide numerical tests of specific hypotheses. The ability to answer specific questions has a price, in that these analyses are accurate only if certain assumptions concerning the data are valid. Therefore, a brief discussion of these assumptions, the effects of violating them, and some remedial actions or alternative analytical techniques is presented below using ANOVA as an example.

Analysis of variance

173. The ANOVA has been widely used and abused in the analysis of biological data. In the past few years there has been intensive discussion on the appropriateness of using ANOVA to analyze data from field studies such as impact investigations (Underwood 1981; Heck and Horowitz 1984; Hurlbert 1984; Millard and Lettenmaier 1986; Stewart-Oaten, Murdoch, and Parker 1986). It has been argued that because critical assumptions of ANOVA are usually violated in field applications, the resultant interpretations are invalid (Hurlbert 1984). These assumptions are that (a) the main effects and interaction terms in the mathematical model are additive, (b) the error terms are independent and normally distributed, (c) the variances are homogeneous (equal), and (d) samples are taken from a normally distributed population (Millard, Yearsley, and Lettenmaier 1985).

174. Violation of the assumption of independence of error terms (sample independence) can have serious effects on the validity of conclusions (Glass, Peckham, and Sanders 1972). For most experiments, the randomization scheme employed dictates the independence of the residuals (sample independence); however, for some experiments, and almost all impact studies, even randomization will not alleviate the problem of dependent errors. Violation of sample independence can occur either spatially or temporally. For example, Green (1979) described a disposal area and a reference area that were to be sampled quarterly using random samples within areas. With such a design, samples within areas and from the same sampling time are likely to be correlated and

therefore nonindependent. Such data cannot be properly analyzed with ANOVA because the test results and subsequent interpretation may be in error.

175. The assumption of "homogeneity of variances" is critical and, with the normality assumption, it is often invalid for biological data. Failure to meet this assumption increases the probability that the null hypothesis will be rejected when it is actually true (Type I error), and an impact may be inferred when none exists. If this assumption is proven to be invalid, variance stabilizing transformations (e.g., square root) can be used. If the transformed data satisfy the assumption of homogeneity, then ANOVA can be used on the transformed data, and any conclusions drawn will be valid for the untransformed data. If unequal variances cannot be corrected with a transformation, an approximate-F test or a suitable nonparametric statistical procedure can be used.

176. The assumption of normality is the least likely to be valid with ecological data. If, as is commonly the case, the range of possible values is restricted (such as weight which must be positive and count which must be a positive integer or zero), the assumption of normality is incorrect. However, a fair amount of departure from exact normality can be tolerated with little practical effect on the properties of standard ANOVA procedures (Scheffe 1963, Underwood 1981). Furthermore, if the violation can be rectified by means of a normalizing transformation, the transformed data can be used in a valid ANOVA, provided that caution is used in the interpretation of transformed data. Alternative nonparametric testing procedures that meet the requirements of the experimental model can be used to verify the conclusions of the ANOVA under the assumption of nonnormal residuals.

177. Millard, Yearsley, and Lettenmaier (1985) reached three conclusions concerning the effects of temporal and spatial correlation:

- a. The probability of a Type I error for tests of environmental change due to an intervention (e.g., power plant start-up) is likely to be inflated if the observations are positively correlated in time or space.
- b. Spatial correlation will usually be stronger than temporal correction for typical sampling frequencies, for instance, bimonthly to monthly.
- c. Spatial correlation is of greatest concern when the errors at the control (treatment) stations are more highly correlated than the treatment-control pairs.

178. An important question is, How can one detect the presence of time or serially related correlations? Drapier and Smith (1966) give an excellent

treatment of this problem, as well as problems of other violations. The nonparametric runs test on the residuals is used to test the hypothesis of time-related correlation. This test is based on the sign of the residuals and the distribution of these signs. It is a quick and easy procedure to use, and the testing procedure is fairly powerful. Other techniques that can be used are simple lag-one correlation coefficients (Millard, Yearsley, and Lettenmaier 1985).

Alternative statistical approaches

179. The use of ANOVA or other statistical procedures for analyzing field data without regard for sampling design or verification of necessary assumptions is ill advised. As noted earlier, correlation among samples may lead to the conclusion of an impact when in fact no impact has occurred (Millard, Yearsley, and Lettenmaier 1985). Such erroneous results could lead to unnecessary restrictions on project activities. Alternatives to the common statistical models are discussed in the following paragraphs. Designers of environmental impact studies should consider such alternatives but maintain a keen awareness of the underlying assumptions and the potential for erroneous conclusions.

180. Millard, Yearsley, and Lettenmaier (1985) offer several suggestions for analyzing aquatic monitoring data. If temporal correlation is detected, multivariate time series analysis should be applied. If only spatial correlation is present, a multivariate analysis of variance should be used. Another recent suggestion is the use of a difference model that uses the sampling times as replicates (Bernstein and Zalinski 1983; Stewart-Oaten, Murdoch, and Parker 1986). Impact and reference areas are sampled simultaneously, and the difference between impact and reference samples for a given sampling time is used in the analysis (Figure 31). A t-test is used to evaluate the hypothesis that there is no difference in the "before" and "after" difference scores. This model requires multiple surveys to accurately detect change.

181. An alternative method of analyzing difference model data is to use a 2 × 2 mixed ANOVA. The test for a significant location-by-condition interaction is equivalent to the t-test suggested above. The t-test is much easier to compute, but ANOVA provides more information. This design detects those changes over and above the naturally occurring temporal changes. If the ANOVA design were used, the appropriate denominator needed to calculate the F-statistic is the pooled time-by-location interaction variance, not the

residual (error) variance used by default in most software packages. A large condition-by-location interaction compared to a small pooled denominator will indicate a significant impact (Bernstein, Smith, and Thompson 1985). While the difference design appears to be a good substitute for ANOVA, it does have a disadvantage in that it requires sufficient "before" sampling to establish a relationship between impact and reference areas.

182. Analytical statistical techniques for field impact study applications are in a state of flux, with commonly used approaches receiving considerable criticism. Analysis of variance and other inferential statistics should be applied with caution, with a healthy regard for underlying assumptions and the effects of violation. Difference models appear to be a viable replacement for ANOVA, although before-and-after sampling is a requirement for their application.

Multivariate exploratory techniques

183. Exploratory techniques, as noted earlier, are most often used to discern patterns in large data matrices or when no prior information exists for the study area. In either case, it may be impossible to formulate specific, testable hypotheses, and thus the purpose of the analyses will be to suggest such hypotheses for future testing. However, multivariate exploratory techniques are often useful in their own right to facilitate presentation or display of the data. Multivariate techniques can be used to analyze the spatial and correlation structures of variation within a set of data. If an ANOVA is planned in addition to multivariate analyses, the sampling sites should include the natural range of variability within the impact and reference areas, so the power of the ANOVA to detect a correlation between environmental factors and abundances (Heck and Horowitz 1984) will not be reduced. Multivariate techniques that are commonly used are ordination, principal components analysis, factor analysis, reciprocal averaging (correspondence analysis), and detrended correspondence analysis.

184. Bray-Curtis ordination has been widely used in biological studies. Ordination is a projection of a multidimensional system onto a two- or three-dimensional map (Figure 32) (Fredette 1980). An ordination matrix consists of entities (samples) and attributes (species abundance, biomass, etc., of the samples). The Bray-Curtis method has three steps: "(1) calculating a distance matrix, (2) selecting two reference points (either real or synthetic samples) for determining the direction of each axis, and (3) projecting all

samples onto each axis by their relationship to the two reference points" (Beals 1984).

185. Principal components analysis (PCA) is a mathematical technique used to "reduce a data set with a relatively large number of correlated variables to a data set with fewer uncorrelated variables that retain most of the information content of the original data" (Stauffer, Garton, and Steinhorst 1985). However, unless the data set is homogeneous, PCA components often do not have ecological meaning. Studies by Clymo (1980), Gauch and Whitaker (1972), and others have demonstrated that Bray-Curtis ordination is far superior to PCA unless "the data set consists of a small number of relatively homogeneous samples" (Beals 1984).

186. Factor analysis is an extension of principal components analysis. The shortfalls of PCA also apply to factor analysis. Canonical correlation analysis, another multivariate technique, is the simultaneous rotation of axes through species space and environmental space, so that one finds axes of best correlation between environmental gradients and compositional gradients. Canonical correlation is not a useful tool since it is even more sensitive to nonlinear data than PCA (Beals 1984).

187. A useful multivariate technique that is considered by some to be superior to Bray-Curtis ordination is reciprocal averaging (RA). Reciprocal averaging is an eigenvector method that simultaneously rotates the axes in species space and samples space until the correspondence of each succeeding pair of axes is maximized. This technique can handle more heterogeneous data than other ordination techniques (Beals 1984). However, RA does have a major drawback in that it is good for only one axis. The second axis tends to arch and is difficult to interpret. Hill (1979) and Hill and Gauch (1980) introduced detrended correspondence analysis, a technique that eliminates the arching effect and eliminates the trend between the first and second axes. The second axis becomes more interpretable ecologically (Beals 1984).

188. Another exploratory data analysis technique is classification (or cluster) analysis (Figure 33). The object of classification analysis is "to produce a number of tolerably discrete groups or patterns of co-occurrences" (Clifford and Stephenson 1975); these then lead to testable hypotheses. Boesch (1977) provides an excellent discussion of the various attributes of this program. The major drawback to cluster analysis is that, although groups or clusters are formed objectively, the interpretation of the results is

purely subjective. A change in any one of the input parameters will alter the output dendrogram.

189. Response surface analysis (RSA) is a technique that offers the advantage of ordering and finding relationships in data, as well as being readily interpretable by individuals with little expertise. The output from RSA resembles a topographic map (Figure 34), as stations with similar attributes are grouped into regions separated by contours. Assuming that ecologically important data are analyzed, the size and rate of change of the impact area can be monitored.

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Table 1

Summary of Physical Monitoring Tools

Tool	Function	Regular or Special Use	Cost	Usable Data Return Time	Ease of Data Interpretation	Data Collection	Limits	Miscellaneous
Loran-C	Positioning	Regular	Low	Fast	Easy	In-house	Low accuracy	Signal interference can be local problem
Short-range microwave	Positioning	Regular	Moderate/ high	Fast	Easy	In-house/ contract	25-mile (40-m) limit; setup required	Accurate to ±3.0 ft (±0.9 m)
Total stations	Nearshore position and bathymetry	Special	Moderate/ high	Moderate/ fast	Easy	In-house/ contract	2.5-mile (4-m) offshore limit	Very accurate (±0.1 ft (0.03 m)); automation affects processing time
Global positioning system (satellite)	Positioning	Special (regular after 1992)	Low/ moderate	Slow/ moderate	Easy/ hard	Contract	Limited use until all satellites deployed	Postprocessing of data required for maximum accuracy
Depth sounders (Fathometers)	Bathymetry	Regular	Moderate	Slow/ moderate	Easy	In-house/ contract	Accuracy to ±0.7 ft (±0.2 m)	Require correction for accurate results
Swath survey Fathometers	Bathymetry	Special	Moderate/ high	Slow/ moderate	Easy	In-house/ contract	Useful only in low-energy conditions	
Stationary bathymetric systems	Bathymetry	Special	Low/ moderate	Moderate/ fast	Easy	In-house	Limited spatial coverage	Sonic altimeters; reference rods
Side-scan sonar	Mapping fringe bed forms	Special	Moderate	Fast	Hard	In-house/ contract	Useful only if disposal/native material different	Interpretation requires training
Subbottom profiler	Internal structure compaction	Special	Moderate	Fast	Hard	In-house/ contract	Trained interpreter required	Special models are useful in sand/gravel
Grab sampler	Surface sediment samples	Regular	Low	Fast	Easy	In-house	Surface sample only	Detailed information requires lab work

(Continued)

Table 1 (Concluded)

Tool	Function	Regular or Special Use	Cost	Usable Data Return Time	Ease of Data Interpretation	Data Collection	Limits	Miscellaneous
CS^3 and Gamma sled	Mapping mound fringe	Special	High	Moderate/ fast	Moderate	Contract	Dissimilar native/ disposal material required	May have more use in contaminated sites
Shallow penetrating cores	Mapping mound fringe; sediment properties 0 to to 10 ft (3 m)	Special	Low/ moderate	Slow/ moderate	Easy/hard	In-house/ contract	Difficult to penetrate sand/gravel	Cost varies--box corer, gravity, piston, diver assistance
Deep penetrating cores	Investigating sediment properties 0 to 40 ft (12 m) below seafloor	Special	High	Slow/ moderate	Easy/hard	In-house/ contract	Costly, big mobilization effort	Vibracores, drill rigs
Sediment-profiling camera	In situ sensing of sediment/benthos; map fringe	Special	Moderate/ high	Moderate/ fast	Easy/hard	Contract	Difficulty penetrating sands	Excellent reconnaissance tool, especially for benthic data
Video/remotely operated underwater vehicles	Mapping mound fringe, bed forms	Special	Moderate/ high	Moderate	Easy	Contract	Need clear water; positioning difficult	
Airborne remote sensing	Shoal measurements, bathymetry	Special	Low/ high	Moderate/ fast	Easy	Contract	Need clear water; new technique with potential	Electromagnetic profilers for cloudy water
Engineering tools	Measurement of geotechnical properties	Special	Low/ moderate	Moderate/ fast	Easy/hard	In-house/ contract	Each tool specific to one measurement	Variety of tools; cost savings potential
Current meters	Current speed and direction	Regular	High	Slow	Easy/hard	Contract	Vulnerable to loss/ damage	Variety of types
Drogues (sedbed drifters)	Current tracking (direction)	Special	Low	Moderate	Easy	In-house	Limited to nearshore for collection	Transponders can be attached for tracking

Table 2

Summary of Sampling Characteristics of Benthic Sampling Devices

Gear	Weight*	Sample Width m	Sample Area m	Quantitative?**	Depth of Sample (Firm sand)†	Deposit†† Firm Sand	Deposit†† Mud	Sea Depth††,‡ Shallow	Sea Depth††,‡ Shelf	Sea Depth††,‡ Deep Sea	Different Sea Conditions	Ship Size§
Macer-GIROQ sampler	H	0.5		Q	0	+	+	+	+			SML
Epibenthic sled (Hessler and Sanders)	H	0.8			0	+	+			+		ML
Epibenthic sledge (Alfred et al.)	H	2.3		SQ'	0	+	+			+		ML
Rectangular dredge	L	0.3–1.3			0	+	+	+	+	+	+	SML
Small biology trawl (Menzies)	L	1.0			0	+	+	+	+	+		ML
Anchor dredge (Forster)	L	0.5		SQ'	3	+	+	+	+	0		SM

(Continued)

Source: Eleftheriou and Holme 1984.

* Total weight (with any additional weights included): L, <100 kg; M, 100–200 kg; H, >200 kg.

** Codes are Q, quantitative; SQ, semiquantitative; SQ', semiquantitative if odometer wheel fitted.

† Penetration of sampler into firm sand: 0, surface sample only; 1, 1- to 10-cm penetration; 2, 10- to 20-cm penetration; 3, >20 cm penetration; M, above penetration depths but in soft mud only.

†† Codes are +, suitable; blank, possible application; 0, unsuitable.

‡ Shallow, diving depth (i.e., <30 m); shelf, 30–200 m; deep sea, >200 m (i.e., slope and abyss) (", from submersible).

‡‡ Sea conditions (most sampling gear cannot be used under severe conditions of swell, waves, or currents): +, instruments likely to obtain a sample under such conditions; 0, these instruments can be used only under calm conditions and/or absence of strong currents.

§ Size codes: S, launch with power hoist; M, trawler; L, large research vessel.

(Sheet 1 of 4)

Table 2 (Continued)

Gear	Weight	Sample Width m	Sample Area m	Quantitative?	Depth of Sample (Firm sand)	Deposit Firm Sand	Deposit Mud	Sea Depth Shallow	Sea Depth Shelf	Sea Depth Deep Sea	Different Sea Conditions	Ship Size
Anchor dredge (Thomas)	L	0.6			2	+	+	+	+			SM
Small anchor dredge (Sanders)	L	0.29		SQ	1	+	+	+	+	0		SM
Anchor dredge (Sanders et al.)	H	0.57		SQ	2	+	+		+	+		ML
Anchor-box dredge	H	0.5	1.33	SQ	1	+	+		+	+		ML
Petersen grab	L		0.1*	Q	1	0	+	+	+		0	SM
Campbell grab	H		0.55	Q	2	+	+		+	+		ML
Okean grab	L		0.08*	Q	1	+	+	+	+	+		SML
van Veen grab	L		0.1*	Q	1	+	+	+	+		0	SM
Ponar grab	L		0.055	Q	1	+	+	+	+	0		SM
Hunter grab	L		0.1	Q	1	+	+	+	+	0		SM
Smith-McIntyre grab	L		0.1	Q	1	+	+	+	+			SM
Day grab	L		0.1	Q	1	+	+	+	+			SM

(Continued)

* Other sizes available.

Table 2 (Continued)

Gear	Weight	Sample		Quantitative?	Depth of Sample (Firm sand)	Deposit		Sea Depth			Different Sea Conditions	Ship Size
		Width m	Area m			Firm Sand	Mud	Shallow	Shelf	Deep Sea		
Orange-peel grab	M		Various	Q	1	+	+	+	+	+	+	ML
Baird grab	L		0.5	Q	2	+	+	+		0	0	SM
Hamon grab	H		0.29	SQ	2	+	+	+	+			ML
Holme grab	M		2 × 0.05	Q	1	+	+	+	+			M
Shipek grab	L		0.04	Q	1	+	+	+	+	0		SM
Birge-Ekman grab	L		0.04	Q	M1		+	+	+			SM
Reineck box sampler	H		0.06*	Q	3	+	+	+	+	+		ML
Lubs sampler	M		0.06-0.25	Q	M2		+		+	+		ML
Haps corer	L		0.015	Q	M3		+	+	+			SM
Knudsen sampler	M		0.1	Q	3	+		+	+	0	0	SM
Suction sampler (True et al.)	L		0.1	Q	3	+		+	+	+"	0	SM
Suction sampler (Kaplan et al.)	L		0.1	Q	3	+	+	+	0	0	0	S
Suction sampler (Thayer et al.)	L		0.07	Q	3	+	+	+	0	0	0	S

(Continued)

* Other sizes available.

(Sheet 3 of 4)

Table 2 (Concluded)

Gear	Weight	Sample Width m	Sample Area m	Quantitative?	Depth of Sample (Firm sand)	Deposit Firm Sand	Deposit Mud	Sea Depth Shallow	Sea Depth Shelf	Sea Depth Deep Sea	Different Sea Conditions	Ship Size
Flushing sampler (van Arkel)	L		0.02	Q	3	+	+	+	0	0	0	S
Diver-operated suction sampler (Barnett & Hardy)	L		0.1	Q	3	+	+	+	0	0	0	

(Sheet 4 of 4)

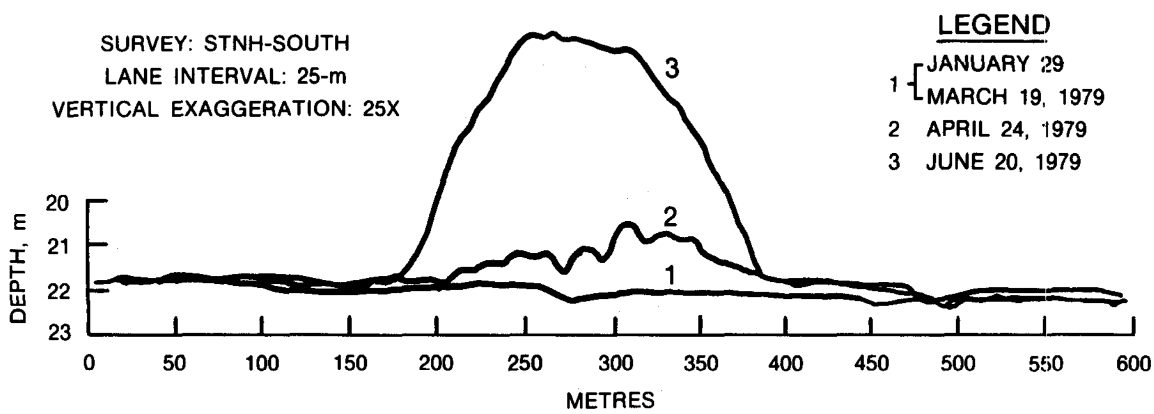


Figure 1. Bathymetric cross section from the Stanford New Haven disposal site capping operation in Long Island Sound (from Science Applications, Inc. 1985)

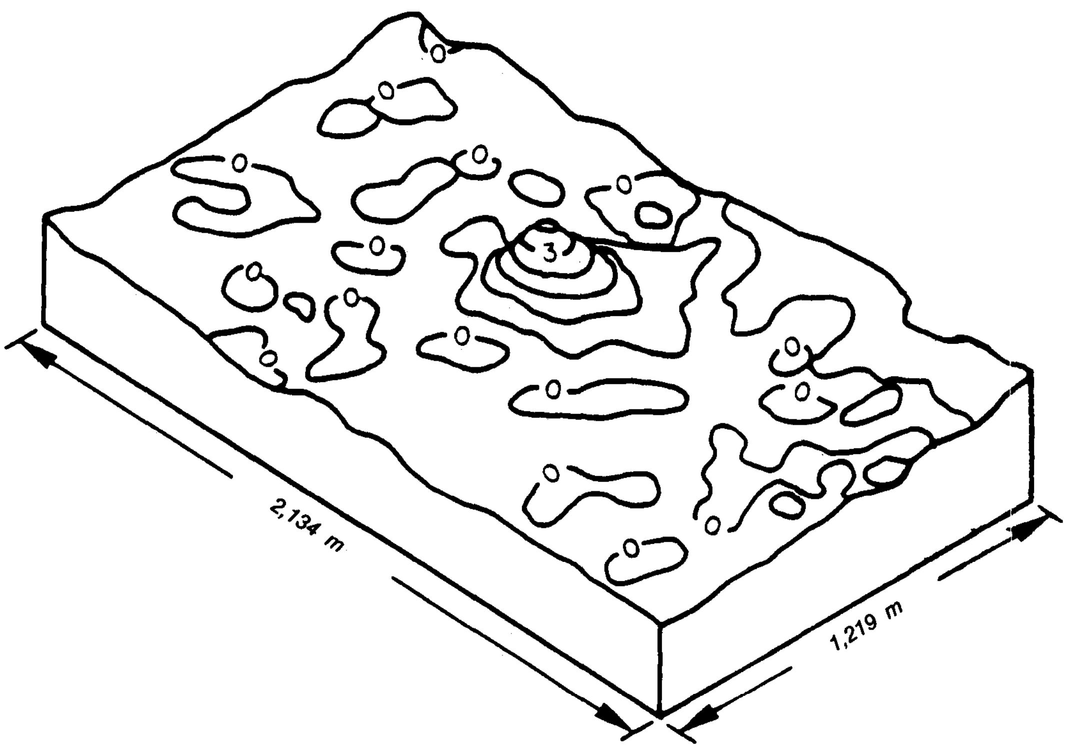


Figure 2. Contours of elevation differences due to disposal operations at the Dam Neck disposal site (contours in metres)

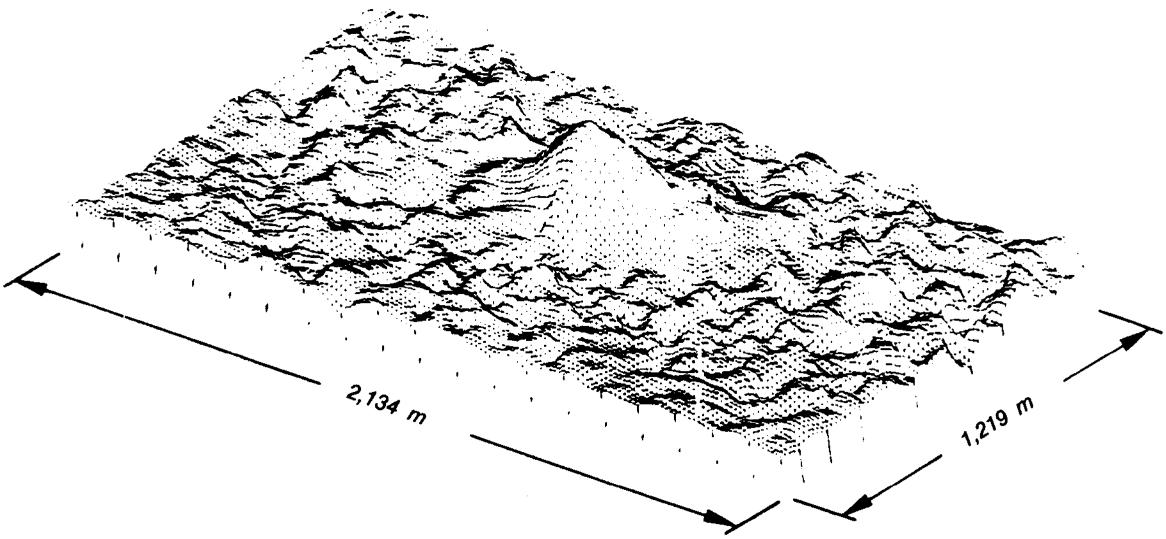


Figure 3. Three-dimensional plot of the Dam Neck disposal site (note mound in the center)

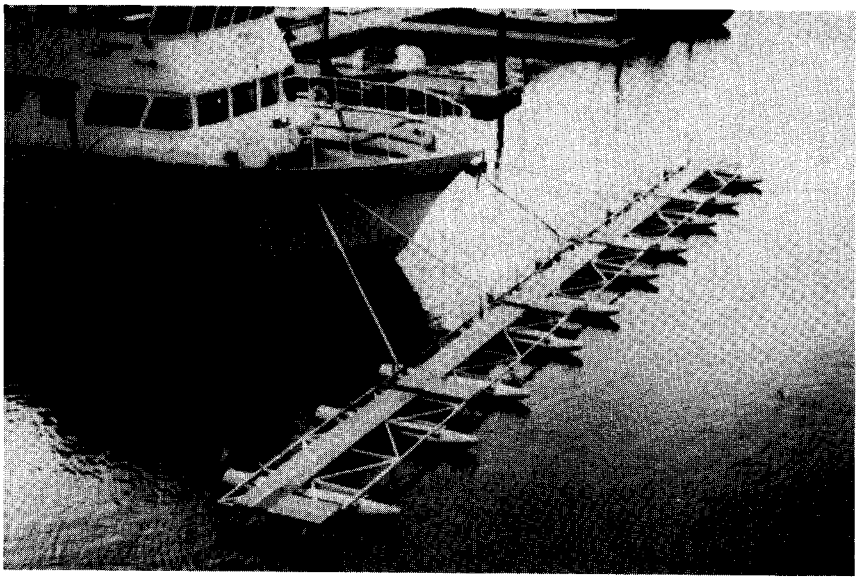


Figure 4. Swath system

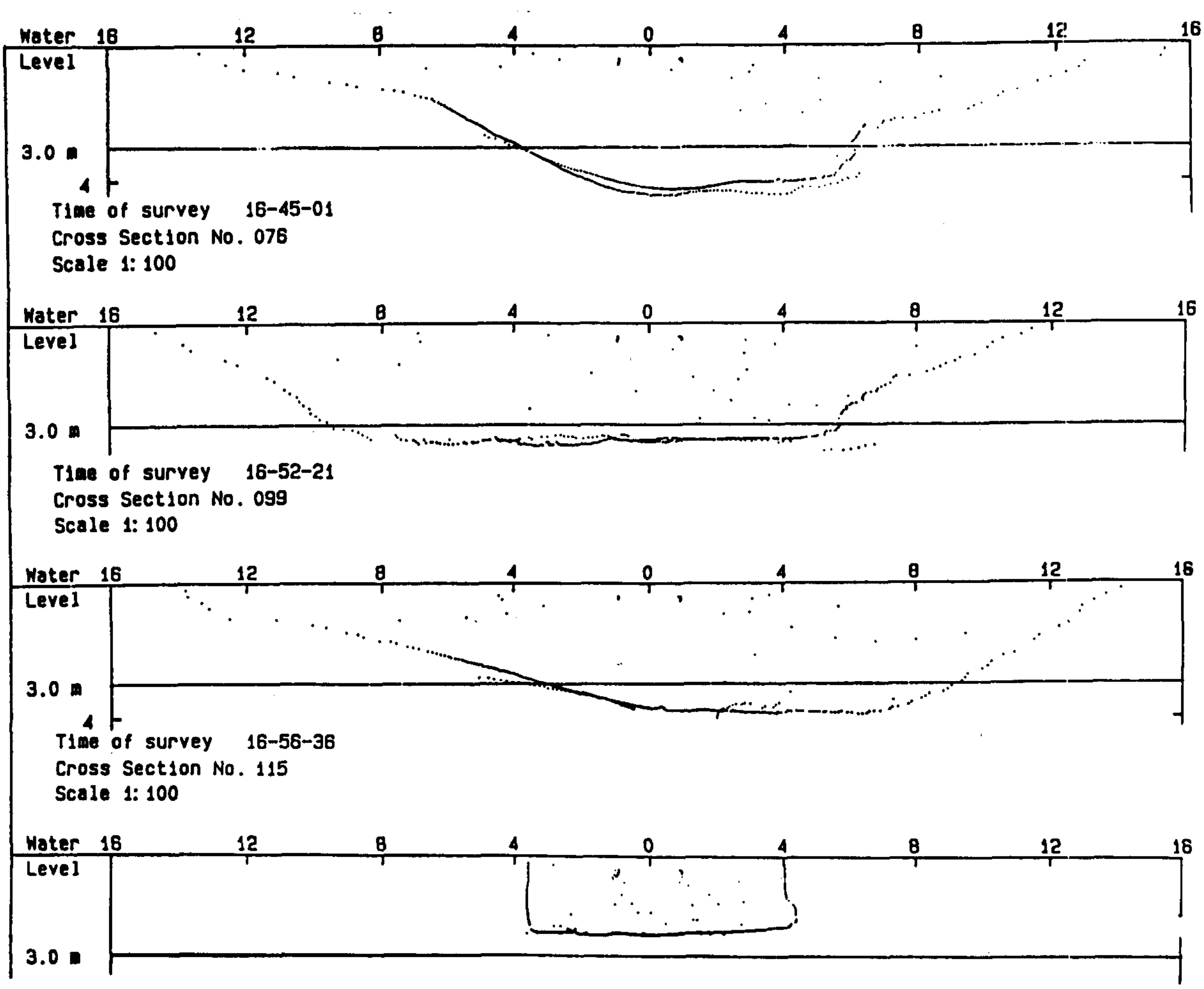
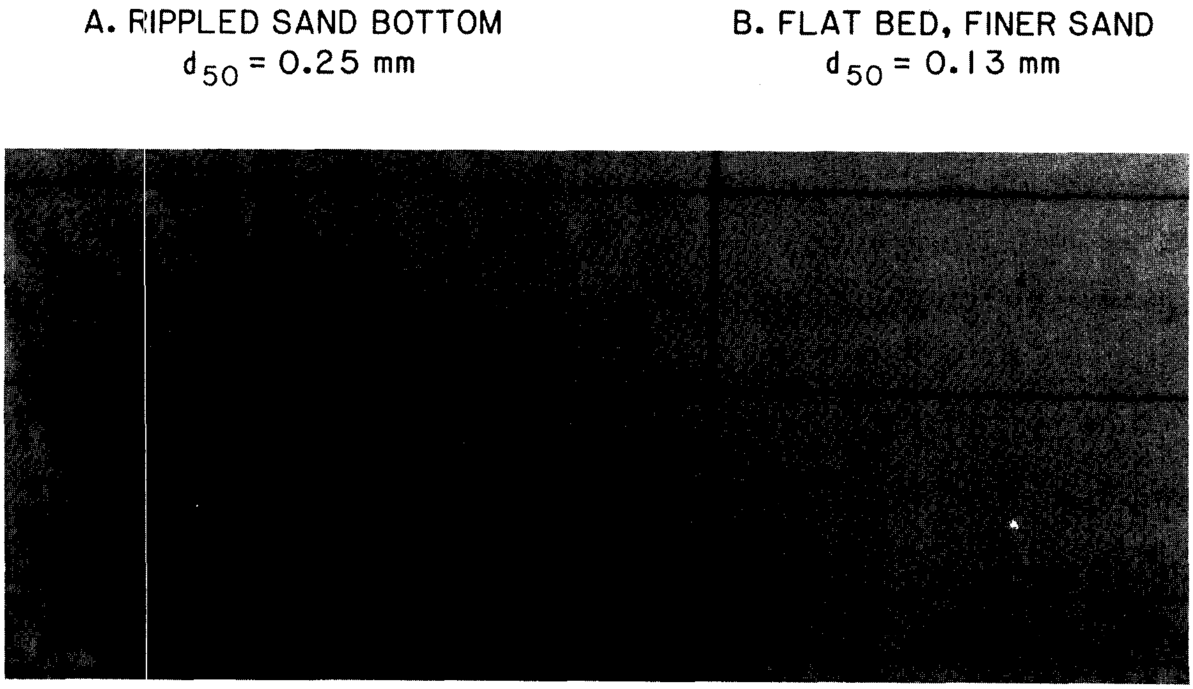


Figure 5. Sample cross sections from a scanning profiler (after Ulvertech America, Inc. 1985)

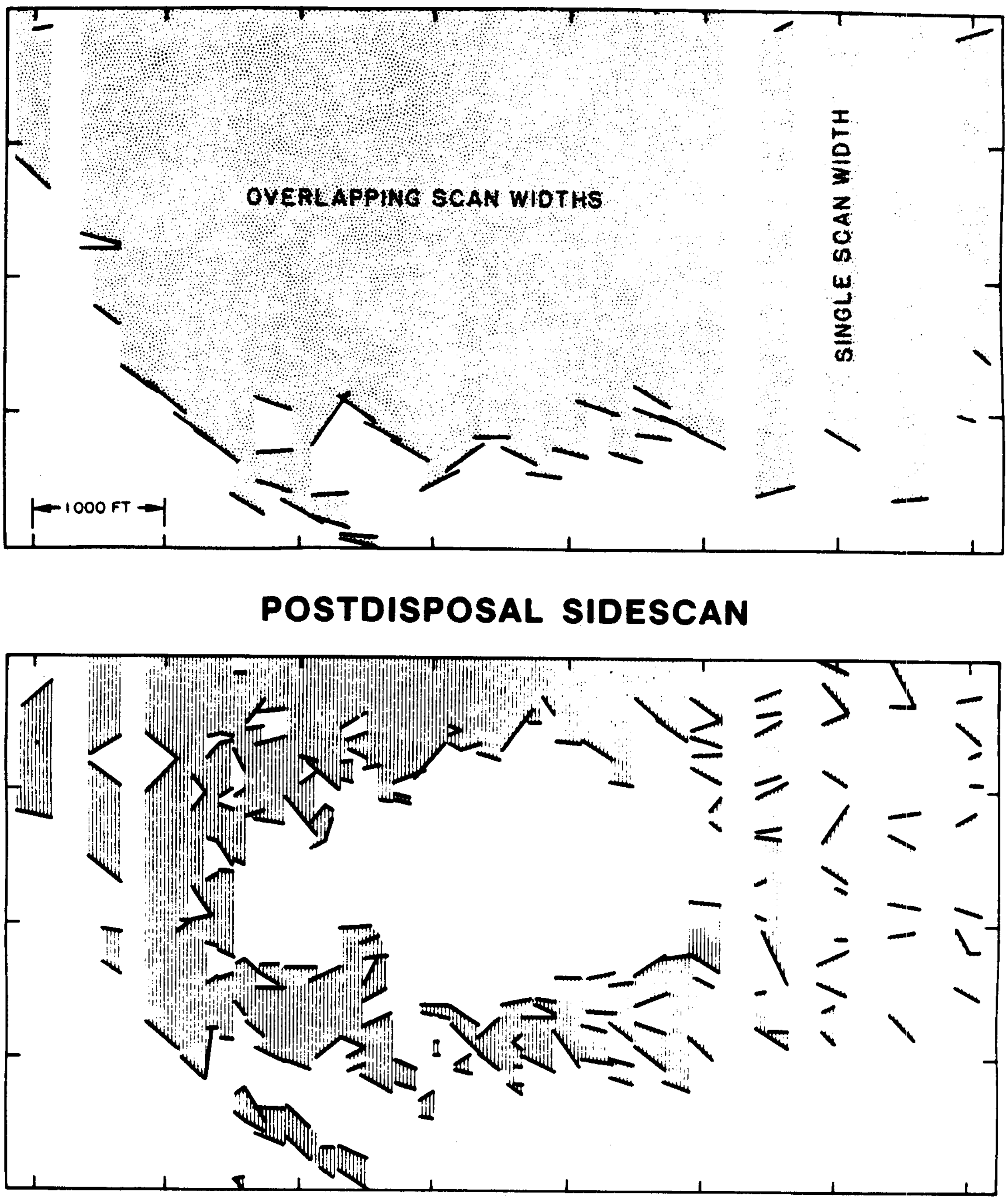


a. Rippled sand bottom (d_{50} = 0.25 mm)

b. Flat bed, finer sand (d_{50} = 0.13 mm)

Figure 6. Side-scan sonar record of Dam Neck disposal site showing the difference between the native sand bottom (left) and the disposal sediments (right)

PREDISPOSAL SIDESCAN



POSTDISPOSAL SIDESCAN

Figure 7. Predisposal and postdisposal maps of the Dam Neck disposal site produced from side-scan sonar records. The large low-backscatter area in the center of the postdisposal map represents the footprint of the disposal mound. Smaller areas scattered farther afield represent thin deposits of the finer-grained material

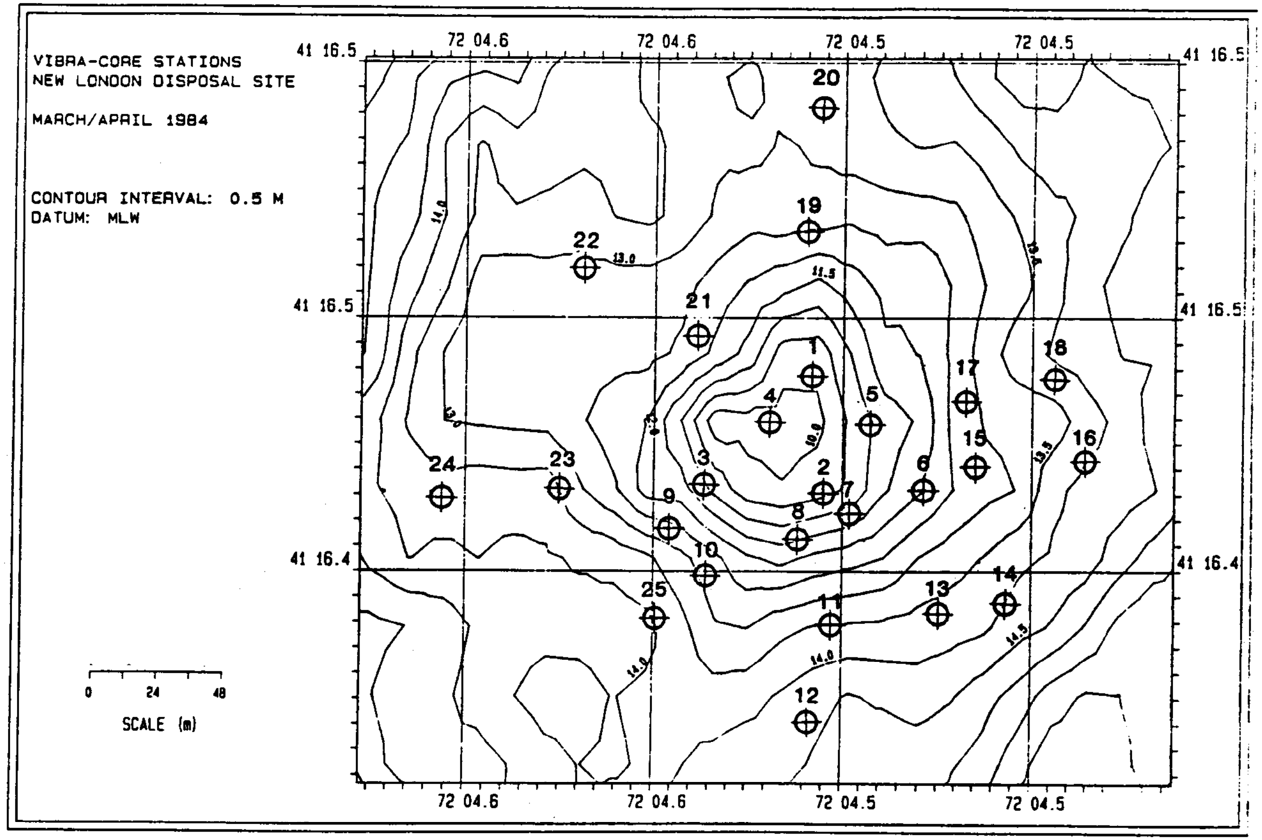


Figure 8. Densely spaced core locations at the New London, CT, disposal site

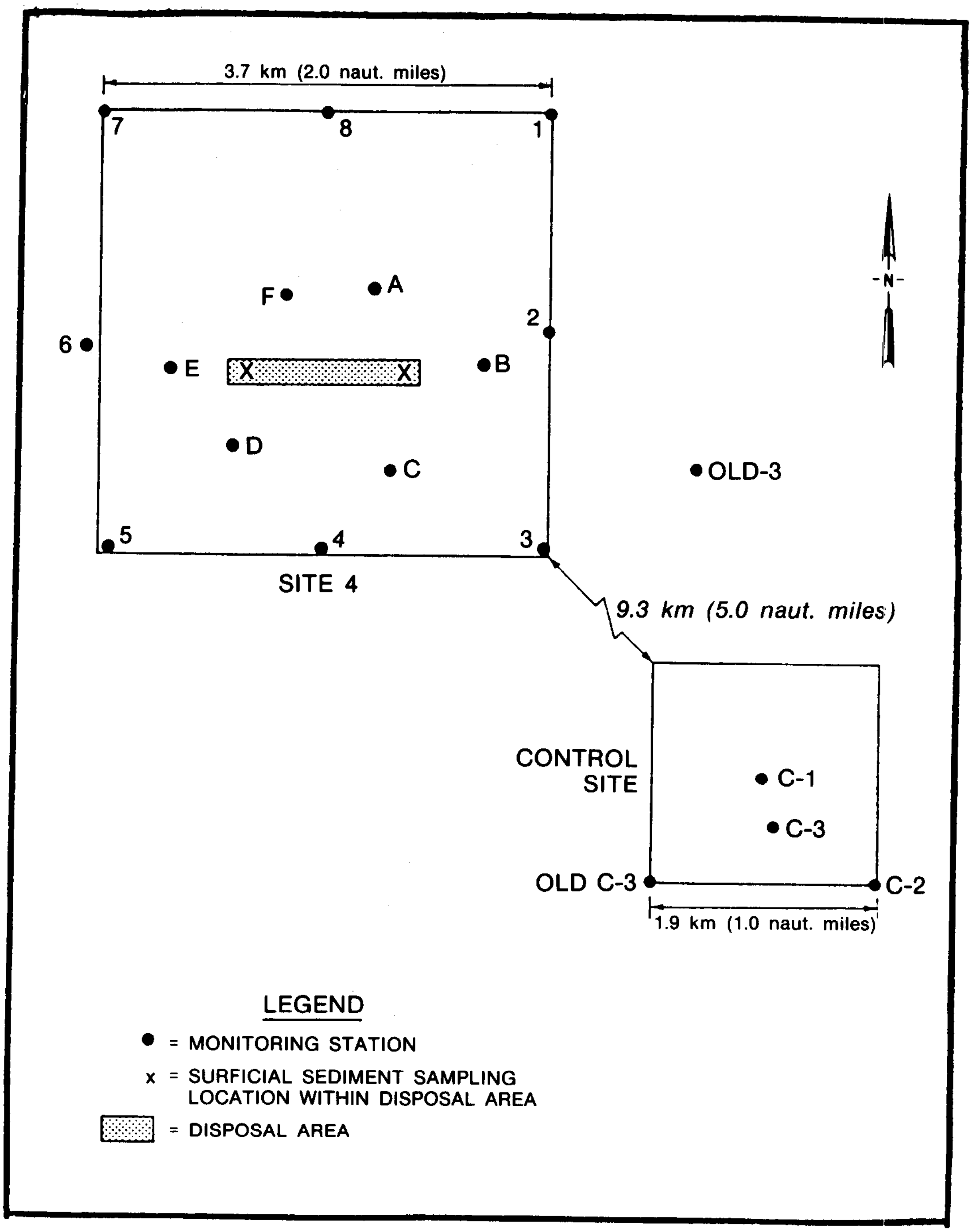


Figure 9. Sampling locations for the Tampa Bay disposal site (from Continental Shelf Associates 1986)

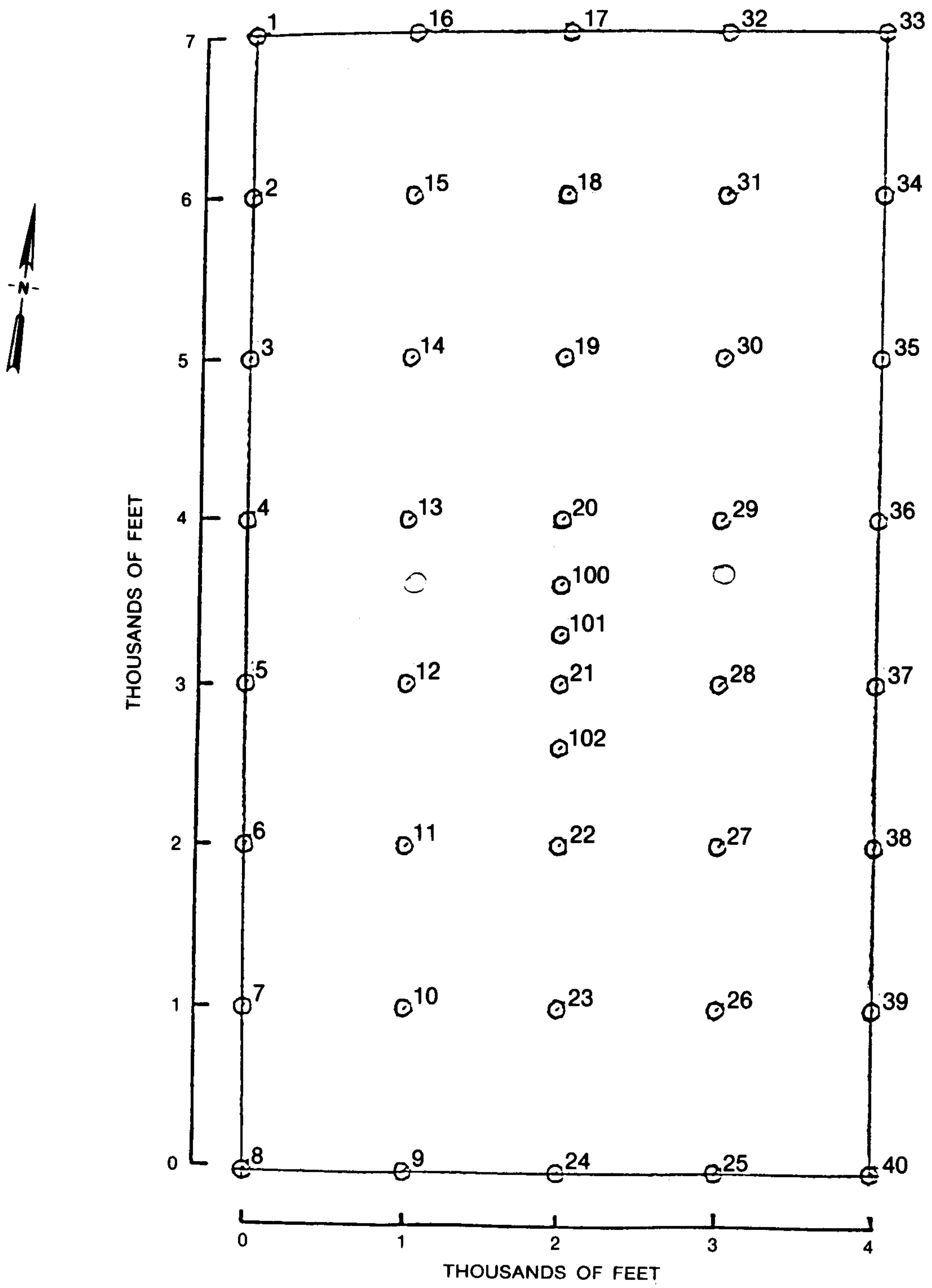


Figure 10. Sampling locations for the Dam Neck disposal site (Note: extra three stations at the center--100, 101, 102)

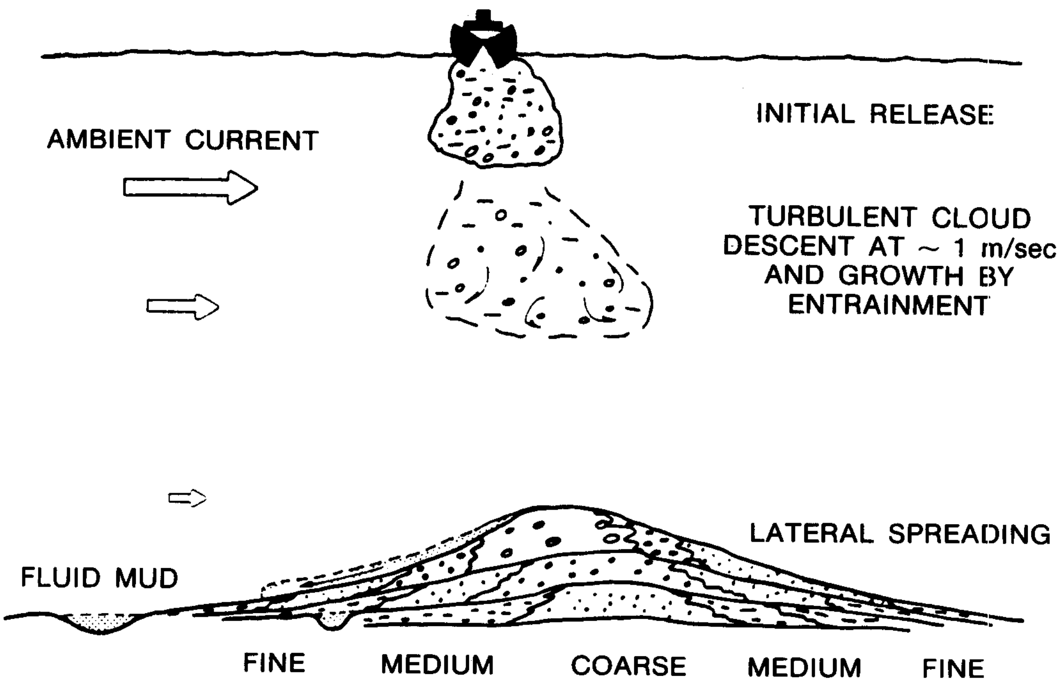


Figure 11. Radial sorting of disposal material

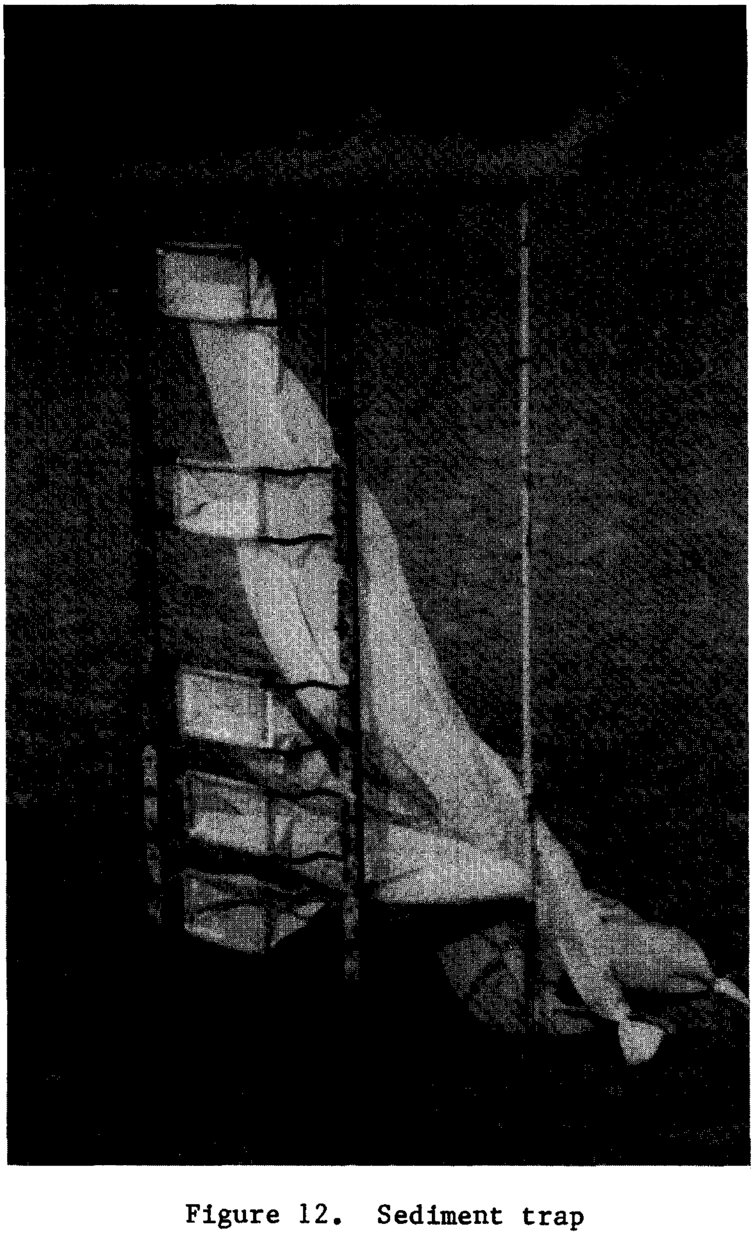


Figure 12. Sediment trap

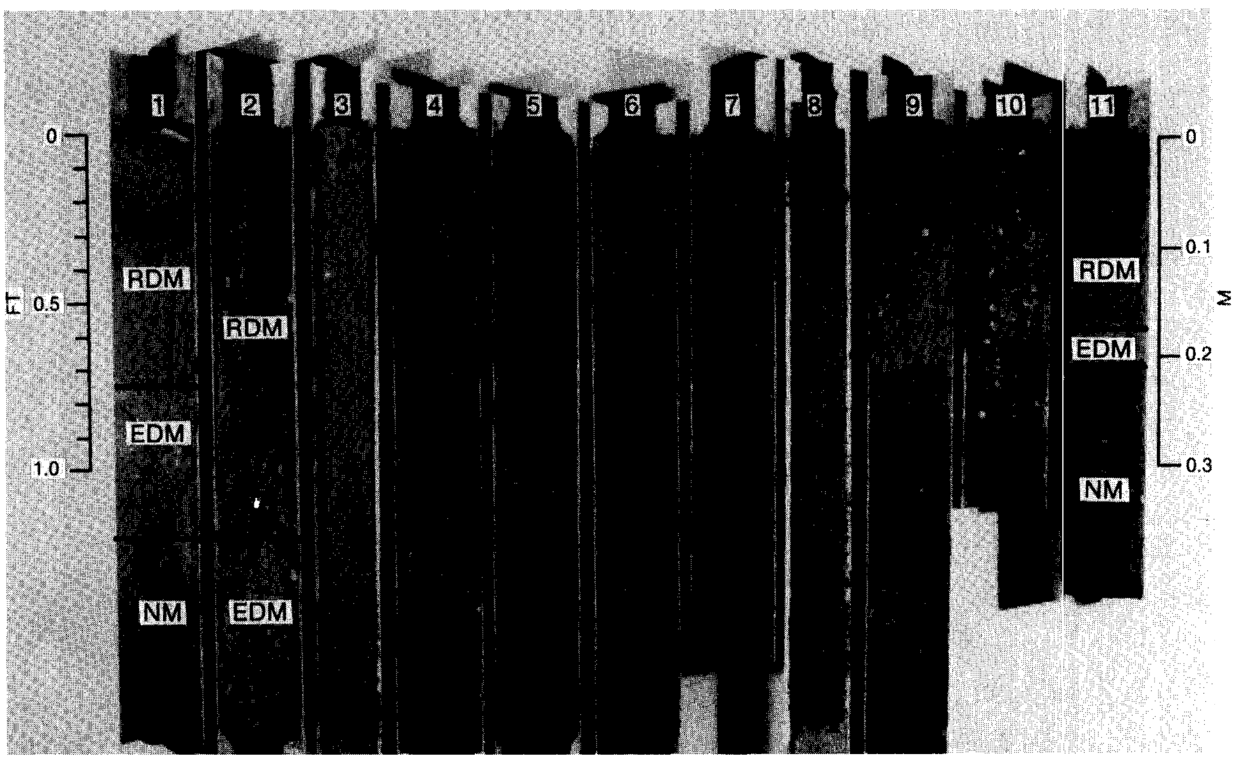


Figure 13. Dam Neck disposal mound core photographs. Coarser sands from an earlier deepening operation (EDM) and native material (NM) are revealed in cores 1, 2, and 11 that penetrate the overlying finer grained recent maintenance dredged material (RDM). Cores 3 through 10 contain only RDM. The distinction between the different types of materials is much clearer in visual observations and color photographs

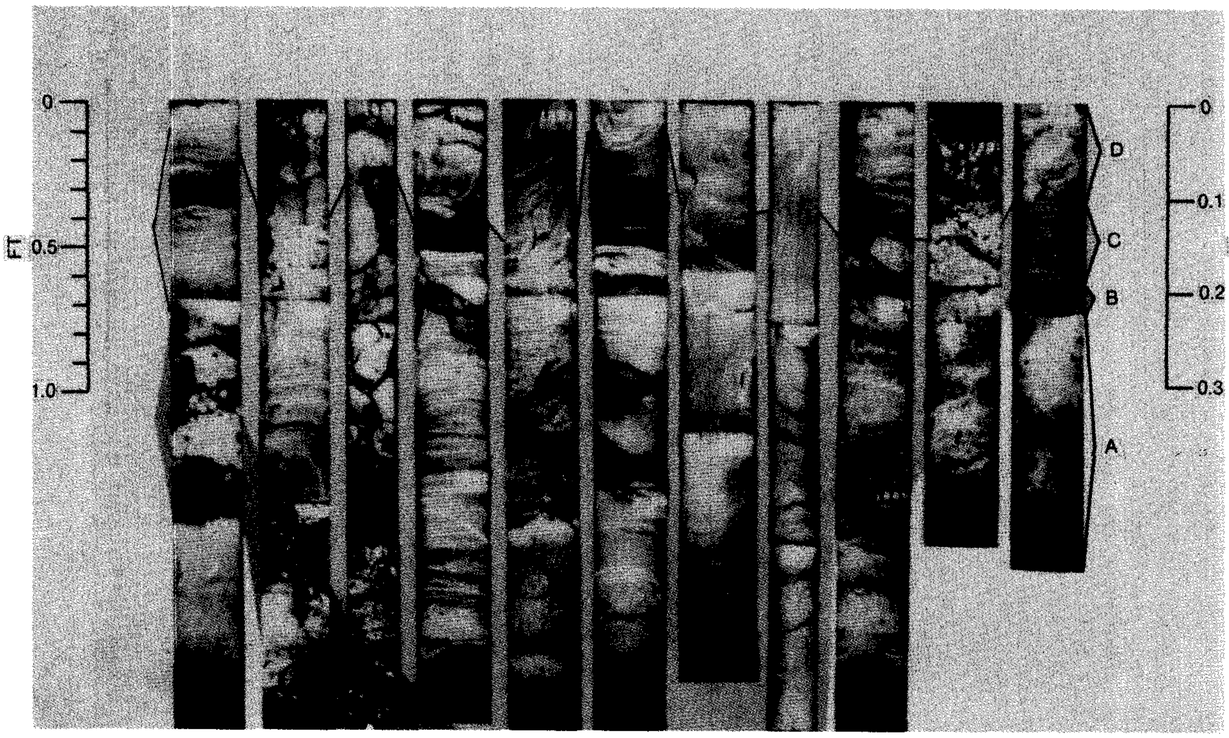


Figure 14. Dam Neck disposal mound core x-rays. Native (A), early disposal (B), and recent disposal materials (undisturbed, C, and reworked, D) are easier to distinguish with radiographs than with visual inspections

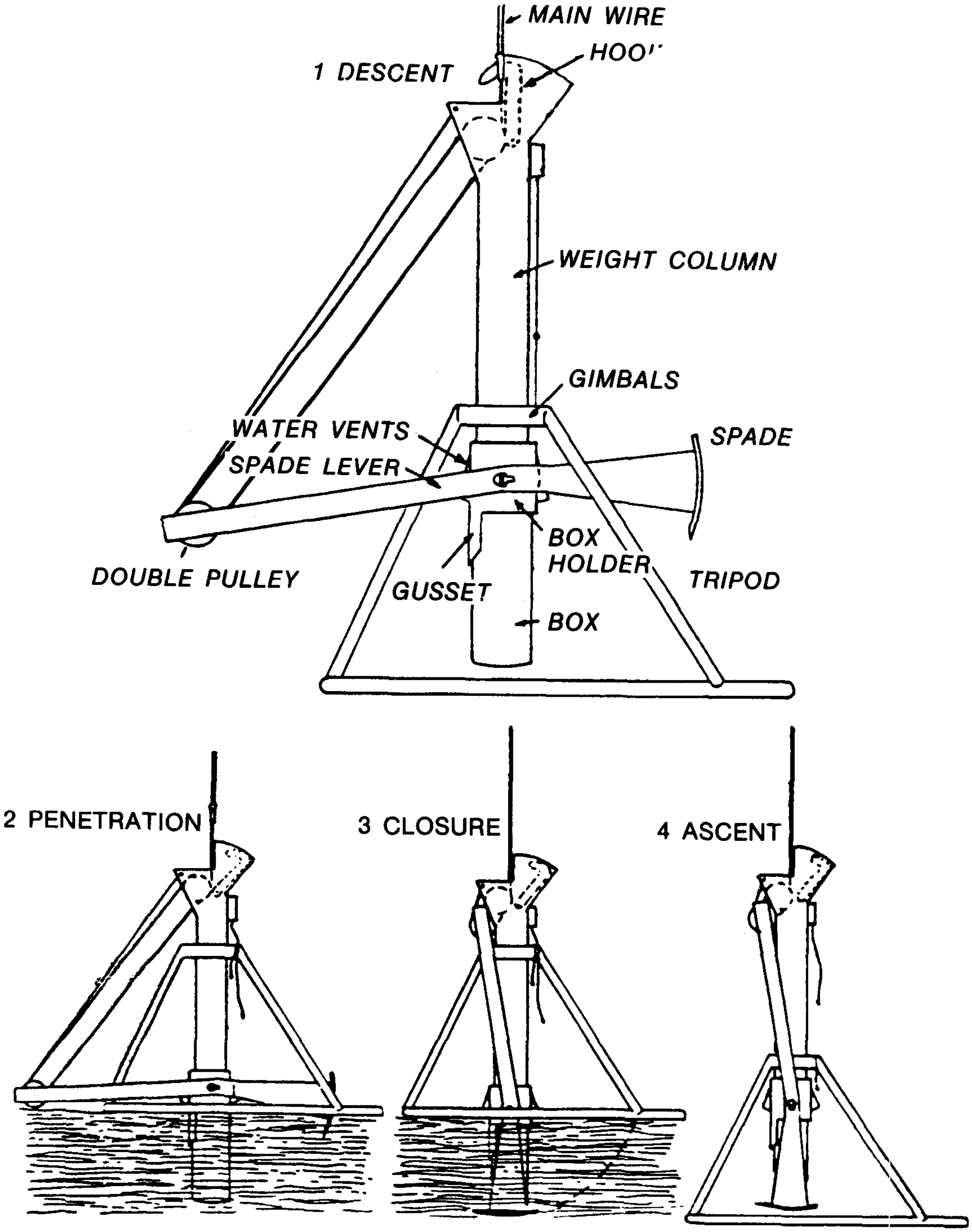


Figure 15. Box corer (from Lee and Clausner 1979)

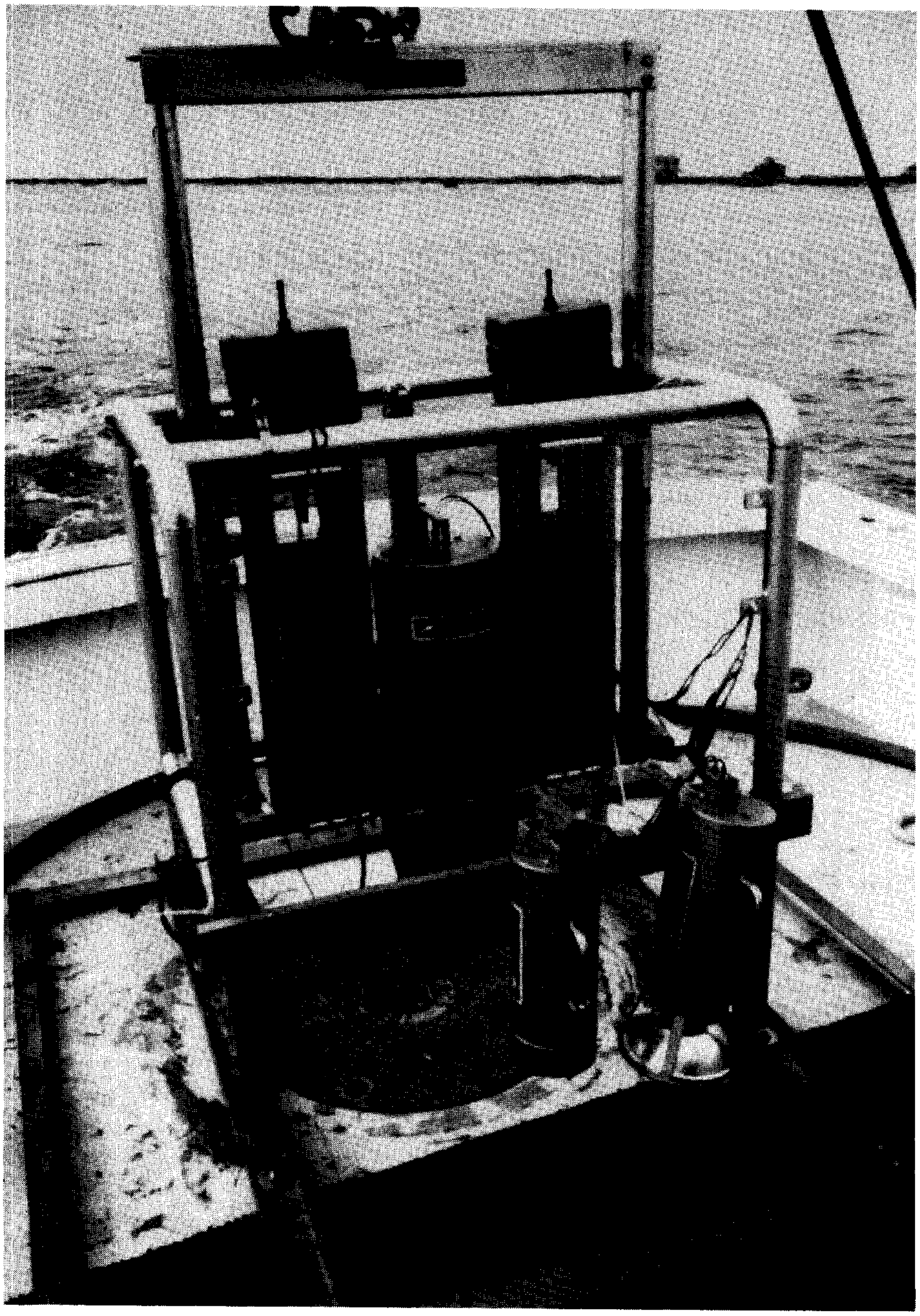


Figure 16. Sediment-profiling camera

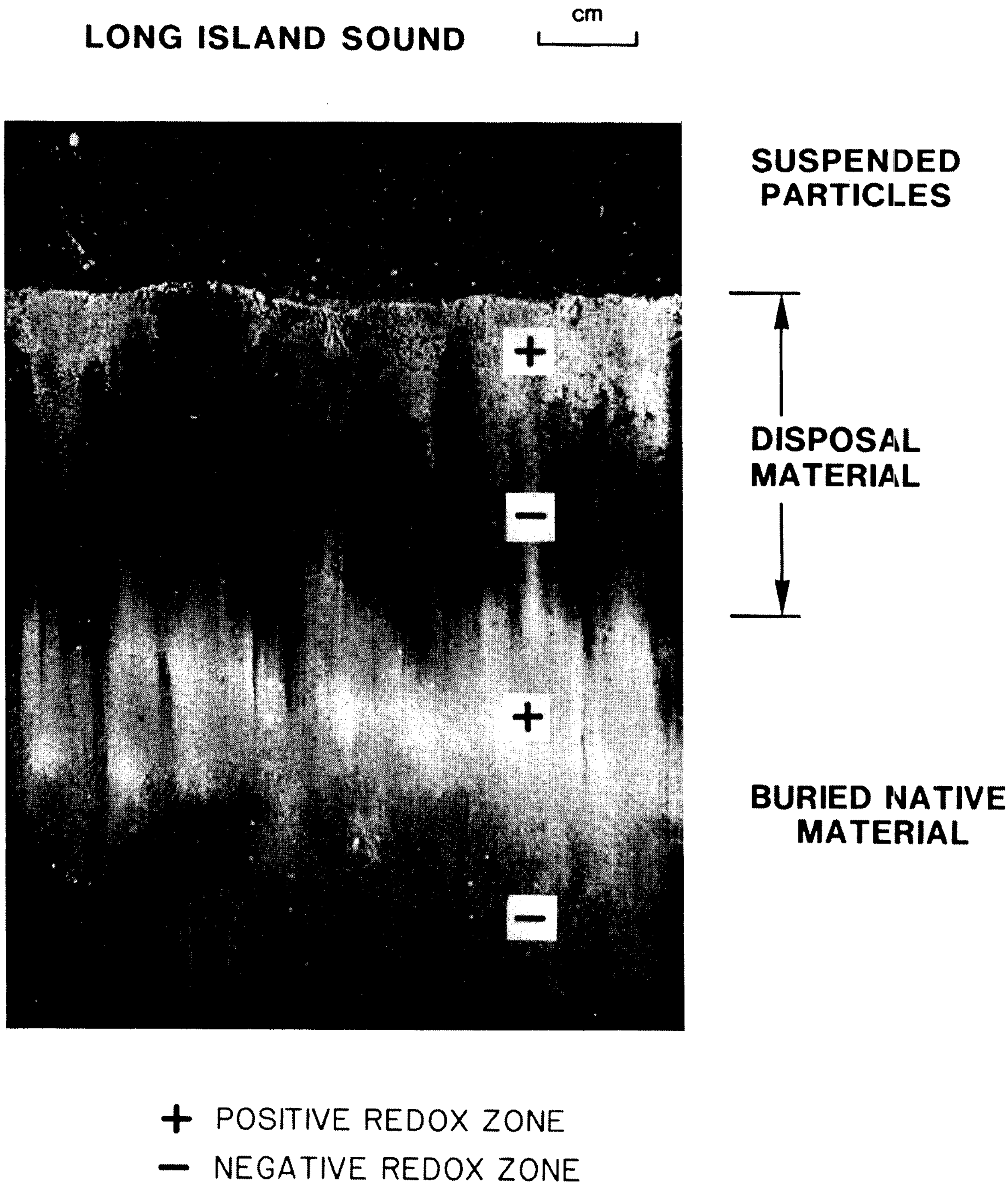


Figure 17. Sediment-profiling camera photograph of disposal material overlying native material, Long Island Sound

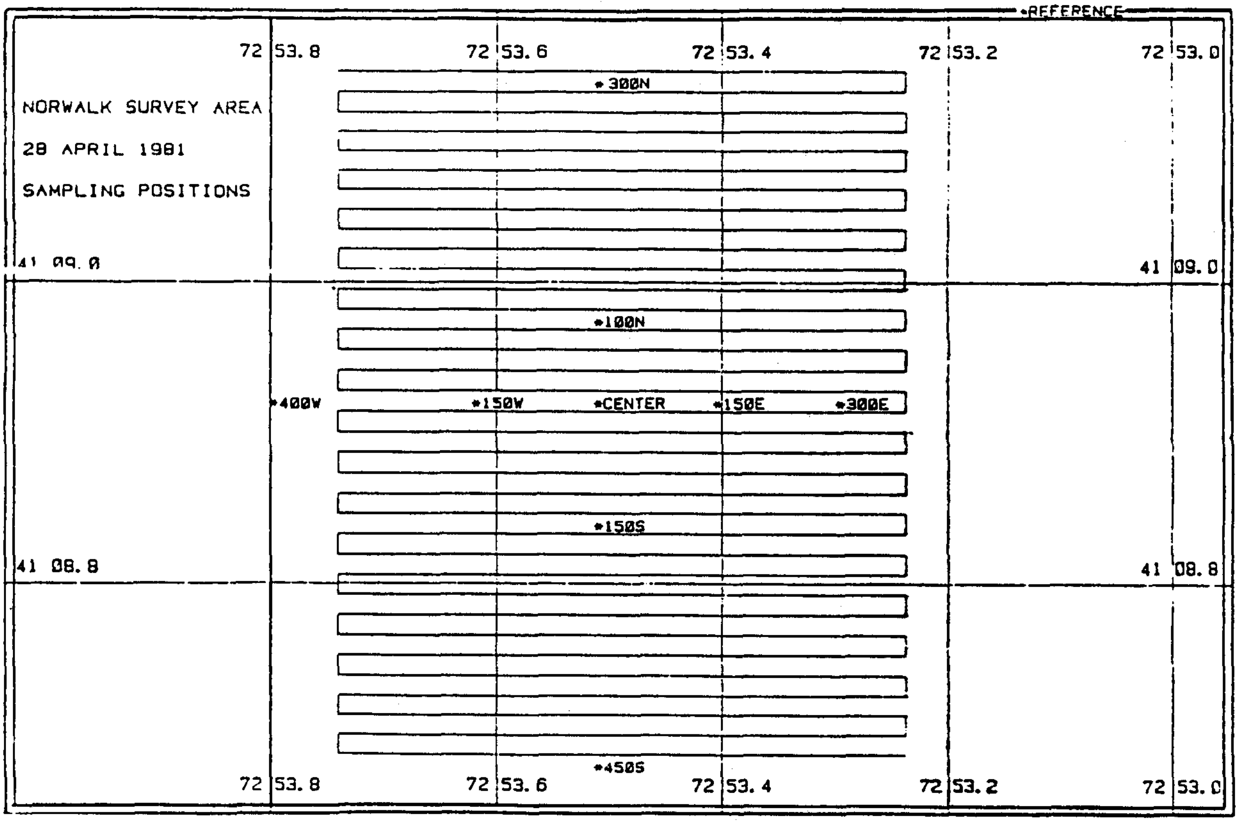


Figure 18. Typical sediment-profiling camera sampling pattern (from Morton, Stewart, and Germano 1984)

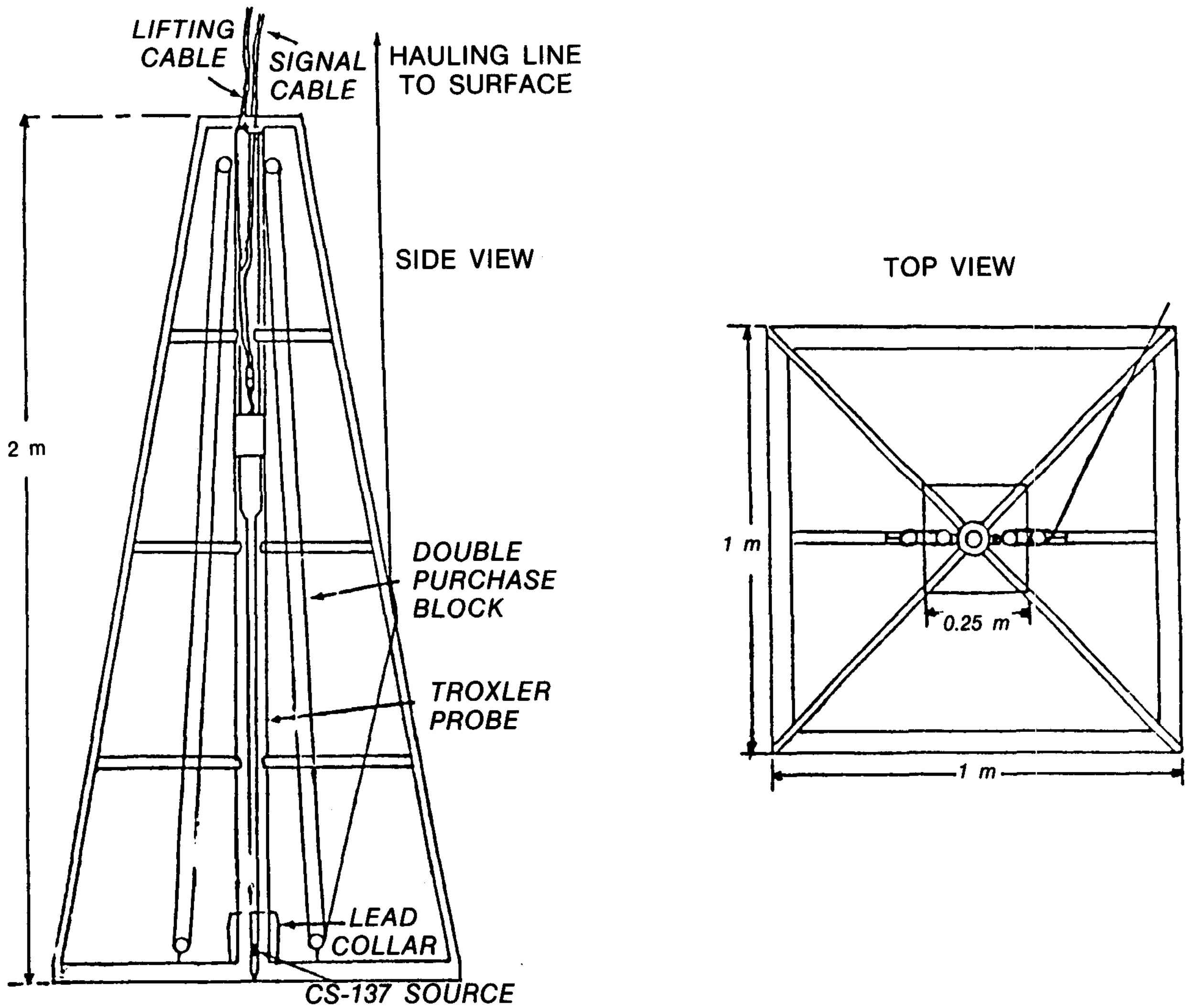
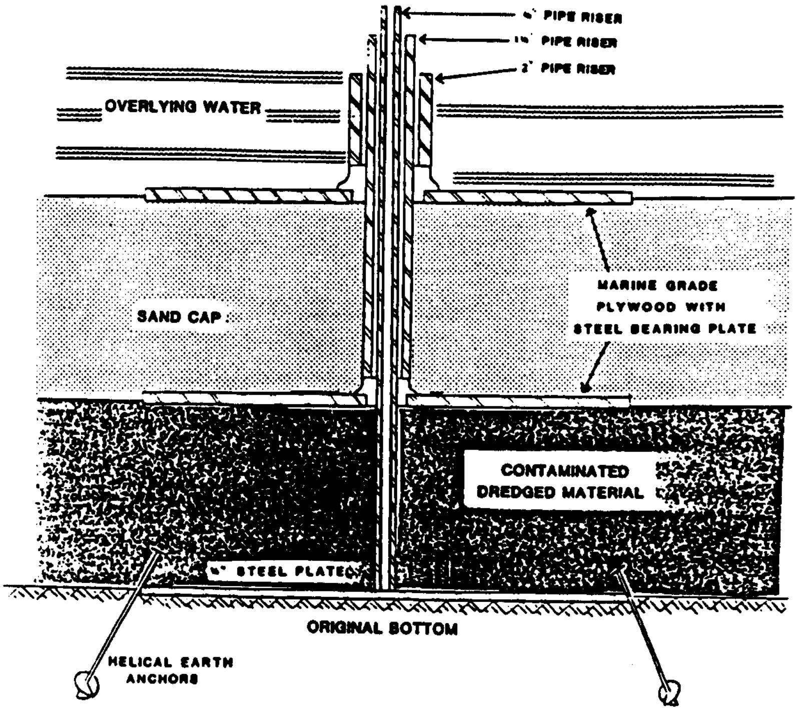
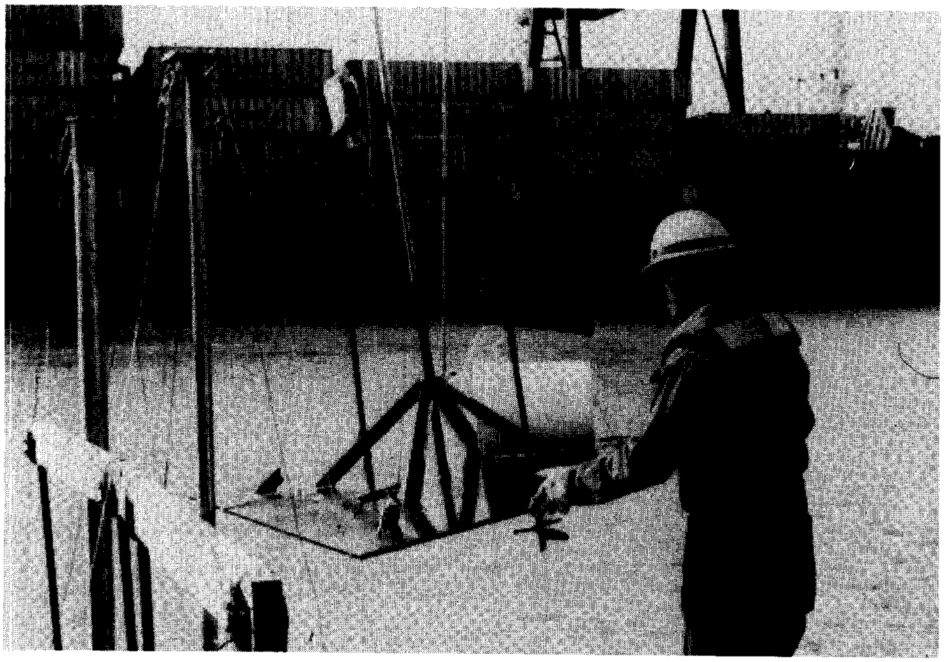


Figure 19. Nuclear density probe (from Morton, Stewart, and Germano 1984)



a. Schematic



b. Photograph prior to placement

Figure 20. Settlement plate (from Truitt 1986)

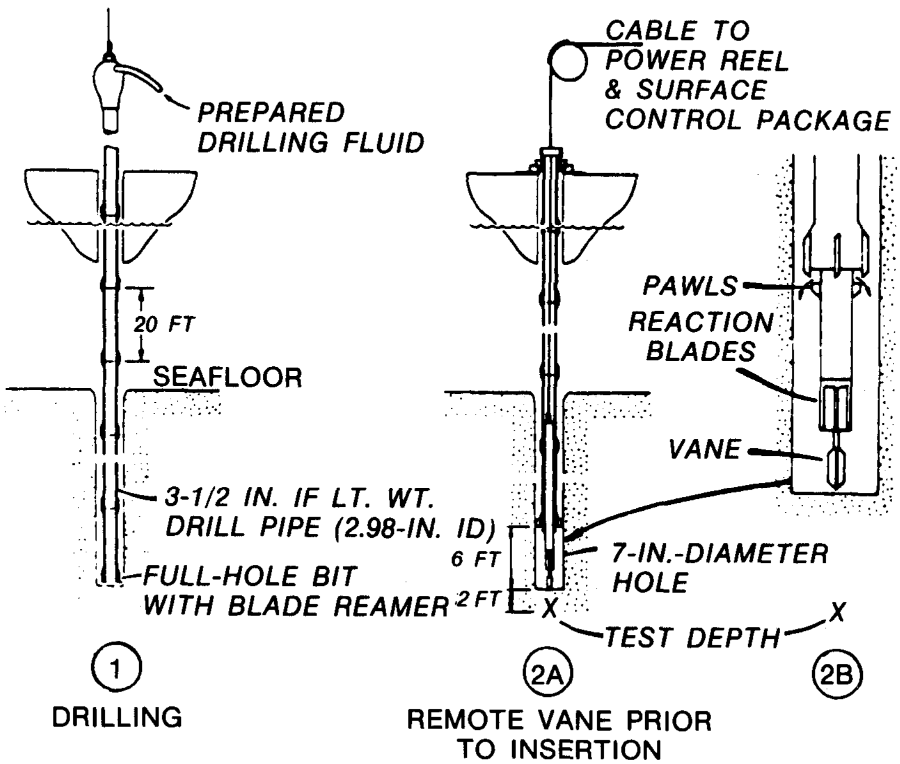


Figure 21. Field vane shear device on a wireline

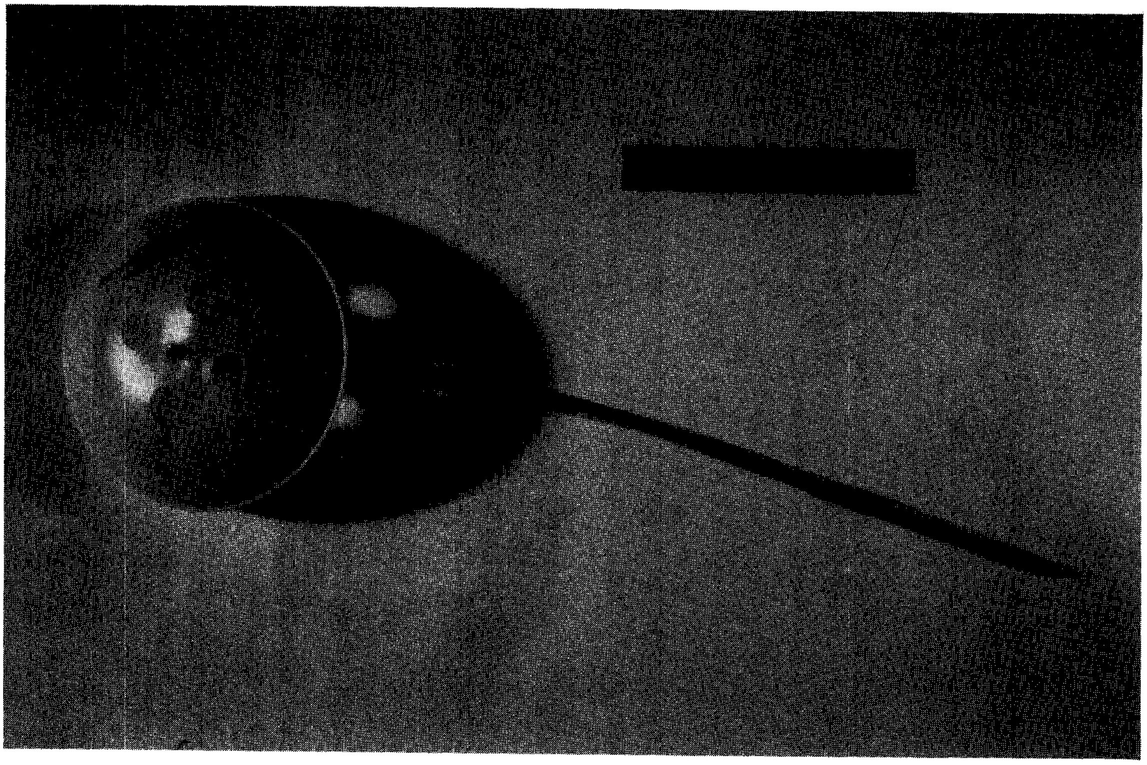
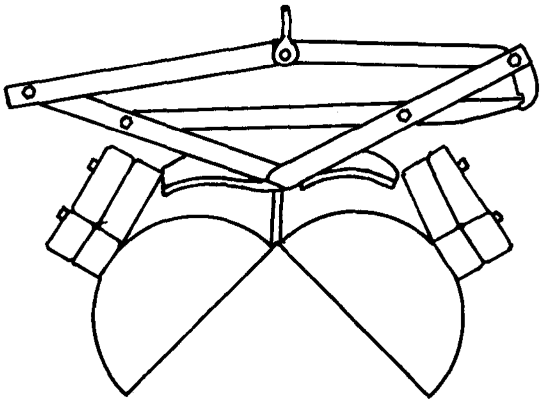
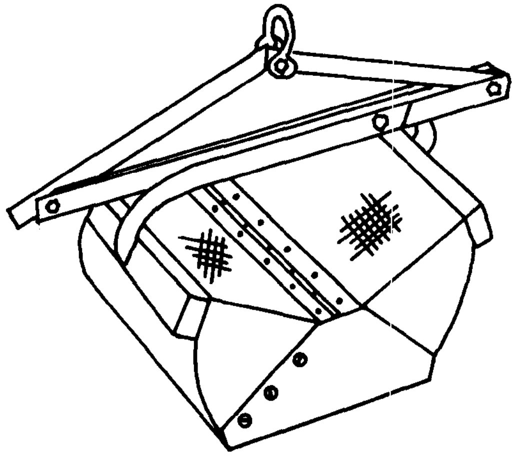


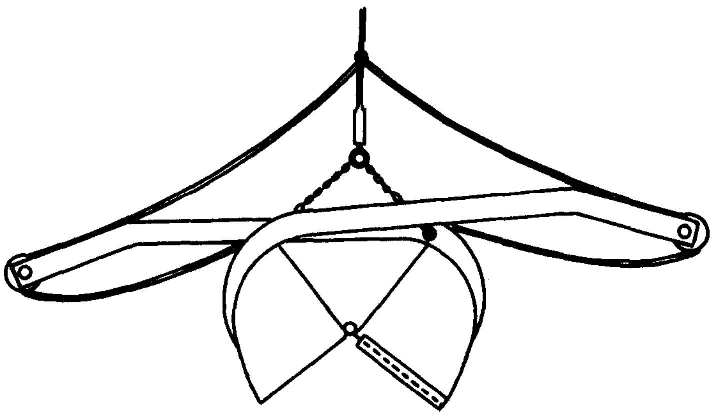
Figure 22. Seabed drifter



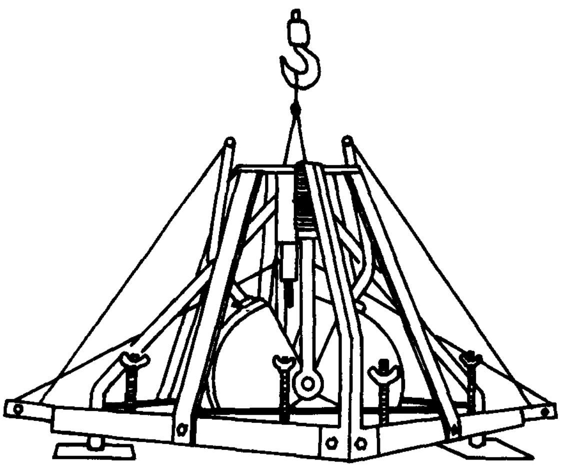
a. Petersen grab



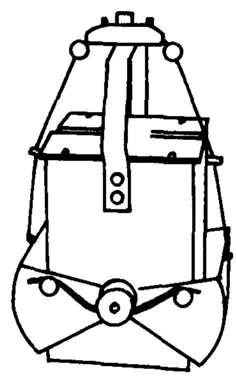
b. Ponar grab



c. van Veen grab

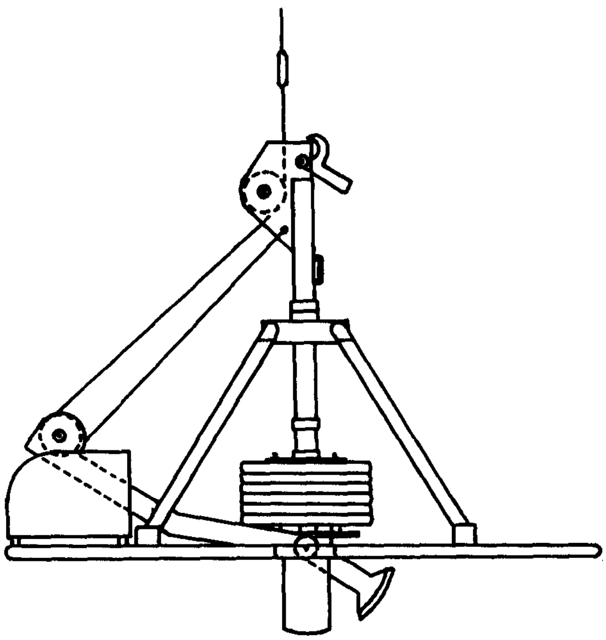


d. Smith-McIntyre grab

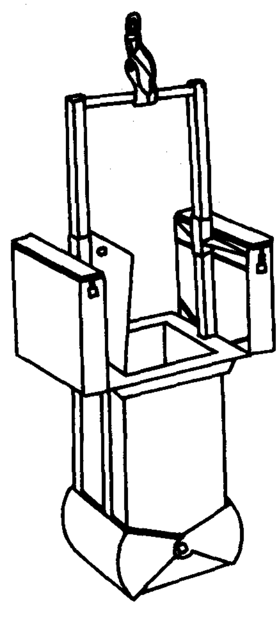


e. Ekman grab

Figure 23. Commonly used benthic grab samplers



a. Reineck box sampler



b. Gray-O'Hara box corer

Figure 24. Commonly used benthic box corers

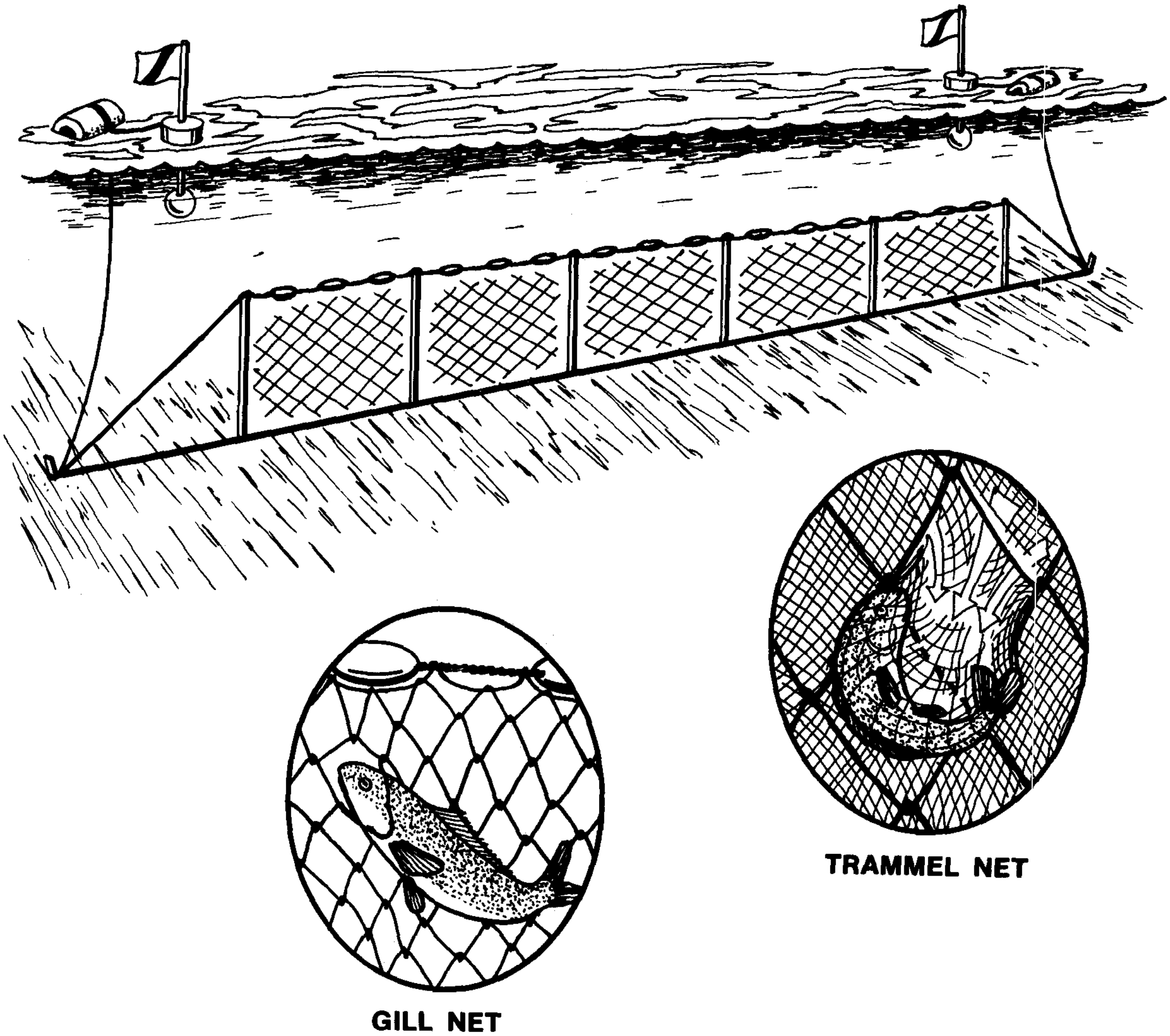


Figure 25. Gill net and trammel net (from Nielsen and Johnson 1983)

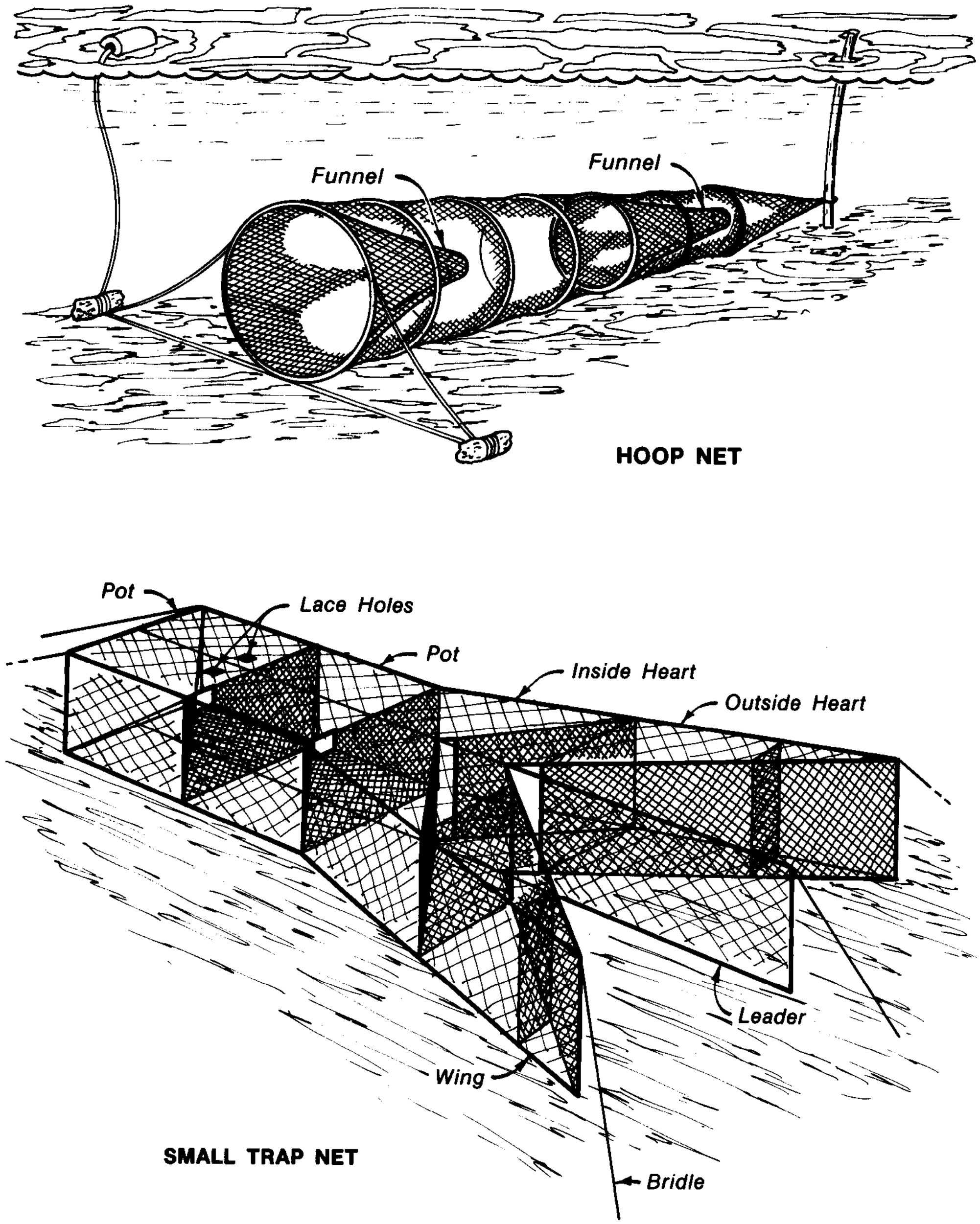
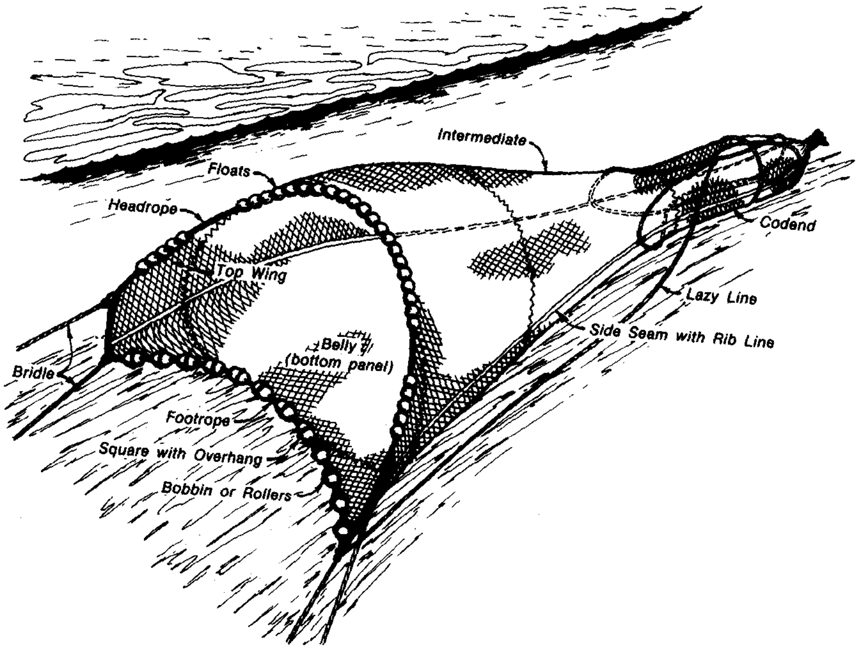
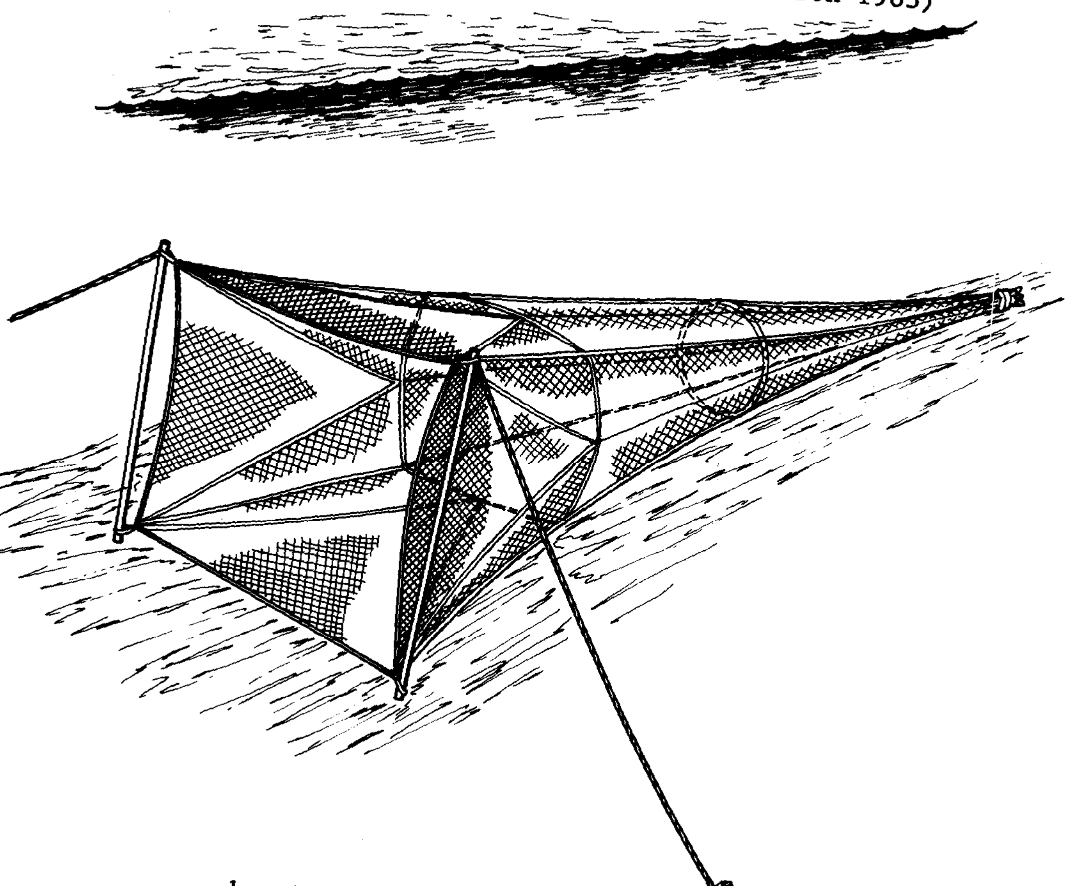


Figure 26. Hoop net and trap net designs (from Nielsen and Johnson 1983)



a. Otter trawl (from Nielsen and Johnson 1983)



b. Beam trawl (from Lagler 1978)

Figure 27. Otter and beam trawl designs

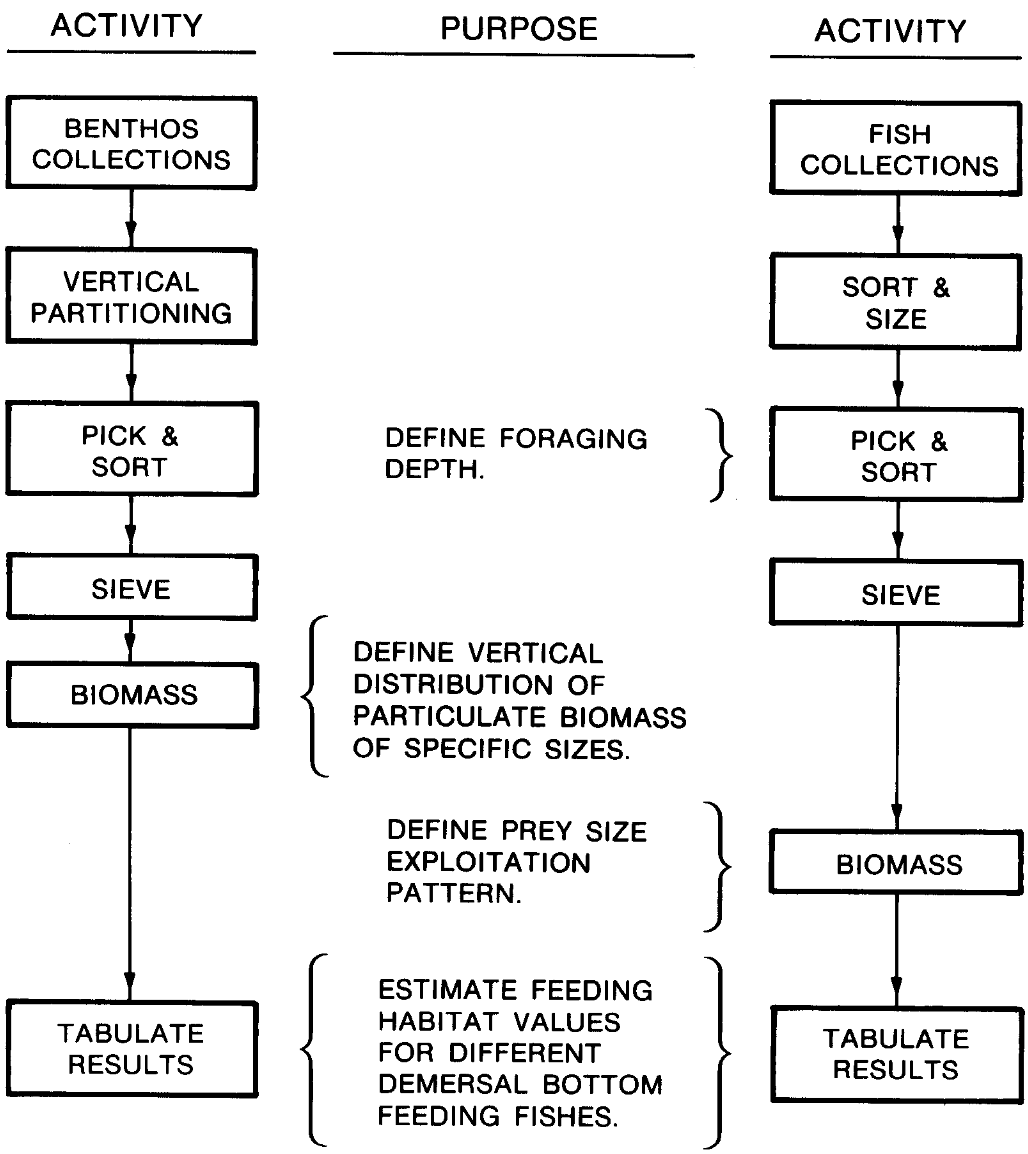


Figure 28. Flowchart for use of the BRAT

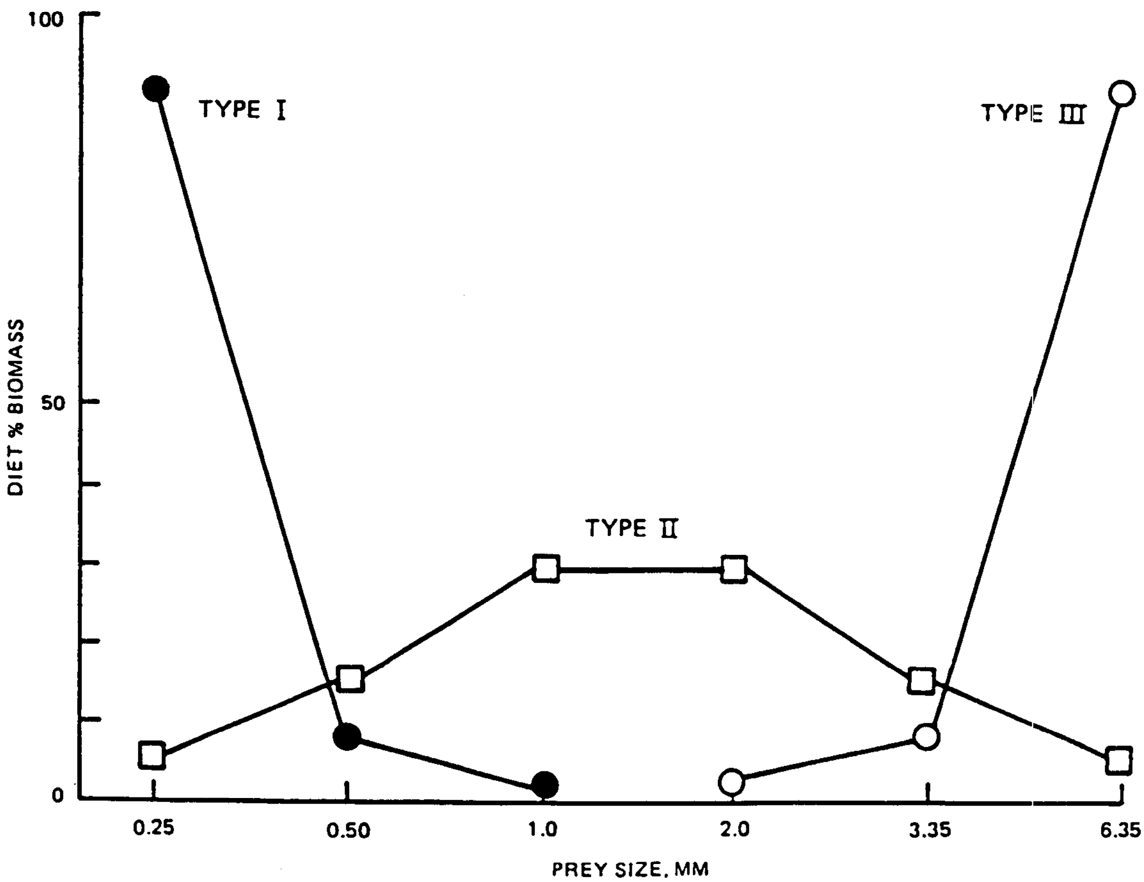
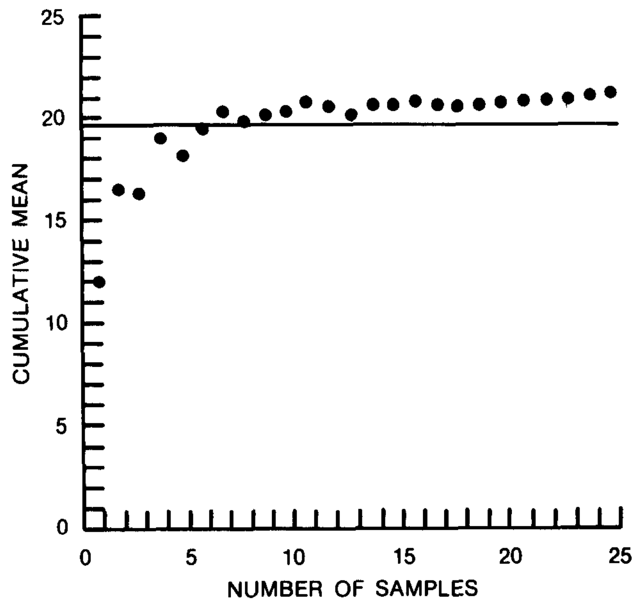
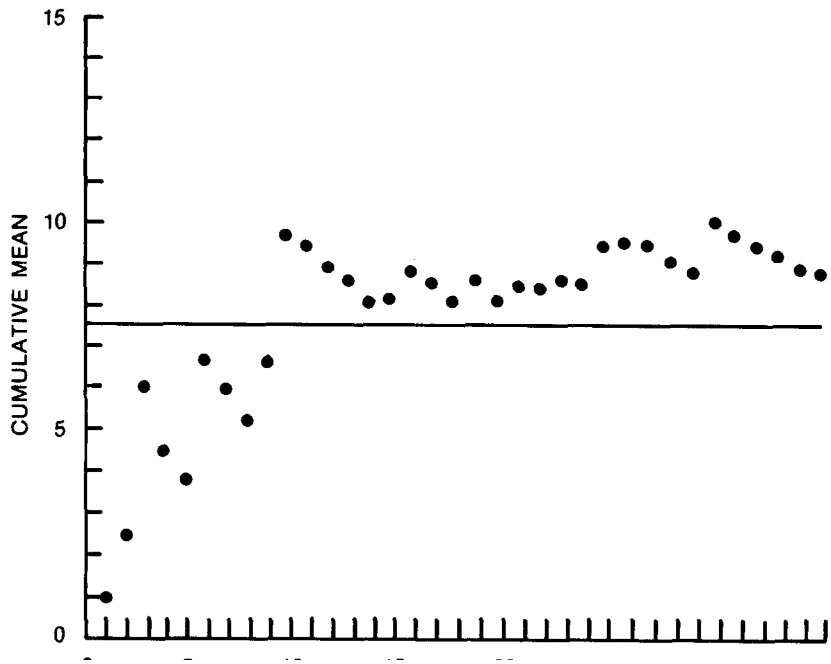


Figure 29. Verifying prey size selectivity (Type I eats primarily small prey, Type II eats primarily intermediate size prey, and Type III eats primarily large prey)



a. Example of curve in a population with random distribution



b. Example of curve in a population with aggregated distribution

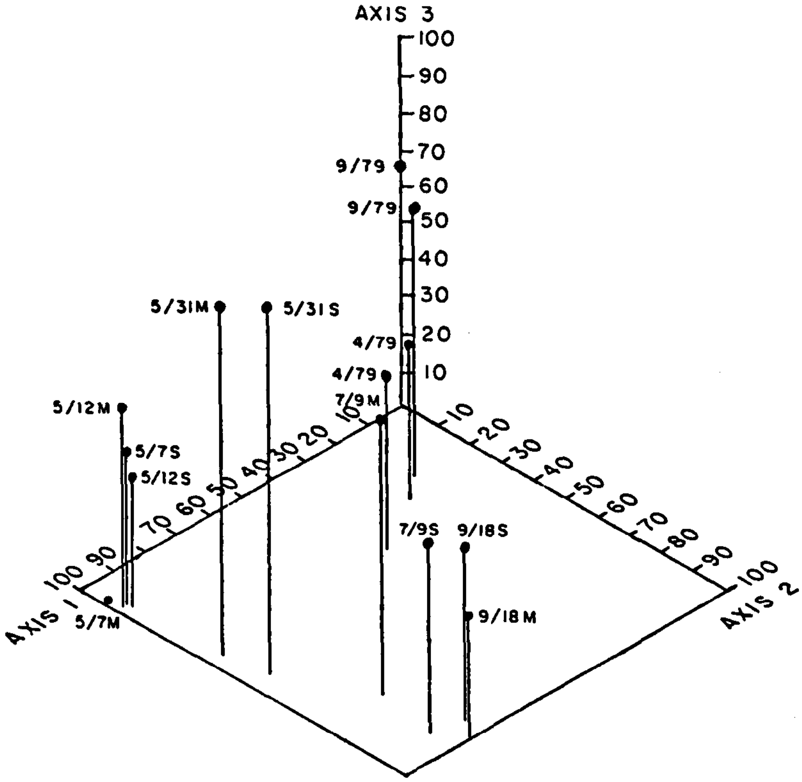
Figure 30. Cumulative mean graphic technique for estimating minimum number of samples

CONDITION		LOCATION		CHANGE
		IMPACT	REFERENCE	
	t1			B1
	t2			B2
BEFORE	.			.
	.			.
	tn			Bn
	t1			An+1
	t2			An+2
AFTER	.			.
	.			.
	tn			A2n

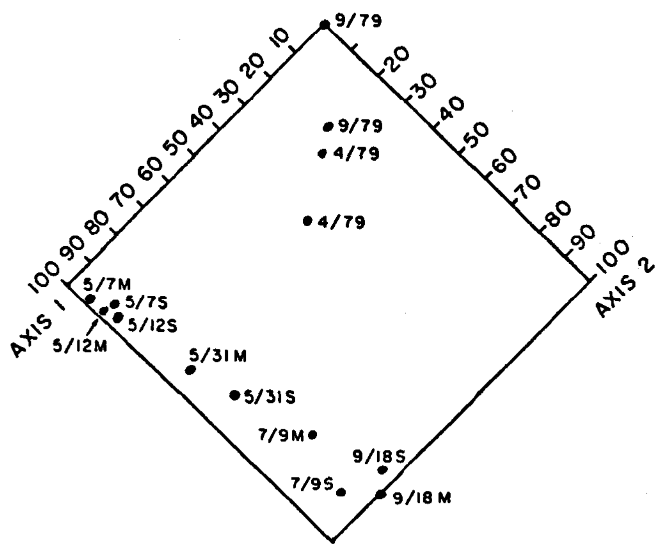
WHERE tn = THE NUMBER OF TIMES BOTH LOCATIONS ARE SAMPLED DURING EACH CONDITION.

An,Bn = THE DIFFERENCE BETWEEN IMPACT AND REFERENCE LOCATIONS EVALUATED AT EACH TIME.

Figure 31. Generalized sampling design for using a difference model to analyze impact study data



a. Three-dimensional



b. Two-dimensional

Figure 32. Example ordination showing distribution and relationship of samples in three- and two-dimensional ordination space. Samples are arranged based on presence and abundance of benthic invertebrates (from Fredette 1980)

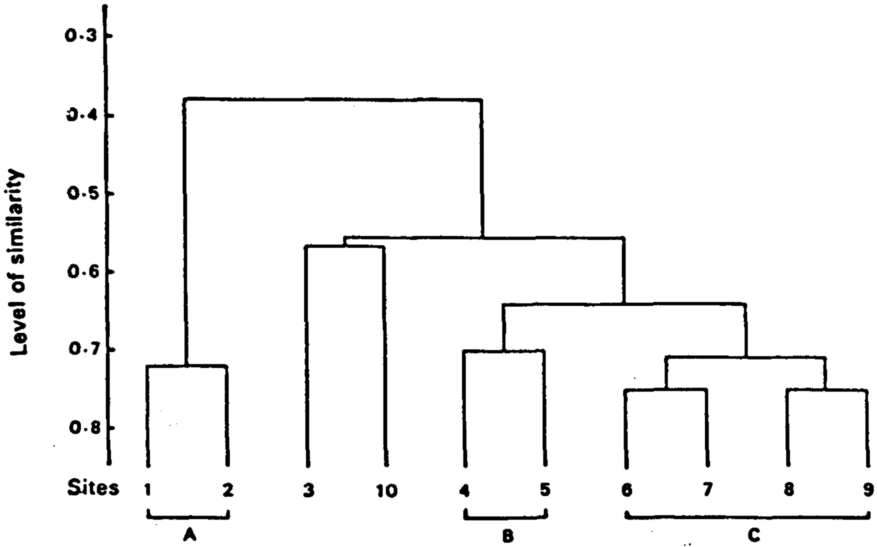
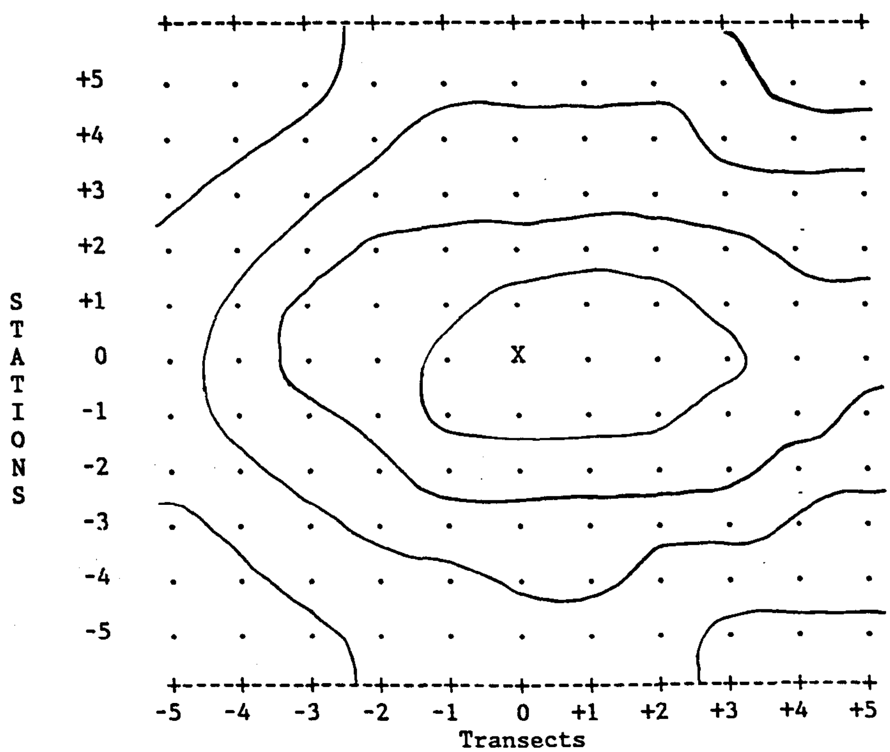


Figure 33. Typical cluster analysis showing relation of sample sites to one another and identification of site groups (with similar community composition/abundance)



Note: Coordinate position (0,0) represents the center where disposal occurred.

Figure 34. Results of response surface analysis based on simulated benthic data for an open-water disposal site. Contours group together the stations with similar species abundances. Data were available for each sampling station denoted by dots