FIELD STUDY OF AN UNCONFINED SPOIL DISPOSAL AREA OF THE GULF INTRACOASTAL WATERWAY IN GALVESTON BAY, TEXAS

D. E. BASSI and D. R. BASCO
Coastal and Ocean Engineering Division
Civil Engineering Department
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TAMU-SG-74-208

C. O. E. Report No. 174

TEXAS A&M UNIVERSITY SEA GRANT COLLEGE

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This research is a result of Sea Grant Project entitled A Study of Dredge Spoil Dispersal in Galveston Bay. It is partially supported through Institutional Grant #04-3-158-18 to Texas A&M University by the National Oceanic and Atmospheric Administration's Office of Sea Grant, U.S. Department of Commerce.

$3.00

Order from:

Department of Marine Resources Information
Center for Marine Resources
Texas A&M University
College Station, Texas 77843

ABSTRACT

Dredge spoil obtained from maintenance dredging of the Gulf Intracoastal Waterway is presently disposed in unconfined, submerged spoil areas alongside the channel. Of interest, for economic and environmental reasons, is the dispersion of the spoil area with time. Grain size analysis of bottom sediment samples, depth soundings and wooden stakes were employed in field investigations to determine the approximate location of material from one such spoil area over a five month period after disposal.

Immediately following deposition, over 40 percent of the spoil (based on original in-channel volume) had left the designated spoil area and spread out over the bay floor primarily as a mud-density flow. Eventually spoil covered an area about three times larger than the original spoil area. Return of the spoil to the newly dredged channel did not appear significant during the study period primarily because of the predominant direction of tidal currents and due to the presence of a submerged dike along the channel.

A brief summary of dredging and spoil disposal practices is also included.

ACKNOWLEDGMENTS

This report was prepared by the senior author in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering at Texas A&M University. The junior author served as graduate advisor. Support for the project was partially provided by the NOAA Sea Grant Program at Texas A&M University and by the Texas Engineering Experiment Station.

The authors wish to express their appreciation to the Galveston District Office of the Corps of Engineers, particularly George Rochen and Eddie Cobb for providing access to some of the data presented herein. Also, the interest and support of the Garrett Construction Company is gratefully acknowledged. The time and effort spent in reviewing the report by Dr. Arnold Bouma and Dr. Harry Coyle is also appreciated.

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INTRODUCTION

Background Information

For the past half century, periodic maintenance dredging of United States harbors and waterways has been necessary in order to keep these areas navigable. In recent years, the United States Army Corps of Engineers has authorized an annual average of 380 million cubic yards of dredging at a cost of $150 million, nationwide. Approximately 80% of this work is classified as maintenance, that is, redredging of channels that have shoaled excessively. Over 60% of this dredged material is disposed of by dumping in open waters of the estuary or offshore (Boyd, et al., 1972). Indications are that at least some of this work can be attributed to material that has moved out of the spoil dumping area and back into the newly dredged channel by whatever means of transport (Ippen, 1966, p. 654).

Many types of dredging and spoil disposal have been used with varying degrees of effectiveness. Certainly, in at least some cases, a lack of complete understanding of the processes involved has resulted in less efficient handling of spoil and has increased the amount of maintenance dredging needed, per unit of time, to keep a particular waterway open.

"Proceedings of the Coastal Engineering Conferences", American Society of Civil Engineers, has been used as a pattern for style and format throughout this report.

In the past, decisions concerning the methods of dredging and spoil disposal and the location of spoil areas have been based almost entirely on economics, with little consideration given to the physical properties of the area. As long as the spoil material did not appear to run directly back to the newly dredged channel, obstruct navigation, or interfere with local fishing grounds, it was deposited as economically as possible, which usually meant right alongside the channel.

The recent increase in concern over environmental quality has resulted in criticism by various authors of the continued use of many of these spoil areas (Train, 1970). However, the acute lack of information relating to all facets of dredge spoil disposal practices makes for difficulties when attempting to design improvements in the system.

One navigation project that has required repeated maintenance dredging since its construction is the Gulf Intracoastal Waterway. This inland channel must be maintained at a depth of 12 feet and a width of 125 feet in order for it to remain navigable. The Corps of Engineers has the responsibility of scheduling maintenance dredging whenever it is needed. Normally the dredge spoil is deposited on land but whenever the channel crosses large open bodies of water, such as Galveston Bay, the spoil is placed in submerged, unconfined spoil areas alongside the channel. During the twelve years preceding 1972, the Galveston District of the Corps has authorized an annual average of 11.1 million cubic yards of maintenance dredging, at a cost of \$1.7 million, for the 390 miles of waterway under their jurisdiction. This is in addition to material dredged from tributary and connecting channels such as the Houston and Texas City ship channels. Approximately 50% of this material is placed in submerged unconfined spoil areas adjacent to the channel. From Corps records, it appears that maintenance dredging is performed about every three years for most sections of the waterway, some areas requiring more frequent dredging than others (U.S. Army, 1961-1971).

Shoaling and filling of channels is the result of natural forces that are always present in estuaries, attempting to restore a state of equilibrium to the system. Tidal currents, waves, and wind set-up will agitate and disperse bottom layers, shoaling channels and requiring dredging to restore the original dimensions. Submerged, unprotected spoil mounds, being composed of the finer silts and clays deposited during maintenance dredging, will be more affected by environmental forces than will the natural bay floor. It seems likely that the spoil material will be spread out over the bay floor, outside of the boundaries of the designated "spoil area" and even transported back to the channel. It now becomes apparent that factors other than economics should be considered when selecting spoil disposal sites, namely, all environmental and hydraulic properties of the subject estuary. The method of dredging and spoil disposal will also significantly influence the spreading of dredge spoil and so must be investigated fully.

Objectives of Study

The principal objective of this study will be to investigate the effects of certain environmental forces in determining the distribution of dredge spoil up to six months after deposition in one unconfined open water disposal area in Galveston Bay, Texas. Studies will be limited to gross environmental forces and effects that can be measured using simple techniques or data from others. Several different field techniques for measuring the changes or movements in spoil will be employed and analyzed as to their effectiveness in producing meaningful results.

A secondary objective of this study will be the collection, through literature search, questionnaires, and personal interviews, of the latest criteria in use for spoil site selection in Texas. In connection with this will be a review of the most common dredging and spoil disposal practices now in use.

LITERATURE REVIEW

Only recently has the subject of dredging and spoil disposal been of concern to warrant significant study. Primarily, published research efforts relate only to biological or chemical effects on an estuary caused by the influx of polluted spoils or polluted spoil effluent water. Few investigations have been made of the spoil bank itself, the physical effects of the environment on the spoil bank and the resulting changes taking place in the spoil bank, i.e., its ultimate configuration or destination.

One of the earliest studies, that of Hellier and Kornicker (1962), investigated the spreading of dredged sediment by means of spoil flowing outside the bounds of the spoil area and later erosion of the spoil bank. Colored gravel was used to mark the sediment surface, subsequent sediment deposition on the gravel being detected by means of core samples. Sediment deposition was found to occur up to one half mile from the dredge, effects at greater distances not being detected.

Harrison (1967) studied spoil buildup on an "oyster ground" located eight tenths to two miles from the outfall of an onshore disposal site. Steel rods implanted in the bottom were used to measure sediment buildup, which was recorded by divers. Water depths in the area were 6 to 10 feet. Live oysters were placed nearest the outfall in the test area prior to dredging and harvested at the end of the four month project to determine what deleterious effects dredge spoil might have on them. The low (4.4%) oyster mortality rate and the negligible amounts of deposition recorded on the steel rods, led to the conclusion that the spoil outfall had no effect on this particular area.

Another study, that of Sustar and Ecker (1972), studied dredge spoil deposited in 36 feet of water by hopper dredge. This study of the San Francisco Bar utilized graduated stakes implanted in the bottom as well as flat plates to collect sediment, aerial photography, and current drogues. Observations by divers showed that maximum accumulation of sediment in the spoil area never exceeded two inches, due to turbulence and spreading of the material during descent. Flat plates were not effective in measuring sediment deposition. Long term accretion did not occur on the spoil area due to erosion by tidal currents.

In a very comprehensive report, Cronin (1970), investigated the gross or large scale physical and biological effects that would result from dredging and open water disposal of some 1,900,000 cubic yards of bottom materials in upper Chesapeake Bay. Dredging was accomplished by pipeline dredge and spoil released downward against a horizontal deflector plate about six feet below the water surface. Water depth was about 15 feet. It was found, by means of hydrographic surveys, that deposited spoil covered an area five times as large as the disposal "site" to a minimum depth of one foot. Approximately twelve per cent of the spoil pile had disappeared after 150 days. Suspended sediments were carried a maximum of 3.1 miles from the point of deposition but virtually disappeared within 2 hours after pumping ceased. Effects on bottom organisms were also studied.

An equally comprehensive study of spoil deposition in Rhode Island Sound, conducted by Saila (1972), related observations of speed and direction of bottom currents to observed and potential spoil movements. The amount of spoil on the disposal site was found to be essentially the same as that reported dumped, although patches of spoil were found as much as a mile outside the dump site. Also, the spoil formed a low cone, 16-18 feet high and a mile in diameter in the center of the dump site and extended from one quarter to one half mile outside the designated disposal area. Some biological effects were also documented.

O'Neal and Sceva (1971) studied the effects of dredging projects on Water Quality at various locations in the Northwest United States. Generally these studies dealt only with dredging effects on biological systems. However, in a study of Bellingham Bay, Washington, grain size analysis of bottom core samples revealed that significant transport can take place out of a spoil area by means of a "submarine mud-flow" on a downhill slope. Dredge spoil was detected up to 1000 feet from the boundaries of the spoil area by this method.

One additional study, that of Smith (1967), involved the use of radioactive tracer material to follow spoil movements in the Firth of Forth, Scotland. Here, findings resulted in the abandonment of one spoil area when it was shown that material deposited there quickly moved upstream and within two months redeposited in the navigation area. Another disposal area was adopted when tests there indicated that deposited spoil would remain there or be carried out to sea. A summary of materials and methods involved with the use of radioactive tracer material was also presented.

The use of movable bed hydraulic models for the study of spoil displacement is becoming more common. A paper by Price and Kendrick (1969) discusses experiments on movable bed hydraulic scale models for evaluation of dredging effects and factors affecting spoil sites. The use of hydraulic models for selection of possible future disposal sites was examined. An actual model study conducted by Simmons, et al., (1969) investigated sediment movement out of a spoil area located adjacent to Galveston Harbor entrance, Texas. This study utilized crushed coal as the bed material. Results showed that spoil disposal by means of sidecast dredging will result in spoil quickly returning to the channel, also that spoil placed in one section of an existing disposal site would eventually return to the channel.

Another model study, that of Homan (1963), used crushed gilsonite, an oil shale, to simulate shoaling and spoil movements in the Oakland-Alameda area of San Francisco Bay, California. The model test indicated that approximately 30 percent of deposited spoil would be carried to sea while four percent would return to the navigation channel. Alternative disposal sites were also studied.

A slightly different application of the movable bed model was reported on by Harris (1963) in a study of Savannah Harbor, Georgia. In this study, methods were developed for inducing sediment deposition in areas where dredging and spoil disposal were more economical. The model test showed that 89 percent of the potential shoal material could be made to deposit in a more desirable location away from the navigation channel.

A fixed bed hydraulic model was used in the design and evaluation of a deep draft navigation channel for Matagorda Bay, Texas, as described by Rhodes (1962). Several tentative locations and configurations of dredge spoil mounds were tested to determine optimum location of the mounds in relation to circulation patterns and currents within the bay.

All of these studies attest to the importance of and the need for additional research in the area of dredge spoil dispersion. Nearly all of the above research resulted in significant savings in time and money when applied to the particular areas in question. However, these results were not generally applicable to areas other than those with which the studies were concerned. This in itself would seem to warrant additional work in almost any area that has not previously been investigated. But more important than this is the need for knowledge relating to the behavior of all forms of dredge spoil under all types of conditions. Only by study of such depth can sufficient cause and effect generalizations be drawn towards application to other areas.

CURRENT DREDGING PRACTICES

The ultimate destination of spoil can be significantly affected by the type of dredging equipment used and the method of spoil disposal employed. Equally important is the intelligent selection of a site for disposal of spoil. Following is a brief summary of the more common types of dredges as well as spoil handling methods now in practice in this country. Included is an outline of some of the guidelines that are presently being used in the selection of spoil disposal sites.

Mechanical Dredges

The most common type of mechanical dredge is the bucket dredge. This is commonly a standard excavating crane mounted upon a barge and moved about by means of small tugs or workboats. The bucket may be either a clamshell, orangepeel or dragline type. Spoil disposal is usually accomplished by dumping the spoil into a hopper barge alongside to be carried away or pumped out to some disposal area. These dredges are particularly effective when dredging confined areas such as around docks or piers, often working from the pier itself, dumping spoil into waiting trucks to be hauled away. As a category, mechanical dredges account for only two percent of the nearly 300 million cubic yards of maintenance dredging done annually in the United States. All of the mechanical dredges have a disadvantage in that they greatly disturb the bottom, creating excessive turbidity in the surrounding area. The irregular bottom produced by mechanical dredging is also a source of turbidity and can aggravate future shoaling in the channel (Odd, 1966).

Hydraulic Dredges

This method is the most effective for moving large quantities of material at low unit cost. Hydraulic dredges all depend on the use of a large centrifugal pump to lift the material from the bottom to the surface. From here it is pumped to some designated spoil area or to an awaiting barge alongside. Some hydraulic dredges discharge material into their own hold.

Pipeline Cutterhead Dredge

This is the most predominant type, accounting for 69 percent of the annual maintenance dredging done by the Corps of Engineers (Boyd, et al., 1972). Usually built upon a barge hull, this dredge utilizes a revolving cutter, located at the end of the suction pipe , to break up deposits so they may be drawn into the suction pipe more easily. Spoil is then pumped to some disposal area thousands of feet away, or into a hopper barge alongside. With the aid of booster pumps, the larger dredges can move huge quantities of material, up to 5000 cubic yards per hour, over any practical distance. The fact that most of the material broken up by the cutter is drawn into the suction pipe means that turbidity is greatly reduced in the vicinity of the dredge. Properly designed, interchangeable cutter heads allow one dredge to excavate a variety of materials, from soft clay and silt to hard coral and blasted rock.

Hopper Dredge

Also called the draghead dredge, this type is constructed on a ship type hull and is capable of dredging at speeds of up to seven knots under its own power. The suction pipe is equipped with a flattened, "vacuum cleaner" type of fitting which is dragged along the bottom, sucking up large quantities of material. Spoil is normally discharged into onboard hoppers, allowing effluent water to spill over the side until the hoppers are filled with solids, at which time dredging ceases and the dredge travels to some dumping area, usually offshore, for disposal. The practice of overflowing the effluent water has been met with disfavor by environmentalists due to the extreme turbidity plume produced and as a result has been eliminated in some areas. Some hopper dredges are capable of side-casting, that is, discharging the spoil through a long boom up to 300 feet off to the side of the channel while dredging. This practice is also under criticism due to the turbidity produced. This method also allows a greater runback of material into the newly dredged channel in some cases. Hopper dredges account for 24 percent of all maintenance dredging done on the United States, including a fraction of a percent done by sidecasters (Boyd, et al., 1972). For further review of dredging methods and equipment, see Huston (1967,1970), Johnston (1965) and Long (1967).

Spoil Disposal Methods

Due to the wide variety and condition of spoil material encountered in new work and maintenance, the method of disposal will vary from location to location. Its proper selection must entail consideration of the short-term and long-term fate of the spoil as well as its effects upon the environment.

Open Water Disposal

About two-thirds of all dredge spoil is disposed of in open water, the remainder being placed in diked or undiked disposal areas on shore (Boyd, et al., 1972). Generally, hopper dredges dispose of material by dumping in open water offshore or in deeper areas of the estuary. Pipeline dredges also lend themselves to economical open water disposal extending their discharge pipes on pontoons for thousands of feet to designated "spoil areas" alongside the channel. Spoil is pumped into the disposal area, forming underwater mounds, or hopefully, a low "dike" which parallels the channel a few thousand feet off to the side and which may or may not become emergent. Subsequent spoiling is done behind these mounds, hopefully to preclude the return of spoil to the channel. Breaks are allowed at intervals in the spoil area to allow circulation of tidal currents and passage of boat traffic. The effectiveness of these low dikes in containing spoil is of primary concern in this study.

After many successive maintenance dredging operations, some submerged open water disposal areas have become emergent consolidated islands capable of supporting plant growth and even heavy construction and roadways, as in the case of Atkinson's Island and Pelican Island in Galveston Bay.

Ejection of spoil through a plain, open discharge pipe some distance above the water surface usually creates extensive turbidity around the disposal site. To alleviate this problem the pipe may be modified by addition of a downspout or splash plate to inject the spoil beneath the surface of the water. A new development, applied in Florida (Civil Engineering, 1970) and currently undergoing its first application in Texas, is the silt curtain or "Turbidity Barrier". This is simply a floating, weighted, anchored, vinyl impregnated Nylon screen that surrounds the dump area much like a seine or gill net and is designed to prevent currents from carrying silt and sediment away from the disposal site. It may be moved along with the dredge pipe as dredging proceeds. So far its application has been limited to waters less than twelve feet deep.

In some areas the economics of open water disposal is being replaced by the greater retention and less water quality impairment available with onshore disposal. Open water dumping in the Great Lakes has essentially been eliminated in favor of diked disposal ashore. Due to the highly polluted nature of spoil encountered there, hopper dredges have been redesigned for direct pump out to onshore diked disposal areas (U.S. Army, 1968a). In the Delaware Estuary, maintenance dredging has been reduced by 70 percent since changing from open water rehandling basins to "sump rehandler" barges. Originally, spoil was dumped into deep dredged basins close to shore and then pumped to diked areas on shore. However, high velocity tidal currents scoured much of this material out and transported it directly back to the channel, resulting in the failure to reach authorized dimensions in the channel. Utilizing an old hopper dredge as an intermediate sump to which to pump spoil and from which to pump ashore, and by elimination of all spills or overflows of hoppers, maintenance costs were reduced and the authorized dimensions were reached in the channel for the first time (Cable, 1969).

Other areas are experiencing changes in policy regarding disposal methods. In Texas, the Corps of Engineers is currently working with the Environmental Protection Agency and the Texas Parks and Wildlife Department in re-evaluating all open water spoil areas now being used for disposal of maintenance dredging (Cobb, 1973). Several areas have already been abandoned, largely as a result of their encroachment on known oyster reefs or nurseries. As far as can be determined, the possibility of spoil returning to the channel is not a criterion for abandonment. Also, the abandonment of one open water disposal site does not necessarily imply that the spoil will afterwards be placed on land disposal areas. New open water sites may be opened.

Onshore Disposal

Disposal on land areas usually entails the construction of dikes or levees to contain the spoil. The area behind the dike eventually fills and the effluent water overflows, via weirs, to return to the bay or estuary being dredged. Upon consolidation, the spoil area may be reclaimed as valuable real estate, suitable for building construction. Less suitable areas may be made into wildlife habitats or utilized as a source of sanitary landfill (Boyd, et al., 1972). Since the land subject to this type of spoil disposal is often productive coastal salt marshes, the use of diking and filling has been criticized and the alternative, undiked spoil disposal has been recommended (Windom, 1972).

When spoil is dumped into undiked areas and allowed to spread over the marsh, it initially destroys the marsh but eventually the area is reclaimed naturally and the marsh is restored. Of course, heavy concentrations of pollutants will affect this regeneration and may delay this return to marsh land. Some studies have been conducted involving the creation of marsh land by artificial reseeding or replanting of spoil dump areas that are within the tidal zone (Vittor, 1971, Woodhouse, 1972).

The open water rehandling basins mentioned earlier with reference to the Delaware Estuary have some utility when properly designed to prevent the return of spoil to the estuary. This usually entails excavation of an open water dumping pit, protected on three sides by levees and with access available to dump barges or hopper barges. The basin is periodically dredged of material which may be brought from several different locations. Optimum practice is to centrally locate the basin in respect to the various dredging projects in progress and also as near as practical to some diked spoil area to which spoil placed in the basin can be periodically pumped (Cable, 1969).

With the increased concern for environmental impact resulting from the dredging and disposal of polluted sediments, open water disposal will come under increasing criticism, resulting in the adoption of some form of onshore disposal of spoil for many areas to provide maximum retention of spoil and lessen the pollution load on the estuary as well as lighten the maintenance dredging load.

Selection of Disposal Sites

Site selection remains a matter of economics, with the primary consideration being that the site be as close as possible to the dredging area. In recent years, this requirement has been modified by additional constraints based on the impact of spoil disposal on the overall environment of the bay or estuary in question. The Corps of Engineers retains responsibility for selection of new sites, within limitations imposed by various governmental agencies. The agencies contacted by the Corps when selecting new sites in Texas are:

1. Department of the Interior.
    - A. Environmental Protection Agency.
    - B. National Park Service.
    - C. Bureau of Sport Fisheries (Fish and Wildlife Service).
2. Department of Agriculture--Soil Conservation Service.

3. Texas Water Quality Board.
4. Texas Parks and Wildlife Department.
5. Texas Water Development Board.

The authority of the above agencies in site selection or approval as well as criterion for spoil site selection was ascertained by means of a questionnaire (Appendix, p.74). The results obtained by this method indicate that the authority of any of these agencies is limited to making suggestions and recommendations with little power of enforcement. Random and infrequent monitoring of dredging activities may be carried out by the Texas Water Quality Board, the Bureau of Sport Fisheries, or the Environmental Protection Agnecy. Usually cooperation is good and close coordination with the Corps results in most requests being met. Some of the many factors that are considered by the Corps as well as the above agencies in formulating decisions may be briefly listed below:

1. Laboratory analysis of pollutants, i.e., heavy metals, BOD, COD, hydrocarbons, volatile solids, etc. This may determine the need for containment of spoil, necessitating land disposal or construction of dikes.
2. Disposal methods--whether open water or land disposal are available.
3. Location of disposal site in regard to:
   A. Dredging area--cost is directly related to distance.
   B. Developed land--whether residential or commercial.

C. Wildlife sanctuaries.

D. Coastal fauna such as oyster reefs.

4. Description of site such as elevation, strength of soil, possibility of inundation and types of vegetation. This determines, for instance, the maximum height at which dikes and fill may be supported by the substrate.
5. Size and capacity--will the site satisfy present and future needs?
6. Additional modifications necessary, such as weirs, dikes or channels to control drainage.
7. Types of dredging possible.
8. Ownership and availability--rights may affect cost directly.
9. Length of time spoil area will be in service.
10. Views of local interests--any objections?
11. Ultimate use of the site.
12. Anticipated public reaction.

Further development of these criteria, including applications to actual dredging projects, may be found in the literature (Hoffman, 1970, U. S. Army, 1968a).

The above items are for the most part directly economic in nature. Additional very important considerations that are also basically economic in an indirect way are the mutual physical effects of spoil mounds and estuarine hydrodynamics on one another. These factors were mentioned by the above agencies as being considered, but only in the light of their adverse effects on fisheries and wildlife resources on the estuary. Overall hydrodynamics of any estuary will be a function of such elements as circulation patterns (currents), wave heights and periods, tidal influences, bottom topography, temperature and salinity gradients, fresh water inflows and prevailing winds. Each of these factors, with the exception of the last two, will respond to a physical change in the estuary in such a way as to not necessarily be obvious to a cursory examination and which may be detrimental to the status quo. Likewise, these same environmental forces will act on and distribute a spoil mound so that its ultimate destination may not be that which is planned or desired. Thorough understanding and accurate representation of all these factors acting together is no easy task. The Bureau of Sport Fisheries employs field representatives who, by virtue of personal experience, have sufficient empirical knowledge so as to make fairly accurate judgements regarding spoil disposal in their areas of familiarity (Misso, 1973). For the most part, however, full consideration cannot be given to these factors because of the limited knowledge and experience regarding dredge spoil behavior.

Hydraulic or numerical models may be employed with success but usually their cost precludes designing them for the sole purpose of selecting spoil disposal sites (Price, 1967). Often a model is available from a related study of the same area and could be easily modified for the necessary purpose. The Texas Water Development Board has developed many numerical models of Texas Bays and estuaries during their water quality studies. The models are generally concerned with such regimes as fresh water inflow, overall circulation and salinity patterns, pollution, dispersion and flushing characteristics. These could often be adapted for use in selection of spoil sites and determination of their effects on the hydraulics of the bay.

The Corps of Engineers Waterways Experiment Station has constructed large physical models of such areas as Galveston and Matagorda Bays, Mobile Bay, New York Harbor and others. Indeed, the physical model of Matagorda Bay proved invaluable in determing the optimum location of spoil mounds as relating to circulation and currents in the bay (Rhodes, et al., 1962).

One final method, if all else is inadequate, is field testing of the actual disposal sites themselves. By such means as radioactive tracers or dyed sediment particles, one many determine the dispersion characteristics of a sample spoil in a particular area and thus select a "best" site from that standpoint (Smith, 1967, Crickmore, 1967).

In the future, with the increased competition for coastal real estate and the growing limitations on open water disposal, it will become increasingly difficult to locate sites for the disposal of dredge spoil that are both economical and provide the most efficient retention of spoil.

From the questionnaire it was learned that the most important criteria for spoil site selection are direct economics and environmental quality. The physical behavior of the dredge spoil is only considered from the standpoint of its effect on the biological systems of the estuary, although spoil behavior can be very important economically also. Much additional research is needed regarding the processes of dredge spoil erosion, deposition and transportation before decisions can be made including such factors.

SPOIL TRANSPORT MECHANISMS

It is not the purpose of this discussion to delve into the very complicated theoretical mechanics concerning sediment transport and deposition in estuaries. Rather, it is intended to provide general correlations applicable between gross physical forces and resultant effects generally accepted as current state of the art.

From the outset it should be made clear that in all phases of this study, Galveston Bay is at all times considered to be classified as a typical, shallow, well-mixed estuary, with negligible vertical salinity gradient. This assumption is based in part on the very low fresh water inflow rates in existence as compared to the tidal current flows. This combined with the shallowness and wide expanse of Galveston Bay results in mean salinity differences of around two parts per thousand between the top and bottom water layers (Bobb, et al. 1970). Overall salinities in the bay proper may vary from 26 to 32 ppt. seasonally with much wider ranges encountered in smaller connecting bays and channels (Fisher, 1972). Generally, Galveston Bay fits one accepted definition of the typical well-mixed type of estuary which requires that the mean variation in salinity changes less than 50% over the entire water column at any station and at any time (Ippen, 1966). This assumption may break down following prolonged periods of heavy rainfall, such as follows one of the seasonal hurricanes, but these effects are short-lived and likely exert less influence on the sediments and hydrology of the bay than the winds and waves associated with such storms. Realizing this property of Galveston Bay simplifies considerations in all phases of the study. For instance, current velocities recorded in the top several feet may be taken as representative of the average velocities across the entire water column depth of four to six feet. Net time averaged current direction should be downstream at all levels as should net sediment transport. The classical salt water-fresh water interface, with vertical upward flow across it should not exist and effects of this phenomenon such as flocculation along the interface will not be considered. Flocculation in general shall be mentioned, but not as relates to a salt water wedge interface.

Theoretically, a sediment particle is subject to two modes of transport, bed load and suspended load. Controlling factors are not the same for these two processes and generally authors have considered them as separate phenomena, although both are always in existence in estuaries to some extent. Classical theories always begin with some consideration of a "critical shear" required to initiate erosion of a particular grain size. This is usually expressed as some function of water depth, slope, tractive forces between particles, and levels of turbulence, or more briefly, for the purpose of simplification, the fluid velocity. This relation was effectively expressed by Postma (1967), as shown in Fig. 1.

As can be seen from Fig. 1 the critical erosion velocity increases directly with grain size for grains above about 0.2 mm. Below this size, in the silt and clay range, degree of consolidation becomes

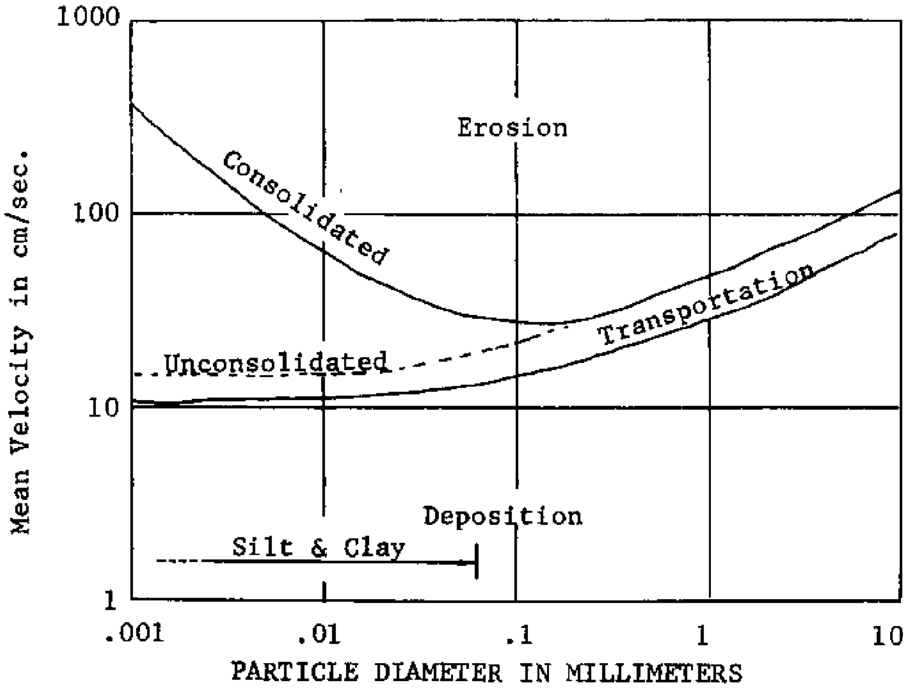

Fig. 1. Modes of sediment behavior as related to fluid velocity. (Postma, 1967).

a controlling factor in that the highly consolidated clays require a greater velocity to initiate erosion. In this size range, the upper line of Fig. 1 indicates highly consolidated material, the dotted line, unconsolidated or loose material, with degrees of consolidation distributed in between.

Also apparent in the figure is the important difference in the critical erosion and deposition velocities for all grain sizes. Generally erosion requires a 30% greater velocity than deposition. This difference becomes more marked as the sediments become finer and more consolidated. The physical significance of this is that a fluid mass is able to carry as suspended load material that it would not be able to scour at that same velocity. Also, once a particle has been eroded from the bed, it may not resettle until the velocity drops sufficiently to allow deposition. This is an important factor in the creation of shoals in estuaries.

One of the properties of all clay-sized particles in suspension is the presence of negative charges on the surface of each particle. This results in their tendency to repel one another. These charges are affected by the temperature and pH, and are reduced by dissolved ion concentration in the surrounding fluid. Concentrations of 1000 ppm salinity usually results in the complete dissipation of these charges, allowing colliding particles to stick together, a process known as "flocculation". These clumps or "flocs" of particles have a larger diameter than the individual particles, resulting in a greater settling rate and a faster consolidation time. Thus particles which were easily carried in suspension in a river, upon contact with the saline water of estuaries, tend to flocculate and settle out of suspension more readily. Flocculation is enhanced by any process which increases the collision frequency of particles, such as weak turbulence or shear stress as might be found along an irregularly dredged bottom, or around pilings or other obstructions (Odd, 1966, Krone, et al., 1962b). However, any increase in this shear stress above that small amount needed to produce flocculation, will produce scour, as the critical value is reached.

It has been documented that much of the shoaling that takes place in navigation channels originates from the wide shallow areas of the bay, and not exclusively from spoil areas or from sediments carried in from outside the estuary (Einstein and Krone, 1961, Wicker, et al., 1965, Nichols, et al., 1967). The shallowness of most estuaries is such that water movement due to wave action may sometimes be felt at the bottom. Waves can begin to feel bottom when the water depth is approximately equal to one-half of the wavelength. Thus, in Galveston Bay, any wave longer than fifteen feet must produce some back and forth water movement on the bottom. Such movement will not be as effective in causing transport as it will scour, the displaced sediment then being subject to transport by the prevailing tidal current. This back and forth movement may also be an aid to flocculation, should it be below the critical value required for scour.

Table I presents a brief, partial summary of the expected wave properties associated with the average wind velocity and fetch length found in the study area. The horizontal component of wave orbital velocity acting on the bottom is also presented. It is this velocity plus the proper component of tidal current velocity that must be compared to the critical erosion velocity when determining the possibility of erosion of the bottom sediments. It can be seen from this table that any winds greater than 12 miles per hour can produce horizontal bottom velocities in excess of that needed for erosion.

For complete understanding of all mechanisms of sediment transport that exist in an estuary, it is necessary to study some processes that are more the result of man's activities (dredging) than of nature. In the chápter on dredging practices, it was seen that spoil is often

TABLE I. SUMMARY OF CALCULATED WAVE DATA FOR THE STUDY AREA. (After Wiegel, 1964. Calculations based on a fetch length of three miles.)

Wind Velocity (mph)	Wave Height (feet)	Wave Period (sec.)	Wave Length (feet)	Water Depth (feet)	Horizontal Velocity Component @ Bottom (cm/sec)
12	0.96	2.18	18	2	58.5
				4	23.2
				6	11.1
				8	5.4
25	1.88	2.27	25	2	105.7
				4	42.0
				6	19.9
				8	9.8

discharged through a plain open-ended pipe and allowed to flow out naturally over the spoil area. There are three possible things that may now happen to this spoil; it may fall directly to the bottom and form some sort of pile; it may become suspended and remain in the water column some length of time determined by its fall velocity during which time it will be carried some distance away by the tidal current; or it may become part of a "flow", induced by the high density nature of the sediment-water suspension, which spreads out over the bottom, becoming initially mixed with the upper layers only to a limited extent. This "flow" would be more pronounced when performing maintenance dredging due to the fine silty nature of the material encountered and the lack of highly consolidated or hard material that would be necessary to form a distinct pile. In addition, the lack of wave-induced turbulence, and the weak tidal currents generally encountered in estuaries would allow such an underwater flow to exist more easily and thus carry sediments over a wider area. The material originally suspended during discharge may be carried back and forth over several tidal cycles and spread out over such a wide area as to be completely undetectable by simple measuring techniques. In addition, whatever spoil pile that may form during disposal will be more exposed to wave action and currents and so might be expected to erode relatively quickly, becoming spread out over the surrounding floor.

We now have a basic picture of the forces acting on dredge spoil and an idea of what to expect from its behavior under natural environmental conditions. Ideas in this chapter are not necessarily limited to Galveston Bay. They could be applied to any estuary with the general properties of Galveston Bay, that is, a shallow, well-mixed estuary with low fresh water inflow and low tidal ranges. For more information beyond this brief summary, including the supporting theoretical mathematics, readers are referred to works by Graf (1971), Raudkivi (1967), Leliavsky (1966), Rouse (1966) and Krone (1962 a,b, 1963 .

Let us now examine a typical spoil area to see how it behaves.

EXPERIMENTAL PROCEDURE

Preliminary Information

The Site

The Gulf Intracoastal Waterway enters Galveston Bay from Bolivar Penninsula, crosses the Houston Ship Channel and Pelican Island, then passes under the Galveston Causeway Bridge and a portion of the West Bay before again becoming landlocked (Figs. 2 and 3). The area under study is that portion of the waterway and adjacent bay floor, approximately 3000 yards northeast of the Causeway bridge. Minimum channel depth in the area is authorized at 12 feet. Dredging is usually done to 16 feet as "advance maintenance". Just prior to this study, depths at mean low tide ranged from eight to twelve feet in the channel proper to four to six feet for the surrounding bay floor to zero depth for a few emergent banks within the spoil area. Bottom deposits consist of dark colored fine silty sand with many small pieces of broken shell. Mean grain size of the sands present is 0.11 millimeters, a very fine sand. Prior to dredging, sediments in the spoil area contained about 40% silt, this amount decreasing with distance from the spoil area, to about 20% for the natural bay floor. Channel bottoms naturally contained much more silt, up to 60%.

The tides affecting Galveston Bay are predominately diurnal type, with a mean and spring range of about 1.1 and 2.1 feet respectively. Normal tidal current velocities in the study area are on the order of

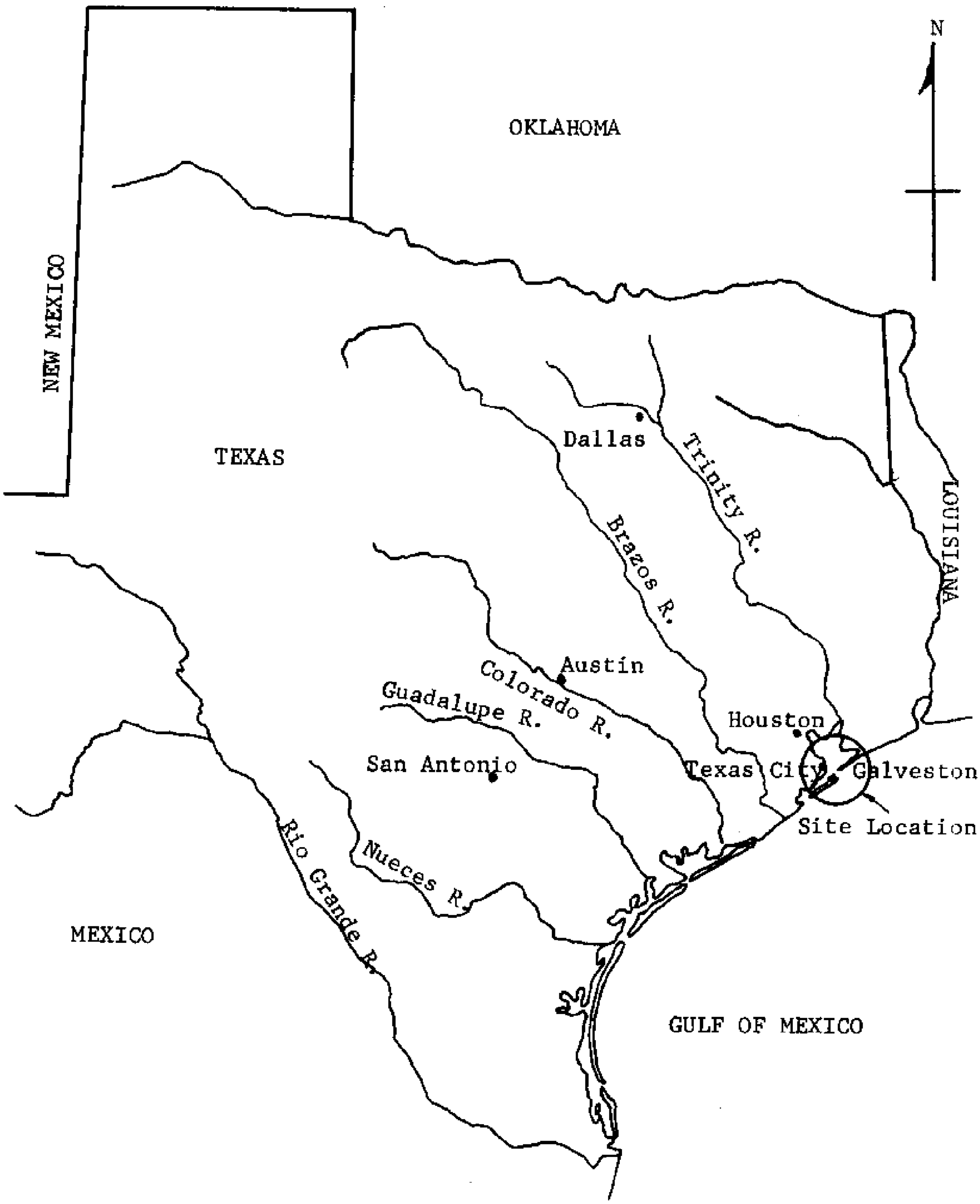

Fig. 2. General Area Map

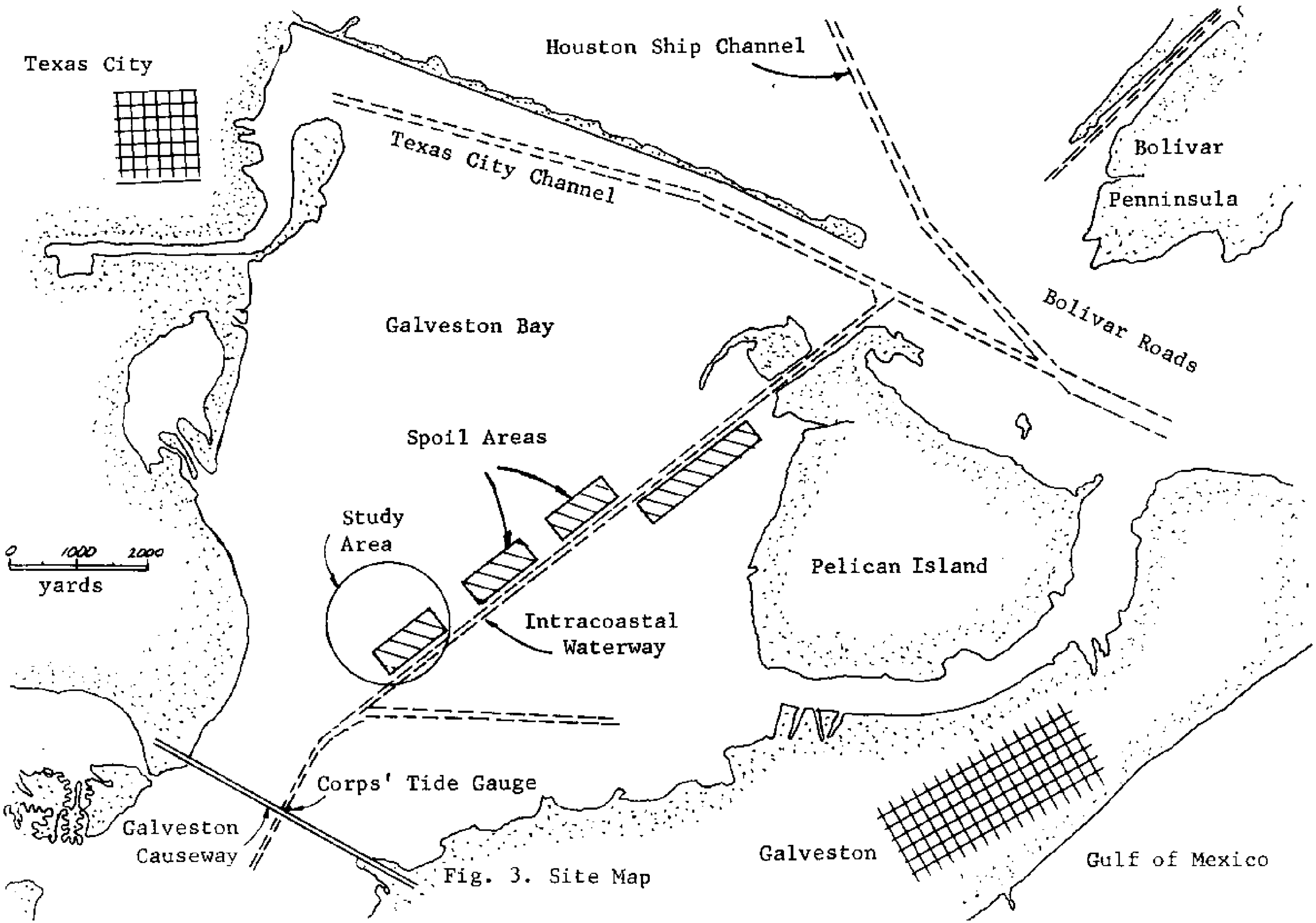

Fig. 3. Site Map

1.0 feet per second (Fisher, 1972). It is significant that the physical configuration of this particular area produces ebb and flood tidal currents that always flow across the study area in a direction away from the channel (Fig. 4). This was not realized until verified experimentally during the course of this study. In addition to the normal tidal current, there exists a varying state of turbulence due to wave action. Average winds in the area are generally southwesterly at an average velocity of 12 miles per hour. However, strong winds up to 25 and 30 miles per hour are common in the spring and fall months coinciding with frontal passages. These winds are capable of producing intense wave action which is likely a significant form of disturbance and erosion of the bottom sediments.

The area is heavily fished by shrimp trawlers, their drag nets producing turbidity clouds that reach for thousands of feet. No direct measurements were taken as to their effect on bottom silt layers, including spoil, but it is also probable that these trawlers play a part in distributing spoil over the bay floor.

This particular site was chosen from a selection of several others primarily because of the dredging schedule set up by the Corps. This timetable would allow ample time prior to and following the work to obtain and report on necessary data. The site was also easily accessible and contained several permanent surveying platforms that would be useful for certain portions of the study. The shallow water depth at the site would simplify measurements considerably. Also, this particular area, being confined between Galveston Island and the

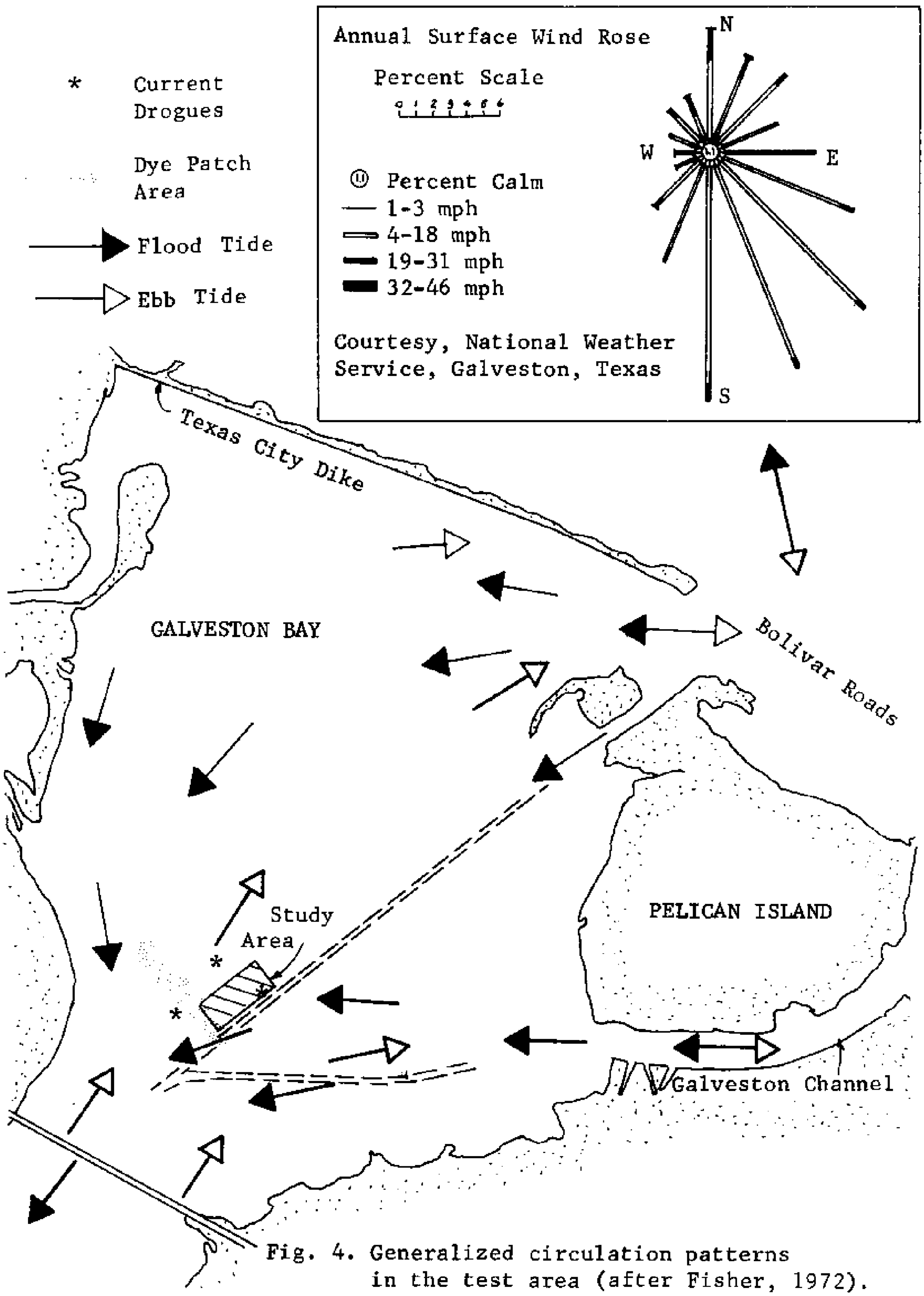

Fig. 4. Generalized circulation patterns in the test area (after Fisher, 1972).

mainland, would provide a tidal current stronger than that in other areas of the bay, hopefully providing more meaningful data. One final advantage to this site is the fact that the Corps of Engineers maintained a continuously recording tide gauge located at the causeway bridge. The proximity of this gauge lent considerable accuracy to measurements of tidal cycles affecting the site.

The Dredging Method

Dredging of the area under study was accomplished between May 4th and May 11th, 1973, by the 16" hydraulic pipeline cutterhead dredge "Padre Island", owned by Garrett Construction Company, Corpus Christi, Texas. The floating discharge pipe ejected material horizontally about two feet above the surface of the water (Figs. 5 and 6). Specifications called for dredge spoil to be deposited along the back limiting lines of the disposal areas until deposits become emergent to 1½ feet above Mean Low Water, at which time the spoil pipe should be relocated but remain along the back boundary of the spoil area. The interior of the spoil area could not be filled until this line of spoil was completed. At no time did deposits become emergent, therefore all spoil was placed along the back edge of the spoil area, approximately 2000 feet from the centerline of the channel. Generally, spoil consisted of dark sandy silt with some small pieces of shell. Occasionally the dredge would encounter some consolidated clay in the dredging process and this would form small submerged mounds within the spoil area. The normal silt of the

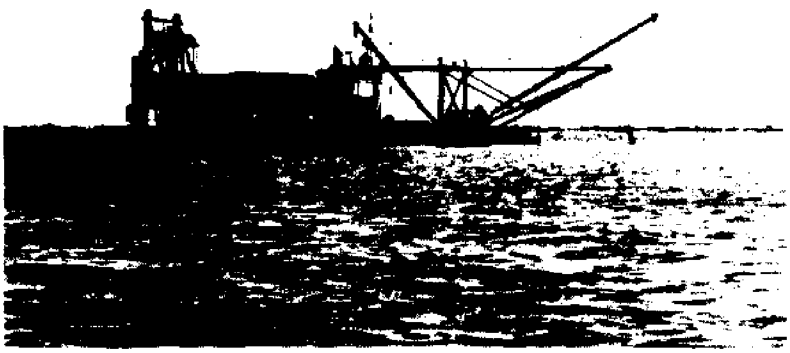

Fig. 5. Pipeline cutterhead dredge "Padre Island"

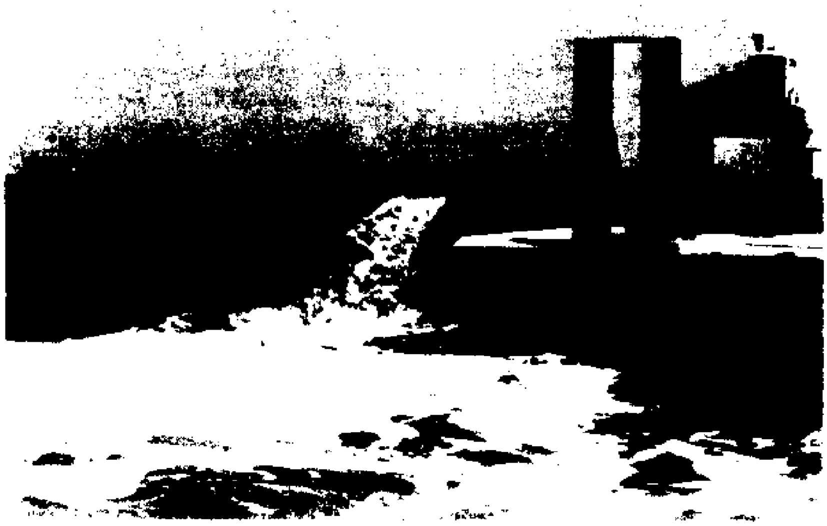

Fig. 6. Dredge effluent discharge

channel was not seen to form similar mounds.

Corps of Engineers records and Garrett Construction Company records indicate that approximately 110,000 cubic yards of spoil was placed in the spoil area. This figure is derived from cross sectional profiles of the channel prior to and following dredging and actually only indicates the amount of material removed from the channel.

Study Methods

Environmental Data

Due to the short term nature of this study and the limited facilities available, it was decided to use data from other sources as much as possible. Tide records as well as current velocity and salinity data were available from the Corps of Engineers Galveston District Office. U. S. Weather Bureau charts provided prevailing wind data.

Instantaneous current velocity and direction in the vicinity of the spoil area was obtained by two methods; aerial photos of fluorescein dye streaks and by current drogues. Aerial photos were analyzed using a computer technique developed by Burgess and James (1971), designed to reveal current direction and velocity at several discrete points concurrently for over two hours. The maximum velocity detected during this cycle by this method was 1.1 feet per second. Measurements by this method were taken during the flood tide.

Current drogues were in the form of a four foot long semi-submerged vertical spar buoy, which floated with a minimum of its length emergent. Current velocity and direction was obtained by stopwatch and compass as the drogue was carried over a known distance by the current. These measurements were taken during the ebb tide. The maximum velocity detected by this method was 0.8 feet per second.

Neither of the above current velocity values should be taken as the maximum current velocity possible in the vicinity of the study area. Galveston tides are very much influenced by local weather conditions and can vary widely from predicted tidal cycles.

Physical Data

Several methods were considered for monitoring changes in bottom elevation due to deposition, erosion, or transport of spoil. The use of colored gravel to mark the datum, based on the work of Hellier and Kornicker (1962) was tried without success. The intensity of mixing due to wave action was greater than anticipated and a preliminary layer of coarse (¼") gravel was dispersed and practically disappeared following just one storm in the area. One probable reason for the success of this method in the previous study lies in the shallowness (2 to 3 feet) of the water in the area plus the protection by nearby islands from wind induced wave action. In addition, the extreme softness of the unconsolidated upper sediments of Galveston Bay allowed much of the trial gravel to sink beneath the surface, obscuring results considerably.

Graduated stakes with increments of length marked directly on the stake proved successful in the San Francisco Bar study (Sustar and Ecker, 1972) but the waters of Galveston Bay are generally too murky for this type of underwater observation (visibility is usually only a few inches). One similar method, that proved workable and which afforded much simpler observations was the use of permanent, unmarked, 2" x 2" wooden stakes, driven into the bay floor and emergent to about two feet above MLW (Fig. 7). The distance from the top of each stake to the bay floor was measured using a wooden pole marked in tenths of a foot. The pole was prevented from entering the bay sediment by means of a large flat plate at the bottom. The stake readings were simple, direct and required little analysis for interpretation. Changes in the "readings" were exactly interpreted as the bottom elevation change at that point. Surface water activity affected only the ease with which readings were taken. Care was needed in closely reproducing the intensity with which the measuring pole was forced to the bottom, as any excess force could result in non-representative readings.

Due to the shallowness of the water, the stakes were never exposed to more than 8 feet of water column, so were fairly resistant to dislodgement by wave action. However, the slight back and forth movement of the surface waters, caused by passing waves, combined with the constant upward pull of bouyancy, resulted in most stakes lifting very slowly out of the bottom. This process was slow enough to allow meaningful data to be taken by means of the stakes

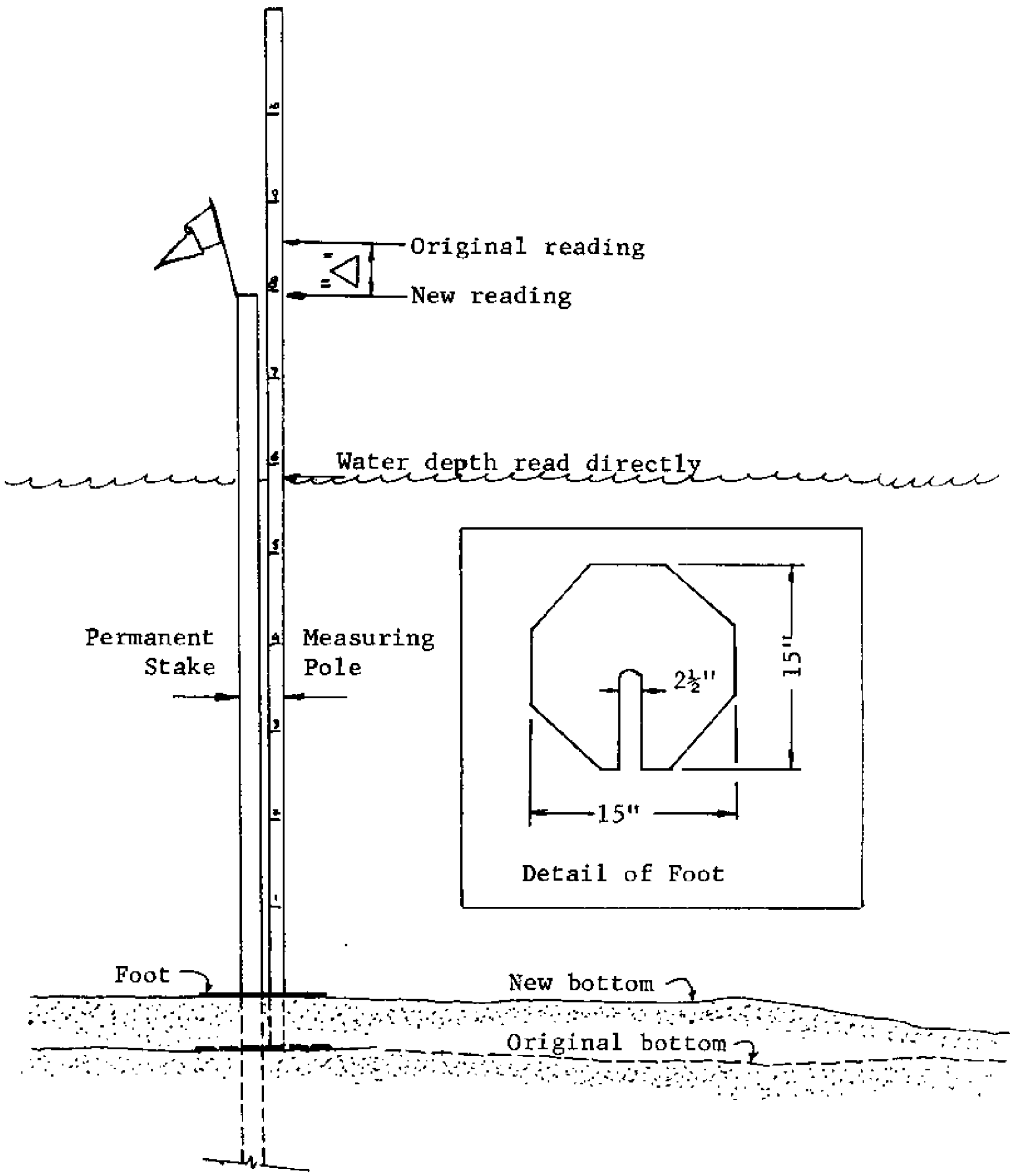

Fig. 7. Diagram of Stake Measuring Operation

even though a significant number of them were eventually lost. Shrimp trawlers or other boats probably collided with a number of stakes, as many were found broken at the mudline, but not dislodged.

Stakes were placed at various locations around and within the spoil area, up to 3000 feet from its boundaries, hopefully in areas not subject to effects from adjacent spoil areas (Fig. 8). In addition, two Corps' survey piles between the spoil area and the channel were utilized for measuring bottom elevation.

Background readings were taken for four months prior to the actual dredging, to determine the natural rate of siltation in the bay. This was found to be negligible, being insufficient to offset the slow rate of lifting of the stakes mentioned earlier.

Hydrographic surveys were performed throughout the study area in conjunction with the stake measuring procedure. These surveys were taken by means of the same graduated wooden pole used to measure the stakes. A standard lead line could not accurately detect the bottom in some areas that were very soft due to spoil buildup. All hydrographic readings were made in reference to the water surface elevation and afterwards were referred to mean sea level by comparison with Corps of Engineers' tide gauge records for the area.

Bottom samples were taken at various locations surrounding and within the spoil area, using a standard Birge-Eckman type grab sampler. A few shallow core samples were taken for comparison, using a 35 mm. diameter core tube. All samples were analyzed by wet sieving

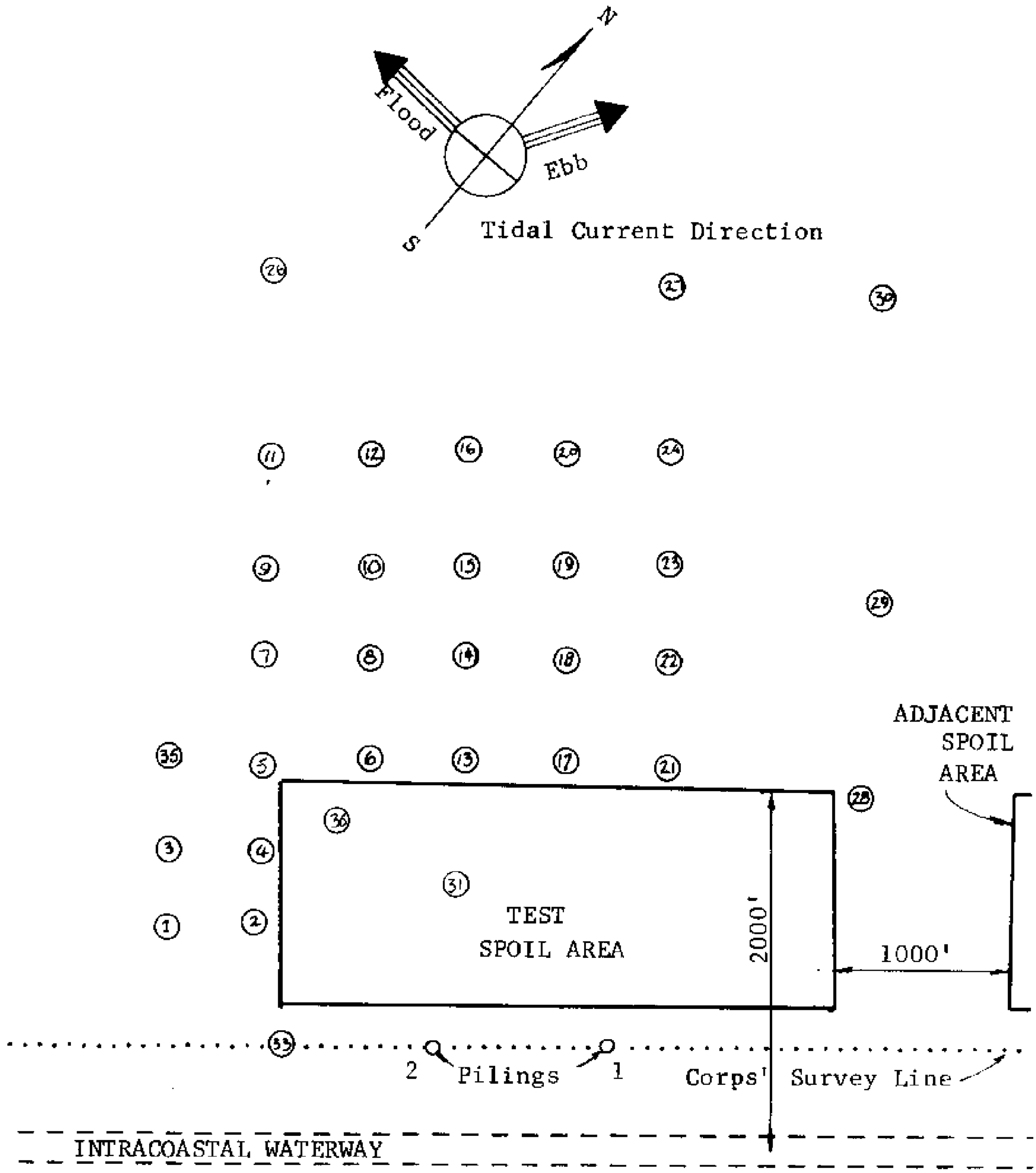

Fig. 8. Test Area Layout

for percent silt and sand, and some for percent shell. That portion retained on a 200 mesh sieve (0.074 mm.) was classified as sand, that retained on 40 mesh (0.42 mm.) as shell. Fines passing the 200 mesh sieve were collectively labeled silt. No particle size determination was run on this fraction or on the shell fraction. A standard 5 mm. visual accumulation tube determined gradation of the sand fraction. Any increase in the percent of silt contained in the sediments surrounding the spoil area, over and above that determined to be natural or background sedimentation, would be attributed to sediment transport from the spoil area. The high percentage of silt present in the channel bottoms should cause an increase in bottom silt whenever this material comes to rest.

DISCUSSION OF RESULTS

Generally, results in this study spring from two different data sources: (1) outside field work where parameters were physically measured, and (2) surveys of literature and data from others, including circulation of questionnaires. The second data source was used in determining overall or long-term environmental factors that could not be practically measured in the field. This was also the source for certain parts of the chapter on dredging practices. Each method produced results of a slightly different nature and shall be discussed separately.

Field Studies

Bottom Topography

Results in this section were obtained by three methods: (1) graduated stakes, for determination of bottom elevation changes at discrete points, (2) depth soundings, for construction of general area-wide bottom profiles, and (3) grain size analysis of bottom sediments, for detection of fine silt originating from dredge spoil. It was originally intended that the stakes would provide the most complete information on spoil movements. However, the disappearance of over half of the stakes during the course of this study precluded their full utilization. A complete summary of all stake data may be found in Table II. It should be made clear that the numbers shown on this table represent the distance from the bottom of the bay floor to the top of the stake, in feet. A decrease in this amount, i.e., a negative difference (Δ), indicates accretion around the bottom of the stake.

In reading a stake, it was necessary to maneuver a small boat alongside the stake long enough to effect an accurate measurement. High winds and waves often hampered this job considerably. Data taking was cut short or cancelled several times due to the weather. High tides associated with storm surge often completely covered some stakes resulting in their not being read until the next trip Most of the missing data in columns III and V, Table II, are a result of these problems.

Dredging was accomplished between May 4th and May 11th, 1973. Note columns II and III, Table II, representing conditions prior to any dredging. Differences (Δ) there generally read positive. This is an indication of the upwards movement of the stakes mentioned earlier. Column IV shows accretion for all but a few stakes, of amounts ranging from negligible to nearly a foot. If the supposed lifting of the stakes is a continuous process, then the differences shown here would represent even greater accretion. This accretion is of course due to dredge spoil spreading, which is detected up to the limits of the area then bounded by stakes.

Subsequent readings shown in columns V, VI and VII indicate that this lifting is a continuous process, which proceeds until the stake leaves the bottom. This accounts for most of the missing stakes. However, a few stakes show that in a few areas, some spreading of

TABLE II

SUMMARY OF STAKE DATA

	I	II		III		IV		V		VI		VII	
	1/19/72	2/3/73		4/12/73		5/9/73		6/17/73		7/1/73		8/26/73	
#	L	L	Δ	L	Δ	L	Δ	L	Δ	L	Δ	L	Δ
1	8.45	8.45	00	8.37	-07	8.30	-01	---		8.35	05	8.70	35
2	9.00	9.00	00	9.05	05	9.10	05	---m		---		---	
3	8.55	8.56	01	---		8.70	14	8.62	-08	8.65	03	8.50	-15
4	8.00	8.08	08	8.10	02	8.27	17	7.80	-47	7.68	-12	8.10	42
5	9.50	9.51	01	9.55	04	9.30	-15	9.40	10	9.40	00	9.35	15
6	9.35	9.32	-03	9.48	16	9.35	-13	9.27	-08	9.35	08	9.50	
7	9.95	10.05	10	---		10.10	05	---		10.00	-10	---	
8	8.28	8.31	03	---		8.25	-06	---		---m		---	
9	8.20	8.21	01	---		8.20	-01	---m		---		---	
10	9.57	9.50	-07	---		9.50	00	---		---m		---	
11	8.22	8.25	03	8.20	-05	8.15	-10	---		---m		---	
12	9.03	9.04	01	---		8.90	-14	---		---m		---	
13		8.55		8.55	00	8.10	-44	8.10	00	8.22	12	---	
14		8.80		---		8.80	00	---		8.85	05	8.85	00
15		8.51		---		8.60	09	---m		---		---	
16		8.95		---		8.90	-05	---m		---		---	
17		8.18		8.29	11	7.30	-99	---m		---		---	
18		8.47		---		8.30	-17	---		---m		---	
19		8.50		---		8.40	-10	---		---m		---	
20		7.90		---		7.85	-05	---		---m		---	
21		8.96		9.15	19	8.80	-16	8.70	-10	---m		---	
22		8.33		---		8.10	-23	---		---m		---	
23		8.00		---		7.90	-10	---		---m		---	
24		8.64		---		8.55	-09	---		---m		---	
26						9.60		10.28	11	9.80	20	---	
27						10.17		---		---m		---	
28						9.50		---		9.78	28	9.80	02
29						9.95		9.40	10	10.35	40	10.50	15
31						9.30		7.24	04	9.50	10	9.55	05
33						7.20		8.65	05	7.30	06	7.35	05
35						8.60		7.60	10	---m		---	
36						7.50		6.30	-05	7.85	15	8.00	15
Pile 1				6.30		6.35	05	11.00	00	6.32	02	6.30	-02
Pile 2				11.04		11.00	-04			11.03	03	11.10	07

--- Stakes not read at that time.
---m Missing stakes.

"L" in feet.
"Δ" in 1/100's foot.

spoil is still taking place up to six weeks following dredging. If it is present, the existence of spreading in other areas is apparently masked by the upward movement of the stakes.

No stakes were installed between the spoil area and the channel. Had any been placed here, they would have been destroyed by the floating discharge pipe as it proceeded along the channel with the dredge. However, two large permanent survey pilings were present in this area and were utilized in the same manner as the smaller measuring stakes (fig. 4). No spoil buildup was detected at any time at these pilings. This would seem to indicate that no spoil is returning to the channel via this route.

Bottom soundings were performed at more infrequent intervals than were the stake readings. These readings were taken prior to dredging, one week following dredging and 22 weeks following dredging. The resulting contour maps (figs. 9,10 and 11) clearly indicate the presence of dredge spoil. In figure 9, the probable last remains of the old spoil "dike" that was deposited with the original dredging of the channel, can be seen. This dike was originally composed of the virgin clay usually encountered in new work, and was so placed to preclude the return of spoil to the channel. Material from the current job was placed behind this dike just inside the back limiting boundary of the spoil area and shows up quite distinctly in figure 10. A very small, discrete pile was formed in the upper left hand corner of the area when the dredge encountered a small amount of firm clay. Probably there are a few other such mounds but their small size has

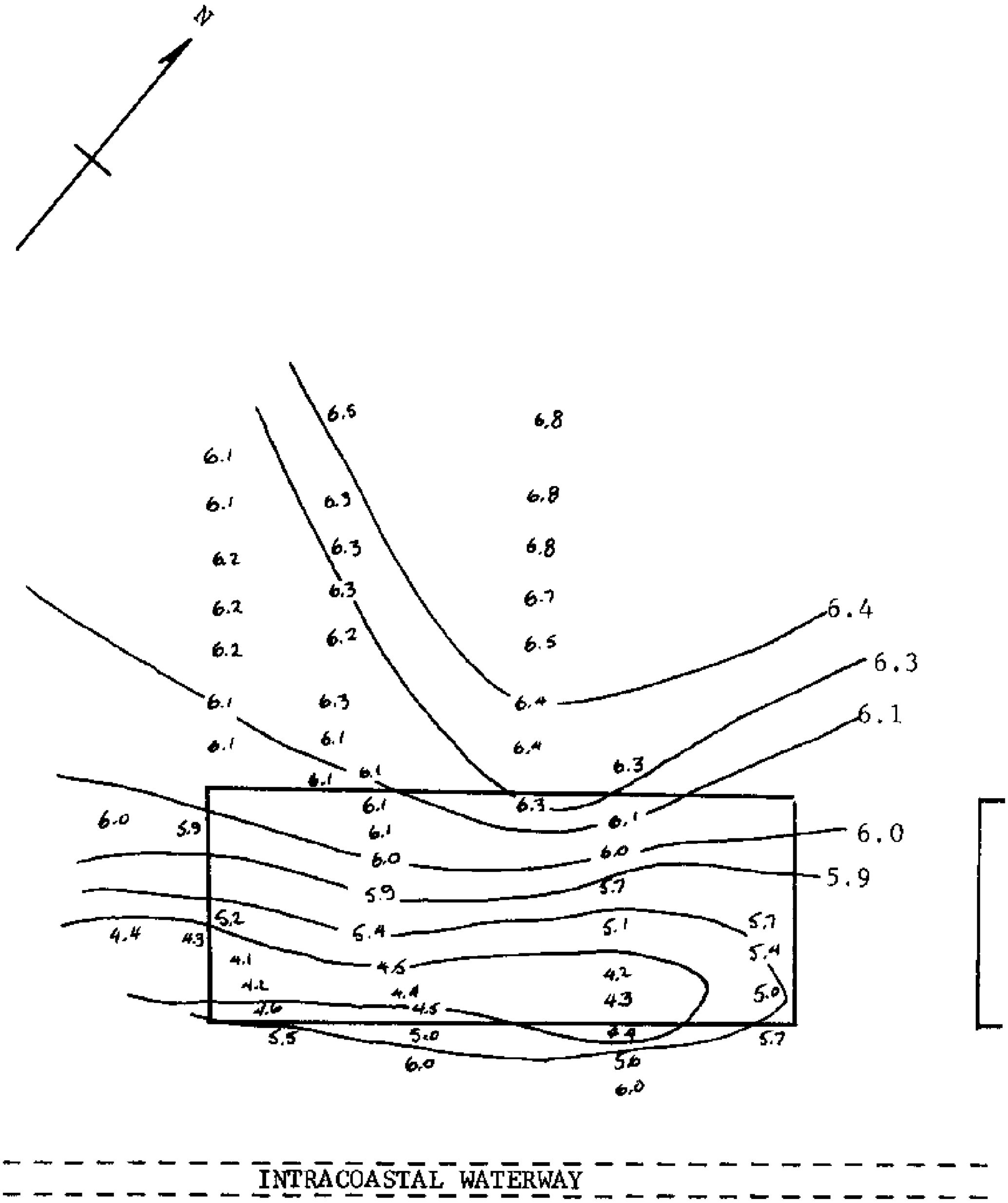

Fig. 9. Bottom profile prior to dredging--March, 1973.

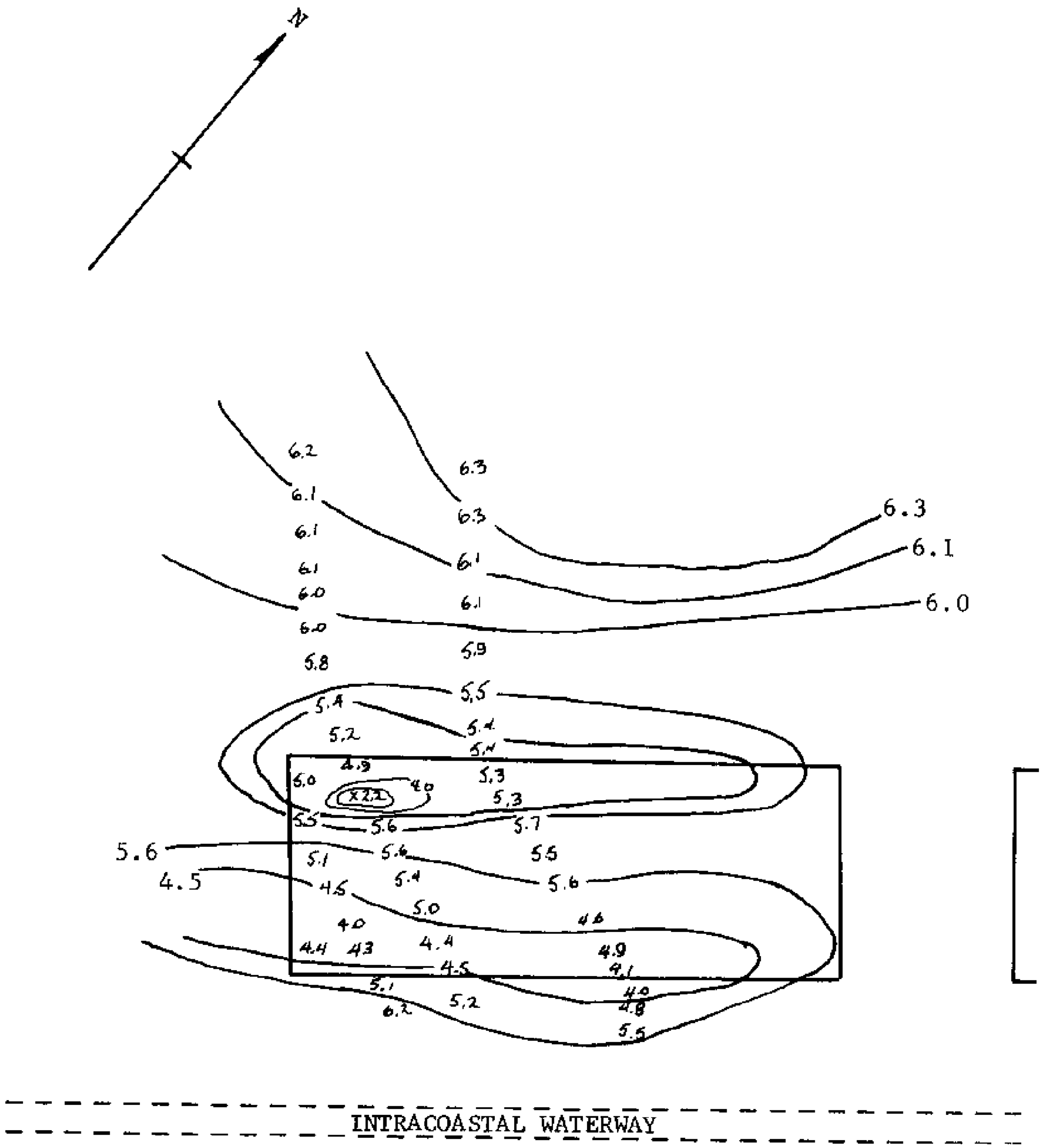

Fig. 10. Bottom profile one week following dredging.

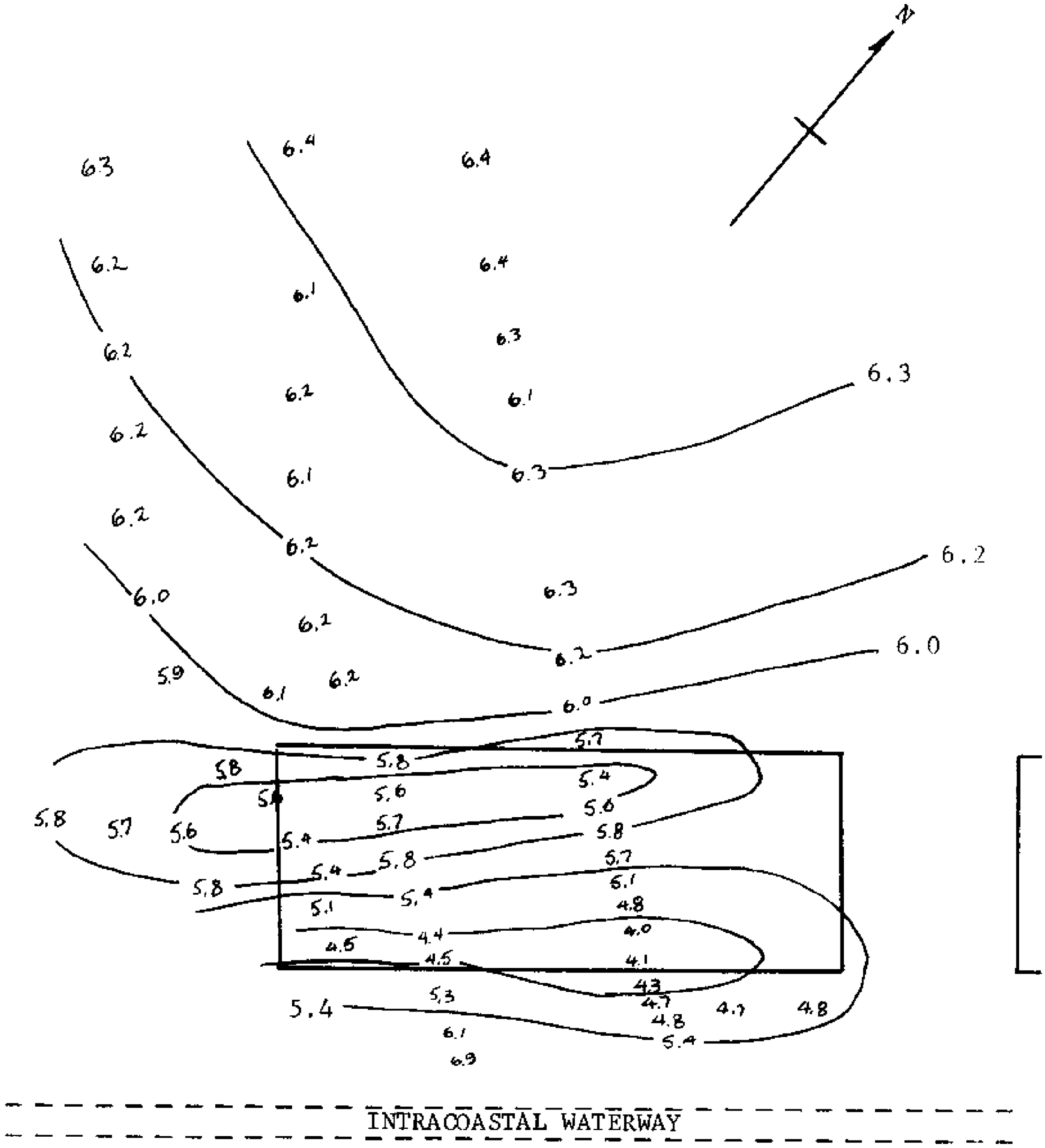

Fig. 11. Bottom profile 22 weeks following dredging.

resulted in their escaping detection. Indeed, the mound indicated in figure 10, which was discovered accidentally, could not be relocated when the stake marking its location (#36) was lost. Figures 10 and 11 indicate extensive spreading over the bay floor, away from the channel.

Bottom contour changes may be detected at least 1000 yards from the boundaries of the spoil area. Spoil does not appear to spread into the interior of the spoil area. This would again tend to eliminate the possibility of the immediate return of spoil to the channel.

One additional bit of information was derived from the bottom contour changes of this area. By manual numerical integration between the contour surfaces within the designated spoil area before and after dredging, an approximate value was obtained for the amount of spoil remaining on the site at these times. After one week 58,000 cubic yards was accounted for inside the spoil area. This was 53 percent of the 110,000 cubic yards accepted by the dredging contractor and the Corps as being placed in the spoil area. After 22 weeks, only 41,000 cubic yards was found in the area. Apparently 63 percent of the spoil had left the spoil area by this time. Perhaps this explains why, over the years, there has been no appreciable build up of material in this spoil area.

Sediment Analysis

Results of the grain size analysis of bottom sediments are presented in figures 12 and 13. The contour lines of figure 12 represent

⑪ Indicates sample number as found in Table III
13.9 Indicates percent silt determined experimentally.

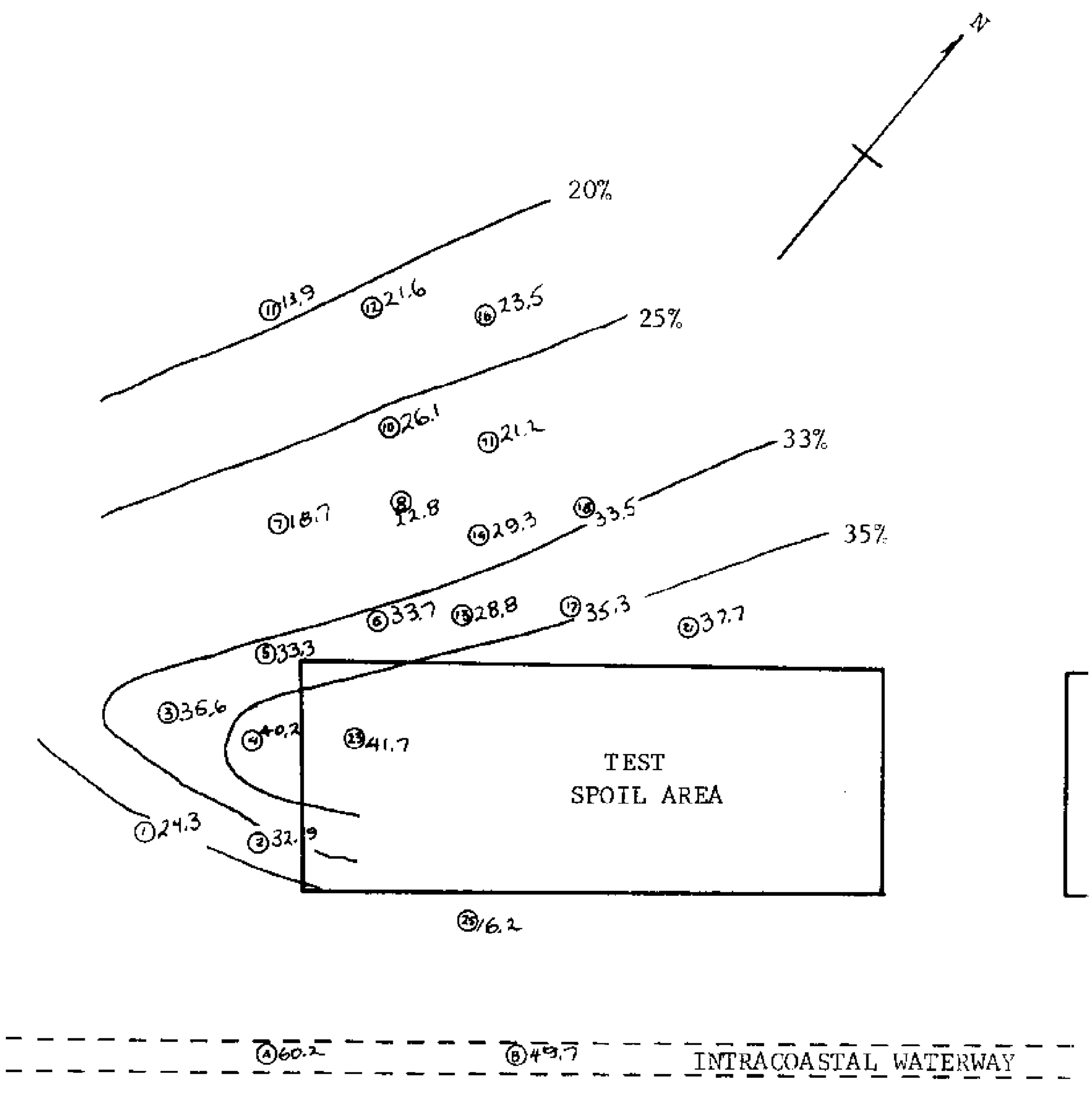

Fig. 12. Percent silt in bottom sediments prior to dredging.

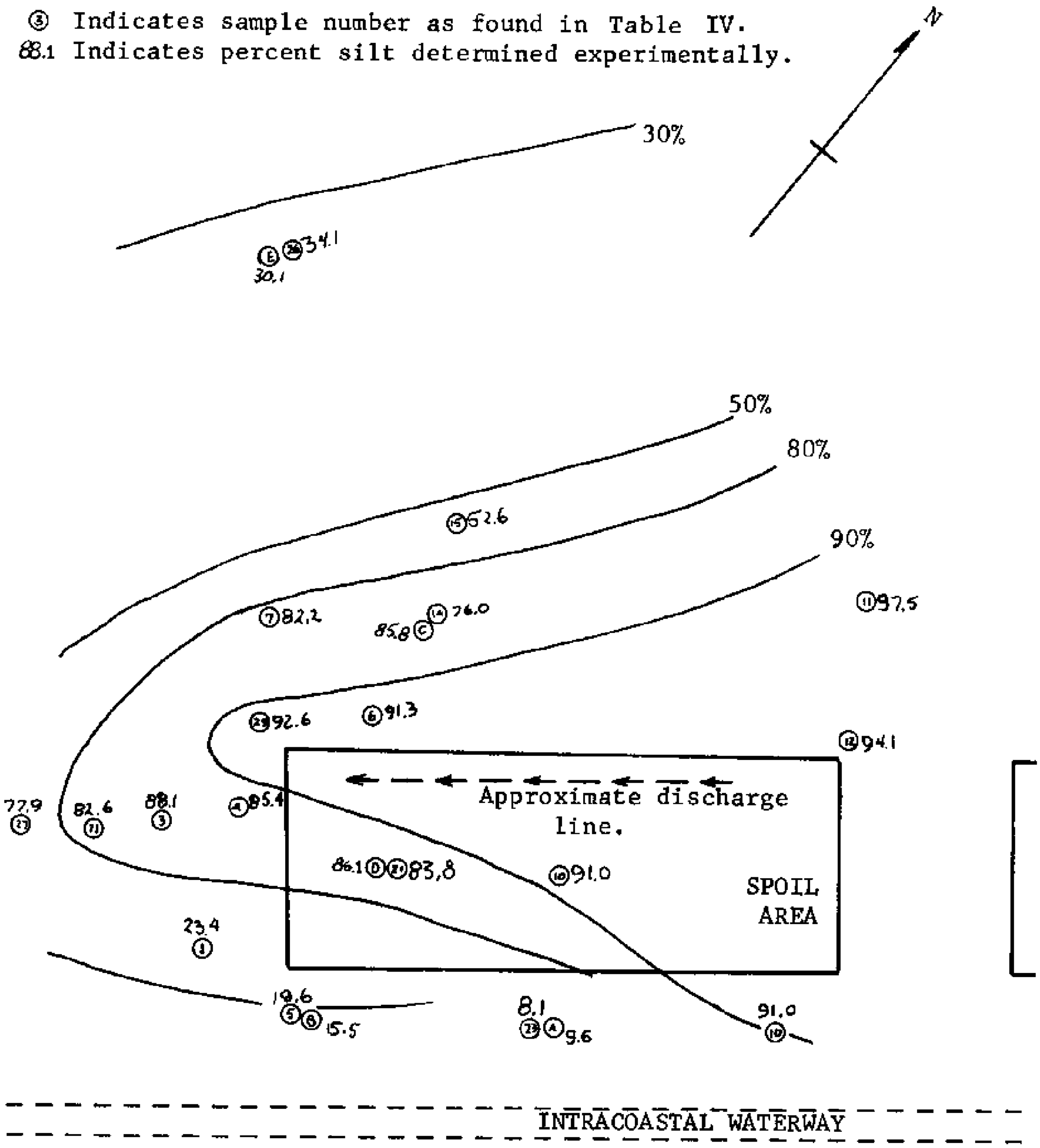

Fig. 13. Percent silt in bottom sediments 15 weeks following dredging.

Table III. Grain size analysis of samples taken prior to dredging. (See fig. 12 for sample locations.)

Sample No.	% Shell	% Sand	% Silt
1	19.4	56.2	24.3
2	16.8	50.1	32.9
3	8.7	55.6	35.5
4	6.9	52.8	40.1
5	10.8	55.7	33.3
6	4.7	61.5	33.7
7	17.7	63.5	18.7
8	6.5	65.5	27.8
10	14.6	62.3	26.1
11	16.7	69.2	13.9
12	11.6	66.6	21.6
13	5.3	65.8	28.8
14	5.3	65.2	29.3
71	11.0	67.7	21.2
16	12.5	63.9	23.5
17	3.4	61.2	35.3
18	5.8	60.5	33.5
21	8.1	54.1	37.6
23	12.1	46.3	41.4
25	18.5	65.2	16.2
A	3.2	36.5	60.1
B	1.2	49.0	49.7

Table IV. Grain size analysis of samples taken fifteen weeks following dredging. (See fig. 13 for sample locations.)

Sample No.	% Shell	% Sand	% Silt
1	25.2	51.3	23.3
3	1.2	10.6	88.1
4	0.9	13.7	85.4
5	9.5	70.8	19.6
6	0.2	8.5	91.3
7	0.1	16.4	82.2
10	0.1	8.8	91.0
11	0.0	2.5	97.3
12	0.1	5.8	94.1
14	0.4	23.5	76.0
15	4.6	42.8	52.5
21	0.1	15.9	83.7
23	0.8	91.0	8.1
25	0.2	7.1	92.5
26	9.0	56.8	34.1
27	0.5	21.5	77.8
71	1.0	14.3	82.6
A*	2.1	88.2	9.6
B*	14.3	70.1	15.5
C*	0.1	14.0	85.7
D*	0.0	13.8	86.0
E*	17.6	52.2	30.1

conditions prior to dredging. Spoil spreading in the direction of the predominant flood tide current is clearly indicated. Effects of the ebb tide current are not as obvious and are no doubt masked by the adjacent spoil area. The low concentrations of silt found between the channel and the spoil area result from the existence of the original low "dike" mentioned earlier. This elevated area is more subject to wave scour and is not favorable for sedimentation of very fine material. All that is found here are larger sand particles and pieces of shell.

After dredging, a dramatic increase in silt content is detected up to 1000 yards from the discharge area. In the discharge area itself, silt content rose to a maximum of 90 percent of the composition of the bed material, well above that found in the channel bottoms prior to dredging. Most likely, some sorting of spoil takes place in the fall from the dredge pipe and during the lateral spread over the bay floor. Fine silts would tend to concentrate in the upper portions of the layer. Sorting of sediments in the channel is not possible due to the agitation caused by constant heavy ship traffic.

Sediment analysis indicates more extensive spreading of dredge spoil than do depth measurements. While grain size analysis cannot be used to determine the thickness or elevation of the uppermost layers, it is extremely effective in detecting changes in composition of layers that are too soft and unconsolidated for direct physical measurement. We can now detect what appears to be spreading around the northeast corner of the spoil area towards the channel (fig. 13).

This effect is not seen with other methods. Since only one sample was taken from this point, it would be difficult to conclude for certain that spoil was flowing in this direction. This is one area in which more data would have been valuable.

A diagram combining the results of all three study methods is shown in figure 14. The boundary between areas which definitely contain spoil, and those which contain no spoil, was quite distinct towards the south and east. To the northwest, in the wide reaches of the bay, effects blended in and it was difficult to detect the difference between spoil and natural bay bottom. Areas adjacent to the neighboring spoil area were affected by its sediments so that no real results could be obtained here.

Environmental Data

The only physical measurements taken in this area of study were current measurements. Airphoto analysis of dye patches and observations of current drogues were the two methods used. It happened that the dye study took place on a flood tide and the drogue measurements were all taken during ebb tides. Both methods revealed maximum current velocities of roughly one foot per second during the time of measurement. The fact that the current flowed from the channel towards the spoil area for both tidal cycles is significant. This would greatly decrease the amount of spoil returning to the channel. However, it would be unwise to consider these few measurements as representative of the current velocity and direction at all

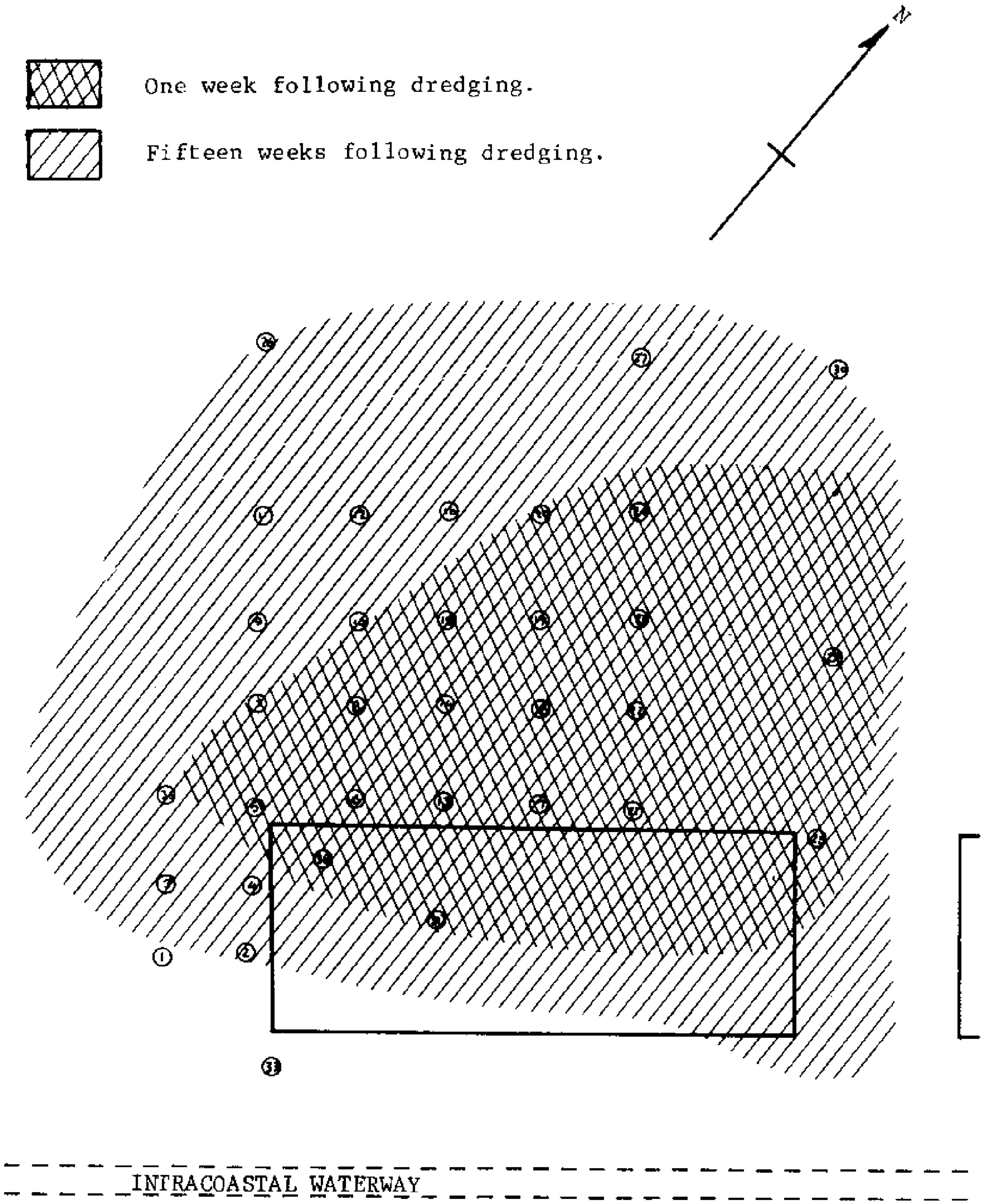

Fig. 14. Approximated spoil distribution following dredging.

times. Local tides are very dependent on the weather, particularly wind directions, and can vary widely from predicted values. Much additional data would have to be taken over a long period of time before definite conclusions could be drawn regarding current patterns at the site.

Other Data

Long-term or average environmental conditions were obtained from other sources as much as possible. The National Weather Service, Galveston, Texas, provided all wind data. General circulation patterns are from Fisher (1972). Information of tidal cycles was obtained from a Corps of Engineers' tide gauge near the study area. No quantitative information was available on wave characteristics in the area.

The tide data is the only information that represents actual conditions present during the study period. The other data did not show local fluctuations in conditions or extreme values which may have existed, such as storms. For more comprehensive understanding of the forces affecting the site, more detailed study of the environmental parameters mentioned above would be desirable. This could entail installation of recording instruments at the study site itself for the duration of the study.

The factors considered by various agencies in selecting or approving dredge spoil disposal areas were obtained by means of a questionnaire (Appendix, p.74). Replies were necessarily brief due to the format of the questionnaire but several important facts were apparent. All of the agencies contacted indicated that their primary concern is in the area of pollution control, with most emphasis being on the effects of polluted spoil on fish and wildlife resources. The effects of spoil areas on tidal flows or circulations was listed by most as a consideration but only in the light of possible adverse effects on the biological community. In short, the effect of spoil location on future shoaling and repeated maintenance dredging is not a major consideration of these agencies.

Analysis

A review of sediment transport mechanisms indicates that there are several factors which control spoil movements in estuaries. Very briefly, these factors are grain size, degree of consolidation, and bed current velocity. If the sediment characteristics of an estuary are fairly constant throughout the estuary, current velocity becomes the controlling factor in determining variations in sediment behavior. This current velocity is a combination of the tidal current velocity plus the horizontal component of wave orbital velocity at the bed. From Table I, p. 28, it was seen that wave orbital velocity increases as depth decreases. In the study area, unconsolidated sediments at a depth of less than four feet would be subject to erosional velocities due to wave orbital motion alone whenever surface winds reached twelve miles per hour. A decrease in depth could initiate shoaling of waves over shallow water, which would greatly increase erosional tendencies.

In an area such as Galveston Bay, which generally has a uniform bottom depth, the tendency of erosion due to wave orbital motion is essentially constant throughout the estuary. Tidal current velocities may vary depending on geography, but in most areas, the flat bottom attests to the fact that erosion and deposition are uniformly distributed. This flat bottom in turn tends to keep these dynamic processes uniformly distributed. It now becomes apparent that creation of dredge spoil mounds in an estuary such as Galveston Bay aggravates erosion of the spoil mound.

In the dredging project described in this study, it was specified that spoil be piled to a maximum height of one and one-half feet above mean low water. This could not be achieved due to the fluid nature of the dredge spoil. However some materials such as consolidated clays could be made to form such elevated mounds. These mounds would then be situated in an area of maximum erosion potential. It would appear to be more desirable to discharge spoil in a manner such to create many low spoil mounds, less subject to erosion than to concentrate spoil in a few elevated mounds highly subject to erosion. Perhaps spoil disposal in a relatively thin layer over a wide area would be one method of decreasing erosion and transport from a spoil area.

CONCLUSIONS AND RECOMMENDATIONS

Based on bottom contour changes and sediment grain size analysis, it appears that the predominant force directing gross spoil movements in the study area is tidal current velocity. Estimated values of wind induced wave orbital velocity at the sediment surface indicates this parameter to be capable of scour at depths less than four feet or at wind velocities over 25 miles per hour. When tidal currents are below critical values required for scour, wave orbital velocity alone may cause suspension of sediments, allowing transport by the tidal currents to take place.

Dredge spoil was found to occur up to 1000 yards from the point of discharge within one week following dredging. As much as 47 percent of the material placed inside the confines of the spoil area was carried out of the area within one week of deposition. At the end of five months, 63 percent had been carried out of the area.

The original dike, placed parallel to the channel during initial construction, was effective in containing spoil and preventing its immediate return to the channel, although there were some indications of sediment flowing around this dike and back to the channel.

Permanent measuring stakes driven into the bay floor can be made a useful tool in measuring gross sediment movements. Wooden stakes have the disadvantage of working loose over a long period of time. Metal ones could pose a navigational hazard. Properly weighted wooden stakes would solve this problem. Bottom elevation surveys, combined with sediment grain size analysis, proved most effective in this study. Grab samples are preferred over cores because of convenience. No significant difference was noted in the analysis of sediments taken by the two methods. Core samples do allow greater control over the depth of sediment to be analyzed.

The main criterion used by most agencies for spoil site selection or approval appears to be limited to possible adverse effects of such sites on the biological systems in the estuary. The effects of the site on channel shoaling and future maintenance dredging are generally not considered.

The methods used in this study limited observations to more or less qualitative analysis of spoil movements. Since most of the dredge spoil placed in this area appears to move away from the channel, shoaling in this reach must be due primarily to sediments carried in from natural bay bottoms. It would be desirable to know quantitatively which portions of shoal material are spoil and which are natural sediments, the ultimate aim being to determine the possible reduction in maintenance dredging should all spoil be diked or otherwise removed from the system.

The most direct method of quantitative measurement is labelling of an actual sample spoil with some type of radioactive or fluorescent tracer material so that its subsequent movement may be followed in detail. Applications of these methods to the spoil area in question is recommended for a future study, as it would allow comparison with results obtained during this study. It is also recommended that data taken during any similar work in the future include much more environmental data (currents, winds, waves, tides) than was collected here. Installation of recording instruments in the study area itself would be very desirable.

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APPENDIX

GLOSSARY

1. Bed Load. That portion of the total sediment load of a stream which remains in contact with the bed of the stream. Transport is usually in the form of short jumps.

2. Clay. Sediment particles finer than 0.005 mm. This material exhibits cohesion, or a property in which the separate particles tend to stick together.

3. Dispersion. In the context of this paper, that is, spoil dispersion, this is the spreading of spoil material due to turbulent mixing or sediment transport such as bed load.

4. Dredge Spoil. That material removed from a navigation channel by dredging.

5. Estuary. Any semi-enclosed bay with fresh water inflow and subject to sea water and tidal influences.

6. Flocculation. A process by which suspended particles stick together upon collision, forming larger particles which have a greater settling rate. Generally applies only to clay size particles.

7. Sand. Sediment particles between 4.76 mm. and 0.074 mm. in diameter, or between gravel size and silt size.

8. Shoaling. The accumulation of sediments on the bottom due to sediment transport and deposition.

9. Silt. Sediment particles between sand size and clay size. Diameter ranges from 0.074 mm. to about 0.005 mm.

10. Spoil Area. Any area in which dredge spoil is deposited. Spoil areas on land may be diked to contain all spoil except the effluent water, or undiked, so that spoil may spread. Spoil areas in open water may also be diked or undiked, submerged or emergent from the water.

11. Suspended Load. That portion of the total sediment load of a stream which is suspended in the fluid and travels with the velocity of the fluid mass in which it is located.

12. Turbidity. The reduction on light transmission through a fluid due to scatter of light caused by suspended sediments.

QUESTIONNAIRE

1. What is your capacity in working with the Corps of Engineers in selecting new disposal sites? (Check one or more).

   Selection of new sites ____________

   Approval of sites already chosen _________ By whom? __________

   Limited to only making recommendations __________

   Comments: ____

   ____

2. On what do you base decisions regarding any selection or approval of spoil sites?

   Laboratory analysis of spoil material ___________

   Laboratory analysis of site material ___________

   Which analyses are made, if any _______________________________

   Spoil disposal methods ___________

   Location of site in regard to:

   Dredging area __________________________

   Developed land _________________________

   Cultivated land ________________________

   Wildlife sanctuaries ___________________

   Coastal fauna i.e. oyster beds _________

   Effects on tidal flows or circulation __

   ____

   Comments: ____

   ____

3. Do you analyze the spoil area in regard to:

Drainage back to coastal water ____________

Need for drainage weirs or channels ________

Length of time spoil area will be used _____

Possible value as reclaimed land __________

Ultimate amount of spoil to be deposited ___

Comments: ____

____

4. What controls are available to assure that your specifications are being followed?

____

____

____

Name ______________________________

Title _____________________________

Organization ______________________