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Report to the Coastal Erosion Abatement Commission, Commonwealth of Virginia concerning the inventory of sand supplies in the southern Chesapeake Bay

Carl H. Hobbs III
Virginia Institute of Marine Science

Robert J. Byrne
Virginia Institute of Marine Science

Robert A. Gammish
Virginia Institute of Marine Science

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Virginia Institute of Marine Science
School of Marine Science
College of William and Mary

Final Report to the Coastal Erosion Abatement Commission Commonwealth of Virginia concerning the Inventory of Sand Resources in the Southern Portion of Chesapeake Bay

Prepared by

Carl H. Hobbs, III
Robert J. Byrne
Robert A. Gammisch

With contributions by

Robert J. Diaz, Jacques van Montfrans, and Linda C. Schaffner
and
Drake Engineering Company

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FOREWORD

This final report to the Coastal Erosion Abatement Commission concerning the inventory of sand supplies in the southern portion of Chesapeake Bay is a continuation of the work reported on in September 1981 (Byrne _et al_). The report includes technical appendices in addition to the general text.

Because the 1981 progress report received limited distribution, some of the material presented therein is repeated in this report so that the reader will have all the pertinent information in a single document.

INTRODUCTION

In its report to the Governor and the General Assembly of Virginia (Senate Document No. 4, Commonwealth of Virginia, 1979), the Coastal Erosion Abatement Commission found that "there is a need to locate sources of sand supplies for rebuilding public beaches. Certain bottom areas in the lower Chesapeake Bay should be studied as possible sources of sand supply for public beaches." Toward that end, the Commission recommended that "The School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, study and analyze possible sources of sand supply in the lower Chesapeake Bay and vicinity for rebuilding public beaches."

The Commission amplified its recommendation for providing funds to the Virginia Institute of Marine Science for studies as follows:

> to assess the extent and quality of the sands for beach nourishment within the inner approaches to Hampton Roads which would include the entrance to Lynnhaven Inlet, Willoughby Bank, Horseshoe Shoal fronting Hampton, Hampton Flats and other areas in the environs deemed appropriate. This study, to be completed in a period of three to four years, would include:
>
> a. Determination of the extent and quality of sands for beach nourishment purposes in the aforementioned areas;
> b. Study of the most economical means of recovery and transportation of potential sands to the target areas; and
> c. Assessment of the environmental risk of extraction to the associated marine ecosystem.

The Commission's recommendations, which became a charge to the Institute, stemmed from the following reasoning, also from Senate Document No. 4.

> The public beaches at Virginia Beach, Norfolk and Hampton rely upon beach nourishment to maintain their recreational capability and to provide a buffering beach width as protection for the fastland and shoreside facilities....In all cases, locating suitable and economical marine sand sources which can be extracted at acceptable environmental risk is a serious problem. Implementation of the Corps of Engineers plans at Virginia beach would require initial sand volume of 2.5 million cubic yards. If nourishment is the recommended strategy at East Ocean View and Willoughby Spit in Norfolk, about 2.5 million cubic

yards will be required. Combined annual maintenance requirements would be about 250,000 cubic yards.

Studies of the Corps of Engineers (1972) disclosed the existence of a very promising deposit in the Thimble Shoals Channel area, estimated to be about 12 to 19 million cubic yards of coarse sand and gravel. In 1974, about 452,000 cubic yards of material were stockpiled at Fort Story for later use. The extraction was part of an enlargement of the Thimble Shoals navigation channel. While it is encouraging to have such a deposit available, the extraction is only economical if very large volumes are dredged. Consequently, a large storage area would be required. The Corps of Engineers study included reconnaissance work in the zone offshore of oceanfront Virginia Beach. Materials comparable to the Thimble Shoals deposit were not found.

With the exception of about 20,000 cubic yards of sand placed from an upland site in 1979 just west of the Little Creek jetties, all of the prior nourishment sand placed on the East Ocean View-Willoughby Spit area in Norfolk has been derived from dredging operations in the Little Creek entrance and forebay area. In 1975, a channel enlargement was made but the material (about 800,000 cubic yards) was placed on the beaches of the U.S. Navy Amphibious Base at Litle Creek. If the Corps of Engineers study, to be completed in 1982, justifies a nourishment program, approximately 2.5 million cubic yards of sand will be needed. Even without the federal project, the City of Norfolk needs to maintain a sand supply for the East Little Creek-Willoughby Spit area. While sand bypassing from the updrift side of Little Creek remains a possibility, the determination of the feasibility awaits the completion of the sand budget analysis by the Corps of Engineers.

Alternate souces must be evaluated. Willoughby Bank is a source worthy of investigation. During the construction of the second Hampton Roads tunnel, a borrow area on Willoughby Bank adjacent to Fort Wool was utilized to provide foundation sand for the tunnel tube and surcharge for a tunnel island. Subsequent to that, the surcharge material was successfully used as beach nourishment sands at Buckroe Beach in Hampton.

Given the need for beach nourishment sands for the public beaches of Virginia Beach, Norfolk and Hampton, additional investigations of the extractable subaqueous sand resources are required. These investigations would augment the earlier studies by the Corps of Engineers east of the Chesapeake Bay Bridge-Tunnel by extending the assessment to the inner approaches to Hampton Raoads and those areas fronting Hampton and Lynnhaven Inlet.

To these ends in July 1980, the Virginia Institute of Marine Science (VIMS) of the College of William and Mary commenced an inventory to delineate and characterize offshore sources for sand that might be used to nourish the public beaches that rim southern Chesapeake Bay.

The portion of the Bay included in the study (Figure 1) is bounded by the shoreline, the Hampton Roads Bridge Tunnel, a line connecting Northend or Factory Point at the mouth of the Back River in Hampton with the entrance of the Chesapeake Channel through the Chesapeake Bay Bridge Tunnel, and a line running south from there to the vicinity of Cape Henry. On the east, this area overlaps the area investigated by Meisburger (1972). The combination of the two reports provides an assessment of the sand resources from the Virginia Capes west to the Hampton Roads Bridge Tunnel. In the present study we paid particular attention to the shoal areas with geomorphology which suggests they might be sources of sand.

The goal of the study has been to provide a comprehensive assessment of the sand resources that are suitable for beach nourishment coupled with a sufficient assessment of the environmental risks and of the economics of extraction so that it is possible to identify the locations that are most suitable for mining sands to be used for beach nourishment. There are three primary aspects to the study: an evaluation of the sand resources; an assessment of the biological communities associated with the areas of promise; and an engineering assessment, including costs, of various methods of mining the sand and transporting it to specific target areas. The first two elements were completed at VIMS, the last was subcontracted to Drake Engineering of Richmond, Virginia.

Assessment of the geographical extent and the thickness of the sands was performed with borings into the substrate and with sub-bottom seismic lines connecting the borehole locations. The seismic traces sediment horizons which because of physical properties reflect the acoustical signal.

When the sand horizons found in borings coincide with the depth of a seismic reflector the vertical position of the sand horizon between boreholes may be interpolated and the three-dimensionality of the "deposit" thereby outlined. The quality of the sand deposits was evaluated by laboratory analysis of samples from the cores. Of particular importance are the average grain sizes of the sand, the distribution of the grain sizes in a sample, and the quantity of silt and clay that is included with the sand.

The biological assessment focused on the hard clam, the principal resident commercial species, and on the macrobenthos, those invertebrates living within and on the sediments which are the principal food source for finfish and crabs. Field sampling surveys and laboratory analyses provided the basis for quantitative assesments of the hard clam community and relative values of the macrobenthos.

The principal results of the biological and engineering reports are integrated within the body of this report and the separate, full technical reports are reproduced in the appendices.

An interim progress report was submitted to the coastal Erosion Abatement Commission in September 1981. Because that report received limited distribution the relevant material is repeated in this report so the reader will have all of the findings in a single document.

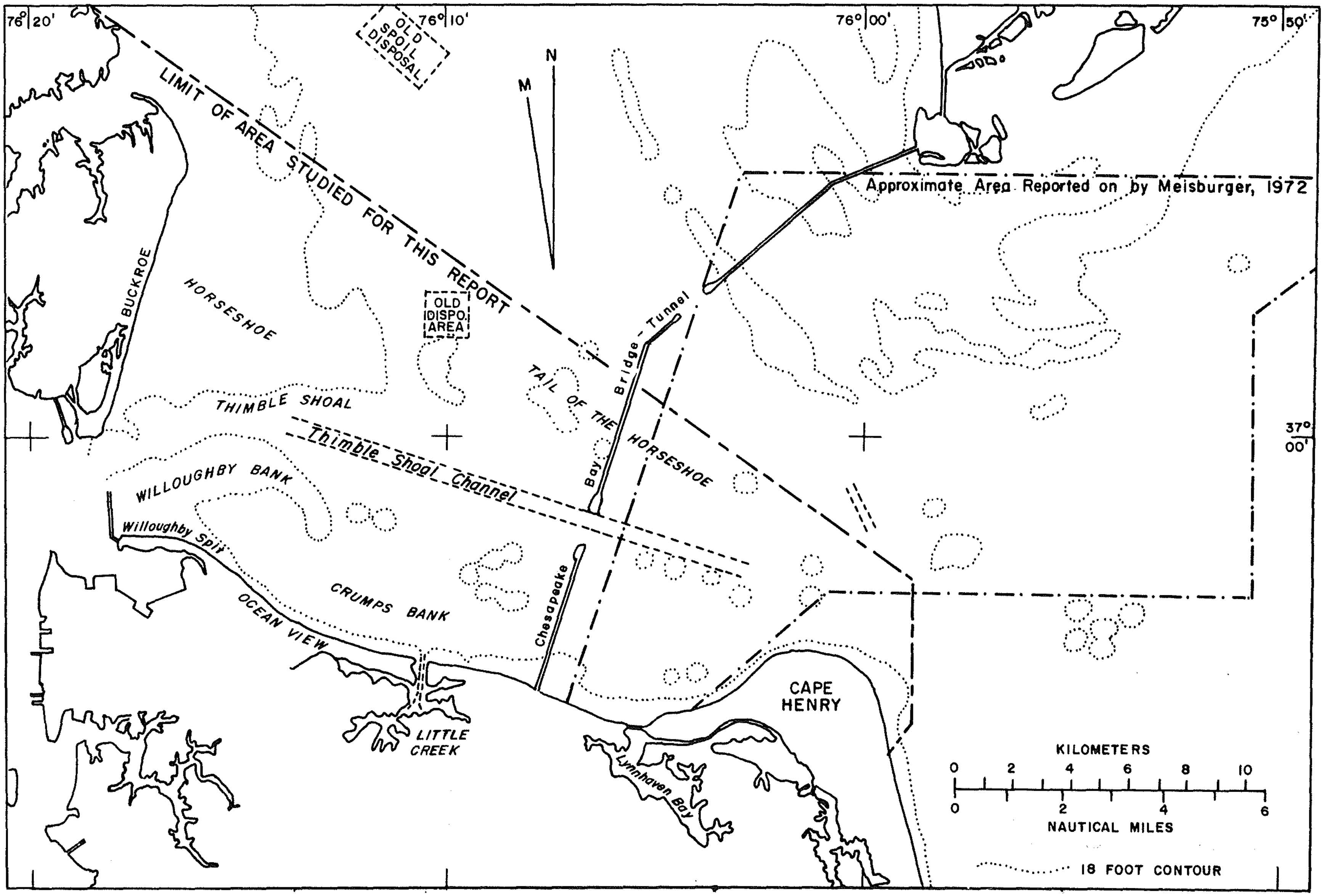

Figure 1: Map depicting the location of the study area.

SUMMARY OF FINDINGS

Within the area encompassed by the study there is in excess of 230 million cubic yards of sand that is suitable for use in beach nourishment. Various environmental, physical, and institutional constraints, however, may limit the volume of sand that is most readily available to approximately 120 million cubic yards. This supply is much greater than currently projected needs for beach nourishment. The areas with suitable sand and less than three feet of unsuitable overburden are shown in Figure 2, and the approximate volumes of the respective sand resources are listed in Table 1.

A. Willoughby Bank. The southern flank of the natural Thimble Shoals Channel to the crest of the shoal is the prime location of suitable sand in this area. The horizon has a maximum thickness of 28 feet at the crest and thins to 3 feet lower on the channel flank. However, comparisons of values of the benthic resources and the hard clam fishery among areas A, B, and C (Figure 2) indicate Willoughby ranks higher and sand excavation from this area would therefore be less appropriate than from the other areas. Also, part of the channel flank falls within a zone restricted by the U. S. Navy (R1 in Figure 2).

B. Horseshoe-Thimble Shoal. This zone has the largest volume of sand suitable for beach nourishment found in the survey, approximately 120 million cubic yards. Part of the deposit (approximately 10 million cubic yards) falls within the aforementioned U. S. Navy restricted area. A second restricted zone (R2 in Figure 2), a firing range at Fort Monroe, could inhibit extraction. These restrictions combined with environmental concerns regarding the hard clam fishery and the inadvisability of extraction close to shore limit the availability of those sections of the deposit. However, these limitations combined would result in loss of availability of only 20 million cubic yards. From the viewpoint of value of the biological resource the Horseshoe-Thimble Shoal area (Zone B in Figure 2) is ranked equivalent to Tail of the Horseshoe (Zone C in Figure 2), but the Horseshoe-Thimble Shoal area (Zone B) has a marginally higher value of benthic resources.

C. Tail of the Horseshoe. The western portion of the Tail of the Horseshoe, designated as C in Figure 2, contains at least 80 million cubic yards of suitable sand. From the viewpoint of environmental concern this zone has the lowest ranking with respect to value of the benthic resources. The thickness of the deposits varies between 5 and 15 feet in thickness.

D. Thimble Shoals Channel-Eastern Beach. In 1972 the Corps of Engineers (Meisburger, 1972) studied this area (Zone D in Figure 2) and determined that it contained approximately 18 million cubic yards of suitable material. The present study confirms the early findings. Approximately 500,000 cubic yards of sand has previously been taken from this area for nourishment at Virginia Beach (through interim storage at Fort Story). If the project to deepen the channels to Hampton Roads to fifty-five feet comes to fruition, approximately 3 million cubic yards of sand from the area would be available. The

Table 1. Volumes of Suitable Sand By Area

Zone	Area	Volume (millions of cubic yards)
A	Willoughby Bank	6
B	Horseshoe-Thimble Shoal	120
C	Tail of the Horseshoe	80
D	Thimble Shoals Channel (Eastern Reach)	18
E	Crumps Bank	2
F	Cape Henry	6
G	Lynnhaven Inlet Basin	1

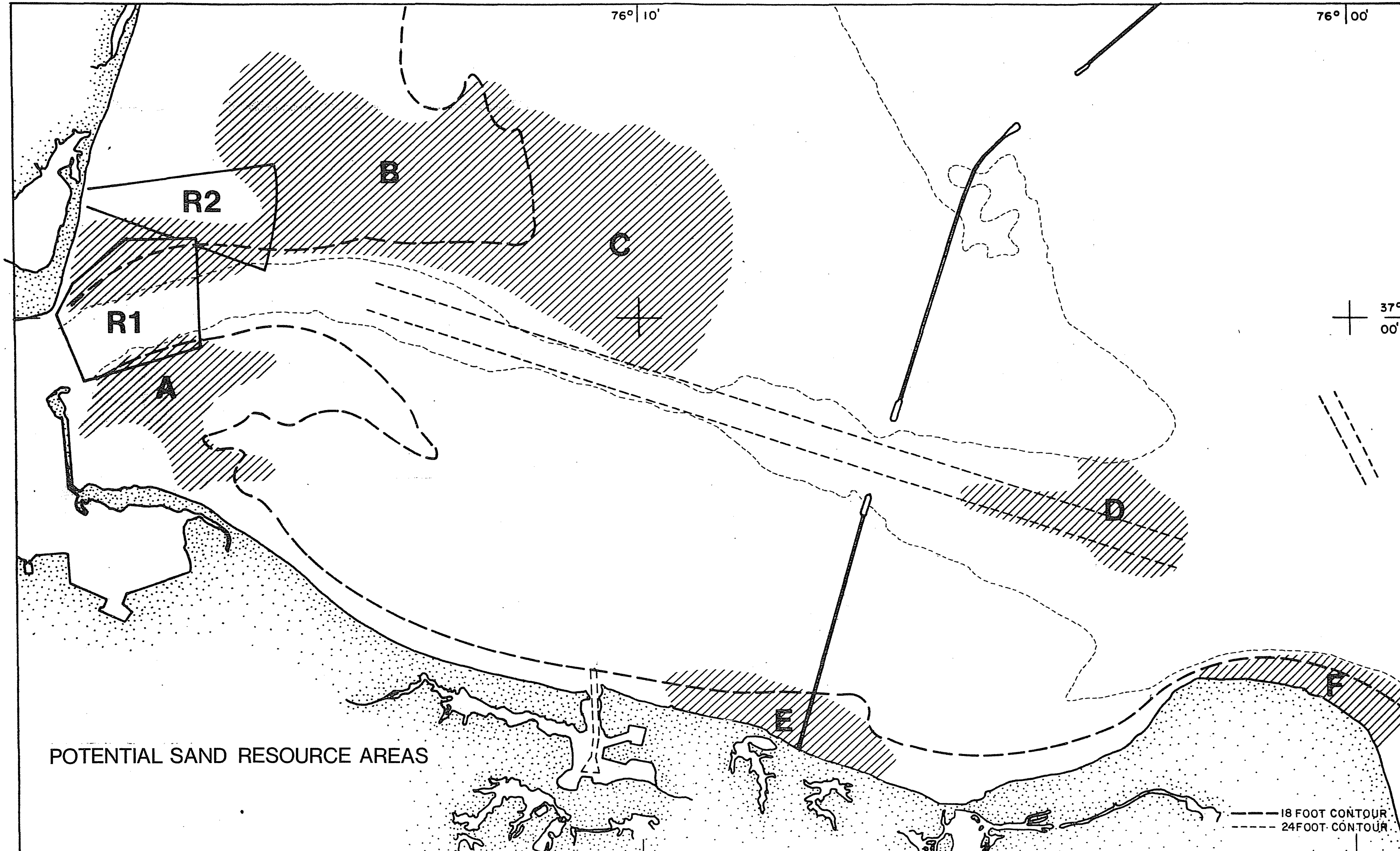

Figure 2: Map depicting the areas with sand resources.

Norfolk District of the Corps of Engineers has made additional barrings and is currently assessing the project.

E. Crumps Bank. The surface sediments in the Crumps Bank area are generally very fine grained salty-sands, grading to medium sands near the Beach. However, a surface deposit between the entrances to Little Creek and Lynnhaven (Zone E in Figure 2) has a thickness between 7 and 20 feet, with a volume of approximately 3 million cubic yards. Given the proximity to shore, extraction of these materials is inadvisable since deepening the nearshore zone will concentrate more energy at the beach.

F. Cape Henry. The nearshore region adjacent to Cape Henry (Zone F in Figure 2) has a sand deposit exceeding 35 feet in thickness with a potential volume between 6 and 15 million cubic yards. However, as in Zone E, this material is close to shore and extraction is inadvisable.

G. Lynnhaven Inlet Basin. Limited investigation inside the Lesner Bridge (Route 60) indicated sand deposits ranging in thickness from 10 to 35 feet which could yield in excess of 11.5 million cubic yards. Additional work would help to delineate the extent of the horizon.

The biological assessment conducted has provided a basis for a relative ranking of the value of the benthic resources of Zones A, B, and C. This assessment deals with bottom resources which would be lost during the excavation process. Additional site specific environmental evaluations would be warranted to address individual proposals for extraction. Presumptive evaluations are not practical since the level of impact would vary as a function of specific location, areal extent, depth of the proposed borrow site, and the methods utilized in dredging. Of prime concern is the potential for the excavated site to be recolonized by a benthic community with resource value equivalent to or higher than the native bottom. The potential for recolonization will depend upon the characteristics of the post-excavation substrate, the rate of sediment filling, and the characteristics of the sediments filling the excavation, and, most importantly, upon maintenance of a sufficient level of dissolved oxygen in the water column to sustain the benthic community. Because of the latter requirement the depth of the excavation below the natural bottom must be carefully evaluated.

The method used in dredging and loading (if a barge or hopper system is used) controls the level of increased turbidity. Increased turbidity can affect the biological activity within the water column. Moreover, the settling of suspended solids can affect the benthic community living in areas immediately adjacent to the excavation site. However, as the sites identified as having suitable sands contain relatively low concentrations of fine grained sediments and organic material, the problem of increased turbidity should not be severe. Nevertheless, the dredging strategy for extraction should be designed to minimize impacts due to increased turbidity.

With respect to cost and engineering there is an interactive set of options pertaining to the methods of dredging, of transporting the sand to the shore, and of distributing the sand along the beach. The location of the excavation site relative to the beach, the intervening water depths, and the quantity of sand to be moved also are factors to be considered. In this study, unit costs (1982 dollars) are based on a presumed requirement for 2.5 million net cubic yards each on the Norfolk beaches (East Ocean View and Willoughby Spit) and in Virginia Beach, and for 250,000 cubic yards at Hampton (Buckroe and Salt Ponds area). From the various options for the Norfolk Beaches the lowest option has the Tail of the Horseshoe (Zone C in Figure 2) as the source and uses a hopper-barge, mooring buoy, and pumping system to excavate a gross of 3 million cubic yards at a net cost of $5.47 per net cubic yard. For the case of Virginia Beach nine alternative methods were examined. The apparently lowest cost option is extraction from the inbound-outbound access channel off the shore of Virginia given that suitable materials are available. The suggested method is hopper-barge from the channel area to a mooring point, and a pipeline discharge to the beach. Transfer of a gross volume of 3 million cubic yards would cost $5.53 per net cubic yard. Direct pipeline pumping to the beach from the access channel would involve extraction of a larger volume of sand and a net cost of $9.34 per net cubic yard. Aside from using the Atlantic access channel other alternatives utilize the eastern reach of the Thimble Shoal channel (Zone D in Figure 2). Costs, depending upon dredging method and distribution, vary between $12.15 and $8.11 per net cubic yard. All these options require an interim storage-site on land; costs are based on the assumption of using Fort Story. The costing of these options for Virginia Beach did not include the possibility of reduced unit costs which may be derived from cost sharing with the deepening of the navigational channels to Hampton Roads.

The strategy for nourishment of the beach in the City of Hampton assumed a one-time net replenishment of 250,000 cubic yards. The source was on Horseshoe-Thimble Shoal with direct pumping by hydraulic dredge. Cost is projected to be $6.79 per net cubic yard.

METHODS

The field work for the inventory of sand resources was conducted in three discrete phases during a 2 year period. The first phase, performed jointly with the Norfolk District, U.S. Army Corps of Engineers, involved taking 45 short (20-foot) vibratory cores and using a 7.0 kHz, sub-bottom profiling unit to discern bedding and structures between the cores within the sediment package. The Corps provided the Elizabeth, a self-propelled crane-barge, and crew along with a marine geologist and a project coordinator. VIMS provided the vibracoring equipment and materials, the sub-bottom profiling unit, navigation equipment, a marine scientist and technicians. The locations of all the cores obtained during the project are shown on Figure 3.

The vibracoring unit uses a steel casing or core barrel with a 3 1/2-inch (8.9 cm) diameter, clear, plastic liner. On the bottom, the unit is free-standing and penetrates the bottom using the energy of a pneumatic, vibrating power-head and gravity. Rate and depth of penetration are automatically recorded on a strip chart. Penetration is complete when the unit has gone to maximum depth or has met refusal. The equipment then is hoisted back onto the barge and the sediment-filled plastic liner, the core, is removed. The cores are then labeled, cut into 5-foot lengths, capped, sealed, and returned to VIMS. In the laboratory the core sections are cut open, described, logged, and sampled. The sediments were classified according to the Unified Soils Classification System (U.S. Army Engineer Waterways Experiment Station, 1960). Individual samples and composit samples from the cores were analyzed for grain-size distribution characterisitcs and suitability as beach-fill.

In November, 1980, the Norfolk District of the Corps published their report "Sub-surface Investigation for Beach Nourishment." In addition to the general text, it contains the logs and grain-size distribution curves for the cores obtained in this joint operation phase of the study.

The second phase of the project was a more detailed investigation of areas that appeared from the data from the first phase, to be likely sources of sand. The Corps did not participate in this phase of the work. During this portion of the study we used the coring unit in its longer, 40-foot mode and obtained 28 additional cores. These cores were analyzed in the same manner as the preceding cores. During this phase, VIMS contracted the use of a crane-barge and pushboat. As before core-site locations were documented with Loran-C fixes and horizontal sextant angles.

In addition to the 7.0 kHz sub-bottom profiles recorded while steaming from one core location to the next, an independent seismic survey was conducted in April 1981. This study was subcontracted to Ocean Seismic Survey of Norwood, New Jersey, and consisted of approximately 120 nautical miles of track lines (Figure 4). The survey was conducted aboard the VIMS research vessel Captain John Smith and utilized; a 3.5 kHz O.R.E. sub-bottom unit, a 100 joule EG&G "Uni-Boom" filtered for 1.5 kHz, a 100 kHz Kline side-scan sonar unit, and a 200 kHz Raytheon recording fathometer to collect a full spectrum of bottom and sub-bottom data. All data were automatically recorded on separate paper strip charts. Navigation coordinates were controlled by a Loran-C microprocessor system combined with a X-Y plotter which provided fix marks for final interpretation and reduction of the data.

The third, and final, phase of field work took place during 1981 when we obtained an additional 30 vibracores. As in the second phase, the corer was used in its 40-foot mode from a contracted crane-barge platform. The sites for these cores were chosen so as to confirm or better define the high-interest areas delineated by the previous year's work. Also some cores were taken in order to better merge the data from the project with the data from an earlier study in an adjacent area (Meisburger 1972).

In all 103 vibrocores were obtained. In addition to the work of Meisburger (1972), unpublished logs of cores held by the Chesapeake Bay Bridge Tunnel Authority and the Virginia Department of Highways have been most helpful. Throughout the course of the project there has been close liason with the Norfolk District, Corps of Engineers.

Laboratory analysis of the cores involved splitting, logging, sampling, and analyzing the individual samples to determine the weight percent silt and clay and the grain-size distribution of the sands. The core logs, are not reproduced as part of this document and are bound separately as Appendix E. In addition to sediment samples taken at specific horizons in the cores, integrated or composite samples were taken. These represent the bulk analyses over several feet of substrate. This procedure was followed since the composite characteristics are what a dredge intersects during excavation. The results of the sieve analyses for the composite samples are given in Appendix E. The most important determinant for suitability of sand for use as beach nourishment is the similarity of the material from the borrow site to the native beach material. In general, the closer the average grain sizes and grain size distributions (standard deviations), the more suitable the material. Slightly coarser and better sorted materials are preferable to finer or less well sorted sediments. There are a number of methods of calculating a "suitability index" or "overfill ratio." These calculations provide information that can be used as a guide in augmenting and verifying the judgements made by professionals based upon their training and experience. The closer the overfill ratio to unity, the better the suitability of the borrow material. The overfill ratio is an estimate of the number of cubic yards of borrow material that must be placed on the beach for one cubic yard to remain after the system has had a chance to be subjected to wave action and to approach equilibrium. Hence, an overfill ratio of 5:1 suggests that for each 5 cubic yards placed on the beach, 4 wash back into deeper water whereas a ratio of 1:1 implies only a minimum of adjustment. The method of calculating the overfill ratio used in this study is the so-called "Dean Method" (Dean 1974; Hobson 1977).

Personnel from the Norfolk District of the Corps of Engineers sampled in beaches of Willoughby Spit and Ocean View in order to characterize the native sediment in August and November 1978.

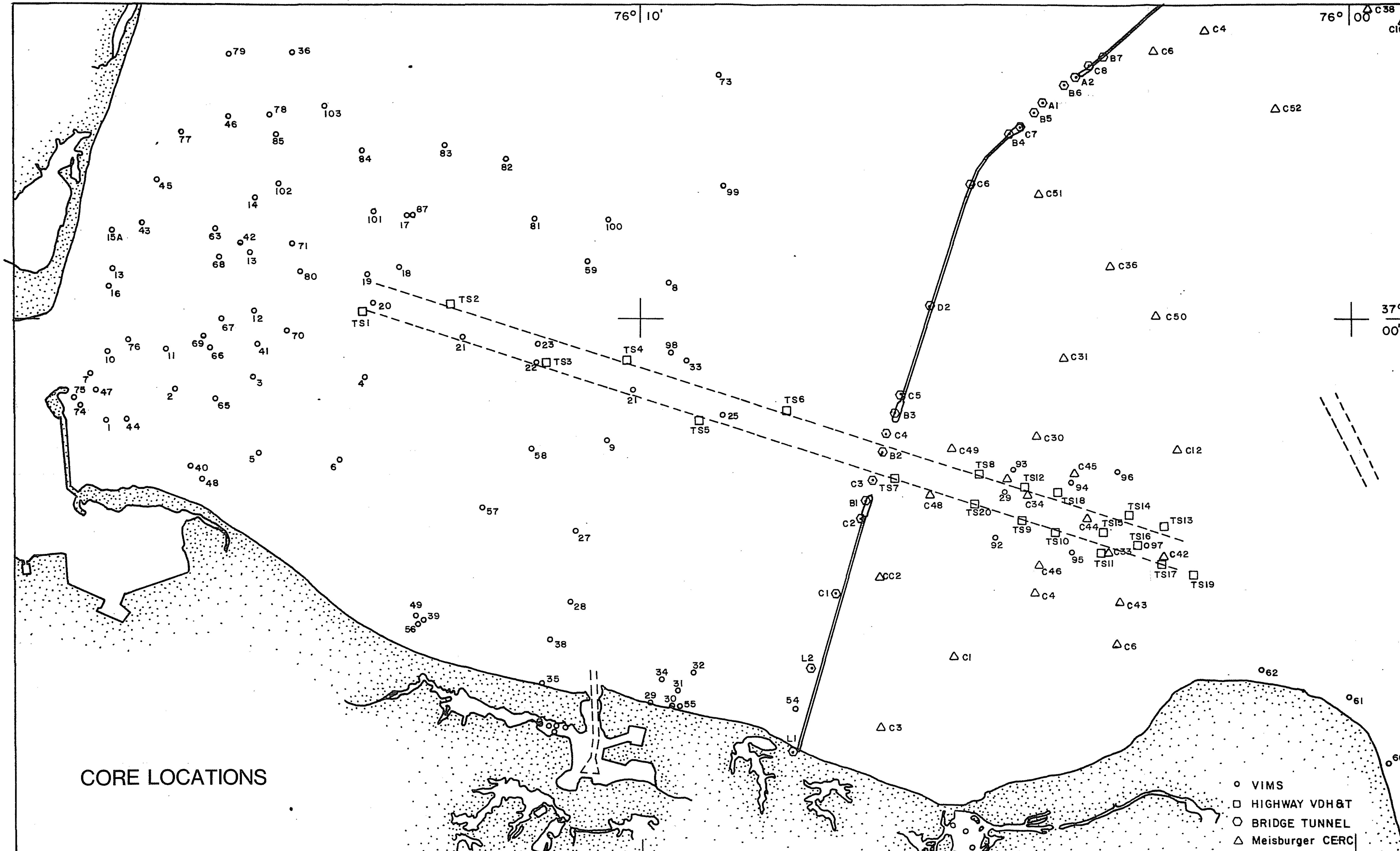

Figure 3: Map depicting the location of cores.

17/18

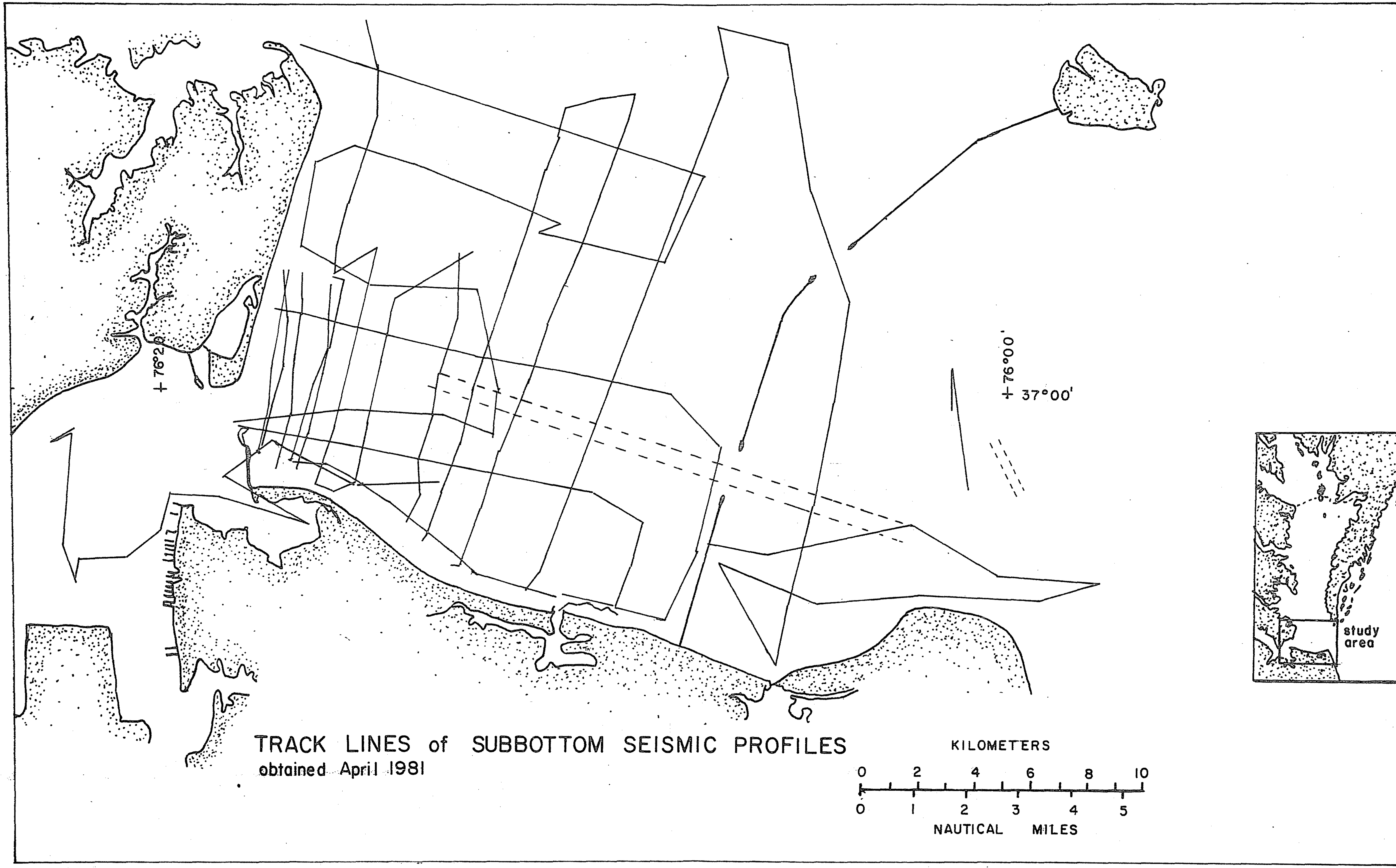

Figure 4: Map depicting the lines of subbottom profiles.

Scientists from VIMS sampled the Buchroe Beach area of Hampton in June 1981. The sediment from Buckroe Beach is finer (smaller grained) than that found on Willoughby Spit and Ocean View. Thus, materials not suitable for use on the Norfolk beaches might sill be usable on Buckroe Beach. The overfill ratios are presented in Appendix A.

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ASSESSMENT OF SAND RESOURCES

Within the area encompassed by the study there is in excess of 230 million cubic yards of sand that is suitable for use in beach nourishment. Environmental, physical and institutional constraints, however, may limit the volume of sand that is most readily available for use to approximately 120 million cubic yards. This supply is much greater than the currently projected needs for beach nourishment. This and the following sections of this report indicate the extent of the sand resources and their areal distribution and assess them in terms of their suitability, the potential impacts of extraction or mining on the biological community, and the costs and methods of extraction.

In reviewing the information collected during the core acquisition and geophysical phases two elements are of major importance. These are the thickness of the deposit with minimal unusable overburden (Figure 5), and the depth below water level of the bottom of the deposit (Figure 6). The importance of the thickness of the deposit of suitable sand is nearly self-explanatory. In general, for deposits of the same areal extent, thicker deposits allow more efficient excavation. But this is somewhat balanced by environmental concerns about the potential for reduced dissolved-oxygen which may occur in a relatively deep pit. The significance of the depth to the bottom of the deposit is that the various techniques of dredging and individual set-ups or pieces of equipment have different depth limitations. Dredging to 60 feet below the water's surface requires considerations different from those of dredging to 35 feet below the surface. The thickness of the unusable overburden is a major factor in the logistics and economics of recovering the sought-after sand. A thin overburden of fine-grained material can be excavated along with the desirable material with few ill consequences other than a slight, detrimental change in the overfill ratio. The handling and, perhaps, rehandling of a thicker overburden increases both the cost and the likelihood of environmental impact. As a consequence of these factors, we have adopted a thickness of fine grained sediment overburden of 3 feet as the limit beyond which a deposit of otherwise satisfactory material will be considered inaccessible.

The discussion in this section is devoted to a description of the available resources without regard to the impacts of extraction on the biological resources. These relative impacts are discussed later. However, our discussion does include potential institutional restrictions on excavation and comments on the impact excavation may have on shore-erosion problems. The latter may be simply stated: It is generally inadvisable to extract sand close to shore as the deepening of the nearshore bottom reduces the frictional dissipation of wave energy. So doing increases the wave-energy expenditure on the shoreface itself with the potential of increasing the rate of shoreline retreat.

Sand Deposits

Willoughby Banks. The outline of potential sand resources is shown in Figure 2, designated as A, and the thickness of sand is shown in Figure 5.

The southern flank of the natural Thimble Shoal Channel to the crest of the shoal is the prime location of suitable sand in this region. the material is a gray fine to medium (0.25-0.75 mm) sand with varying amounts (up to 15%) of silt and clay. The horizon has a maximum thickness of 28 feet at the crest and thins to 3 feet at the flank of the channel. Overfill ratios range from 1.1 to 1.75 for the 6.0 million cubic yards outlined in Figure 5. The increasing water depths from 3 feet at the crest to the channel depth of 45 feet should not affect the area as a viable borrow site. Cores to the south of this area indicate the surface material grades to a very fine silty sand overlying a layer of inorganic clay that thickens landward. The overburden of fine-grained material is considerable on the southern and eastern part of the banks (up to 10 feet in thickness), rendering most of the sand in deeper horizons unaccessible for beach nourishment; however, the volume is appreciable and could be as high as 15 million cubic yards if the overburden were removed.

Noteworthy, however, is the fact that the channel flank deposit falls within a military (U. S. Navy) restricted zone (R1 in Figure 2). Within the zone (U. S. Coast Pilot 3, 1983) "anchoring, trawling, fishing, and dragging are prohibited..." and "no object, either attached to a vessel or otherwise, shall be placed on or near the bottom." This restriction clearly implies that any bottom disturbing activity could be subject to restriction.

Horseshoe-Thimble Shoal-Tail of the Horseshoe

This area has the largest volume of sand suitable for beach replenishment found in this survey (Figure 5), approximately 200 million cubic yards. This area is designated as Band C in Figure 2. The surface material is a light gray, fine to medium grained (0.25 to 0.5 mm) sand containing small percentages of silt and clay. The surface layer ranges from 1 to 4 feet in thickness with little or no overburden of unsuitable material. Below this layer the sand grades to a very clean coarse sand, that ranges in size from 1.0 mm to 2.0 mm. The coarse sand layer ranges from 6 to 30 feet in thickness throughout the region.

Water depths in the entire area range from 10-30 feet allowing easy access to sediments on or below the bottom. As no overburden of unsuitable material is present in this area, the finer grained sand at the surface would have little or no effect of the overfill ratios of 1.02 to 1.70 for the 150 million cubic yards of medium to coarse sand found in this region.

The restriction discussed previously (R1 in Figure 2) also pertains to the southwest corner of the Thimble Shoal zone. The availability of approximately 10 million cubic yards of sand are affected. A second restricted zone (R2 in Figure 2), a firing range at Fort Monroe, could inhibit extraction. However, within this zone

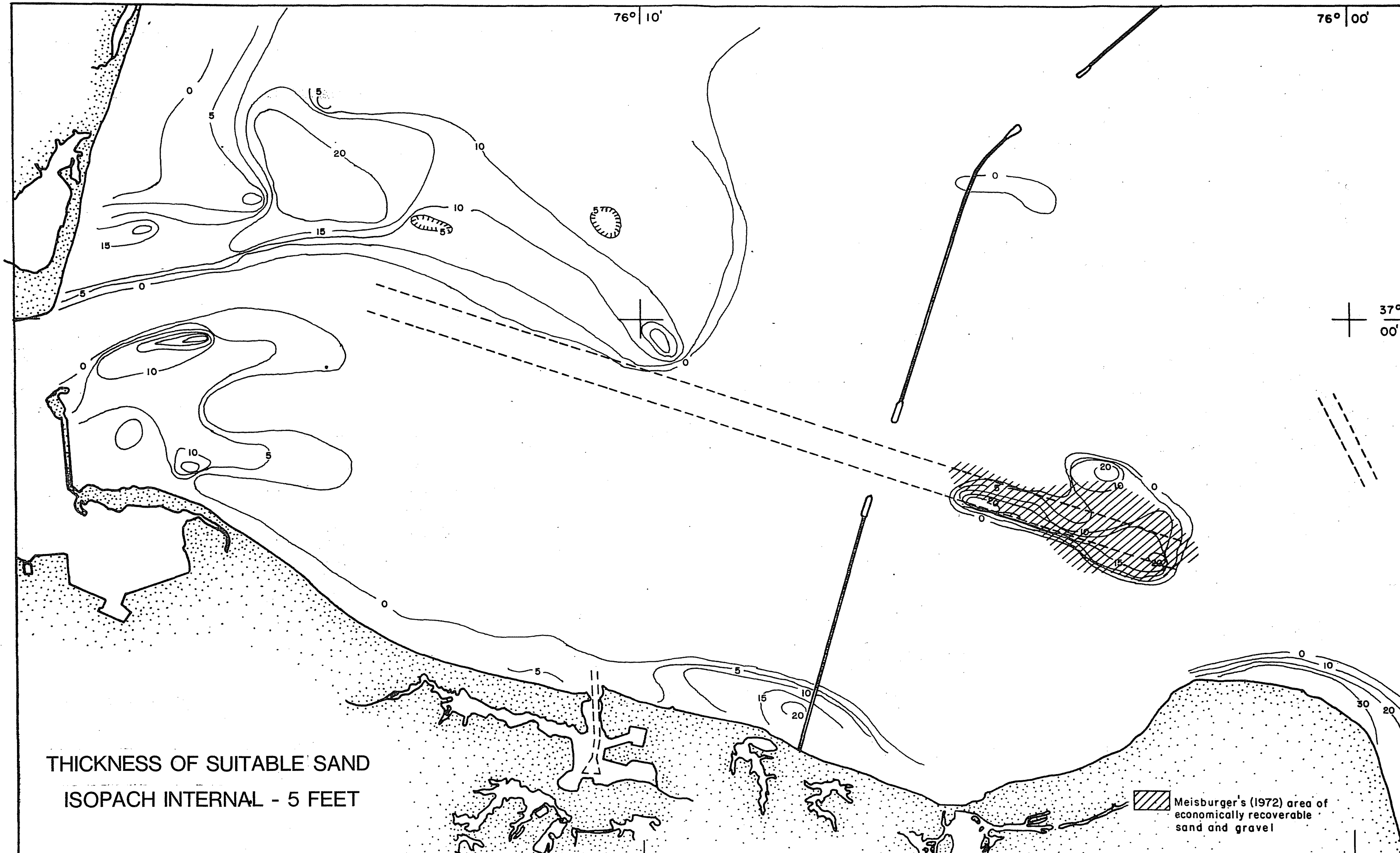

Figure 5: Map depicting the thickness of the deposits of sand.

23/24

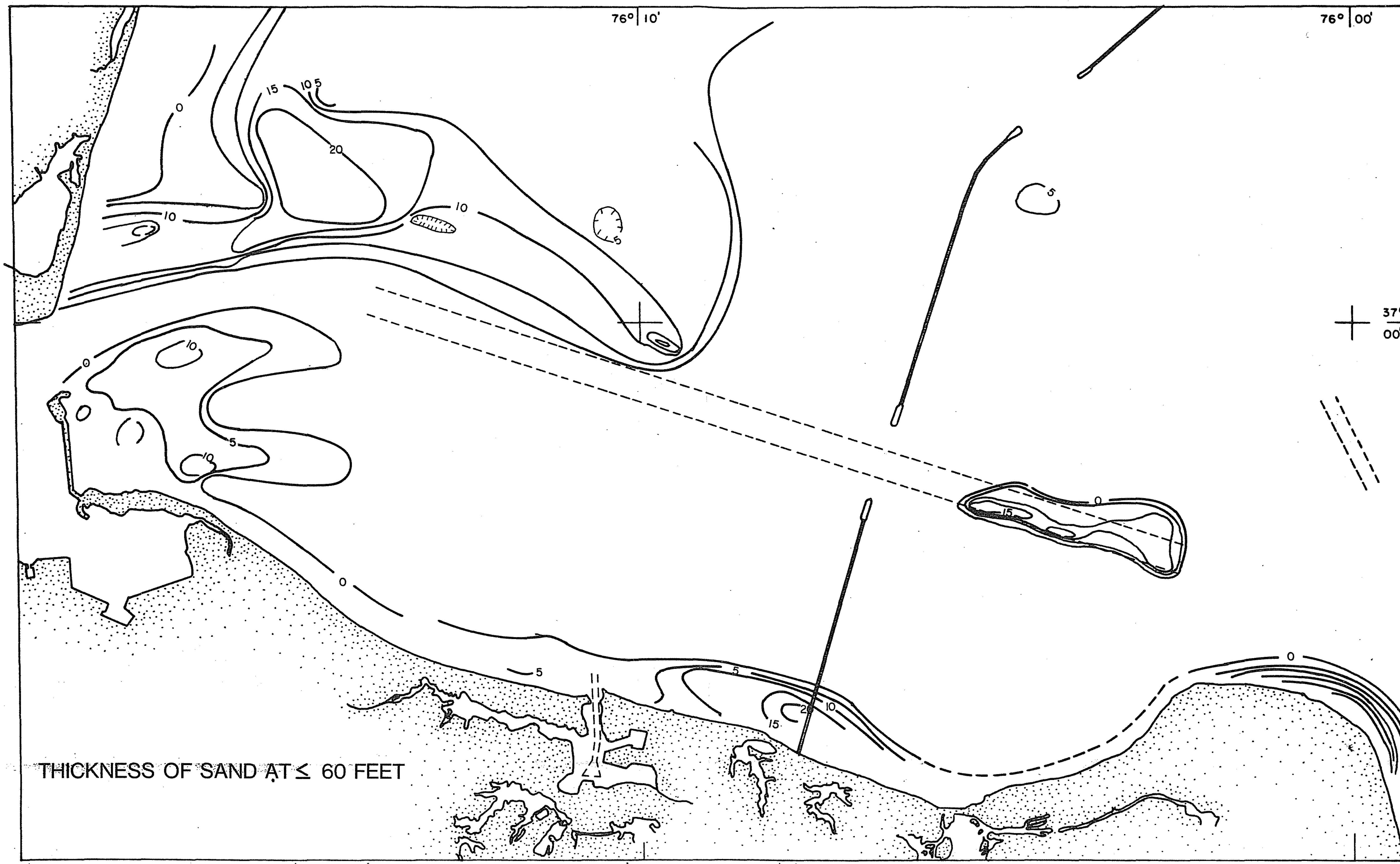

Figure 6: Map showing the thickness of the deposits of sand at depths not greater than 60 feet below the water surface.

environmental concerns and those concerns associated with extraction close to shore are probably more significant.

Thimble Shoals Channel: The east end of Thimble Shoals Channel (Area D in Figure 2) was surveyed by the Coastal Engineering Research Center (CERC) of the Corps of Engineers in 1972 (Meisburger 1972). Cores and seismic profiling delineated a sand-horizon with a volume of 18.4 million cubic yards. Our studies tend to confirm its existance and indicate that most of the material may be suitable for beach nourishment. Meisburger's description of the sand body is as follows:

> The most promising deposit crops out in Thimble Shoals Channel and along a reentrant in the south flank of Tail of the Horseshoe. This deposit is a coarse brown to reddish brown sand and gravelly sand. Data suggest that the deposit extends to and through the Tail of the Horseshoe Shoal to near the south wall of Chesapeake Channel where it decreases to a thin layer...South of the Thimble Shoals outcrop area, the coarse sand body appears to extend under Lynnhaven Roads, but is deeply buried under a silt and silty clay layer...About 3,500,000 square yards of material is exposed, and the volume available in this area is calculated to be 11.9 x 10^6 cubic yards. In addition, about 7.5 x 10^6 cubic yards are estimated to be available in the area bordering the exposure with a removal of no more than 5 feet of overburden.
>
> In terms of mechanical stability (for use on Virginia Beach), the Thimble Shoals material is considered good. Most of the sand grains are quartz which is resistant to mechanical and chemical degradation. Some gravel particles are composed of granitic rock which is partly decomposed. These fragments constitute only a minor fraction of the sediment.
>
> Layers and lenses of well-sorted, clean sand closely matching the beach sand occur in the Thimble Shoals deposit. However, the split cores showed that these layers are generally bedded with interspaced coarse sand mixed with gravel and occasional thin clay partings. The material finer than the native sand will be removed from the beach soon after placement, and the coarser particles will tend to remain.

Additional cores and seismic profiling obtained during this study indicates that 18 million cubic yards of medium to coarse grained sand, with overfill ratios of 1.25 to 1.85 are available in this area. The channel is a candidate for dredging to a depth of 55 feet in the proposed Hampton Roads deepening project. Dredging to 55 feet could yield 3.0 million cubic yards of material. Should the channel be dredged only to 50 feet the yield would be about 1.5 million cubic yards. The amount of this material that is suitable sand for beach nourishment is also being determined by the Norfolk District, Corps of Engineers, as part of the evaluation of the Norfolk Harbor deepening project.

Crumps Bank: The surface sediments in the Crumps Bank area are mostly very fine grained silty-sands, grading to gray medium sand near the beach. Cores at this site show a sand horizon starting at the beach as either thinning or dipping seaward. This horizon has an overburden of inorganic clays and silts that thickens to the north and west.

However, a surface deposit, between the Little Creek and Lynnhaven entrances (Zone E in Figure 2), has a thickness between 7 and 20 feet. The volume of material with an overfill ratio of less than 2.0 is about 3.0 million cubic yards. Given the proximity to shore, extraction of these materials is inadvisable.

Cape Henry: The 3 cores in the nearshore region of Cape Henry (Area F in Figure 2) produced medium to coarse grained sand (0.50 to 1.0 mm) with varying amounts of silt (up to 10%) for the length of the core. The depth of this horizon was determined to be in excess of 35 feet at all 3 locations. The volume of suitable material is calculated to be at least 6.5 million cubic yards. This site has the potential of supplying as much as 15 million cubic yards of suitable material for beach restoration; however, its proximity to the shore may limit the advisability of using much of this material.

Lynnhaven: Four cores were taken inside the Route 60 bridge. Thickness of the surface sand deposit ranges from 10 to 35 feet. This locale could yield as much as 1.5 million cubic yards of suitable sand if the layer be continuous throughout the site. Seismic reflection profiles were not attainable here as shallow water restricted operations to the channel. Additional coring would help delineate the extent of the horizon.

ASSESSMENT OF BIOLOGICAL RESOURCES

An assessment of the biological resources was undertaken in order to provide a relative ranking of the resource value between the various zones found to contain suitable for beach nourishment. The work focused on the macrobenthic communities (benthos larger than 1.0 mm) and on the hard clam (*Mercenaria mercenaria*). The benthic communities are a major link in the estuarine food web, serving as a food source for both commercially and non-commercially important finfish. The hard clam is one of the important commercial species in southernmost Chesapeake Bay. During 1980 the hard-clam fishery in Virginia, with $1,000,000 in revenues, ranked third behind oysters ($10,000,000) and blue crabs ($7,000,000) (Commercial Fisheries Statistics, 1980).

The details of these studies are given in Appendix B; only the principal results are discussed herein. Additional information and evaluation is contained in the U. S. Fish and Wildlife Service report, *Benthic Resources of Potential Sand Sources in the Lower Chesapeake Bay* (Mayne *et al*., 1982).

Hard Clam

The clam survey's sampling stations are shown in Figures 7 and 8, and the findings summarized in Table 2. The western portion of Crumps Bank was found to have the highest per acre value of clams. The western portion of Willoughby Bank, designated the Borrow Pit, also has a high value per acre. The Borrow Pit was formed in 1971 when material was taken for the second Hampton Roads Bridge-Tunnel crossing. Earlier surveys (Haven and Kendall, 1974) for clams over one inch in length documented a significant decrease in clam densities relative to adjacent areas. The shallow water crown of Willoughby Bank had fewer clams. The shallow crown, exposed to relatively high levels of wave and current action may be expected to have a highly mobile substrate.

Discussions with local fishermen at a November, 1981 meeting of the Virginia Working Watermen's Association in Poquoson, and anecdotal information on the historical aspects of the clam fishery support the conclusions of the surveys. The waterman expressed concerns that a major dredging activity might affect water-current patterns and consequently clam recruitment in the area.

Survey results for the areas of Thimble Shoal, and the Horseshoe indicate that the westernmost sector of the Horseshoe (designated as Buckroe Beach in Table 2) contained the highest yeild while most of Horseshoe Bank and Thimble Shoal contained few or no clams.

Macrobenthos

Figure 9 shows the macrobenthos survey's sampling stations. Cluster analysis differentiated the stations into fine groups. Important biological parameters for each group are summarized on a relative basis in Table 3. Densities of benthic organisms were

Table 2. Density and number of clams in each area surveyed and estimated dollar values.*

	Juveniles	Nicks	Cherrystone	Chowder	Total	Calculated Value Per Acre
Crumps Bank (131.3 acres)						
Clams/ft^2	0.04	0.09	0.11	0.18	0.42	
Clams/Total Area	254,913	490,218	607,870	1,019,653	2,372,654	$818./acre
Dollar Value	$0.00	$34,315.	$ 42,550	$30,590	$107,455	
Borrow Pit (15.8 acres)						
Clams/ft^2	0.02	0.10	0.13	0.05	0.30	
Clams/Total Area	16,537	68,512	89,775	37,800	212,624	$773/acre
Dollar Value	$0.00	$ 4,795	$ 6,285	$ 1,135	$ 12,215	
Willoughby Bar (54.6 acres)						
Clams/ft^2	0.003	0.01	0.003	0.01	0.03	
Clams/Total Area	8,151	24,452	8,151	16,301	57,055	$ 50/acre
Dollar Value	$0.00	$ 1,710	$ 570.	$ 490.	$ 2,770	
Buckroe Beach (125.7 acres)						
Clams/ft^2	0.01	0.01	0.00	0.04	0.06	
Clams/Total Area	75,127	56,346	0.00	244,164	375,637	$ 90/acre
Dollar Value	$0.00	$ 3,945	$ 0.00	$ 7,325.	$ 11,270.	
Horseshoe Bank (312.7 acres)						
Clams/ft^2	0.003	0.00	0.00	0.01	0.01	
Clams/Total Area	46,718	0.00	0.00	93,437	140,155	$ 9/acre
Dollar Value	$0.00	$ 0.00	$ 0.00	$ 2,800	$ 2,800	
Thimble Shoals (73.14 acres)						
Clams/ft^2	0	0	0	0	0	
Clams/Total Area	0	0	0	0	0	$ 0/acre
Dollar Value	0	0	0	0	0	

*Note: Clams were grouped into commercial categories and valued at fall, 1981, market prices as follows: Juveniles, length <1.4" @ no market value; Nicks, 1.4-2.3" @ 7¢ ea; Cherrystone = 2.3-3.1" @ 7¢ ea; Chowder = >3.1" @ 3¢ ea.

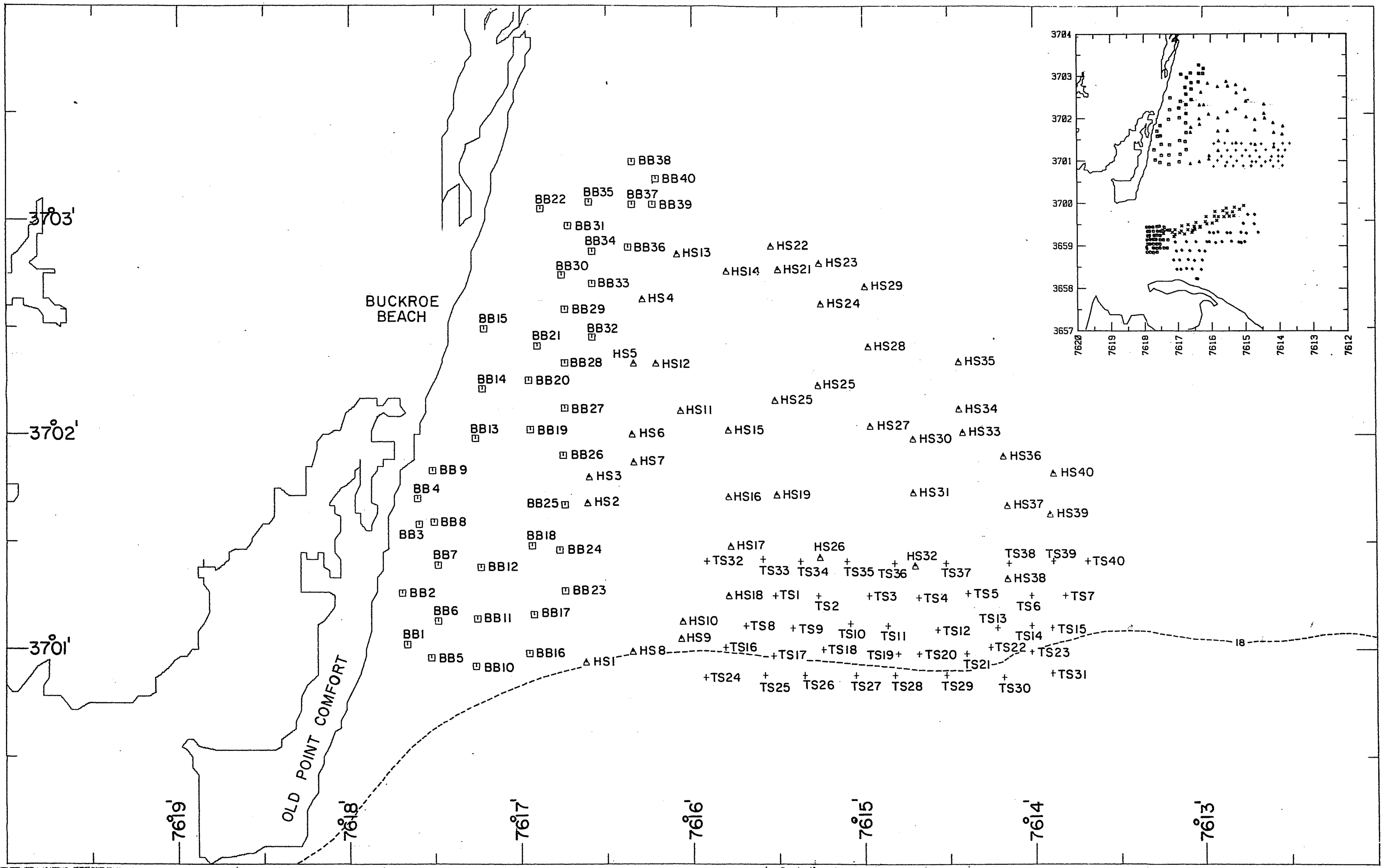

Figure 7A: Map depicting the locations of the clam survey station north of Thimble Shoal Channel.

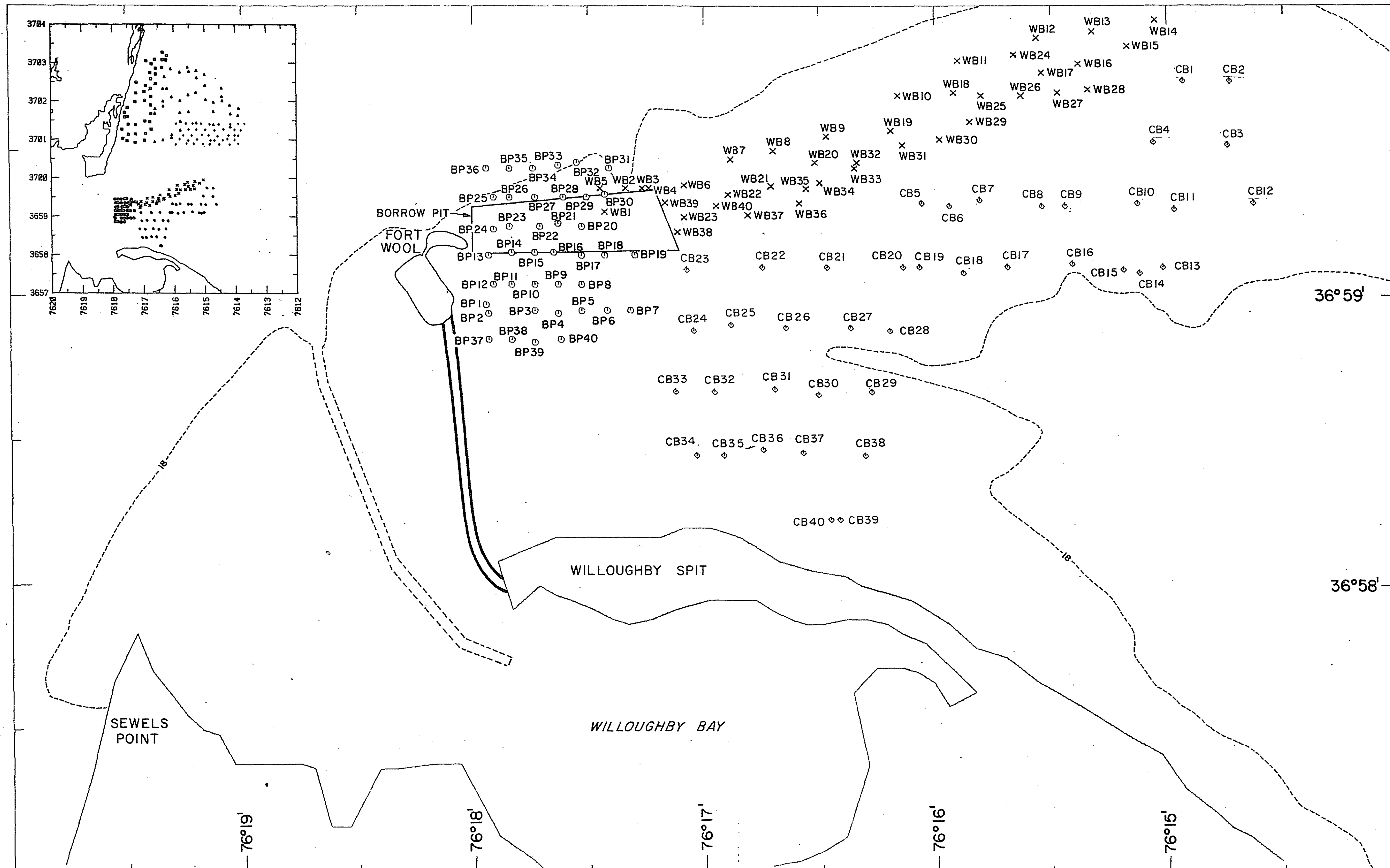

Figure 7B: Map depicting the location of the clam survey south of Thimble Shoal Channel.

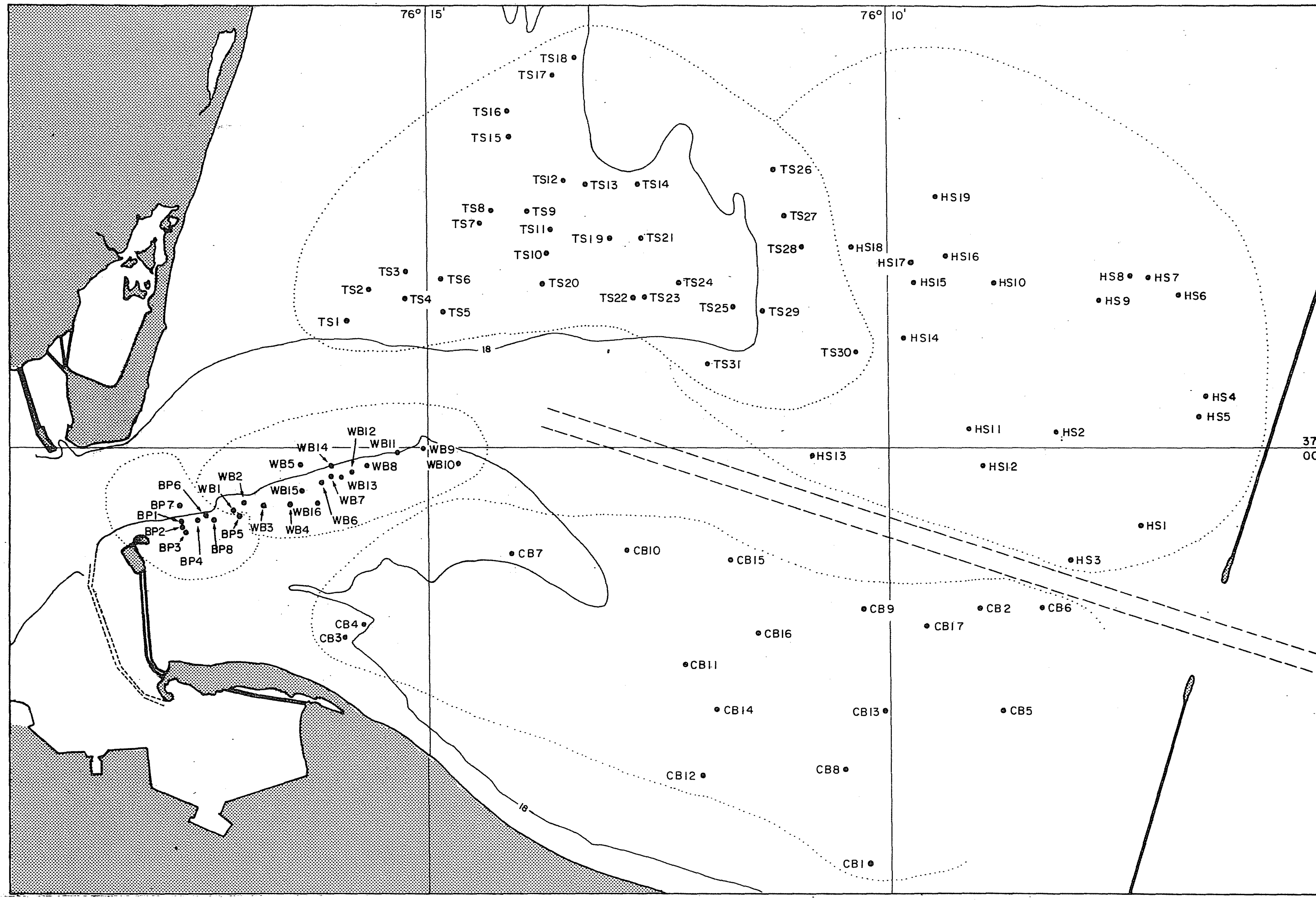

Figure 8: Map depicting the location of the macrobenthos survey stations.
BP = Borrow Pit; WB = Willoughby Bank; CB = Crumps Bank; TS = Thimble Shoal; HS = Horseshoe Bank.

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greatest in the Crumps Bank and Borrow Pit groups of stations. These communities also contained the highest proportions of crustaceans which are very important food items. As well, species richness was relatively high at these stations (27-25 species collected per grab). On the basis of relative resource value Crumps Bank and the Borrow Pit areas rank the highest, Thimble Shoals and Horseshoe Bank as intermediate, and Willoughby Bank (excluding the Borrow Pit sector) as low.

Combined Relative Ranking of Resource Value

Whereas the macrobenthos and clam surveys approach the assessment of the resource's value from different perspectives, the results are convergent and they permit a fairly straight forward combined ranking (Table 4). Horseshoe Bank-Thimble Shoal and Tail of the Horseshoe (zones B and C respectively in Figure 2) have the lowest relative values. Of the two areas, Horseshoe-Thimble Shoals has a somewhat higher macrobenthos value. Thus, in terms of benthic community resources sand extraction in those areas would embody less impact than sand mining in the western section of Crumps Bank, the Borrow Pit section of Willoughby, or the crown of Willoughby Bar (zone A in Figure 2). The crown of Willoughby Bar has an intermediate combined ranking largely because the area had a moderate value with respect to clams.

Table 3. Characteristics of Macrobenthic Groups.

GROUP	WAVE EXPOSURE	DEPTH (feet)	SEDIMENT TYPE	SPECIES RICHNESS	TOTAL ABUNDANCE OF INDIVIDUALS	ABUNDANCE OF CRUSTACEANS	ABUNDANCE OF MOLLUSCS	ABUNDANCE OF POLYCHAETES	RELATIVE VALUE OF THE RESOURCE
Borrow Pit	M to H	10-28	med sand shell	H	H	H	H	H	H
Willoughby Bar	H	8-20	med sand shell	L	L to M	L	L	L	L
Crumps Bank	L	19-23	very fine sand	H	H	M	M	H	M to H
Thimble Shoals	M	17-50	fine sand	M	M	M	M	M	M
Horseshoe Bank	L	16-23	fine to very fine sand	M	L to M	L	M	M	M

* High (H), Moderate (M), and Low (L) are qualitative descriptors for comparison within these groups and are not an absolute measure.

Table 4. Relative desirability of borrow sites for beach nourishment purposes ranked from most to least desirable based on macrobenthic and clam resource data.

Area	Macrobenthic Survey	Clam Survey	Sum	Combined Rank
Thimble Shoal-Horseshoe Bank	3	1	4	1.5
Tail of the Horseshoe	2	2	4	1.5
Willoughby Bar	1	3	4	3
Borrow Pit	5	4	9	4.5
Crumps Bank	4	5	9	4.5

ENVIRONMENTAL CONCERNS

The purpose of this discussion is to highlight those principal concerns which may arise in connection with proposals to excavate sand from those areas identified as suitable for beach nourishment. Most of the concerns will focus on potential ecological impacts associated either directly or indirectly with dredging and the placement of dredged materials. The level of potential impact would vary as a function of the characteristics of the material to be dredged, the exposure to currents and wave action, and the benthic resources. The configuration and location of the borrow site, and the methods of handling the dredged material can be an important determinant in the level of impact. Thompson (1973) and Tuberville and March (1982) provide a brief review of the earlier literature concerning the ecological effects in offshore dredging for beach nourishment.

Obviously there are two geographic areas of concern associated with any beach-nourishment project, the source, or borrow site, and the beach being nourished. Within the context of the sites determined in this study concern is focused on:

1. The loss of the estuarine benthos currently in residence at the borrow site.
2. The recolonization potential of the borrow site.
3. The effects of the enhanced turbidity and possible remobilization of any contaminants associated with the resuspended sediments.
4. The potential, due to alteration of topography, for a modidication of circulation patterns as it may affect habitat conditions in the region close to the bottow site.

It is generally assumed that all of the benthos within the areal limits of the borrow site are sacrificed during excavation. Given this loss, the strategy in design of the borrow site should focus on the balance between the initial loss of resources and maximizing recolonization. The resource value of the benthic communities recolonizing the area will depend upon the character of the post-excavation substrate, the level of current and wave agitation, and of critical importance, on the levels of dissolved oxygen in the waters at the borrow site. Excavation of a given volume of sand may be possible by formation of either a relatively deep depression of small areal extent or a shallower depression of larger areal extent. Whereas the latter appoach would entail greater initial losses of the benthos, the liklihood of the formation of a stagnent water condition is less. The substrate available for recolonization is dependent upon the characteristics of the post-excavation bottom and upon the sediments filling the depression. The latter, in turn, are dependent upon exposure to waves and currents. The rate at which sediments fill the depression is also important since very rapid deposition could preclude development of a stable benthic community until the topography approached the pre-excavation condition. Depending upon the combination of factors, it is possible that the recolonized substrate could have a higher value as a benthic resource (food). For example, filling a borrow site of pure sand by sediments witha larger fraction of silt/clay might improve the resource value of the area. Inadvertent improvement of the value of the benthic resources has likely occurred in the previously mentioned Borrow Pit on Willoughby Bank. In this case the formation of the pit resulted in a substrate with a high concentration of shell on its surface which was recolonized with a rich epifauna that attached to the shell (Appendix B; Boesch and Rockley, 1974). In this case, hydraulic flushing of the pit has apparently continued, a condition desired but generally not assumable.

During dredging, some increase in turbidity at the borrow site is likely. While the zone of influence is limited at the dredge cutterhead (Priest, 1981), the level of additional impact depends upon the in situ concentration of silt and clay in the deposit and whether "economical" loading is utilized in the receiving barge or hopper. Even then, the impacts depend upon whether downspout discharge or surface discharge is used. The increased turbidity may affect primary production (phytoplankton) due to reduced light-penetration, and inhabit zooplankton feeding activity within the turbid plume. Dependent upon localized current patterns and the level of sedimentation from the plume, the benthos in the area fringing the borrow site could be impacted by light burial. It should be born in mind that the sand in the resource areas delineated in this study are native materials which have relatively low concentrations of fine-grained sediments (silt and clay) and of organic material. Nevertheless, the dredging strategy for extraction should be designed to minimize impacts due to increased turbidity.

Significant modification of the water's flow-patterns due to individual extraction projects on the Thimble Shoal or Horseshoe Bank would not be expected as the shoal area is broad. However, in the aggregate, if all the available materials were excavated a significant change in circulation is conceivable. This extreme-case modification will be amenable to assessment in the near future with hydrodynamic, numerical-modelling techniques. In the case of Willoughby Banks the situation is more sensitive given the uncertainty of the role of regional hydrodynamics in recruitment of hard clams on Crumps Bank. The previous borrow site (Borrow Pit) excavated in 1971-1974 has been slow to refill with sediments. This suggests that sources of sediment for resupply may be weak and that long recovery times would follow a large scale modification to the shallow water topography.

The other area of concern is the area being nourished. The problems here are similar to those at the borrow site. The organisms dwelling on the beach over which the dredged sand is placed are likely to be killed, and the local biological community is subjected to increased stress from the temporarily higher turbidity. In general though, the ecological problems at the beach site are less than those at the borrow area. The beach will repopulate relatively quickly. Several environmental studies of the beach-nourishment sites (Courteney et al., 1974, Parr et al., 1978; Cutler and Mahadevan, 1982) indicate that there are no detrimental long term changes in the beach fauna as a result of beach nourishment.

Modification of the offshore topography can also have an effect on the distribution of wave energy at the shoreline by altering wave refraction patterns. In order to evaluate this effect wave refraction analysis were performed for several possible circumstances including a depression of various depth on Thimble Shoal-Horseshoe, simulated excavation on the north flank of Thimble Shoal, simulated increased channel width along Willoughby Bank, and shoreline progradation west of Cape Henry. These results are in Appendix C. Although these topographic modifications do alter wave refraction patterns, none of the simulated excavation appear to result in significant alterations in the distribution of wave energy at the shoreline. It is not possible to anticipate all of the configurations or locations of excavation sites. Those selected reflect the most likely. Excavations close to the shoreline were not simulated because such sites are not advisable as sources as the wave energy, otherwise lost to frictional dissipation in the very shallow water, is concentrated in the shore.

ENGINEERING CONSIDERATIONS

A much greater volume of sand than would be required by a combination of the largest beach nourishment projects which are contemplated is available in the offshore areas of the southernmost portion of Chesapeake Bay. There is an interactive set of options pertaining to the methods of mining or dredging the sand, of transporting it to the shore, and of distributing it along the beach. The location of the borrow area relative to the beach, the intervening bathymetry, and the quantity of sand to be moved also are factors to be considered.

Drake Engineering Company of Richmond, Virginia, under (sub-) contract from the Virginia Institute of Marine Science, addressed these and other items in the report entitled Sand Dredging Study for Beach Nourishment Southern Most Chesapeake Bay Area Including Virginia Beach, Norfolk, and Hampton, which is Appendix D. Some of that report is summarized in the following paragraphs. Costs quoted assume 1982 dollars.

From the assumptions that 2.5 million net cubic yards of sand were to be placed on the beaches of Norfolk and Virginia Beach and that 250,000 net cubic yards were to be placed along the Buckroe Beach area of Hampton, Drake Engineering developed a matrix of alternative methods and ratings factors. This matrix of 3 alternatives for Norfolk, 9 for Virginia Beach, and 1 for Hampton is summarized in Table 5 (see also Figure 1, Appendix D, page 27). The items used in Drake's report and in Table 4 are examples and are not specific recommendations.

As the City of Hampton currently has no specific plans to nourish the public beaches in the Buckroe and Salt Ponds areas, a general example of providing a one-time, net replenishment of 250,000 cubic yards of borrow material was used. According to the consulting engineer's report, this would require the dredging of approximately 337,500 cubic yards, the difference being the normal 25% loss during the mechanical portions of the process. This does not include any compensation for overfill ratios. Using the rule of thumb from the Shore Protection Manual (U.S. Army Coastal Engineering Research Center, 1973) that each cubic yard of sand added to the beach increases the surface area by one square foot, the completed project would add 45 to 50 feet to the width of the mile of public beach (0.3 mile at Buckroe, 0.7 mile at Salt Ponds).

The consulting engineer developed a cost of approximately $1,700,000 or $5.03 per gross cubic yard for the project. The cost analysis assumes the use of a 27 inch-diameter pipeline to transport the dredged material from a site approximately 7,350 feet offshore. Work done since the original criteria were given to the engineer suggests that a borrow site somewhat further offshore would be more advantageous in terms of the quality of material and the diminution of potential adverse impacts. In any event, the generally shallow nearshore area probably precludes the efficient use of other methods of transportation such a a hopper-barge. Thus the hydraulic pipeline and direct, pumped distribution of the material of the beach appear to

Table 5. Matrix of Strategies for Beach Nourishment

A: Norfolk, net 2,500,000 cubic yards

#	Method of Excavation	Method of Distribution	Cost
N-1	27" hydraulic dredge from Tail of the Horseshoe to beach, gross 3,375,000	pump	$26,493,750 total $7.85/gross cu yd $10.60/net cu yd
N-2	Hopper-barge from Tail of the Horseshoe to beach, gross 3,000,000 yds	pump	$13,680,000 total $4.56/gross cu yd $5.47/net cu yd
N-3	27" hydraulic dredge from Willoughby Bank to beach, gross 3,375,000 cu yds	pump	$23,726,250 total $7.03/gross cu yd $9.49/net cu yd

B: Hampton, net 250,000 cubic yards

#	Method of Excavation	Method of Distribution	Cost
H-1	27" hydraulic dredge from nearshore to beach, gross 337,500 cu yds	pump	$1,697,625 total $5.03/gross cu yd $6.79/net cu yd

C: Virginia Beach, net 2,500,000 cubic yards

#	Method of Excavation	Method of Distribution	Cost
VB-1	27" hydraulic dredge from east of the Chesapeake Bay Bridge-Tunnel to Cape Henry, gross 3,375,000 cu yds	pump	$30,368,750 total $9.00/gross cu yd $12.15/net cu yd
VB-1a	same	haul, off road	$25,515,000 total $7.56/gross cu yd $10.21/net cu yd
VB-1b	same	haul, on road	$25,515,000 total $7.56/gross cu yd $10.21/net cu yd
VB-2	Hopper-barge from east of the Chesapeake Bay Bridge-Tunnel to Cape Henry, gross 3,000,000 cu yds	pump	$21,360,000 total $7.12/gross cu yd $8.54/net cu yd

Table 5. (concluded)

#	Method of Excavation	Distribution	Cost
VB-2a	same	haul, off road	$20,280,000 total $6.76/gross cu yd $8.11/net cu yd
VB-2b	same	haul, on road	$20,280,000 total $6.76/gross cu yd $8.11/net cu yd
VB-3	27" hydraulic dredge from Atlantic Coast inbound-outbound channel area to beach, gross 3,375,000 cu yds	pump, direct	$23,355,000 total $6.92/gross cu yd $9.34/net cu yd
VB-4	Hopper-barge from Atlantic Coast inbound-outbound channel area to mooring point, then pipeline, gross 3,000,000 cu yds	pump	$13,830,000 total $4.61/gross cu yd $5.53/net cu yd
VB-5	Hopper-barge from east of the Chesapeake Bay Bridge-Tunnel to pump barge through pipeline, gross 3,000,000 cu yds	pump	$14,970,000 total $4.99/gross cu yd $5.99/net cu yd

be the best means of accomplishing a beach nourishment project such as this.

The City of Norfolk has several options for the nourishment of the beaches in the Ocean View and Willoughby Spit areas. Indeed the City has initiated work. Approximately 480,000 cubic yards of sand have been dredged from the western portion of Little Creek, locally known as Pretty Lake, and about 160,000 cubic yards of sand derived from maintenance dredging of the entrance to Little Creek have been placed at East Ocean View. An additional placement of approximately 550,000 cubic yards of material derived from the dredging project at the U.S. Navy Piers 11 and 12 is planned for completion in fall of 1984. Additionally, the Norfolk District of the U.S. Army Corps of Engineers has a long standing interest in the area and has published (1982) a Draft Feasibility Report and Draft Environmental Impact Statement (for) Hurricane Protection and Erosion Control in Willoughby Spit and vicinity. The Corps's recommended plan is to construct a protective beach 60 feet wide to an elevation 5 feet above mean low water along 10,032 feet (1.9 miles) of shoreline in East Ocean View. The plan includes periodic nourishment of the replenished area and a monitoring program designated to cover the entire 7.3 mile bay-front shoreline of the City. The Corps also suggests the implementation or continuation of several non-structural measures. The estimate of the beach construction alone is $3,101,100. The Corps further states that the best source for the sand in the Tail of the Horseshoe-outer Thimble Shoals area but makes no recommendation as to the methods of transportation. The Corps selected this plan over several others. The list of the less favored plans include nourishment of the full 7.3 mile length of beach to 2 or 3 different levels and the creation of a protective dune.

For the purpose of locating appropriate sand resources, this report addresses the needs of a major nourishment project for the total length of the area. If a significant volume of sand is available at reasonable unit cost, a smaller volume also is available but probably at a slightly greater unit cost. The engineering criterion, following the words of Senate Document No. 4 (1979), was to provide 2,500,000 cubic yards of sand to the beach. If evenly distributed this would provide approximately 195 cubic yards of new sand per yard of beach. This would increase the width of the beach approximately 55 feet, not including any reduction due to overfill ratios.

The consulting engineer (Appendix D) studied 3 alternatives which might be used to satisfy the criterion. The options are summarized in Table 5. Two of the options, N-1 and N-3, use a hydraulic dredge and pipeline to obtain the sand and transport it to the shore and a pump to distribute it along the beach. Both require the excavation of 3,375,000 cubic yards in order to compensate for normal leakage and loss. The Tail of the Horseshoe-outer Thimble Shoal area is the source in N-1; whereas the channel-flanking portions of Willoughby Bank is the source for N-3. Alternative N-2 has the Tail of the Horseshoe-Thimble Shoal area as the source and uses a hopper-barge, mooring buoy, and pump system to accomplish the task. The draft of the hopper-barge renders this method unsuitable for use in the shallow waters of the Willoughby Bank area. This method, however, is more efficient than the hydraulic dredge and pump system and requires that only 3,000,000 cubic yards be dredged to place 2,500,000 cubic yards on the beach.

For the quantity of sand required by the suggested criterion, alternative N-2 is the preferred choice. It is both less costly and more efficient. The unit cost per cubic yard of sand that is dredged is less than the other two options, \$4.56 versus \$7.02 for N-3 and \$7.56 for N-1; the total quantity is less, 3,000,000 versus 3,375,000; and, obviously, the total cost is less, \$13,680,000 versus \$23,726,250 for N-1 and \$26,493,750 for N-1.

The consulting engineer (Appendix D) developed 9 alternative methods by which to provide Virginia Beach with 2,500,000 cubic yards of sand. The alternatives are listed in Table 4. Unfortunately the apparently lowest cost option is a conditional one. The condition being that there is sufficient and satisfactory sand in the vicinity of the inbound-outbound channel off the Atlantic shore of Virginia Beach. Borings by the Corps of Engineers suggest there is sand in sufficient quantity. The next best option, which is less than 10% more costly, uses the confirmed source area just east of the Chesapeake Bay Bridge-Tunnel. Both choices require the use of a large hopper-barge to dredge the sand and to transport it to a mooring point or pump-barge for final transportation to distribution along the beach. They each require the acquisition of 3,000,000 cubic yards of sand in order to provide the beach with a surcharge of 2,5000,000 cubic yards. The loss reflects operating losses and not unstable conditions due to a miss-match of the dredged and "native" sands.

Of the 7 less favorable alternatives, 3 utilize a hopper-barge to dredge sand from the site near the Chesapeake Bay Bridge-Tunnel and to transport it to a stockpile in the vicinity of Cape Henry. They differ in the method of distribution from Cape Henry to the beach front. All suffer from the same problems, namely the need for a site on which to store the sand while it awaits final transportation to the beach and cumbersome system for that final journey. A possible storage site is the beach at Fort Story, provided this were acceptable to the U.S. Government. The transportation and distribution systems are more complex. The most costly, \$7.12 per gross cubic yard is a pipeline to the beach. The advantage to this system is that the fixed pipeline would cause little disruption to traffic and normal commerce. If and where it were necesary for the pipeline to cross a roadway, either the pipeline could be placed in a trench under the road, or the road could be run on a ramp over the pipe. The other alternatives cost less, \$6.76 per yard, but use trucks to move the sand from the stockpile to the beach. The difference between them being the route, one along the beach, the other along the streets and roads. Aside from the obvious disadvantages of a circuit of heavy trucks operating either on the beach or in traffic is the further problem of time. In order to move 2,500,000 cubic yards of sand it would take 20 trucks of 10 cubic yards each running 2 loads each per hour, 12 hours per day almost 2 years to finish the task.

The next option is to use a 27-inch hydraulic dredge in place of the hopper-barge to acquire the sand and move it to the stockpile.

Because the hydraulic dredge is less efficient than the hopper-barge a larger gross quantity of sand (3,375,000 cubic yards versus 3,000,000) and because the unit cost is greater, these options are more expensive than their hopper-barge siblings.

Directly between these 2 groups of 3 alternatives is the use of a 27-inch hydraulic dredge to move sand from the offshore access channel and to pump it directly to the beach.

Comparison of Marine and Terrestrial Sources. The comparison of marine and terrestrial sources of sand for beach nourishment is a three-fold comparison involving cost, scale, and logistics or engineering. If projects of the scale discussed throughout most of this report are planned, then the logistics of trucking the material from inland, even nearby, borrow areas are forbidding. The time required to truck 2,500,000 cubic yards would be prohibitively long, the number of trucks and loads required would have unacceptable consequences on traffic and roads, and so on. On the other hand, the logistics of mining small quantities of sand from offshore sources are also prohibitive as the costs of setting up and taking down the operation require that the job be of sufficient duration or magnitude to depreciate the unit cost. Table 6, using data provided by the consulting engineer who prepared Appendix D, presents the costs of the least costly nourishment projects for Norfolk and Virginia Beach as discussed elsewhere, except here in several scaled-down variations. The rates per cubic yard fall sharply between 500,000 and 1,000,000 cubic yards and continue to decrease, but less rapidly, with increasing volume.

Recent truck-haul projects generally have been relatively small. In 1978, the City of Norfolk paid a private contractor $5.50 to $6.00 per cubic yard for 20,000 cubic yards (D. Mathias, personal communication). The Baltimore District of the U.S. Army Corps of Engineers (1980) estimates costs of $5.59 to $5.69 per cubic yard for projects of 56,200 to 63,900 cubic yards at Colonial Beach on the Potomac River. It is more difficult to derive a cost for truck haul projects in Virginia Beach as the city has, on occasion, used municipally owned borrow pits, hence the cost of material may not be included in the apparent charges to the beach projects. With this in mind, a recent estimate is $4.33 per cubic yard. Earlier costs, using uninflated dollars, are as low as $3.85 per cubic yard for 150,000 cubic yards.

Scale does not have the dramatic impact on unit costs for truck haul projects that it had on dredging projects. The equipment is mobile and commonly available. However, as stated above, truck-haul is not well suited to very large projects. Also there may be problems obtaining large volumes of sand near enough to the beach. Distance is a factor as cost per mile of road travelled plays a critical role in determining the total cost of the operation, but more important is the need for a borrow area. A 20 acre pit, 30 feet deep contains about 1,000,000 cubic yards (1 acre is 4,840 sq. yards). Obviously any commercial operation would require much more land as it is not possible to leave vertical walls and as one is unlikely to find a 30 foot thick layer of suitable material. Whether a land source for a beach nourishment program be one large pit or several smaller sites, a

Table 6. Costs estimates for mining variable volumes of subaqueous sand.

	# of Net Cubic Yards Delivered to the Beach	Gross # of Cubic Yards to be Taken from Borrow Area	Total Cost	Cost Per Gross Cubic Yard	Cost Per Net Cubic Yard
Virginia Beach	500,000	600,000	$ 3,686,531	$6.14	$7.37
	1,000,000	1,200,000	6,234,620	5.19	6.23
	1,500,000	1,800,000	8,899,430	4.94	5.93
	2,000,000	2,400,000	11,564,240	4.81	5.78
	2,500,000*	3,000,000	13,830,000	4.62	5.53
Norfolk	500,000	600,000	$ 3,439,190	$5.73	$6.88
	1,000,000	1,200,000	5,973,380	4.98	5.97
	1,500,000	1,800,000	8,507,570	4.73	5.67
	2,000,000	2,400,000	11,041,700	4.60	5.52
	2,500,000*	3,000,000	13,680,000	4.56	5.47

* The lowest cost option from the alternatives matrix in Appendix E and the discussion of engineering considerations. Options VB4 and V2.

fairly sigificant area would be required and as there is great competition for land use in the coastal area, the cost would be great.

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APPENDIX A

OVERFILL RATIOS

The following table lists the overfill ratios for samples from the cores as potentially placed on the public beaches at Virginia Beach, Hampton (Buckroe), and Norfolk. The ratios were determined using the method of Dean (1974). The ratio is an estimate of the number of cubic yards of material that must be placed on the beach in order for one cubic yard to remain. A ratio of one is ideal. Some of the samples are listed as being "off scale" indicating conditions that do not fit into the method of determination. These samples still may represent very satisfactory material. Hobson (1977) provides a useful discussion of overfill ratios and other beach-work considerations. One should remember that "calculated" overfill ratios are estimates and shold not be taken as absolute. They should not be used without the review and assistance of a trained and experienced coastal scientist or engineer.

Overfill Ratios, R_D, for Virginia Beach, Buckroe and Norfolk.

Sample #	R_D Va. Beach	R_D Buckroe	R_D Norfolk
2-1	1.85	1.02	
2-3	5.0	1.5	
2-6	>10.0	>10.0	
3-1	>10.0	>10.0	
5-2	>10.0	5.0	
5-3	>10.0	2.75	
7-1	1.2	<1.02	
7-2	4.5	1.5	
7-3	>10.0	3.0	
8-1	2.15	1.05	
8-2	1.13	<1.02	
10-1	2.25	1.1	
10-2	1.6	<1.02	
10-3	1.15	<1.02	
11-1	>10.0	3.25	
11-2	>10.0	5.0	
11-3	>10.0	5.0	
12-1	3.0	1.25	
13-1	<1.02	<1.02	
14-1	>10.0	>10.0	
15-1	1.30	<1.02	
15-2	3.0	1.2	
15-2	1.6	<1.02	
15-1	4.0	1.75	
15-3	>10.0	4.5	
16-1	1.75	<1.02	
17-1	>10.0	>10.0	
17-2	1.75	<1.02	
26-1	1.5	<1.02	
30-1	>10.0	1.2	
31-1	1.1	<1.02	
31-2	1.13	<1.02	
31-3	2.0	1.02	
31-4	>10.0	5.0	
32-1	>10.0	3.25	
32-2	>10.0	3.5	
32-3	>10.0	3.0	
33-1	--	--	
34-1	2.0	1.05	
34-3	<1.02	<1.02	
34-4	--	--	
35-1	10.0	2.25	
35-2	10.0	2.25	
36-1	>10.0	2.5	
36-2	3.0	1.15	
37-1	2.75	1.05	
40-2	>10.0	4.0	
40-3	3.0	1.1	
41-1	3.5	1.2	
41-2	10.0	2.0	
43-1	1.0	<1.02	
43-2	2.25	1.10	
43-3	1.9	1.02	
44-1	1.5	<1.02	
48-1	8.5	2.0	
48-2	1.5	<1.02	
50-1	1.5	<1.02	
50-2	>10.0	7.0	
50-3	>10.0	3.0	
50-4	>10.0	3.5	
50-5	>10.0	2.5	
51-1	>10.0	3.0	
51-2	>10.0	4.0	
51-3	>10.0	10.0	
51-4	>10.0	>10.0	
51-5	1.9	1.05	
52-1	1.17	<1.02	
52-2	>10.0	3.0	
52-3	>10.0	3.5	
52-4	4.5	1.45	
52-5	1.9	1.02	
53-1	>10.0	1.10	
53-2	>10.0	>10.0	
53-3	4.0	1.25	
53-4	>10.0	3.75	
53-5	>10.0	2.5	
53-6	>10.0	6.0	
53-7	>10.0	5.0	
54-1	1.3	<1.02	
54-2	1.1	<1.02	

Overfill Ratios, R_D, for Virginia Beach, Buckroe and Norfolk. (continued)

Sample #	R_D Va. Beach	R_D Buckroe	R_D Norfolk
54-3	1.5	<1.02	
54-4	2.5	1.1	
55-1	1.7	<1.02	
55-2	1.5	<1.02	
55-3	2.5	1.05	
55-4	>10.0	10.0	
55-5	>10.0	>10.0	
55-6	>10.0	>10.0	
55-7	>10.0	>10.0	
55-8	>10.0	>10.0	
57-1	1.7	<1.02	
59-1	>10.0	>10.0	
59-2	3.3	1.4	
59-3	1.45	<1.02	
60-1	>10.0	>10.0	
60-2	>10.0	>10.0	
60-3	>10.0	>10.0	
60-4	>10.0	>10.0	
60-5	>10.0	4.0	
60-6	>10.0	>10.0	
61-1	>10.0	>10.0	
61-2	>10.0	>10.0	
61-3	1.75	1.07	
61-4	>10.0	>10.0	
61-5	4.0	1.35	
61-6	8.5	2.0	
61-7	1.5	<1.02	
62-1	1.5	<1.02	
62-2	10.0	2.25	
62-3	>10.0	>10.0	
62-4	>10.0	10.0	
62-5	>10.0	>10.0	
62-6	>10.0	5.0	
62-7	10.0	2.25	
63-1	>10.0	3.0	
63-2	>10.0	10.0	
63-3	>10.0	>10.0	
64-1	>10.0	>10.0	
65-1	>10.0	>10.0	
65-2	>10.0	>10.0	
65-3	>10.0	>10.0	
66-1	<1.02	1.02	
66-2	<1.02	5.0	
66-3	<1.02	>10.0	
68-1	1.9	<1.02	
68-2	1.5	<1.02	
68-3	<1.02	<1.02	
69-1	10.0	2.25	
69-2	>10.0	6.0	
69-3	>10.0	3.5	
69-4	>10.0	3.5	
69-5	>10.0	2.75	
69-6	>10.0	8.0	
69-7	>10.0	4.0	
70-1	10.0	2.75	
71-1	>10.0	>10.0	
71-2	1.75	<1.02	
71-3	1.13	<1.02	
71-4	1.02	<1.02	
72-1	>10.0	3.5	
72-2	5.0	1.6	
72-3	3.0	1.15	
73-1	>10.0	>10.0	
74-1	1.0	1.3	2.7
74-2	3.75	4.7	1.55
75-1	2.75	2.5	1.2
76-1	1.75	2.5	1.0
76-2	1.05	1.2	1.0
76-3	1.7	1.9	1.0
76-4	1.15	3.4	1.0
76-5	1.3	1.7	1.0
76-6	1.35	1.65	1.0
76-7	1.5	1.65	1.0
77-1	13.0	9.0	2.0
77-2	--	--	--
78-1	2.9	3.75	1.3
78-2	1.5	1.85	1.0
78-3	2.0	2.7	1.0
78-4	1.75	2.2	1.0
79-1	--	--	--

Overfill Ratios, R_D, for Virginia Beach, Buckroe and Norfolk. (concluded)

Sample #	R_D Va. Beach	R_D Buckroe	R_D Norfolk	Sample #	R_D Va. Beach	R_D Buckroe	R_D Norfolk
79-2	--	--	--	92-2	1.5	1.85	1.0
80-1	--	--	--	92-3	1.4	1.75	1.0
81-3	--	--	--	92-4	1.3	1.55	1.0
81-8	3.5	4.2	1.4	93-1	--	--	--
81-12	2.0	2.5	1.05	93-2	5.6	7.0	2.0
82-1	19.0	32.0	3.5	93-3	1.6	2.0	1.0
82-2	2.3	3.1	1.0	94-1	1.75	2.3	1.0
83-1	5.7	7.0	7.0	94-2	1.7	2.2	1.0
83-2	--	--	--	94-3	--	--	--
83-3	1.5	1.8	1.0	95-1	30.0	38.0	1.2
83-4	4.5	5.5	2.0	95-2	1.7	2.1	1.0
84-1	--	--	--	96-1	1.9	2.25	1.1
84-2	--	--	--	96-2	2.55	3.6	1.0
84-3	3.5	4.5	1.15	96-3	5.2	7.5	1.3
84-4	1.4	1.7	1.0	96-4	2.3	3.0	1.0
85-1	--	--	--	96-5	4.5	7.5	1.0
85-2	3.9	5.0	1.4	97-1	1.9	2.3	1.1
85-3	--	--	--	97-2	1.2	1.5	1.0
85-4	15.0	19.0	1.75	97-3	3.0	4.0	1.0
85-5	5.0	7.5	1.2	98-1	--	--	--
86-1	--	--	--	98-2	3.8	5.2	1.3
86-2	--	--	--	98-3	1.6	2.0	1.0
86-3	--	--	--	98-4	1.4	1.75	1.0
86-4	--	--	--	98-5	1.0	1.0	1.0
86-5	1.22	1.3	1.0	99-1	2.3	3.0	1.1
87-1	--	--	--	99-2	3.7	4.8	1.75
87-2	7.5	10.0	2.7	99-3	1.15	1.3	1.0
88-1	8.0	17.0	1.1	100-1	8.0	15.0	1.9
88-2	1.15	1.3	1.0	100-2	3.8	5.0	1.75
88-3	3.5	4.5	1.3	101-1	14.0	19.0	3.0
88-4	3.6	5.0	1.3	101-2	12.0	18.0	2.4
88-5	5.0	11.0	1.0	101-3	1.25	1.6	1.0
88-6	9.0	15.5	1.5	101-4	1.25	1.5	1.0
89-1	1.8	2.4	1.0	101-5	1.0	1.05	1.0
89-2	2.0	2.6	1.0	102-1	2.1	2.5	1.2
90-1	5.5	8.5	1.1	102-2	1.3	1.6	1.0
90-2	--	--	--	102-3	1.7	2.1	1.0
90-3	1.85	2.2	1.1	102-4	1.4	1.7	1.0
90-4	--	--	--	103-1	--	--	--
92-1	17.0	28.0	2.9				

APPENDIX B

BIOLOGICAL CONSIDERATIONS

Robert J. Diaz
Jacques van Montfrans
Linda C. Schaffner

Department of Estuarine and Coastal Ecology
Virginia Institute of Marine Science

1983

INTRODUCTION

Our assessment of the relative resource value of sandy bottoms at the mouth of the James River being considered for sand extraction operations are based on two primary avenues of investigation: 1. A single point in time evaluation of benthic (bottom dwelling) communities as an indication of the potential trophic support for Chesapeake Bay fisheries, and 2. A quantitative assessment of hard clam resources and information from local watermen who make part of their living from commercial stocks in the area. Initially, we will consider each of these avenues separately and finally make recommendations based on an evaluation of all data collected.

Benthic Community Assessment: Rationale

Benthic invertebrates are a large and diverse group of animals that encompass many different life styles. These organisms serve as a major link in the estuarine food web, passing energy from primary producers (phytoplankton and plants) and bacteria to top carnivores (fishes and crabs). Many commercially important species utilize the benthos as a food source throughout their life cycle or during juvenile stages. Thus, much of the fisheries harvest from the Bay is dependent on the production of invertebrates living in bottom sediments.

This part of the study was designed to address the potential impacts of sand mining activities on Bay fisheries by determining the relative resource values for macrobenthic (benthos larger than 1.0 mm) communities in the areas under consideration. The major assumptions made in determining relative resource values are: 1. that bottom feeding species such as spot, croakers and crabs, rely directly on the benthos for food, 2. that pelagic predatory species such as bluefish, striped bass and trout, rely directly on the benthos as juveniles or indirectly on benthic production passed through the food chain, and 3. that benthic invertebrate abundance and taxonomic composition at one point in time can represent the relative value of the bottom. Ideally, a true measure of productivity which considers temporal variability should be utilized, but the time and effort necessary for this type of measure were not available. Therefore, the potential impacts of sand mining are cast in terms of the relative resource values of areas within the total project region.

Clam Survey: Rationale

One of the most important commercial shellfish of Chesapeake Bay benthic (bottom dwelling) communities is the hard clam, *Mercenaria mercenaria*. The hard clam fishery in Virginia waters provided over $1,000,000 in revenues during 1980 and ranked third in over all economic importance behind oysters ($10,000,000) and blue crabs ($7,000,000; Commercial Fisheries Statistics, 1980). Unlike oysters and blue crabs, hard clams cannot tolerate salinities which range below 20 ppt for extended periods of time (Castagna and Kraeuter,

1981) and larvae require late spring salinities of about 18 o/oo for successful metamorphosis to the sedentary stage (Haven et al., 1981). Their occurrence is therefore restricted to the more saline portions of the Bay. Additionally, heavy predation on *Mercenaria mercenaria* by blue crabs (Virnstein, 1977; 1979) and cownose rays (Merriner and Smith, 1979) can further restrict the distribution of clams to sandy or muddy sand substrates containing shell hash or rocks (Pratt, 1953; Kraeuter and Castagna, 1977). Such habitats tend to reduce predator effectiveness and enhance the survival of naturally set clams. Tidal and wind generated currents which carry clam larvae also determine local distributions of clam populations in the Bay.

Since numerous factors restrict the distribution of hard clams, any potential human-induced perturbations near areas where commercial clam beds exist must be carefully evaluated. The removal of sand for beach nourishment, for example, could have adverse effects on clam populations by: 1. Inadvertently harvesting extensive clam populations with the dredge cutter head, 2. Altering surficial substrates suitable for clam settlement, 3. Creating deep borrow pits with inadequate circulation to allow subsequent survival of recruited clams, 4. Producing prolonged turbidity over adjacent clam beds during sand extraction activities, and 5. Altering current patterns which have historically allowed sufficient recruitment to sustain a commercial fishery. A survey was therefore carried out to assess the hard clam resources in and around sand deposits at the mouth of the James River found to be suitable for beach nourishment. To further document the distribution of hard clams at the mouth of the James River and adjacent areas, a meeting was held with the Tidewater Working Watermens Association on 12 November 1982. Their questions and comments concerning possible beach nourishment activities were solicited so that our recommendations with respect to dredging effects on clam resources in the area would be based on as comprehensive a data base as possible. Our survey and input from local watermen was used for making recommendations for sand mining activities that would best preserve existing commercially important clam beds.

METHODS AND MATERIALS

Macrobenthic Survey

Macrobenthic infauna were sampled randomly using a 0.1 m^2 Smith McIntyre grab in and around four areas designated as potential sand sources for beach nourishment. These included Thimble Shoals (TS) and Horseshoe Banks (HS) to the mouth of the James River shipping channel and Willoughby Bar (WB) and Crumps Bank (CB) bordering the southern side of the channel. Single samples were randomly taken within each area as follows: area TS: 31 samples total; HS:19; WB:16; and CB: 17. In addition to these four areas, an old borrow pit (BP) at the western end of Willoughby Bar was similarly sampled at stations corresponding to those of a study conducted in 1971 (Boesch and Rackley, 1973). In this case, two replicate grab samples were taken at each of eight established stations to examine recolonization of a dredged site by the macrobenthos. At all stations, a sediment sample was removed from each grab sample and the remaining material was sieved through a 0.1 mm mesh sieve. The organisms and remaining material retained by the sieve was then preserved in 10% buffered formalin containing the vital stain Rose Bengal for later laboratory processing. In the laboratory, samples were rinsed to remove excess formalin and all organisms were separated and identified to species when possible. Sediment samples were analyzed for fines (silt and clay), sand and gravel using the VIMS rapid sediment analyzer (RSA).

Species composition patterns of macrobenthic communities were identified using numerical classification (Clifford and Stephenson, 1975; Boesch, 1977). This technique groups stations based on similarity in species composition and abundance. A Bray-Curtis similarity measure was utilized with a simple average sorting technique.

Clam Survey

A clam survey was conducted at the mouth of the James River in areas determined by a sand inventory survey to contain "suitable" or "possible" sand sources for beach nourishment (Byrne et al., 1981). Those areas included sand deposits off of Buckroe Beach (area BB), on Horseshoe Bank (HS), Thimble Shoals (TS), Willoughby Bar (WB) and Crumps Bank (CB). The old borrow pit (BP) on Willoughby Bar east of Fort Wool that was created between January and August, 1971 during the construction of the Hampton Roads tunnel was also sampled to evaluate the recolonization of this area by clams.

A total of forty stations were randomly established along transects within each area. These were each sampled once using a hydraulically operated patent tong measuring 76 cm (30") x 90 cm (35") with an operational opening of 0.677 m^2 (7.29 sq ft). The basket of the tongs was lined with 1.3 cm (1/2 inch) mesh hardware cloth to retain small clams. Samples were taken by lowering the tongs to the bottom in the open position and hydraulically closing them. The enclosed sample was brought on board, washed through a 1.3 cm (1/2") mesh sieve and the clams were removed for laboratory processing. Observational characteristics of the substrate were also recorded for each sample. Clams smaller than 1.3 cm were collected during the macrobenthic survey (see previous section) and these were used as an indication of recruitment throughout the area. All sampling was conducted from the Virginia Institute of Marine Science research vessel Captain John Smith.

In the laboratory clams were counted and thickness, length and width were measured (Appendix A) using vernier calipers. Those data were further analyzed to calculate density and economic value of clams (Table 1) in each area. The economic value of clams was calculated by using their market value at the time of harvest.

Table 1. Density and number of clams in each area surveyed and estimated dollar values*.

	Juveniles	Nicks	Cherrystone	Chowder	Total	Calculated Value Per Acre
Crumps Bank (131.3 acres or 53.1 hectares)						
Clams/ft^2	0.04	0.09	0.11	0.18	0.42	
Clams/Total Area	254,913	490,218	607,870	1,019,653	2,372,654	$818./acre
Dollar Value	$0.00	$34,315.	$42,550	$30,590	$107,455	
Borrow Pit (15.8 acres or 6.4 hectares)						
Clams/ft^2	0.02	0.10	0.13	0.05	0.30	
Clams/Total Area	16,537	68,512	89,775	37,800	212,624	$773/acre
Dollar Value	$0.00	$ 4,795.	$ 6,285	$ 1,135	$ 12,215	
Willoughby Bar (54.6 acres or 22.1 hectares)						
Clams/ft^2	0.003	0.01	0.003	0.01	0.03	
Clams/Total Area	8,151	24,452	8,151	16,301	57,055	$ 50/acre
Dollar Value	$0.00	$ 1,710	$ 570.	$ 490.	$ 2,770.	
Buckroe Beach (125.7 acres or 50.9 hectares)						
Clams/ft^2	0.01	0.01	0.00	0.04	0.06	
Clams/Total Area	75,127	56,346	0.00	244,164	375,637	$ 90/acre
Dollar Value	$0.00	$ 3,945	$ 0.00	$ 7,325.	$ 11,270.	
Horseshoe Bank (312.7 acres or 126.6 hectares)						
Clams/ft^2	0.003	0.00	0.00	0.01	0.01	
Clams/Total Area	46,718	0.00	0.00	93,437	140,155	$ 9/acre
Dollar Value	$0.00	$ 0.00	$ 0.00	$ 2,800	$ 2,800	
Thimble Shoals (73.14 acres or 29.6 hectares)						
Clams/ft^2	0	0	0	0	0	
Clams/Total Area	0	0	0	0	0	$ 0/acre
Dollar Value	0	0	0	0	0	

* Note: Clams were grouped into commercial categories and valued at fall, 1981, market prices as follows: Juveniles, length <1.4" @ no market value; Nicks, 1.4-2.3" @ 7¢ ea; Cherrystone = 2.3-3.1" @ 7¢ ea; Chowder = >3.1" @ 3¢ ea.

RESULTS

Benthic Community Survey

a. Physical Environment

Measured physical parameters within the study area are summarized in Table 2. Stations within the Borrow Pit are characterized by medium sand sediments with varying quantities of shell and mud. Depths at these stations range from 10 to 28 feet. Inferred bottom disturbance due to waves in this region of the study area is moderate to high. The sediments at Willoughby Bar are medium sands with almost no shell or mud. Wave disturbance is probably high in this relatively shallow (8-20') area. Sediments in the Crumps Bank region of the study area are predominantly muddy, fine sands. This area is relatively deep (19-23') and protected from wave activity. The stations in the Thimble Shoals and Horseshoe Bank areas are characterized by fine sands with small amounts of mud and little shell. Depths at Thimble Shoals and Horseshoe Bank stations range from 17-50' and 16-23', respectively. Inferred wave exposure in these areas is low to moderate.

b. Faunal Composition and Abundance

A total of 13,309 individuals comprising 230 taxa were collected during the study. Of these, 57% were annelids, 14% were molluscs, 10% were crustaceans and 19% represented other taxonomic groups (including anthozoans, nemerteans and echinoderms). The list of species collected is presented in Appendix B.

Five groups of stations were identified in the cluster analysis which very closely followed the topography of the area. This made the task of resource assessment very straight forward. The total character of an area could then be accurately described from our samples. The stations included in each group are shown in Figure 1. Important biological parameters for each group are summarized in Table 3.

Densities of benthic organisms were greatest at stations in the Crumps Bank and Borrow Pit regions. These communities also contained the highest proportions of crustaceans, which are very important food items. Species richness was also relatively high at these stations (25-27 species collected per grab).

Clam Survey

Clam abundances (Table 1) varied considerably within the study area (Figures 2, 3). The greatest density and number of clams occurred in the Crumps Bank area which had an estimated standing crop value of $818 per acre. The impacted Borrow Pit area also contained high densities of clams and was valued at $773 per acre. Few to no clams were found in the remaining four areas. Dollar values per acre were $90, $50, $9 and zero for areas BB, WB, HS and TS, respectively. No clams were found on Thimble Shoal.

Measurement data (Appendix A) indicated that the greatest densities of nicks and cherrystone clams also occurred on Crumps Bank

Table 2. Percent shell-gravel, sand and silt-clay, sediment median particle diameter in Phi units and sediment classification for each macrofaunal station. (BP = borrow pit; WB = Willoughby Bank; TS = Thimble Shoals; W = Willoughby).

Station No.	% Weight Shell-Gravel	Sand	Fines (Silt and Clay)	Median Phi Size	Classification
BP01	3.2	93.9	2.9	1.25	Medium sand
BP02	1.1	97.8	1.0	1.25	" "
BP03	13.8	83.5	2.7	1.75	" "
BP04	0.2	98.9	0.9	1.25	" "
BP05	0.9	98.6	0.5	1.25	" "
BP06	0.8	93.0	6.2	2.00	Fine sand
BP07	1.6	85.4	13.0	2.00	" "
BP08	32.0	63.3	4.7	1.50	Medium sand
WB01	0.0	99.2	0.8	1.50	" "
WB02	11.2	87.5	1.3	1.25	" "
WB03	0.6	97.6	1.8	1.75	" "
WB04	0.1	98.6	1.3	2.25	Fine sand
WB05	6.9	91.4	1.7	1.25	Medium sand
WB06	0.2	99.5	0.3	1.00	" "
WB07	0.2	99.4	0.5	1.00	" "
WB08	3.0	96.9	0.2	0.75	Coarse sand
WB09	2.3	97.2	0.5	1.25	Medium sand
WB10	0.3	98.9	0.8	1.50	" "
WB11	0.2	99.4	0.5	1.25	" "
WB12	0.7	98.9	0.4	1.00	" "
WB13	0.0	99.3	0.6	1.25	" "
WB14	10.5	88.5	1.0	1.00	" "
WB15	4.4	94.1	1.4	1.25	" "
WB16	0.1	98.0	1.9	1.75	Medium sand
CB01	0.4	80.9	18.7	3.25	Very fine sand
CB02	0.2	63.6	36.2	3.25	" " "
CB03	8.1	89.7	2.1	1.00	Medium sand
CB04	7.8	89.0	3.2	1.00	" "
CB05	5.4	83.3	11.3	2.00	Fine sand
CB06	0.0	62.5	37.5	3.25	Very fine sand
CB07	0.8	87.3	11.9	3.00	" " "
CB08	0.3	73.4	26.2	3.25	" " "
CB09	0.7	77.0	22.3	2.50	Fine sand
CB10	1.4	83.7	14.9	3.00	Very fine sand
CB11	0.4	82.9	16.7	3.25	" " "
CB12	0.2	90.3	9.5	3.25	" " "
CB13	0.9	74.8	24.3	3.25	" " "
CB14	0.7	82.0	17.2	3.25	" " "
CB15	1.8	54.6	43.6	3.00	" " "
CB16	2.8	74.1	23.1	3.00	" " "
CB17	1.2	75.7	23.0	2.50	Fine sand

Table 2 (continued)

Station No.	% Weight Shell-Gravel	Sand	Fines (Silt and Clay)	Median Phi Size	Classification
TS01	0.1	98.8	1.2	2.00	Fine sand
TS02	0.0	97.6	2.3	2.75	" "
TS03	0.0	97.7	2.3	2.75	" "
TS04	0.6	97.7	1.7	1.75	Medium sand
TS05	0.0	98.6	1.3	2.00	Fine sand
TS06	0.0	98.0	2.0	2.75	" "
TS07	0.0	98.0	2.0	2.50	" "
TS08	0.0	97.9	2.1	2.50	" "
TS09	0.4	97.5	2.2	2.50	" "
TS10	0.1	98.1	1.8	2.50	" "
TS11	0.2	98.1	1.8	2.50	" "
TS12	0.3	97.6	2.1	2.50	" "
TS13	0.0	98.2	1.8	2.25	" "
TS14	0.2	98.0	1.8	2.25	" "
TS15	0.0	97.7	2.3	2.75	" "
TS16	0.1	97.6	2.3	2.75	" "
TS17	0.1	98.0	1.9	2.50	" "
TS18			NO SAMPLE		
TS19	0.0	98.1	1.8	2.50	" "
TS20	0.4	97.8	1.7	2.75	" "
TS21	0.0	98.5	1.5	2.50	" "
TS22	0.1	98.3	1.6	2.75	" "
TS23	0.0	98.0	2.0	2.75	" "
TS24	0.0	97.9	2.1	2.50	" "
TS25	0.1	98.1	1.8	2.50	" "
TS26	0.4	95.9	3.7	2.25	" "
TS27	0.4	97.0	2.6	2.00	" "
TS28	0.6	97.8	1.6	1.75	Medium sand
TS29	0.0	98.1	1.8	2.50	Fine sand
TS30	0.0	95.1	4.9	2.75	" "
TS31	0.0	95.2	4.8	3.00	Very fine sand
HS01	0.0	94.2	5.8	3.25	" " "
HS02	0.0	95.0	5.0	3.00	" " "
HS03	0.3	61.1	38.7	3.00	" " "
HS04	0.1	98.4	1.5	2.50	Fine sand
HS05	0.3	96.0	3.7	2.50	" "
HS06	0.0	98.3	1.6	2.25	" "
HS07	0.0	98.8	1.2	2.00	" "
HS08	0.1	98.3	1.6	2.00	" "
HS09	0.0	98.4	1.6	2.25	" "
HS10	0.0	93.8	6.2	2.75	" "
HS11	0.0	93.8	6.2	3.00	Very fine sand
HS12	0.2	94.8	5.0	3.00	" " "
HS13	0.1	93.2	6.7	3.25	" " "

Table 2 (concluded)

Station No.	% Weight Shell-Gravel	Sand	Fines (Silt and Clay)	Median Phi Size	Classification
HS14	0.0	97.6	2.3	2.75	Fine sand
HS15	0.0	98.2	1.8	2.25	" "
HS16	0.0	98.6	1.4	2.00	" "
HS17	0.0	98.2	1.8	2.00	" "
HS18	0.0	98.7	1.3	2.25	" "
HS19	0.4	96.3	3.3	1.50	Medium sand

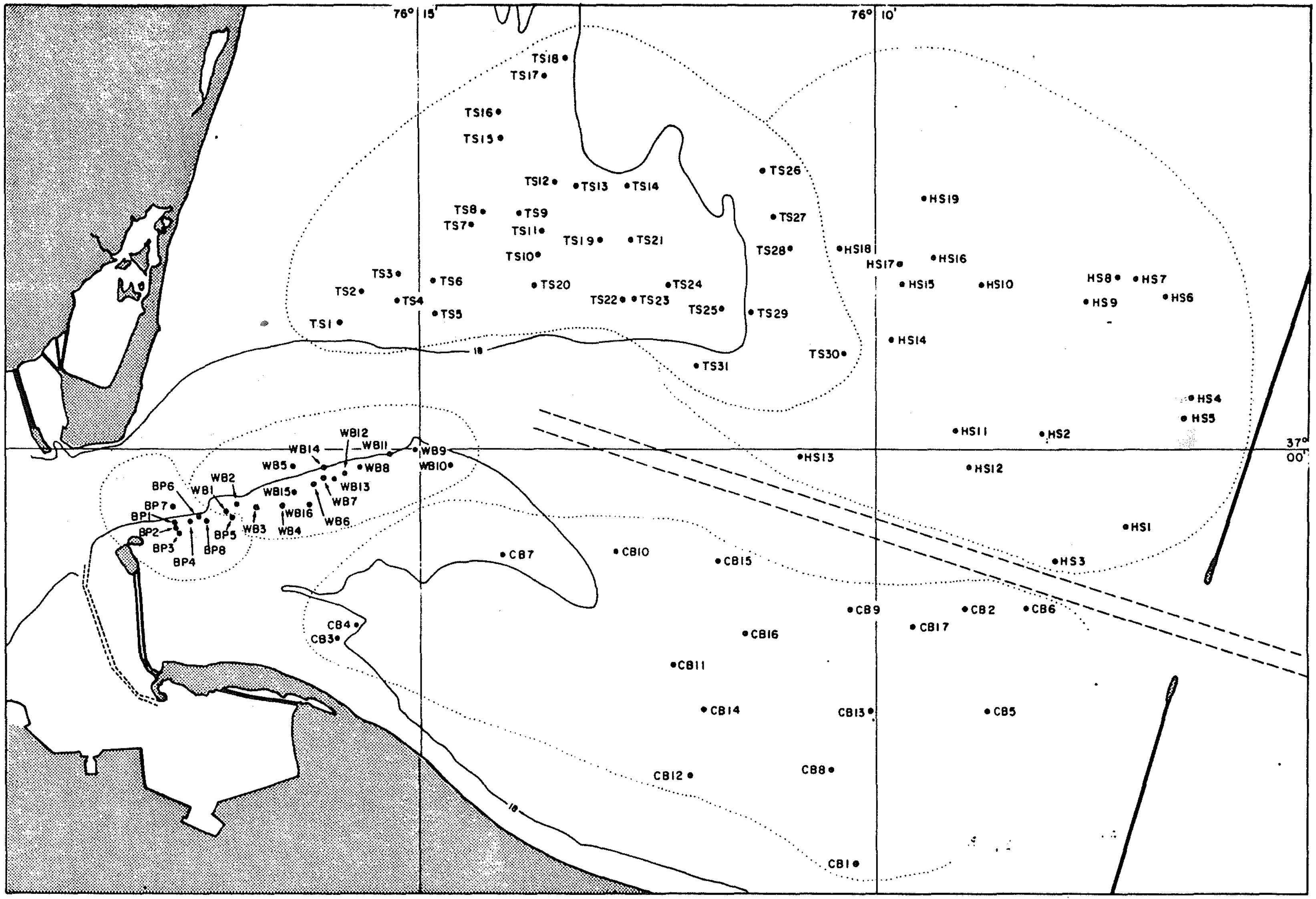

Figure 1: Map depicting the location of the macrobenthos survey stations. BP=Borrow Pit; WB=Willoughby Bank; CB=Crumps Bank; TS=Thimble Shoal; HS=Horseshoe Bank.

Table 3. Important biological parameters for each group of stations identified using cluster analysis.

Group	Richness/$_{0.1\ m^2}$	Mean # of Individuals / m^2	Mean # of Crustaceans / m^2	Mean # of Molluscs / m^2	Mean # of Annelids / m^2
I - Borrow Pit	25	1707	267	170	990
II - Crumps Bank	27	1823	179	143	1378
III - Thimble Shoals	18	1388	136	148	541
IV - Horseshoe Bank	19	949	87	300	757
V - Willoughby Bar	12	856	42	84	168

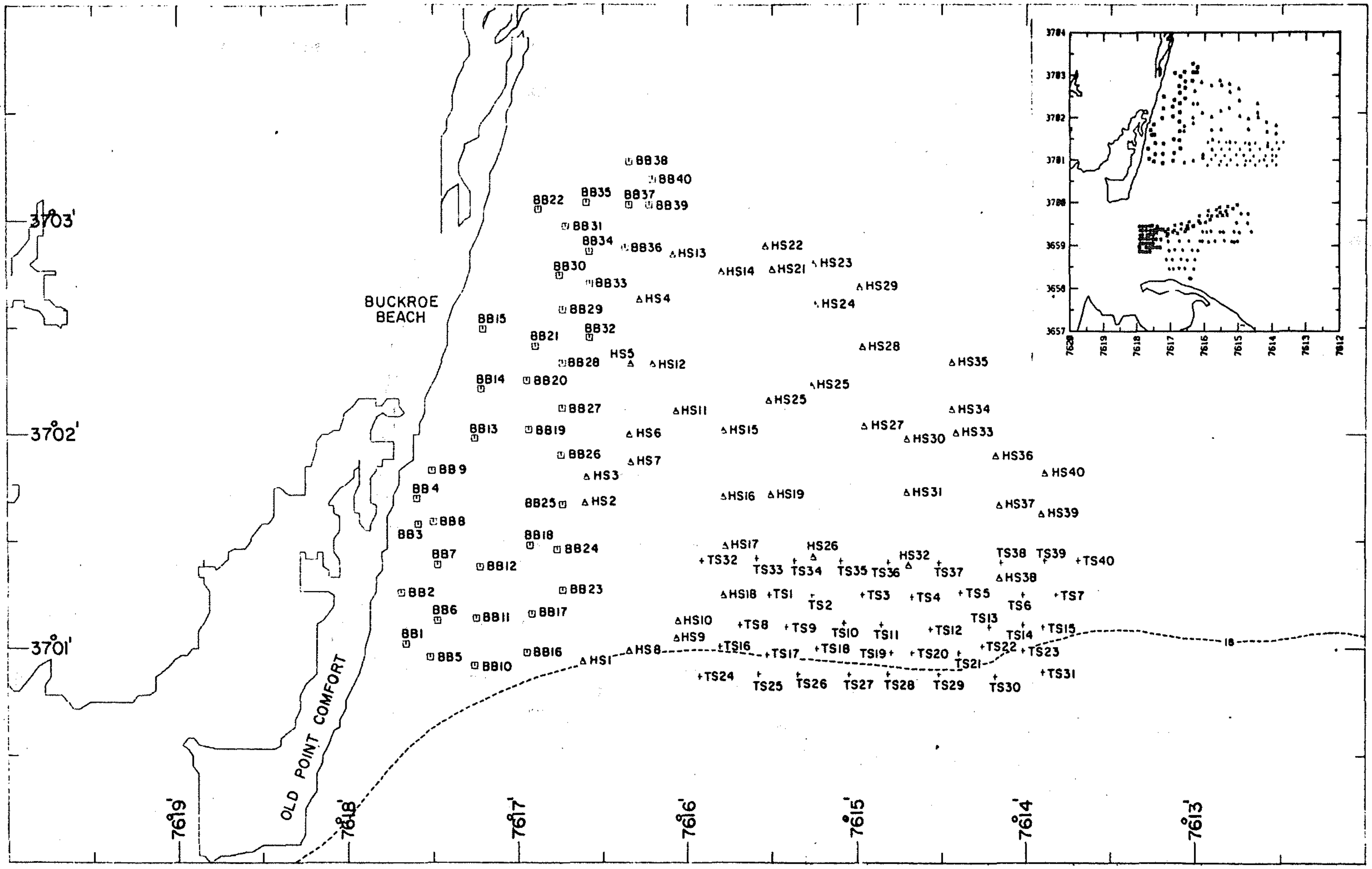

Figure 2: Map depicting the locations of the clam survey station north of Thimble Shoal Channel.

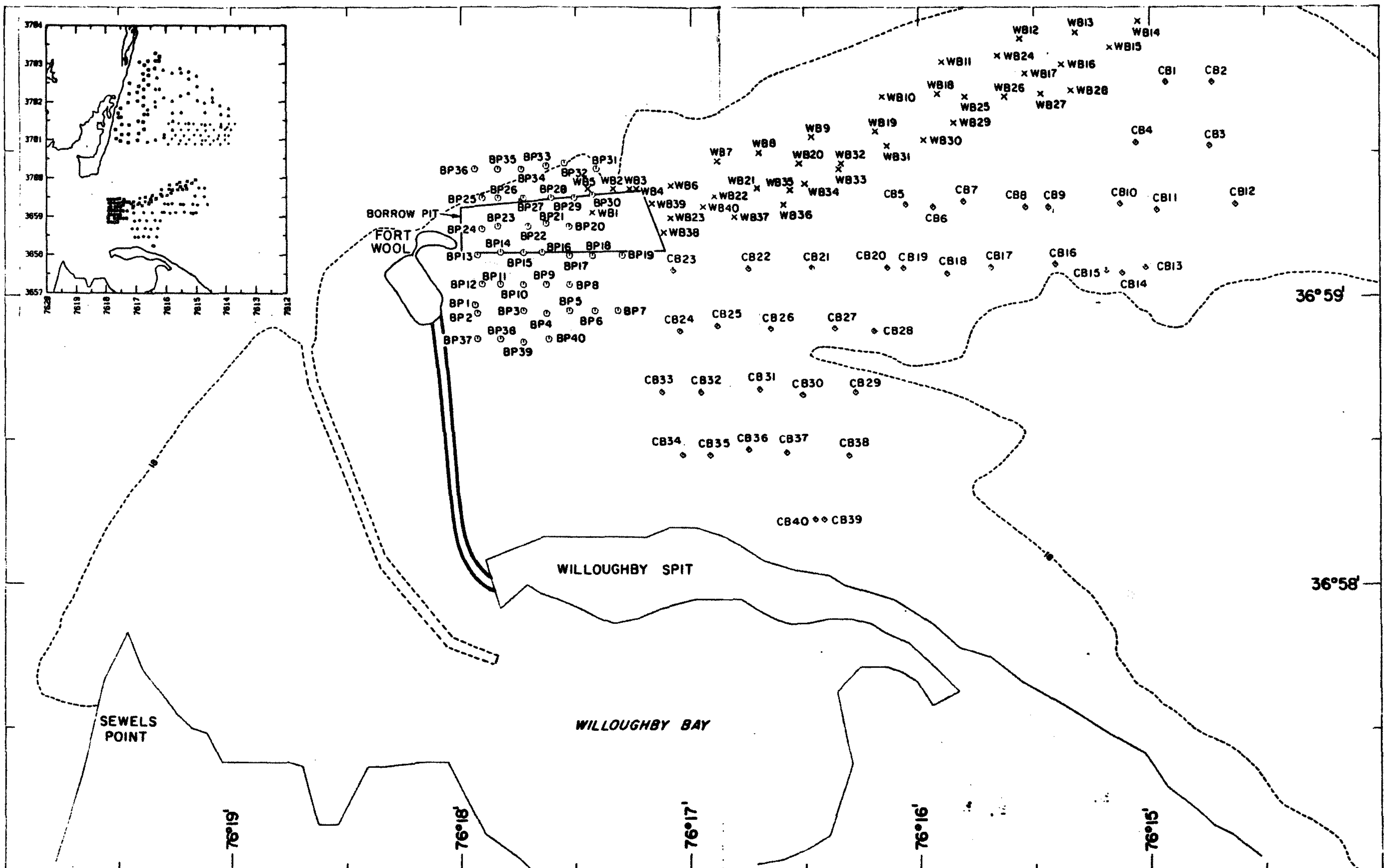

Figure 3: Map depicting the location of the clam survey south of Thimble Shoal Channel.

and the Borrow Pit. Recruitment as indicated by the number of juveniles in patent tong samples was highest on Crumps Bank and was second highest in the Borrow Pit. However, data on the smallest clams in grab samples taken during the macrobenthic survey (Figure 4) indicates that recruitment may be relatively uniform throughout all areas. If this single data set is representative of yearly clam recruitment, perhaps the primary causes for the greatest abundance of hard clams on Crumps Bank and in the Borrow Pit can be accounted for by differential survival rather than increased recruitment.

Verification of clam distributions based on our sampling effort was made by local clammers during a meeting with the Virginia Working Watermens Association (12 Nov. 1982). Additional anecdotal information on the historical harvesting of clams at the mouth of the James River supported the fact that the Crumps Bank area has been and is currently being extensively fished for hard clams. Concerns were expressed by the watermen over the removal of sand from both commercially fished beds and from prominent topographic features in the area such as Willoughby Bank. The removal of such topographic features might alter current patterns in the area and consequently affect clam recruitment on Crumps Bank where most of the commercial harvest in the area originates. Some watermen suggested modeling the system to ascertain changes in currents resulting from the alteration of prominent topographical features at the mouth of the James River. All of these suggestions will be considered in the subsequent discussion section.

DISCUSSION AND RECOMMENDATIONS

Although the macrobenthic and clam surveys each approach the resource value assessment of sand deposits at the mouth of the James River from two perspectives, many of the conclusions are similar. A combined ranking based on data from these surveys (Table 5) shows that the two areas of shared lowest value and therefore greatest desirability as sand extraction sites include Thimble Shoals and Horseshoe Bank. These areas contain very few clams if any and have only a moderate macrobenthic resource value.

Willoughby Bar has an intermediate combined rank largely because the area had a moderate value with respect to clams (but a low macrobenthic value). At the present time we do not know whether enhanced recruitment or differential survival allows for better clam production in the Crumps Bank-Borrow Pit-Willoughby Bank areas. Our data on clam recruitment is based on an assessment at a single point in time and may not accurately reflect recruitment patterns. However, given the historical use of Crumps Bank as a clam fishing ground it is important to give consideration to the question whether mechanical disruption of the Willoughby Bank topography by dredging would influence the curents on Crumps Bank and thereby potential recruitment. Willoughby Bank is more a product of, rather than a control of, local curents (Robert Byrne, personal communication). Flood currents predominate over the shoals between Willoughby Spit and

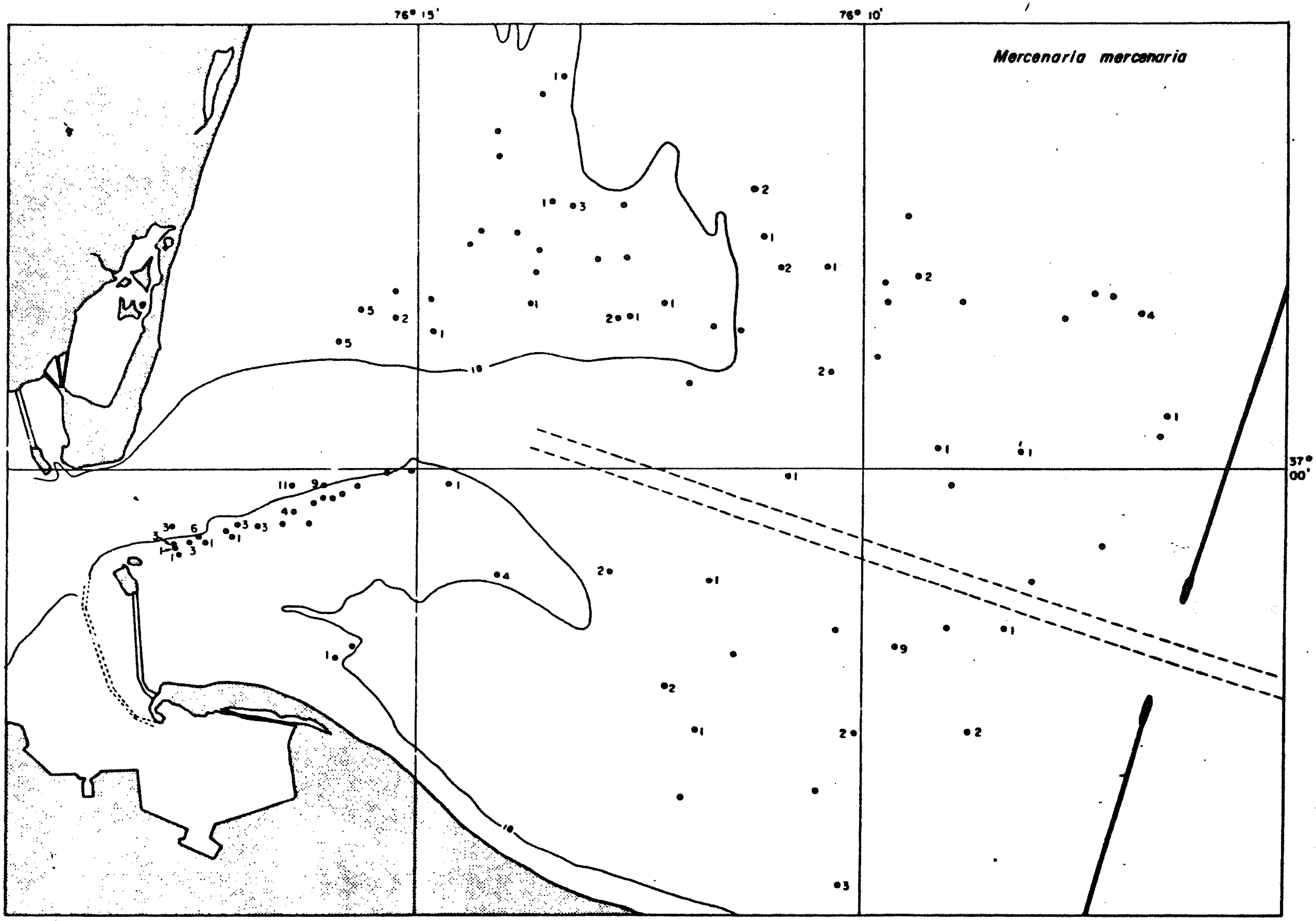

Figure 4: M. mercenaria juveniles collected in the macrobenthic survey.

the Bank (Ludwick, 1981) while ebb currents predominate over the southern portion of the entrance channel (Richards and Morton, 1983). Ludwick (1981) interprets Willoughby Bank as a channel margin shoal which formed from sediment convergence in the central region of the nit circulation cell. More detailed studies of the spatial distribution of currents would be necessary to provide insights into clam recruitment potential or to address with certainty the consequences of large scale excavations on the crown of Willoughby Bar. However, lesser scale excavations on the northern flank of Willoughby Bank would not be expected to exert primary incluence on the currents over Crumps Bank (R. J. Byrne, personal communication).

The Borrow Pit provides an insight into the effects of deep hole formation over a relatively long term (11 years). This feature was created in 1971 where material was taken for the second Hampton Roads Bridge-tunnel crossing and has persisted to the present. The high macrobenthic resource value of the Borrow Pit is due primarily to the increased habitat complexity provided by the large amount of shell at the sediment surface. The shell attracts many epifaunal macrobenthos, particularly crustaceans which are important fish food items. This area also had the second highest clam resource value. There is little information, however, on the value of the Borrow Pit region prior to dredging. Only comparisons with adjacent areas can be made and in this regard the Borrow Pit compares favorably with Crumps Bank.

Relative Resource Value

Macrobenthic (larger than 1 mm) invertebrates are a very large and diverse group of animals that encompass many different life styles. The vast majority of macrobenthos are small and rather obscure, blending in very well with their surroundings. The significance of these animals is that they serve as a major link in the food web of the Bay, passing energy from primary producers (phytoplankton and plants) to top carnivores (fish and crabs). Much of the fisheries harvest from the Bay each year would not be possible without the even greater production of benthic invertebrates.

The areas under consideration for sand mining constitute a sizable portion of the bottom near the mouth of the Bay. In order to address the potential impacts on Bay fisheries of sand mining the macrobenthos were surveyed to determine the relative resource value of the various areas that might be mined. The major assumptions made are: 1) that bottom feeding species (spot, croaker, crabs) directly rely on the benthos for food and pelagic predatory species (bluefish, striped bass, trout) are indirectly tied in some way to benthic production through their prey; and 2) that abundance and taxonomic composition of the macrobenthos at one point in time can be representative of the relative value of the bottom. Ideally a true measure of productivity should be used but time and effort were not available. Therefore, the potential impacts of sand mining are cast in terms of the relative value of one area as compared to another within the confines of the total project area.

Using the cluster analysis the macrobenthic communities grouped very well following the major topographic features of the project area

(Figure 1). The five major groups formed are responding to a combination of sediment grain size, depth, and wave exposure. The physical and biological characteristics of the groups are detailed in Table 4. The Borrow Pit area is the location from which fill material was taken for the second Hampton Roads Bridge-tunnel crossing. It has the highest values for all the biological characteristics. This is due primarily to the increased habitat complexity provided by the large amount of shell in the sediment surface. The shell attracts many epifaunal macrobenthos particularly the crustaceans, which are very important fish food items. In contrast the wave swept Willoughby Bar had the lowest biological characteristic values. The other three groups or areas were intermediate to these two groups.

The assessment of the relative resource value based on the data summarized in Table 1 places the borrow pit area as having the highest resource value of the five groups. This is followed by the Crumps Bank, Thimble Shoals, Horseshoe Banks, and Willoughby Bar groups. Willoughby Bar is definitely the lowest in relative value (keep in mind this evaluation is based solely on macrobenthic communities). Thimble Shoals is slightly higher than Horseshoe Bank in relative value because of the slightly higher abundance of benthos. Crumps Bank had more crustaceans and polychaetes than Thimble Shoals and Horseshoe Bank and consequently a higher relative value, even though Crumps Bank had fewer molluscs.

From the relative resource value approach it then seems the areas that will likely be least disturbed from sand mining, in the short term, are (from least to most affected):

Willoughby Bar
Horseshoe Bank
Thimble Shoals
Crumps Bank
Borrow Pit

In the long run if the sand mining operation does not change the physical nature of the area mined then the above ranking will also be representative of expected impacts. Should the physical nature of the area change then long-term impacts will not be represented by the above ranking.

Table 4. Physical and biological characteristics of macrobenthic station groups formed from cluster analysis.

Station Group	Wave Exposure	Depth	Sediment	Species Richness	Total Abundance of Individuals	Abundance of Crustaceans	Abundance of Molluscs	Abundance of Polychaetes	Relative Resource Value
Borrow Pit	Moderate to high*	10 - 28'	Medium sand, large amounts of shell	High	High	High	Moderate	High	High
Willoughby Bar	High	8 - 20'	Medium sand, some shell	Low	Low to Moderate	Low	Low	Low	Low
Crumps Bank	Low	19 - 23	Very fine sand	High	High	Moderate	Moderate	High	Moderate to high
Thimble Shoals	Moderate	17 - 50	Fine sand	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Horseshoe Bank	Low	16 - 23	Fine to very fine sand	Moderate	Low to Moderate	Low	Moderate	Moderate	Moderate

* Use of the high, moderate, low descriptors is for comparison of station groups within this data set and is not meant to be an absolute measure.

Table 5. Relative desirability of borrow sites for beach nourishment purposes ranked from most to least desirable based on macrobenthic and clam resource data.

Area	Macrobenthic Survey	Clam Survey	Sum	Combined Rank
Thimble Shoal	3	1	4	1.5
Horseshoe Bank	2	2	4	1.5
Willoughby Bar	1	3	4	3
Borrow Pit	5	4	9	4.5
Crumps Bank	4	5	9	4.5

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Appendix A. Measurements in centimeters of clams (<u>Mercenaria mercenaria</u>) collected during the Sand Inventory Clam Survey, 21 Sept. - 30 Sept, 1981. (Note: L = length; W = width; T = thickness).

Station (and # of clams collected)	L	W	T
BP 1 (3)	5.64	5.25	3.02
	5.52	5.04	2.89
	8.45	7.87	3.70
BP 2 (5)	4.46	4.08	2.45
	5.74	5.31	3.17
	6.22	5.55	3.31
	7.65	6.92	3.90
	8.73	8.02	4.60
BP 3 (13)	7.03	6.90	4.12
	7.79	7.67	4.62
	7.68	7.52	4.64
	9.24	8.78	4.85
	5.08	4.72	2.70
	7.87	7.47	4.50
	7.45	7.21	4.38
	8.17	7.58	4.70
	6.41	5.56	3.48
	6.20	5.60	3.60
	7.88	7.38	4.41
	7.63	7.52	4.98
	10.09	9.36	4.97
BP 4 (10)	3.82	3.52	2.06
	4.12	3.81	2.28
	7.55	7.12	4.58
	6.27	5.80	3.54
	7.84	7.33	4.09
	8.09	8.78	5.00
	7.49	6.93	3.90
	8.38	7.95	4.91
	8.76	8.46	4.91
	7.39	broken	broken
BP 5 (3)	4.78	4.18	2.36
	7.59	7.12	4.20
	7.23	6.84	4.52
BP 6 (2)	4.12	3.53	2.00
	5.50	4.76	3.14
BP 7 (2)	4.34	4.00	2.33
	7.75	7.42	4.28
BP 8 (6)	4.18	3.66	2.29
	6.73	5.99	3.72
	7.17	6.34	4.53
	8.68	8.13	4.94
	8.52	7.76	5.04
	9.04	8.25	4.98
BP 9 (1)	7.60	7.04	4.10
BP 11 (5)	4.26	3.78	2.14
	5.79	5.27	3.35
	6.13	5.53	3.22
	9.72	9.07	5.32
	broken	4.63	
BP 12 (3)	7.29	7.07	4.28
	7.10	6.40	3.67
	8.18	7.78	4.19
BP 13 (1)	3.52	3.17	1.91
BP 14 (5)	1.34	1.12	0.60
	3.58	3.15	1.79
	3.25	2.67	1.66
	5.02	4.31	2.66
	5.81	5.00	3.05
BP 15 (2)	3.84	3.43	1.92
	6.84	6.36	3.66
BP 16 (2)	3.31	3.00	1.76
	4.72	3.87	2.77
BP 17 (3)	7.32	6.47	3.76
	7.58	7.00	4.12
	7.82	7.18	4.27
BP 18 (2)	3.92	3.55	1.99
	9.28	8.74	5.24

Appendix A (continued)

Station (and # of clams collected)	L	W	T
BP 22 (2)	5.78	5.50	3.33
	5.89	5.23	2.97
BP 23 (3)	5.12	4.76	3.03
	5.76	5.15	3.22
	6.33	5.61	3.47
BP 24 (1)	2.39	2.10	1.20
BP 27 (3)	2.85	2.50	1.49
	4.57	4.13	2.26
	7.12	6.09	3.35
BP 28 (2)	2.14	1.94	0.98
	4.19	3.74	2.11
BP 31 (2)	6.18	5.76	3.06
	6.72	6.06	3.86
BP 33 (1)	5.29	4.91	2.68
BP 34 (1)	4.48	3.90	2.34
BP 37 (4)	8.03	7.81	4.79
	7.91	7.60	4.87
	7.18	6.71	3.97
	7.32	6.74	3.93
BP 40 (4)	2.08	1.94	1.10
	7.98	7.46	4.41
	7.50	6.79	4.22
	8.72	7.99	4.50
WS 4 (2)	6.83	6.69	4.28
	8.63	7.92	4.83
WS 6 (2)	9.28	9.38	5.48
	10.78	10.03	5.78
WS 7 (2)	7.67	7.32	4.33
	8.19	7.81	4.96
WS 8 (3)	2.24	2.01	1.06
	2.38	2.23	1.16
	7.10	6.60	3.81

Station (and # of clams collected)	L	W	T
WS 9 (6)	3.15	2.83	1.59
	5.12	4.88	2.64
	7.39	6.78	4.10
	9.05	8.56	4.57
	8.68	7.84	4.80
	broken	4.31	
WS 10 (4)	2.74	2.48	1.42
	3.95	3.45	1.97
	9.06	8.85	5.70
	9.68	8.79	broken
WS 11 (1)	1.48	1.35	0.66
WS 12 (1)	8.55	8.24	5.08
WS 13 (2)	8.95	8.87	6.24
	8.93	8.03	4.96
WS 14 (4)	1.73	1.46	0.80
	8.94	8.43	5.24
	9.10	8.72	4.80
	9.92	9.21	5.44
WS 15 (2)	3.81	3.51	2.01
	8.52	8.19	5.03
WS 16 (4)	9.77	9.10	5.54
	7.95	7.00	4.11
	8.65	8.36	5.30
	broken		
WS 17 (2)	2.07	1.85	0.95
	9.30	8.75	5.08
WS 18 (6)	9.00	8.23	4.93
	7.57	6.99	4.07
	6.84	6.22	3.67
	8.70	8.25	5.10
	7.89	7.45	4.70
	9.28	8.55	5.20
WS 19 (1)	8.96	8.58	4.69

Station (and # of clams collected	L	W	T	Station (and # of clams collected	L	W	T
WS 20 (3)	3.70	3.40	1.87	WS 31 (7)	1.63	1.35	0.74
	3.93	3.52	2.07		3.96	3.47	2.01
	10.13	9.96	6.07		4.39	3.78	2.24
					4.63	4.10	2.30
WS 21 (9)	5.58	5.98	3.42		4.99	4.40	2.51
	4.65	4.13	2.32		5.33	4.77	2.88
	5.45	4.88	2.90		8.19	7.90	4.41
	4.23	3.48	2.24				
	7.61	6.93	3.95	WS 32 (6)	2.89	2.62	1.47
	8.69	8.54	5.60		3.99	3.52	2.00
	9.99	9.16	5.34		6.49	6.10	3.55
	7.88	7.30	4.46		7.65	7.18	4.40
	8.79	8.38	5.52		8.53	8.22	4.84
					8.57	7.76	4.65
WS 22 (5)	5.13	4.63	2.63				
	5.68	5.13	3.02	WS 33 (4)	5.83	5.22	3.13
	9.14	8.24	4.90		2.32	2.03	1.17
	6.96	6.40	3.76		5.41	4.69	2.80
	9.31	8.81	4.67		5.47	4.76	2.90
WS 24 (3)	8.70	7.97	4.77	WS 34 (4)	7.93	7.85	5.13
	8.97	8.99	5.18		8.55	7.75	4.36
	8.23	7.59	4.50		7.12	7.06	4.52
					9.63	9.23	5.65
WS 25 (2)	9.50	8.90	5.25				
	8.33	7.92	4.56	WS 35 (4)	3.20	2.78	1.59
					6.84	6.44	3.70
WS 26 (1)	7.68	6.94	3.80		7.85	7.43	4.88
					7.75	7.47	4.58
WS 27 (5)	3.67	3.31	1.87				
	6.08	5.52	3.24	WS 36 (1)	7.98	7.28	4.28
	8.40	7.78	4.32				
	8.46	8.58	5.16	WS 37 (2)	4.97	4.61	2.71
	9.00	8.22	4.86		9.08	8.78	5.47
WS 28 (6)	7.60	7.22	4.49	WS 39 (6)	8.72	8.08	4.74
	5.16	4.74	2.76		7.95	7.47	4.07
	4.48	4.12	2.37		9.45	8.43	5.00
	7.38	6.81	4.00		7.19	6.70	4.16
	8.88	7.97	4.85		5.10	4.38	2.60
	8.08	7.61	4.89		8.43	7.98	4.63
WS 29 (4)	6.09	5.64	3.33				
	7.79	7.86	5.22				
	9.88	9.35	5.45				
	8.32	7.97	4.61				

Appendix A (continued)

Station (and # of clams collected)	L	W	T	Station (and # of clams collected)	L	W	T
WS 40 (9)	7.30	6.92	4.37	BB 36 (3)	8.10	7.54	4.55
	9.00	8.51	5.02		8.48	8.11	4.85
	9.33	8.57	4.73		8.92	8.73	5.23
	6.80	6.15	3.67				
	3.07	2.67	1.58	BB 39 (1)	3.72	3.29	2.00
	7.78	7.35	4.47				
	6.97	6.32	3.43	BB 40 (2)	8.50	7.94	4.93
	2.77	2.38	1.28		9.86	9.09	5.44
	8.60	8.26	5.18				
				HS 1 (2)	10.59	10.00	6.20
WB 2 (1)	5.05	4.50	2.97		9.88	9.88	6.68
WB 4 (1)	3.51	3.07	1.80	HS 4 (1)	3.00	2.58	1.54
WB 6 (1)	2.18	1.93	1.04				
WB 37 (2)	8.34	8.10	4.65				
	9.08	8.71	5.39				
WB 38 (2)	4.69	4.23	2.39				
	6.68	6.51	4.03				
BB 2 (2)	8.35	7.98	4.61				
	9.66	9.07	5.45				
BB 14 (1)	9.14	8.67	5.00				
BB 15 (1)	4.30	3.98	2.31				
BB 21 (1)	2.95	2.57	1.45				
BB 23 (1)	11.62	10.58	6.37				
BB 28 (1)	2.64	2.27	1.29				
BB 30 (2)	9.01	8.32	5.22				
	8.73	8.56	4.94				
BB 32 (3)	2.23	2.03	1.07				
	2.41	2.14	1.21				
	3.91	3.53	2.01				
BB 33 (1)	8.69	8.62	5.37				
BB 34 (1)	10.02	9.55	5.33				

Appendix B

Species List

Phylum Cnidaria
  Class Anthozoa
    Family Actinostolidae
      Paranthus rapiformis
    Family Edwardsiidae
      Edwardsia elegans
    Family Sagartidae
      Actinothoe sp.

Phylum Platyhelminthes
  Class Turbellaria
    Family Stylochidae
      Coronadena mutabilis

Phylum Rhynchocoela
  Class Anopla
    Family Tubulanidae
      Tubulanus sp.
      Tubulanus pellucidus
    Family Lineidae
      Cerebratulus sp.
      Cerebratulus lacteus
      Micrura leidyi

Phylum Echiura
      Echiura sp.

Phylum Phoronida
      Phoronis sp.

Phylum Mollusca
  Class Pelecypoda
    Family Nuculidae
      Nucula proxima
    Family Arcidae
      Anadara ovalis
      Anadara transversa
    Family Lucinidae
      juvenile Lucinid
    Family Veneridae
      Dosinia elegans
      Gemma gemma
      Mercenaria mercenaria
    Family Mactridae
      Mulinea lateralis
    Family Tellinidae
      Macoma tenta
      Tellina agilis
    Family Semelidae
      Abra aequalis
    Family Solenidae
      Ensis directus
      Solen viridis

Class Pelecypoda (continued)

Family Myidae

Mya arenaria

Family Lyonsidae

Lyonsia hyalina

Family Pandoridae

Pandora trilineata

Family Anomiidae

Anomia simplex

Class Gastropoda

Family Crepidulidae

Crepidula convexa

Crepidula fornicata

Crepidula plana

Family Naticidae

Polinices duplicatus

Family Columbellidae

Astyris lunata

Family Muricidae

Eupleura caudata

Urosalpinx cinerea

Family Nassariidae

Nassarius vibex

Family Cerithiidae

Bittium sp.

Bittium varium

Cerithium atratum

Family Pyramidellidae

Odostomia engonia

Turbonilla interrupta

Family Acteonidae

Acteon punctostriatus

Family Retusidae

Acteocina canaliculata

Family Epitoniidae

Epitonium sp.

Epitonium multistriatum

Epitonium rupicolum

Family Corambidae

Doridella sp.

Family Dendrodorididae

Doriopsilla pharpa

Family Dorididae

Doris verrucosa

Phylum Annelida

Class Polychaeta

Family Phyllodocidae

Eteone heteropoda

Eteone lactea

Eulalia sanguinea

Phyllodoce arenae

Class Polychaeta (continued)

Family Polynoidae

- *Lepidametria commensalis*
- *Lepidonotus variabilis*
- *Malmgrenia* sp.

Family Chrysopetalidae

- *Bhawania goodei*

Family Glyceridae

- *Glycera* sp.
- *Glycera americana*
- *Glycera dibranchiata*
- *Hemipodus roseus*

Family Goniadidae

- *Glycinde solitaria*

Family Nephtyidae

- *Aglaophamus verrilli*
- *Nephtys* sp.
- *Nephtys incisa*
- *Nephtys picta*

Family Syllidae

- *Autolytus* sp.
- *Brania clavata*
- *Exogone dispar*
- *Exogone verugera*
- *Parapionosyllis longicirrata*
- *Streptosyllis* sp.

Family Hesionidae

- *Gyptis brevipalpa*
- *Microphthalmus* sp.
- *Podarke obscura*

Family Pilargidae

- *Sigambra tentaculata*

Family Nereidae

- *Nereis* sp.
- *Nereis acuminata*
- *Nereis succinea*

Family Capitellidae

- *Capitella* sp.
- *Heteromastus filiformis*
- *Mediomastus ambiseta*

Family Maldanidae

- *Asychis elongata*
- *Clymenella* sp.
- *Clymenella torquata*
- *Praxillella* sp.

Family Opheliidae

- *Ophelia bicornis*

Family Spionidae

- *Boccardia* sp.
- *Scolelepis squamata*
- *Spio* sp.
- *Spiophanes bombyx*

Class Polychaeta (continued)

Family Spionidae (continued)

- *Streblospio benedicti*
- *Paraprionospio pinnata*
- *Polydora* sp.
- *Polydora ligni*
- *Polydora socialis*
- *Polydora websteri*
- *Prionospio (Minuspio)* sp.
- *Prionospio pygmaea*

Family Paraonidae

- *Aricidea* sp.
- *Aricidea catherinae*
- *Aricidea cerrutii*
- *Aricidea wassi*
- *Cirrophorus lyriformis*
- *Paraonis fulgens*

Family Chaetopteridae

- *Spiochaetopterus oculatus*

Family Owenidae

- *Owenia* sp.
- *Owenia fusiformis*

Family Sigalionidae

- *Sthenelais boa*

Family Sabellaridae

- *Sabellaria vulgaris*

Family Onuphidae

- *Diopatra cuprea*
- *Onuphis eremita*

Family Dorvilleidae

- *Schistomeringos rudolphi*

Family Eunicidae

- *Lysidice ninetta*
- *Marphysa sanguinea*

Family Arabellidae

- *Arabella iricolor*
- *Drilonereis* sp.
- *Drilonereis longa*
- *Drilonereis magma*

Family Amphinomidae

- *Pseudeurythoe paucibranchiata*

Family Magelonidae

- *Magelona rosea*

Family Orbinidae

- *Scoloplos fragilis*
- *Scoloplos robustus*
- *Scoloplos rubra*

Family Cirratulidae

- *Caulleriella* sp.
- *Tharyx* sp.
- *Tharyx setigera*

Class Polychaeta (continued)

Family Amphictenidae

Cistena gouldii

Family Ampharetidae

Asabellides oculata

Family Terebellidae

Amphitrite ornata

Loimia medusa

Polycirrus eximius

Terebella sp.

Family Serpulidae

Hydroides dianthus

Family Sabellidae

Sabella microphthalma

Class Oligochaeta

Oligochaete sp.

Phylum Arthropoda

Subclass Ostracoda

Family Sarsiellidae

Sarsiella texana

Sarsiella zostericola

Subclass Malacostraca

Order Cumacea

Family Diastylidae

Oxyurostylis smithi

Order Isopoda

Family Anthuridae

Ptilanthura tenuis

Ptilanthura tricarina

Family Idoteidae

Chiridotea sp.

Chiridotea arenicola

Chiridotea caeca

Chiridotea nigrescens

Edotea triloba

Erichsonella filiformis

Order Amphipoda

Family Ampeliscidae

Ampelisca sp.

Ampelisca abdita

Ampelisca macrocephala

Ampelisca vadorum

Ampelisca verrilli

Family Bateidae

Batea catharinensis

Family Corophiidae

Cerapus tubularis

Corophium sp.

Corophium simile

Corophium tuberculatum

Erichthonius brasiliensis

Unciola sp.

Unciola serrata

Order Amphipoda (continued)

Family Gammaridae

Elasmopis levis
Melita appendiculata
Melita nitida

Family Haustoriidae

Acanthohaustorius intermedius
Acanthohaustorius millsi
Protohaustorius deichmannae
Protohaustorius holmesi

Family Lillejeborgiidae

Listriella barnardi
Listriella clymenellae

Family Oedicerotidae

Synchelidium americanum

Family Phoxocephalidae

Paraphoxus spinosus
Rhepoxynius sp.
Rhepoxynius epistomus

Family Pleustidae

Pleusymtes sp.

Family Stenothoidae

Parametopella cypris
Stenothoe minuta

Family Caprellidae

Caprella equilibra
Caprella penantis
Paracaprella tenuis

Order Mysidacea

Family Mysidae

Neomysis americana

Order Decapoda

Family Ogyridae

Ogyrides alphaerostris

Family Cancridae

Cancer irroratus

Family Callianassidae

Callianassa atlantica

Family Porcellanidae

Euceramus sp.

Family Paguridae

Pagurus longicarpus

Family Majidae

Libinia sp.

Family Pinnotheridae

Pinnixa sp.
Pinnixa sayana

Family Xanthidae

Eurypanopeus abbreviatus
Eurypanopeus depressus
Neopanope texana sayi
Panopeus herbstii

Order Cirripedia
Family Balanidae
Balanus amphitrite
Phylum Pycnogonida
Family Pallenidae
Callipallene brevirostris
Family Tanystylidae
Tanystylum orbiculare
Phylum Echinodermata
Class Ophiuroidea
Family Amphiuridae
Amphiodia atra
Class Holothuroidea
Family Synaptidae
Leptosynapta tenuis
Phylum Hemichordata
Class Enteropneusta
Family Harrimaniidae
Saccoglossus kowalewskii
Phylum Chordata
Class Ascidiacea
Family Molgulidae
Molgula sp.

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APPENDIX C

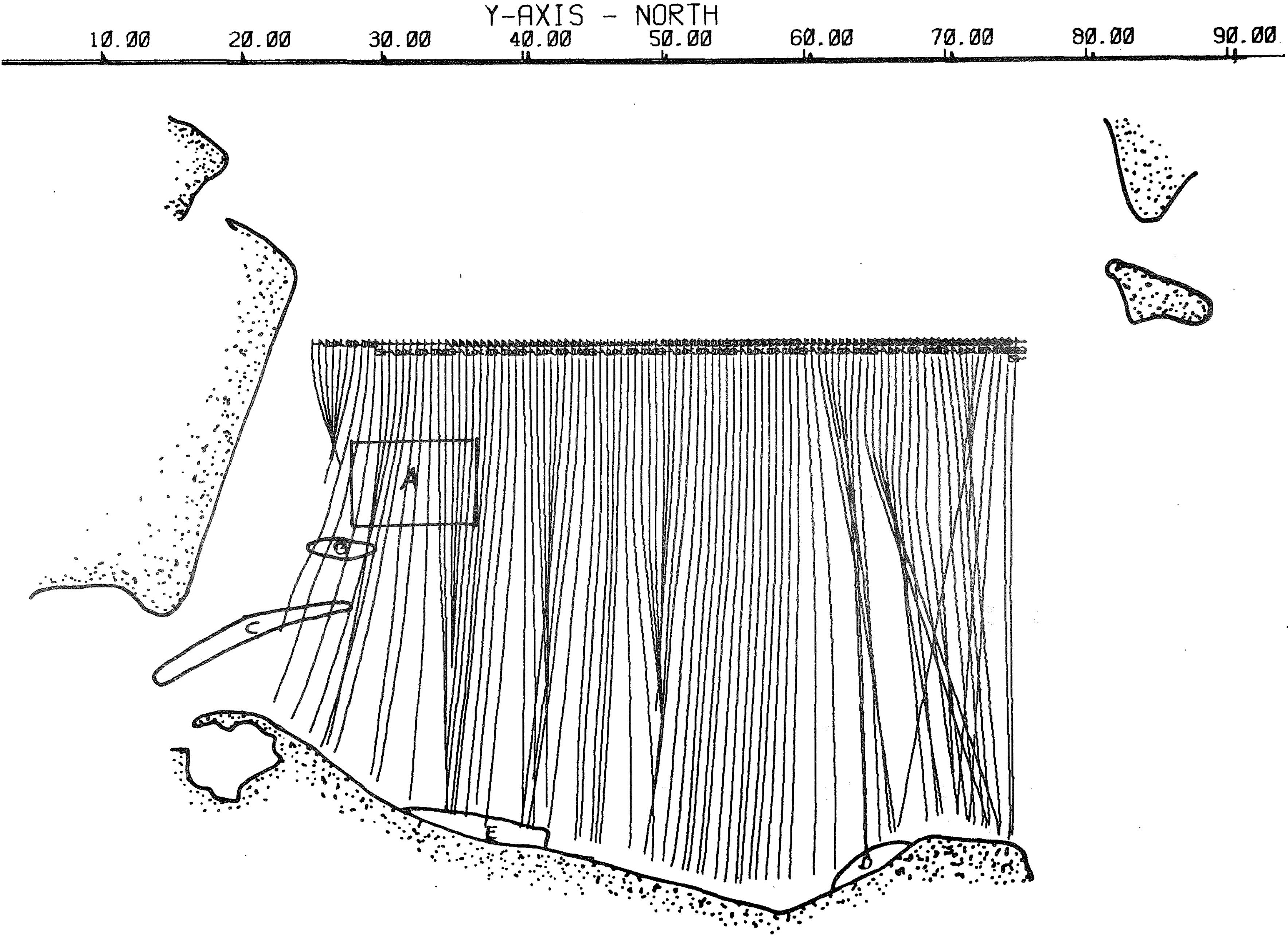
WAVE REFRACTION

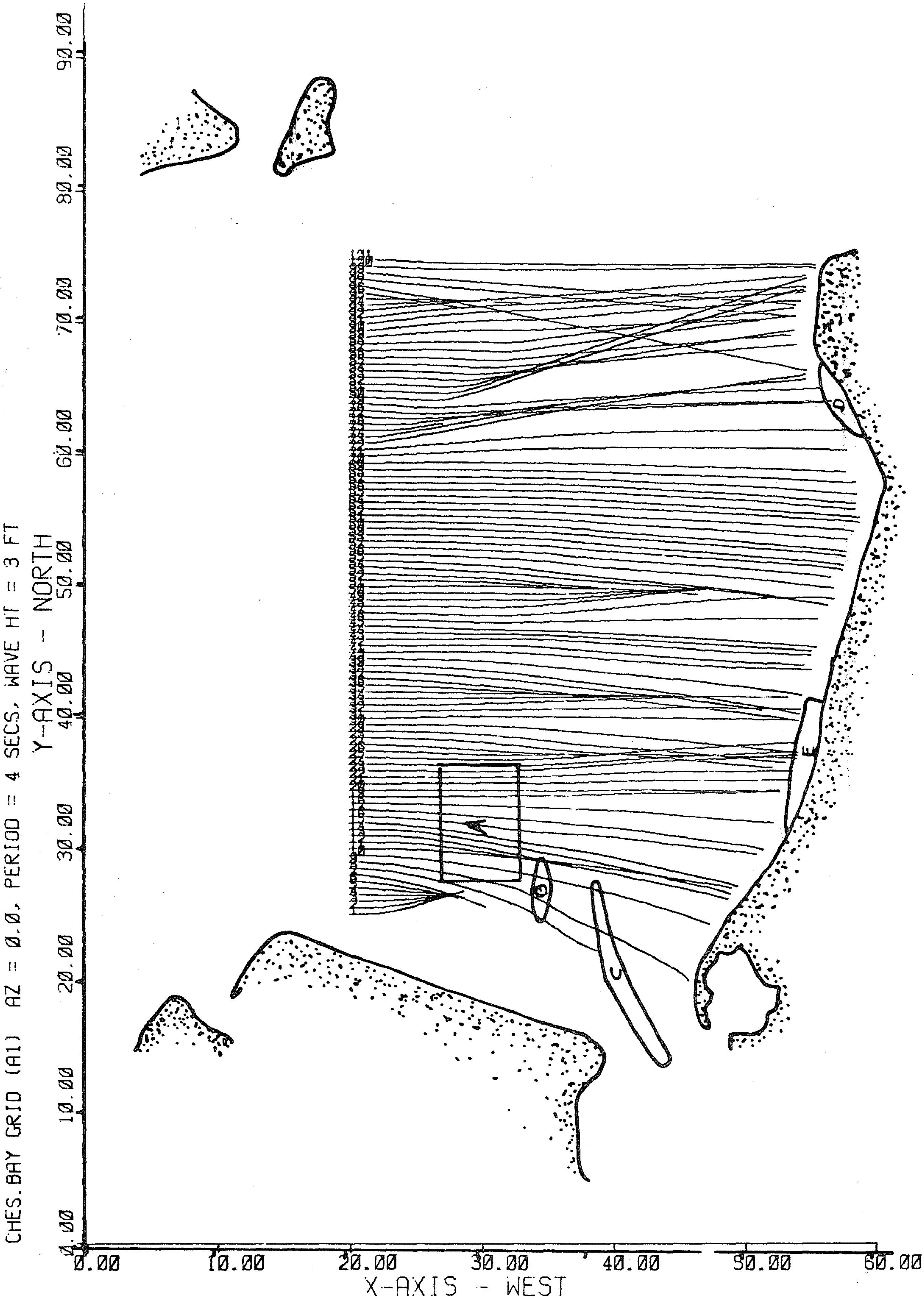
The following wave refraction diagrams depict the wave orthogonals, lines perpendicular to wave crests, in portions of southernmost Chesapeake Bay. The various parameters are listed below. Not all of the possible combinations were run.

A. Water Level - Mean low water
B. Wave Height - 3 feet
C. Wave Period - 4 seconds
                 6 seconds
D. Wind Direction - North 0°
                  - Northeast 45°
                  - East 90°
                  - Southeast 135°
                  - Northwest 315°
C. Bottom - Existing conditions
    Al - a 3 foot deep, steep side rectangular hole in outer Thimble Shoal
    A2 - same but 6 feet deep
    A3 - same but a gradual taper from the surface to 10 feet
    B - increased width on north flank of channel
    C - increased width of channel along Willoughby Shoal
    D - shoreline prograded as shown
    E - shoreline prograded as shown

Although the changes made to the bathymetry do alter the wave refraction patterns, none of the alterations appear significant.

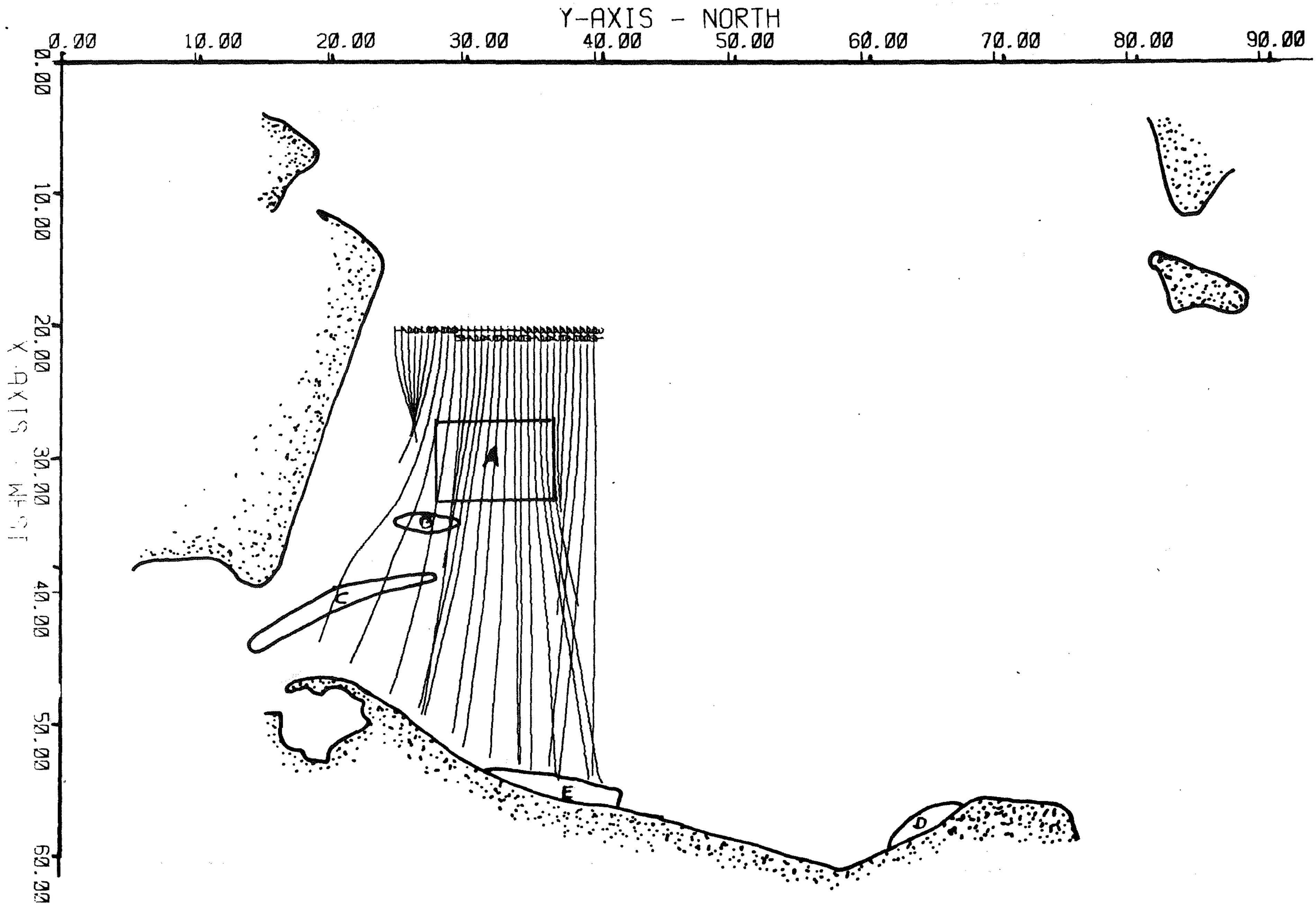
S.BAY GRID (NO) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT



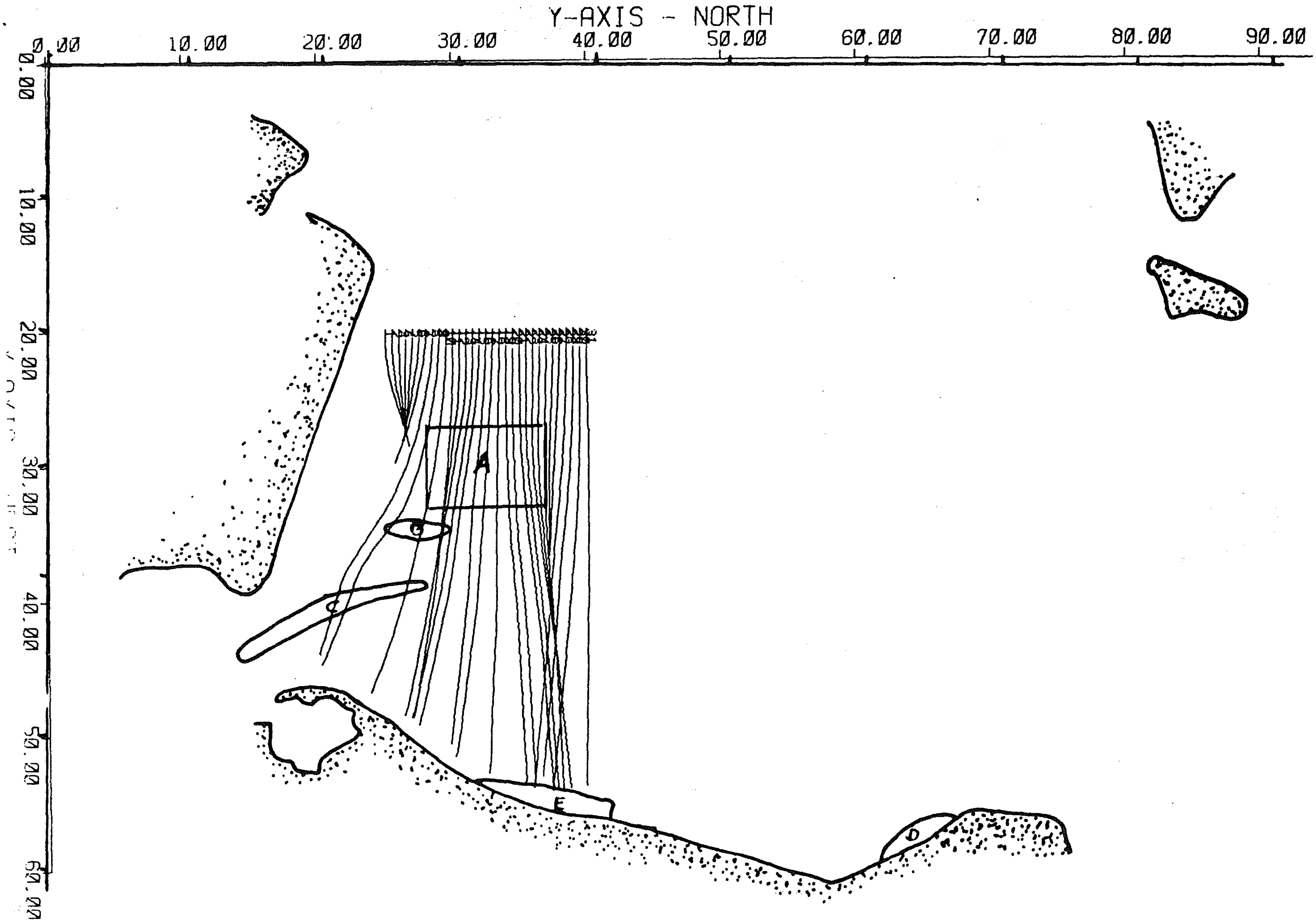


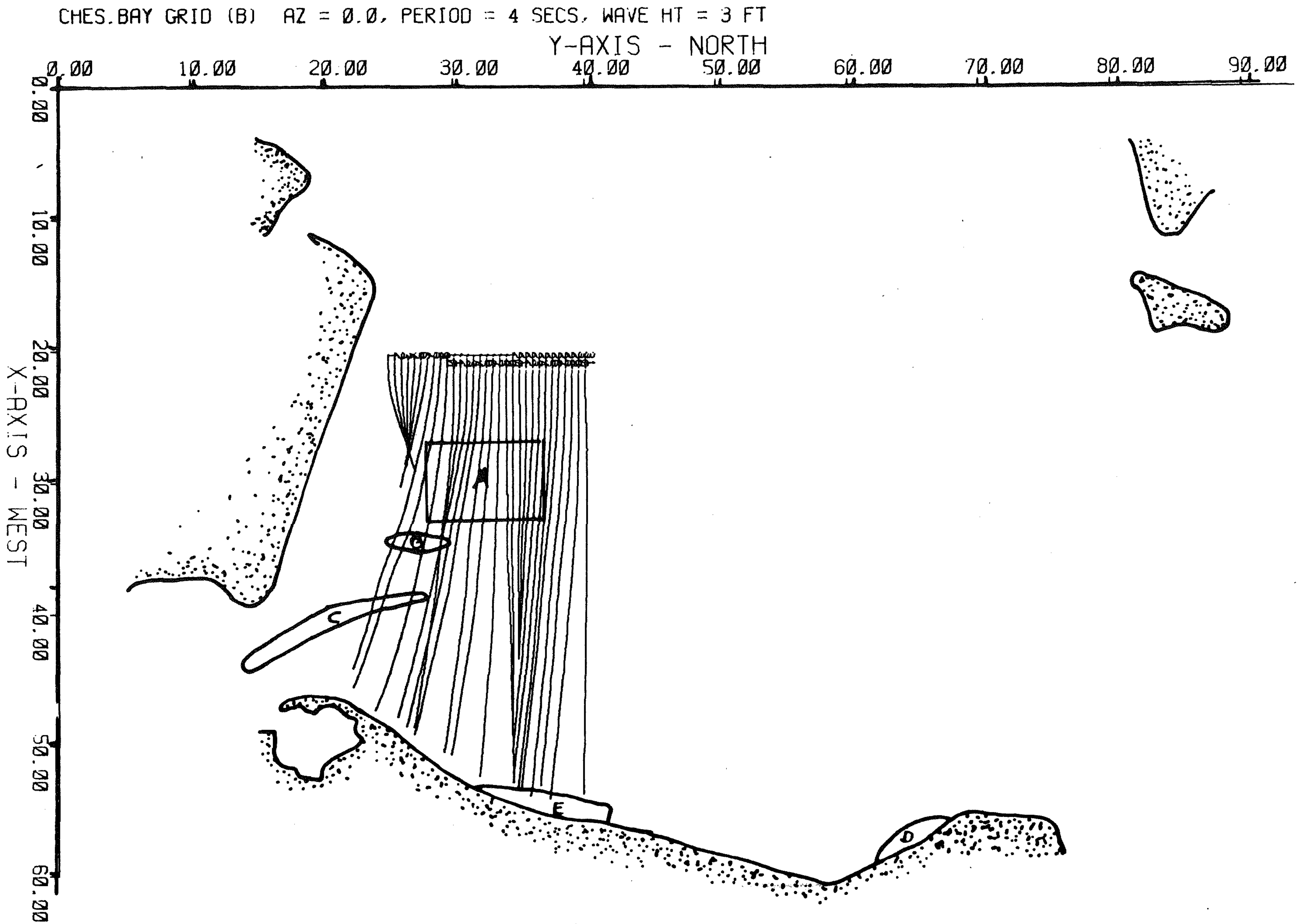
CHES.BAY GRID (A1) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT
Y-AXIS - NORTH
X-AXIS - WEST
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
A
B
C
D
E

CHES.BAY GRID (A2)   AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT

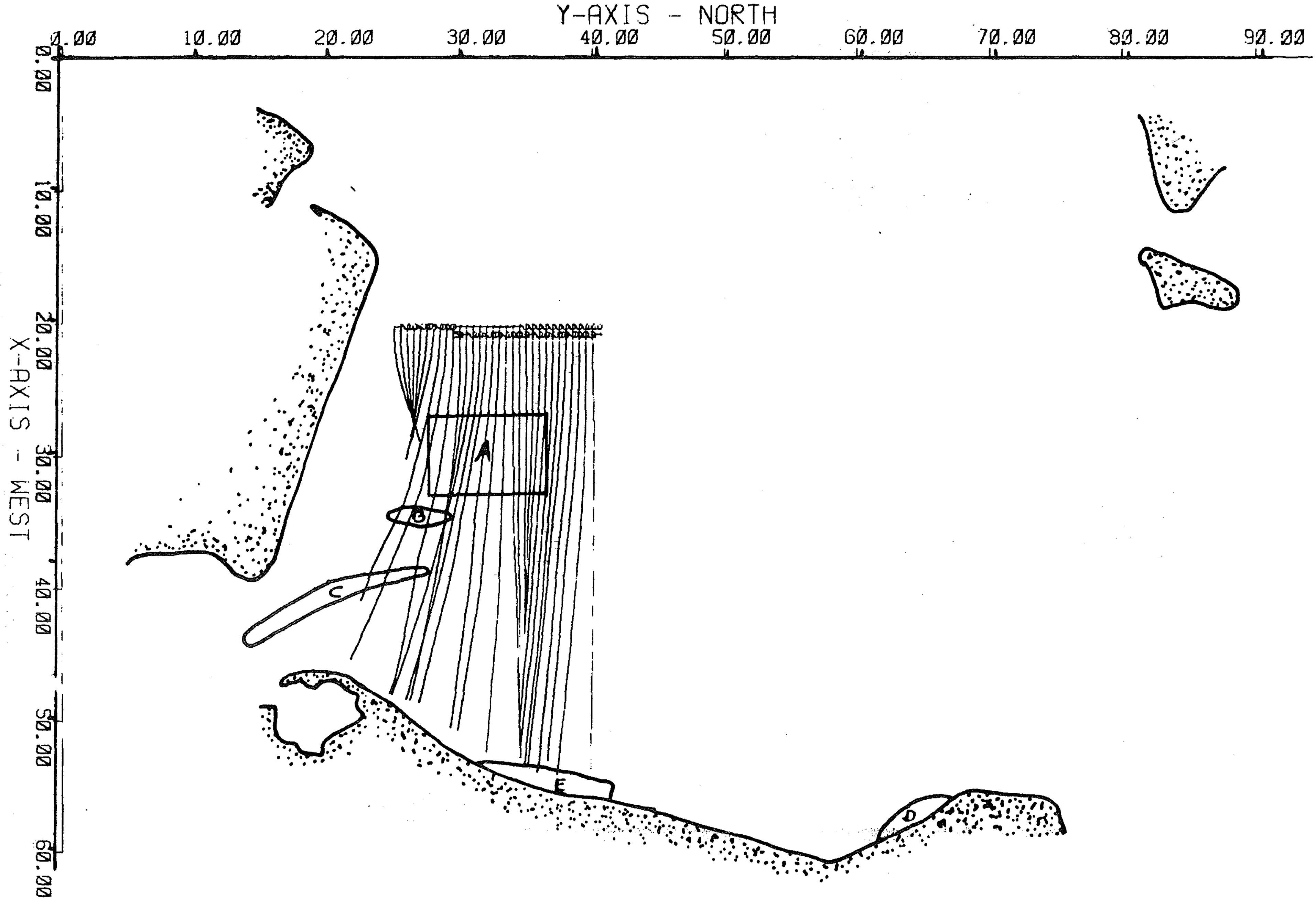


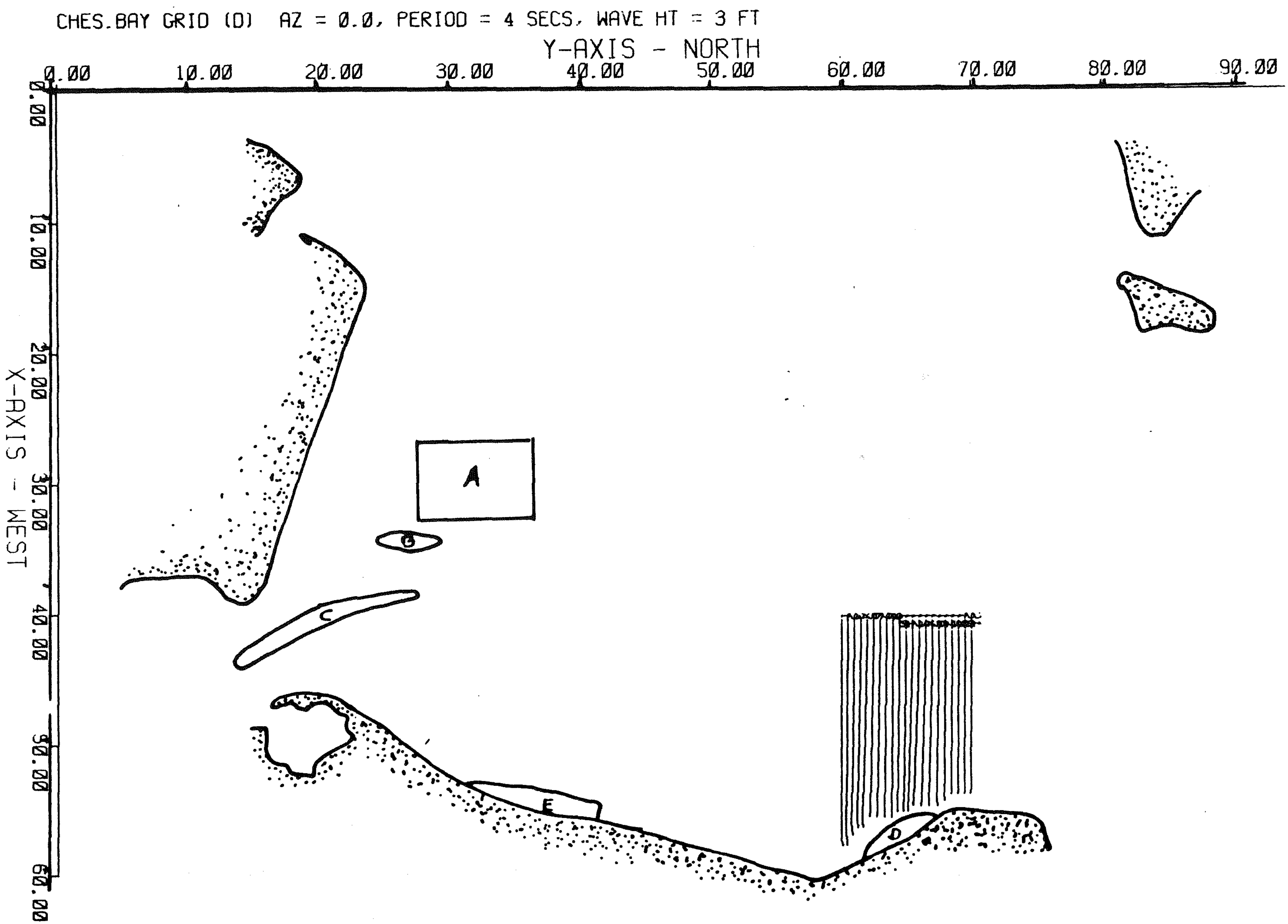
CHES.BAY GRID (A3) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT

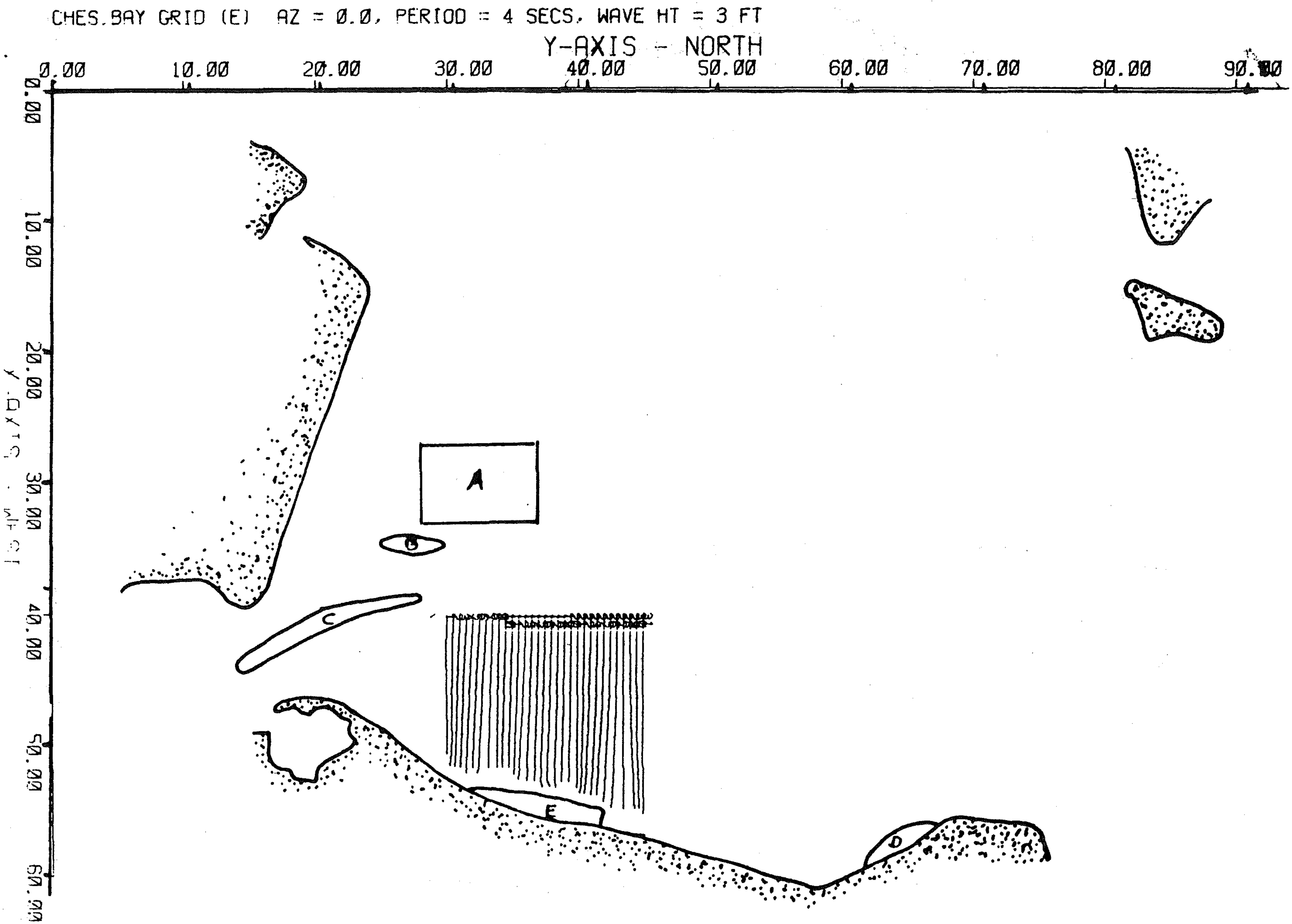



CHES.BAY GRID (B) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT
Y-AXIS - NORTH
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
X-AXIS - WEST
0.00
10.00
20.00
30.00
40.00
50.00
60.00
A
G
C
E
D

CHES.BAY GRID (C)   AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT

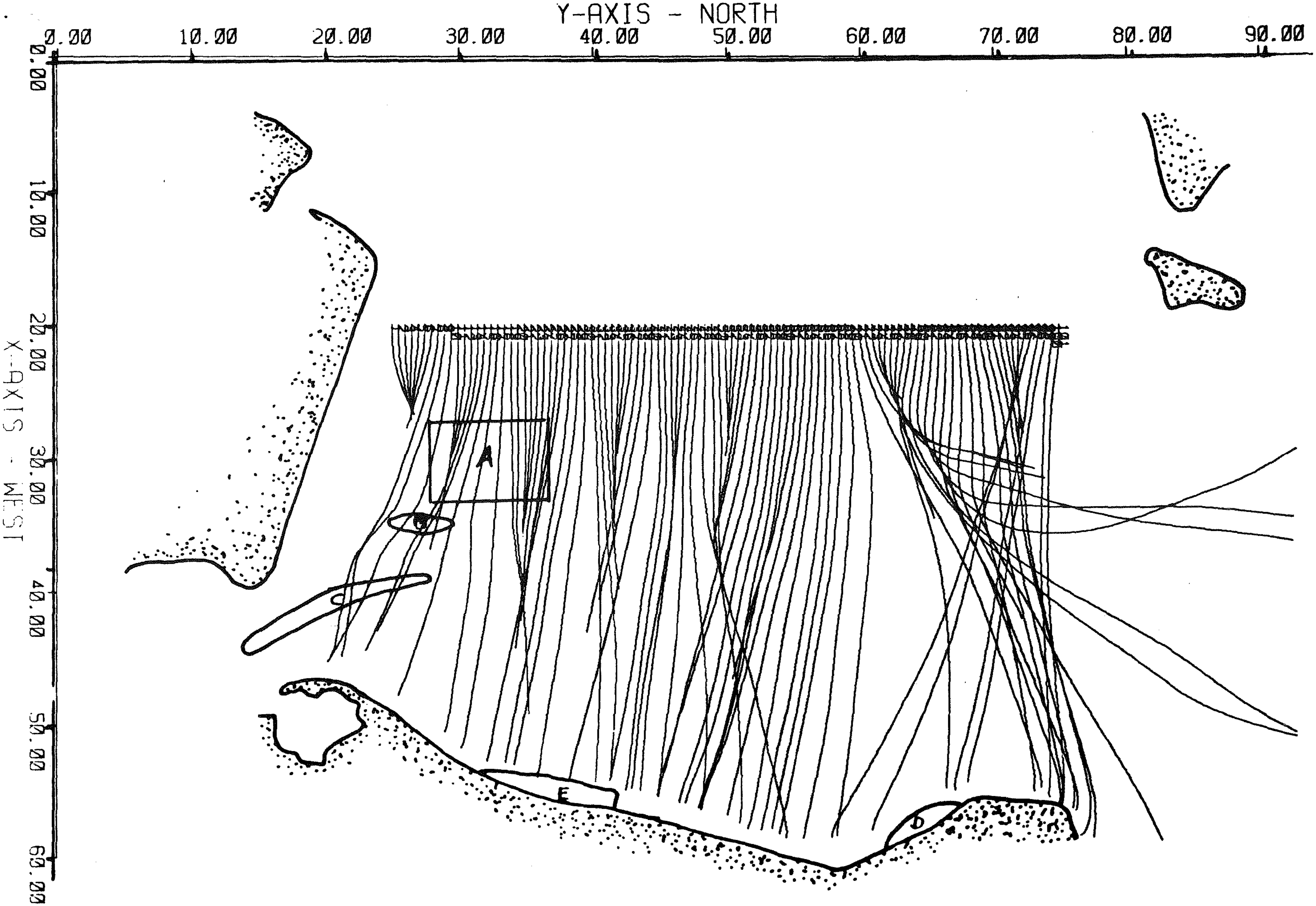



CHES.BAY GRID (D) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT
Y-AXIS - NORTH
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
X-AXIS - WEST
0.00
10.00
20.00
30.00
40.00
50.00
60.00
A
B
C
D
E

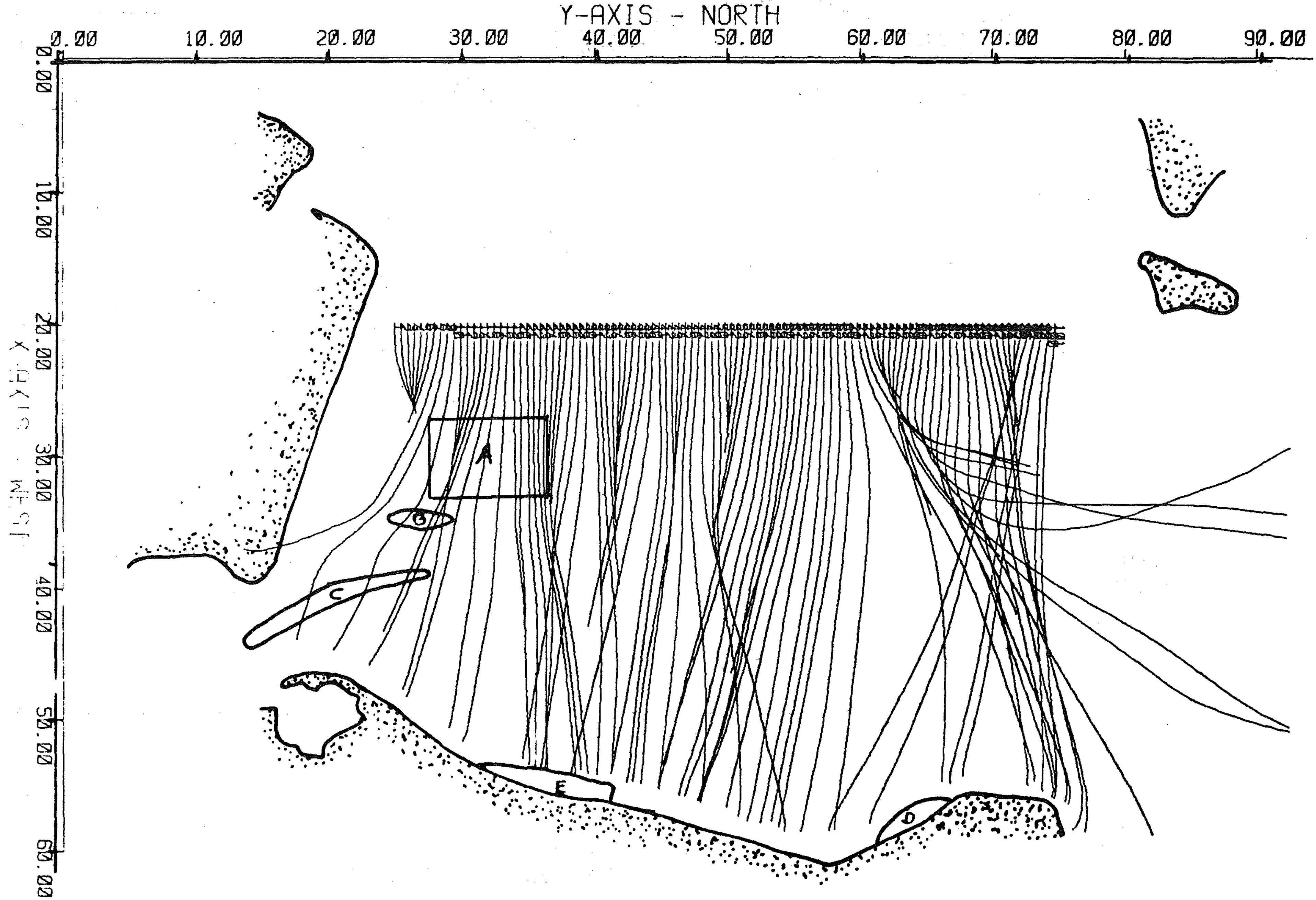


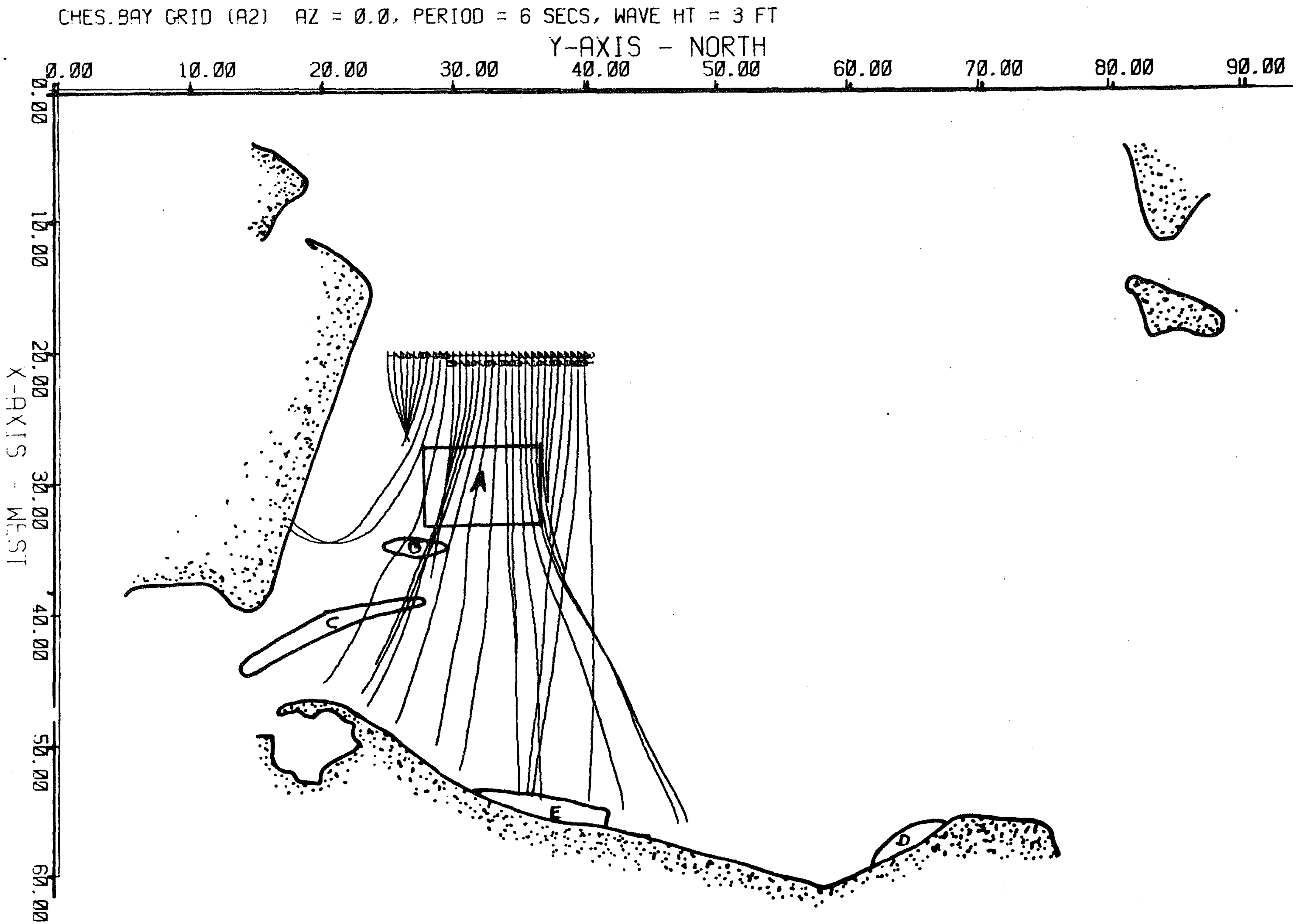
CHES.BAY GRID (E) AZ = 0.0, PERIOD = 4 SECS, WAVE HT = 3 FT
Y-AXIS - NORTH
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
A
B
C
D
E

CHES.BAY GRID (NO) AZ = 0.0, PERIOD = 6 SECS, WAVE HT = 3 FT



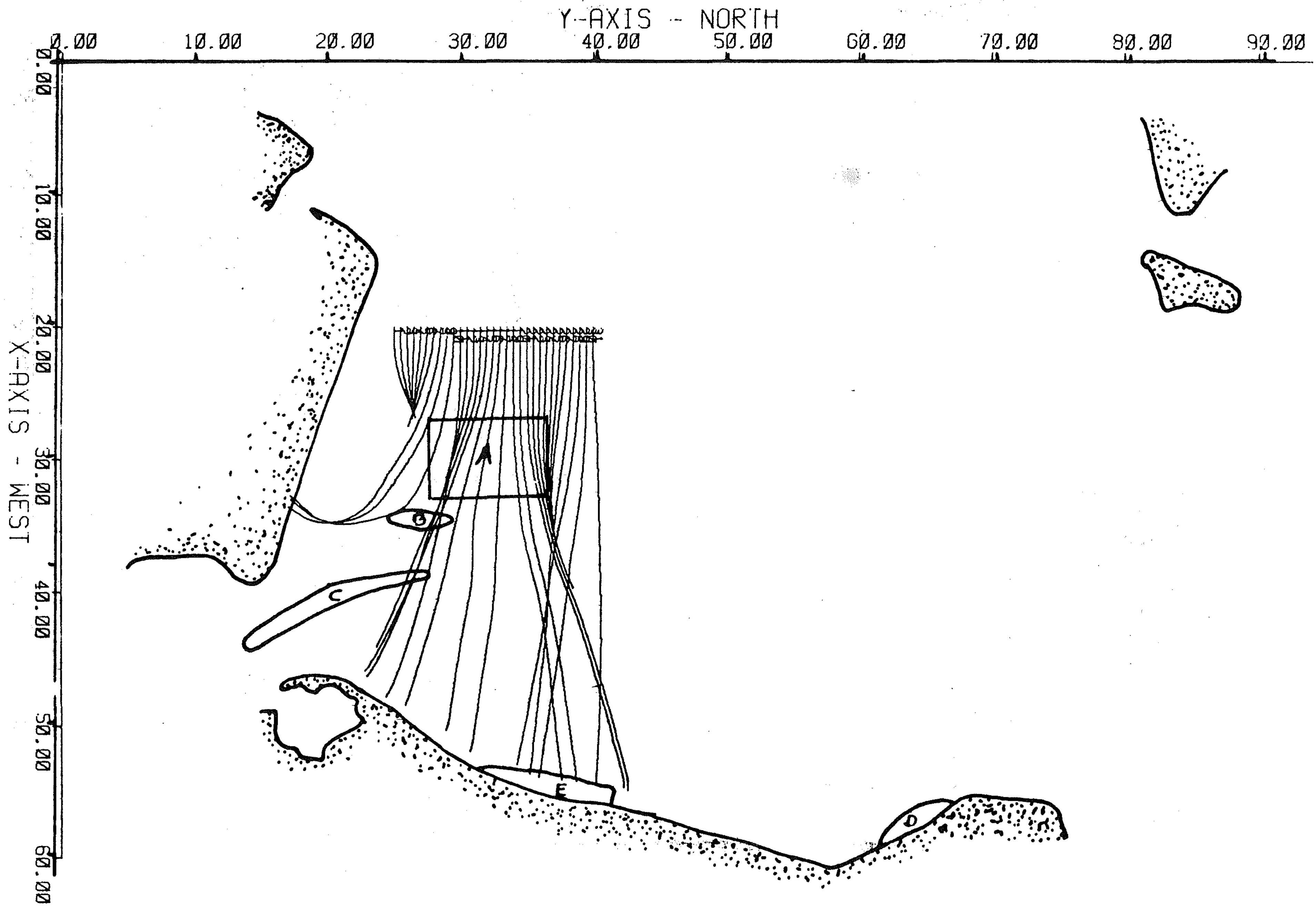
CHES.BAY GRID (A1) AZ = 0.0, PERIOD = 6 SECS, WAVE HT = 3 FT

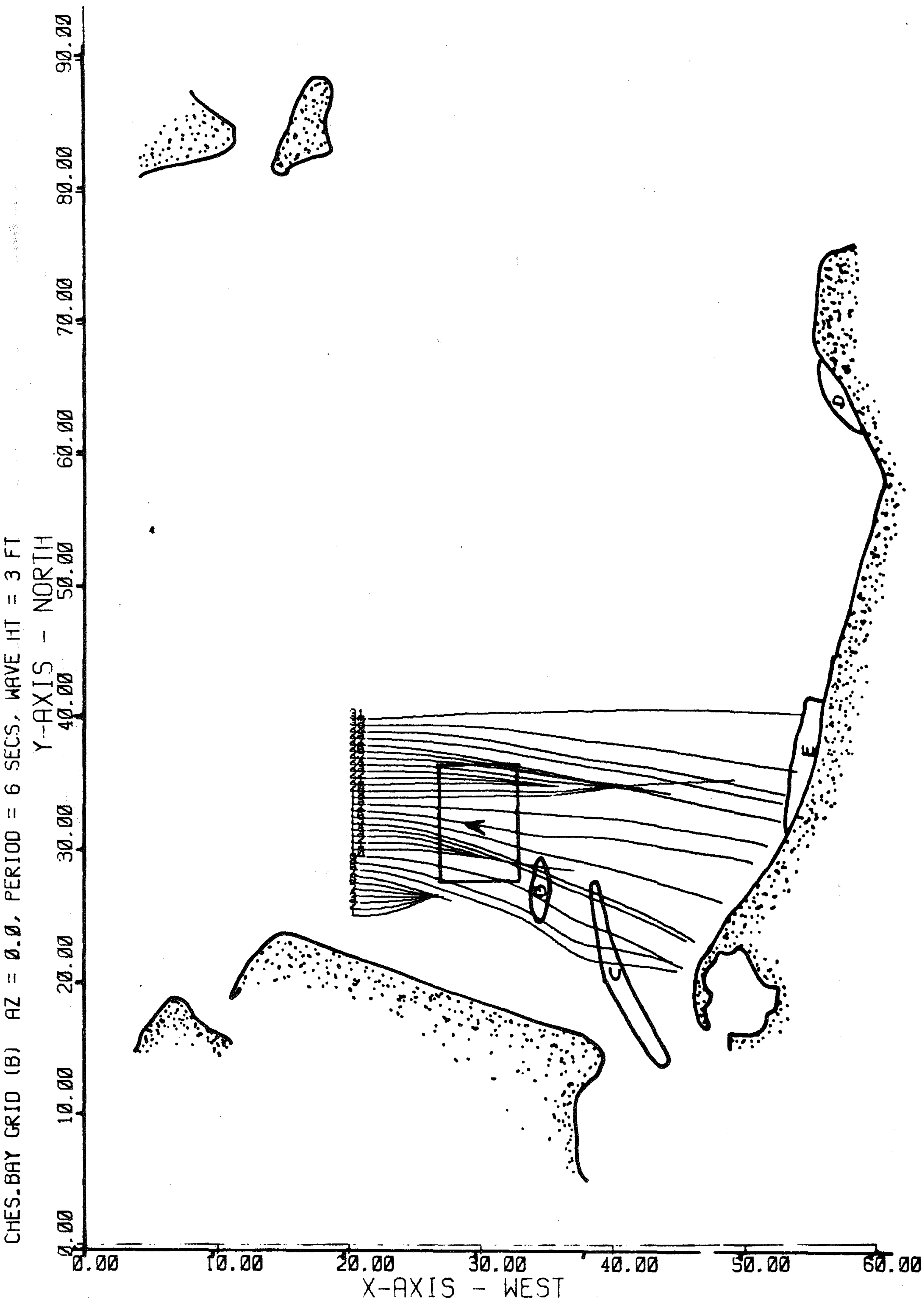




CHES.BAY GRID (A2) AZ = 0.0, PERIOD = 6 SECS, WAVE HT = 3 FT
Y-AXIS - NORTH
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
X-AXIS - WEST
0.00
10.00
20.00
30.00
40.00
50.00
60.00
A
B
C
D
E

CHES. BAY GRID (A3) AZ = 0.0, PERIOD = 6 SECS, WAVE HT = 3 FT

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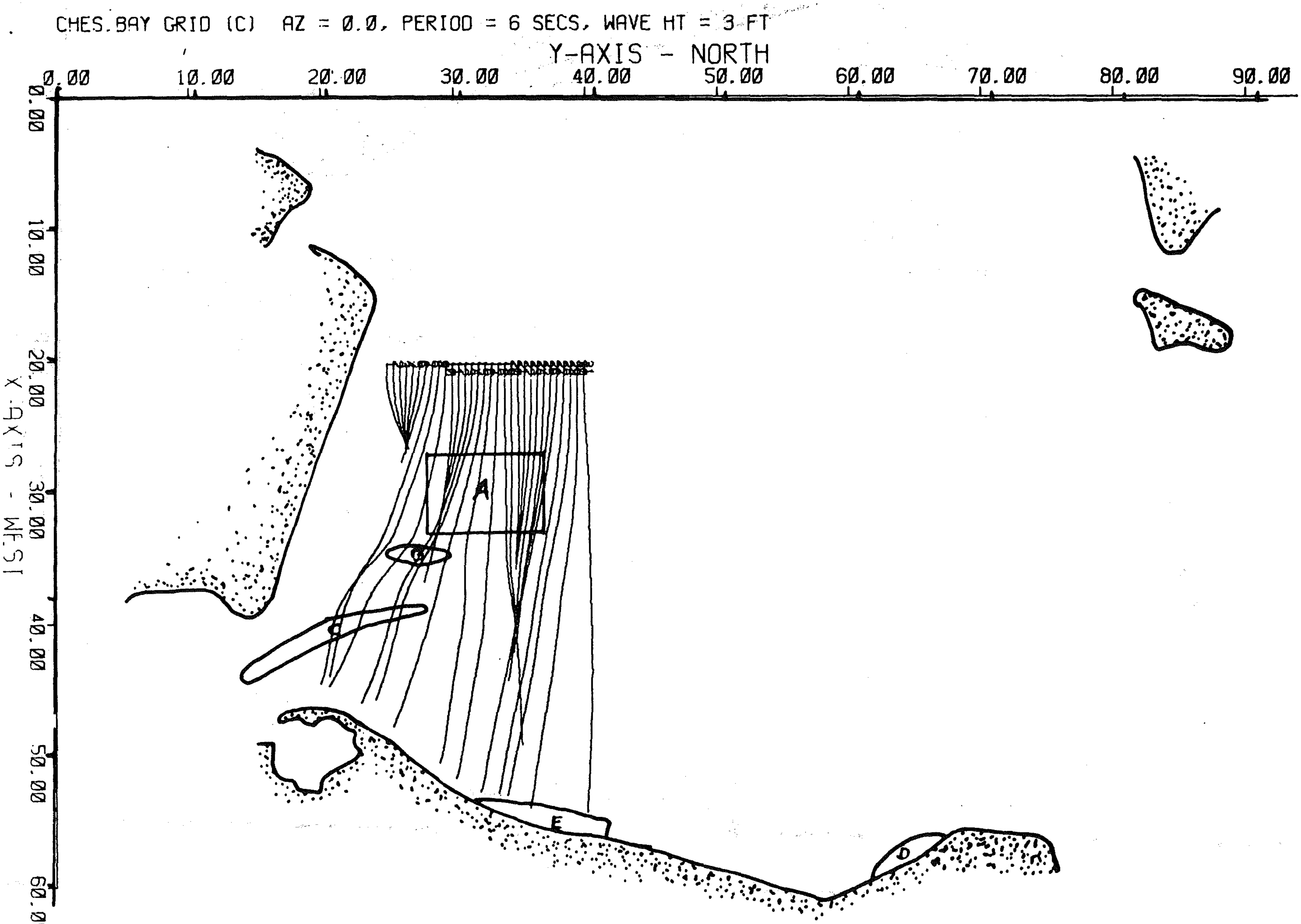
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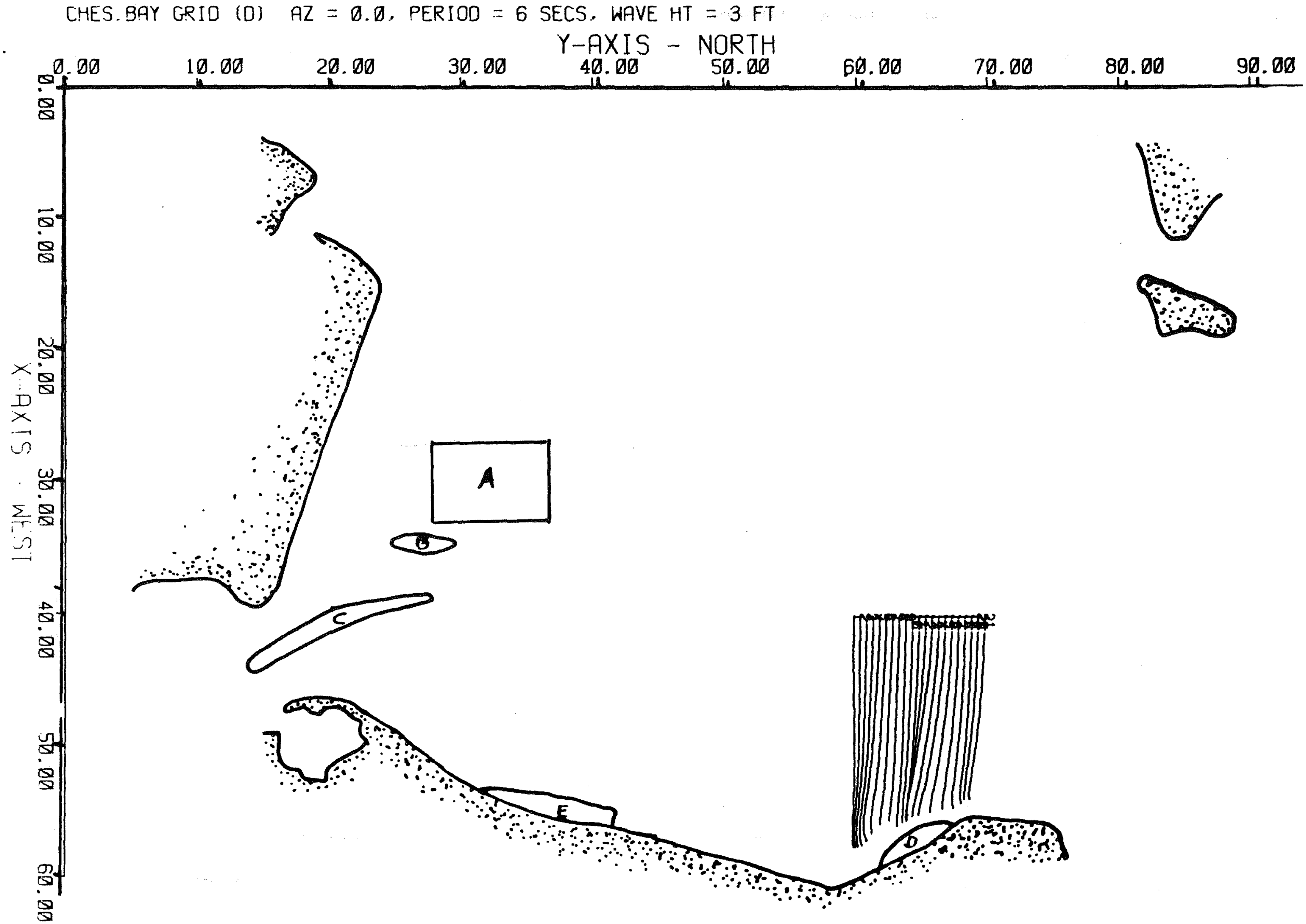

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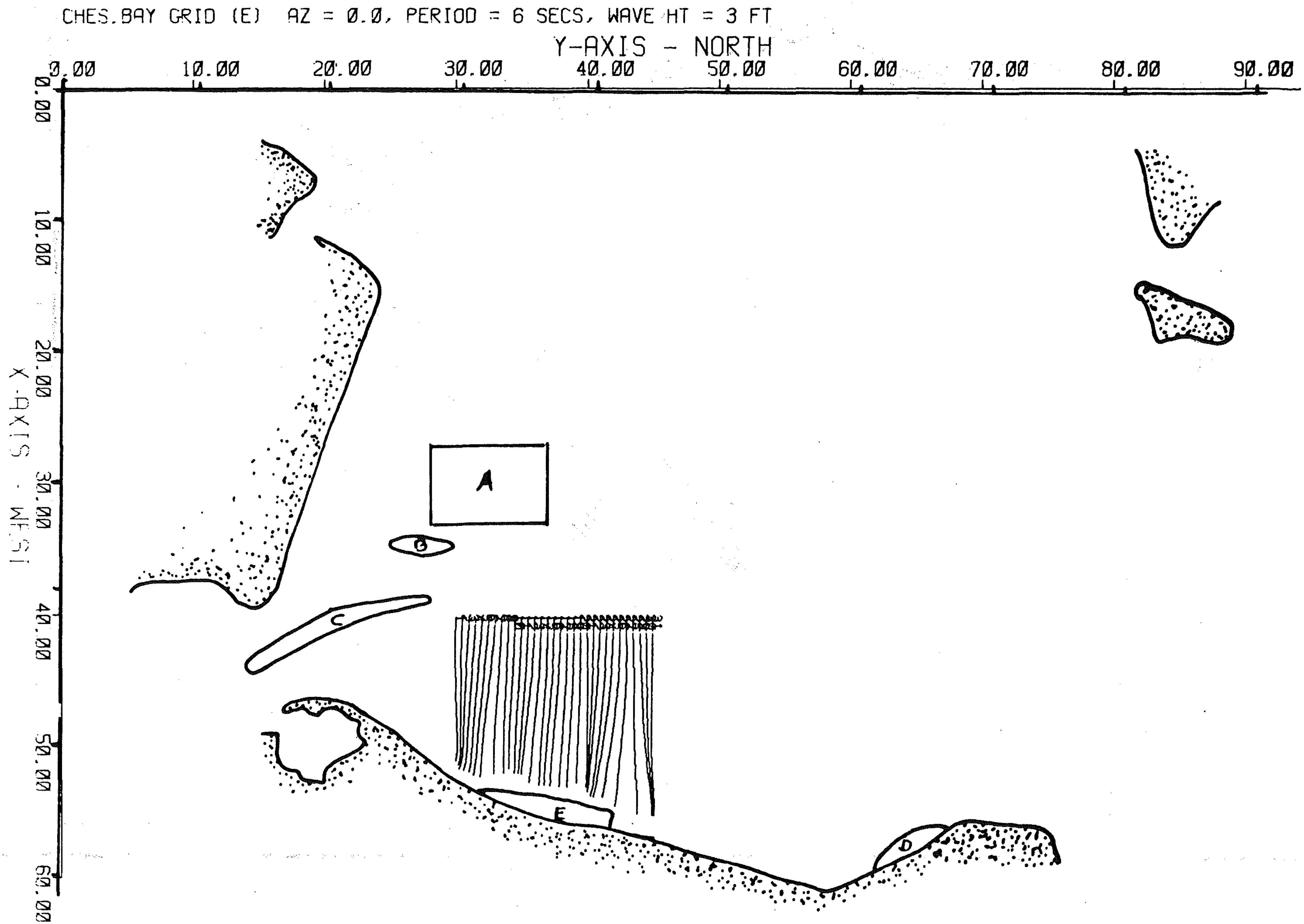
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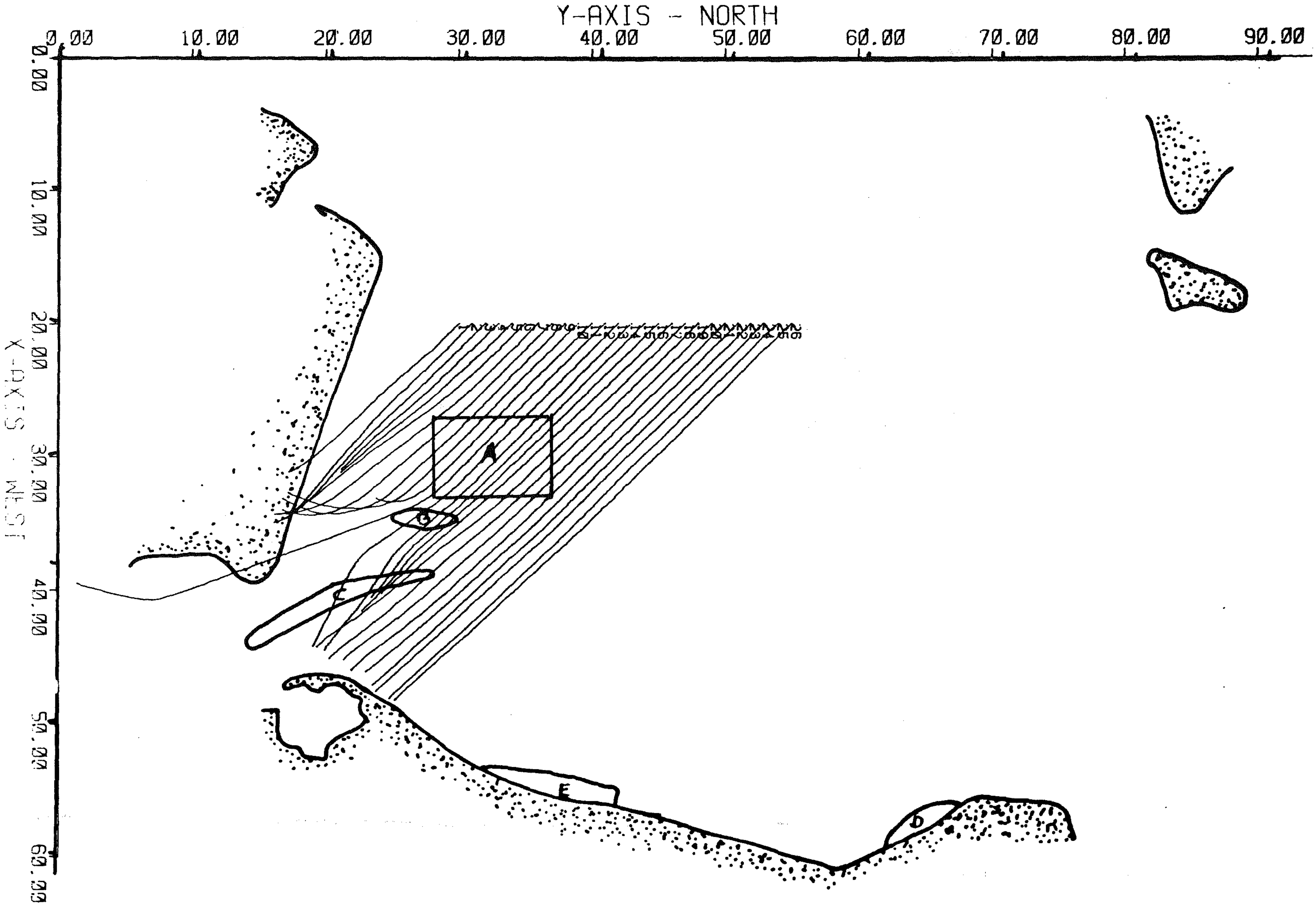

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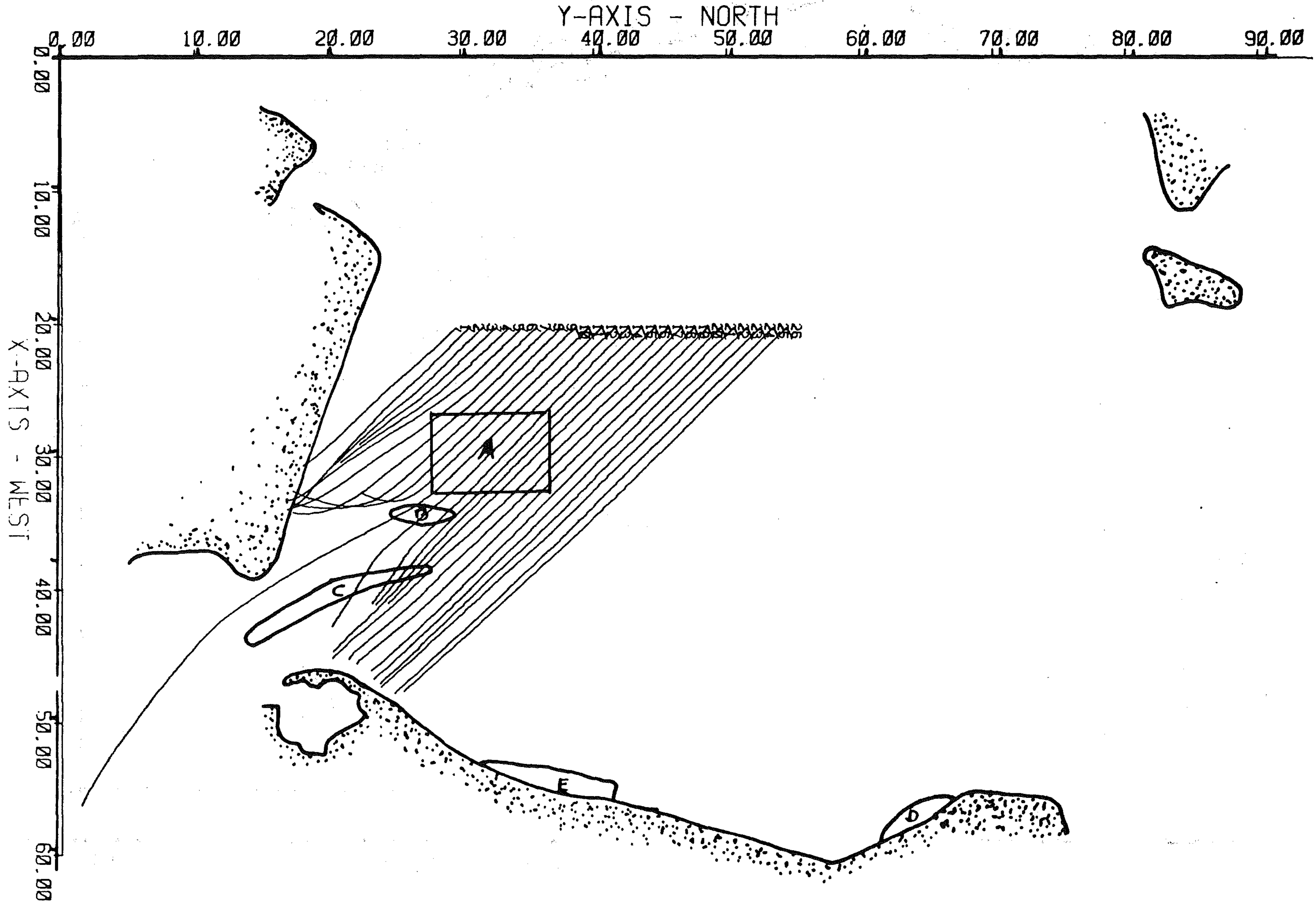

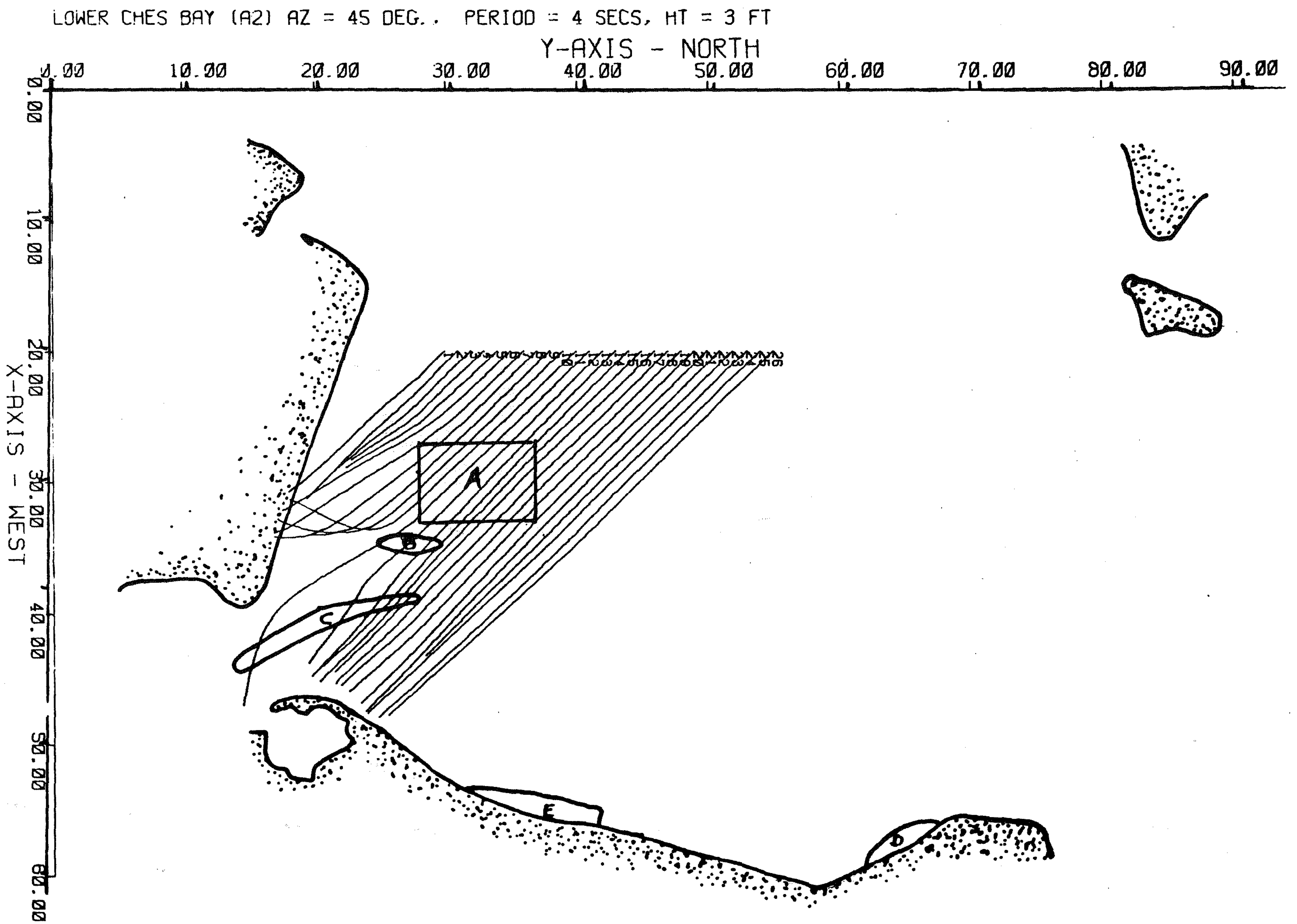
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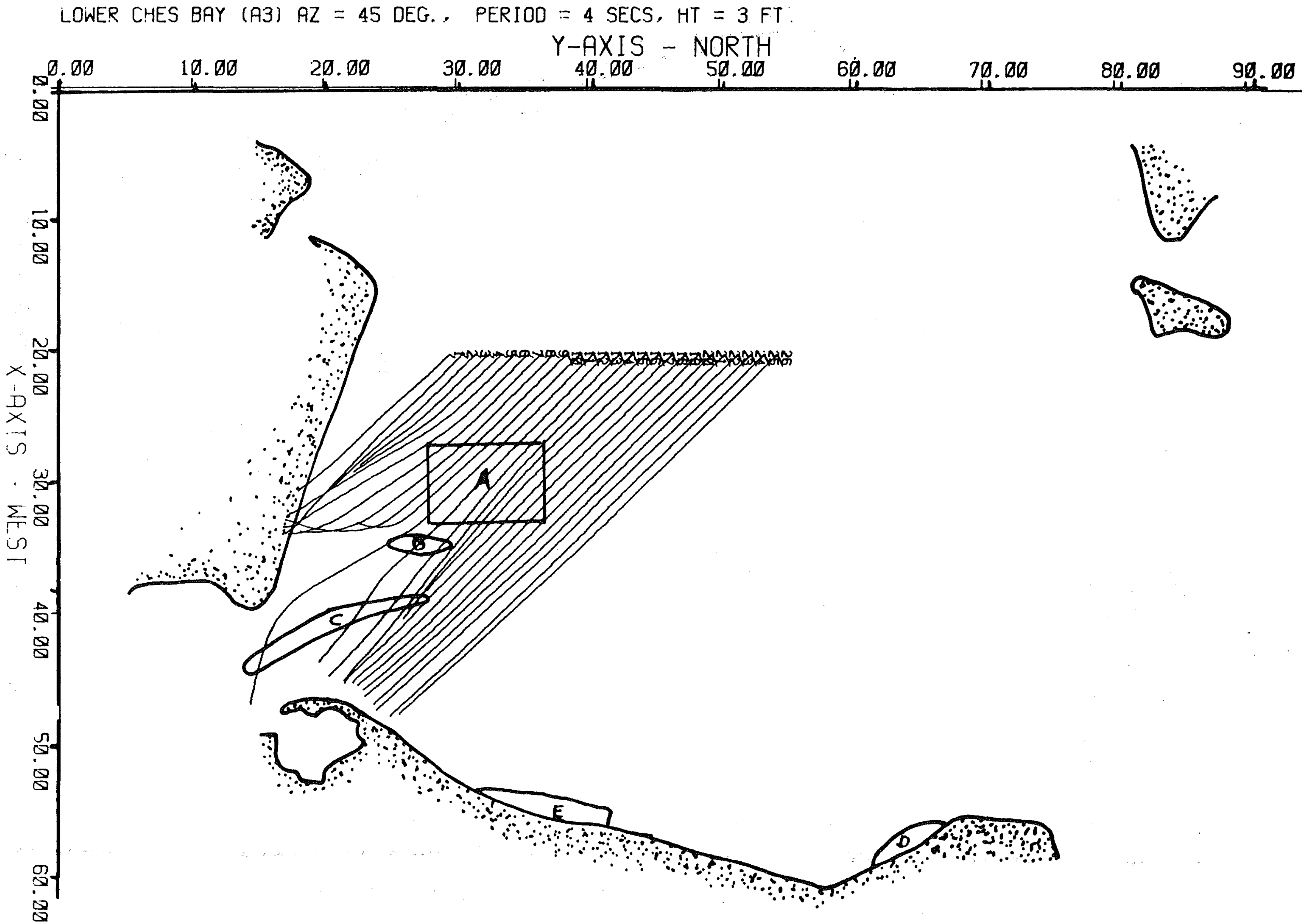

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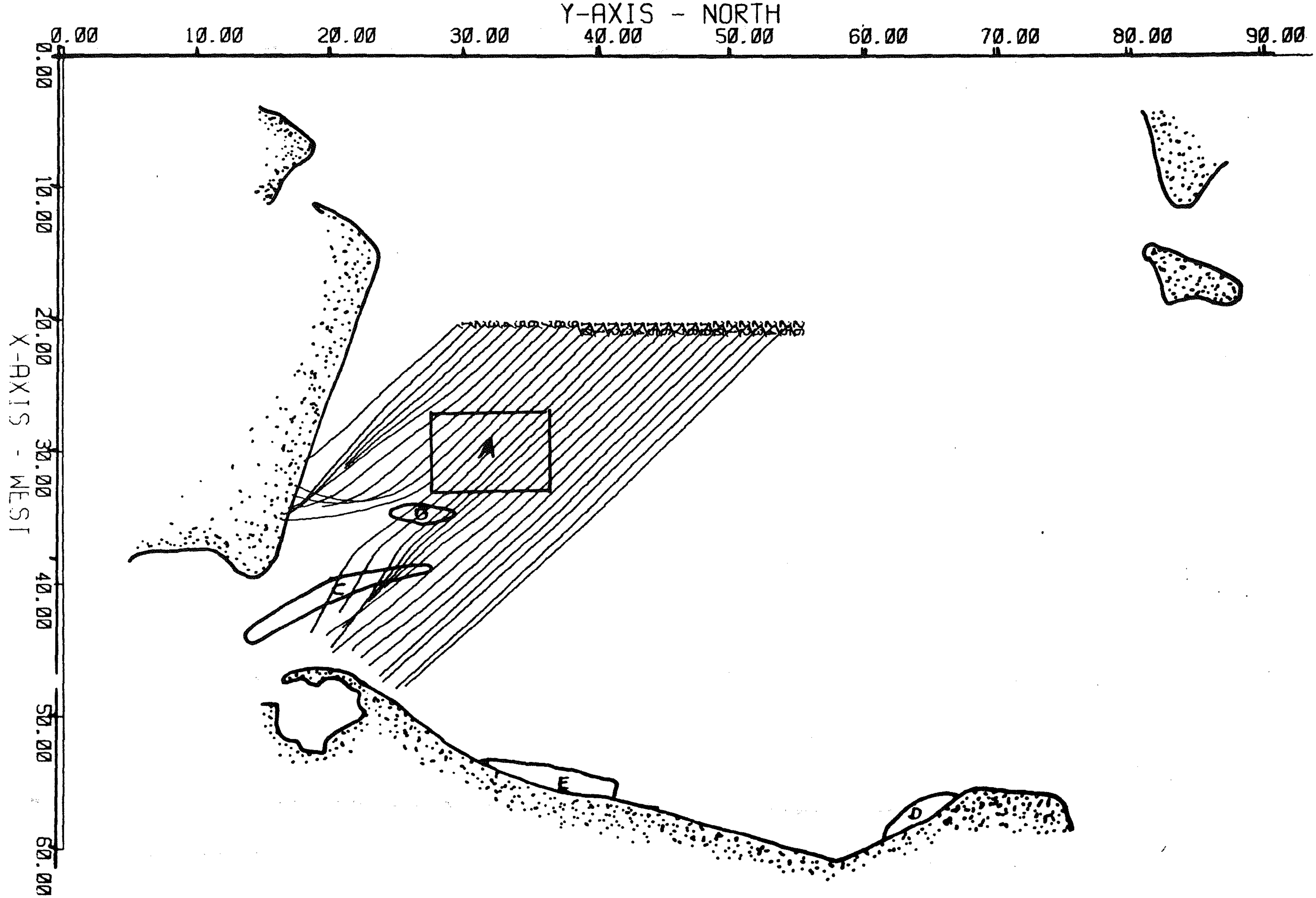

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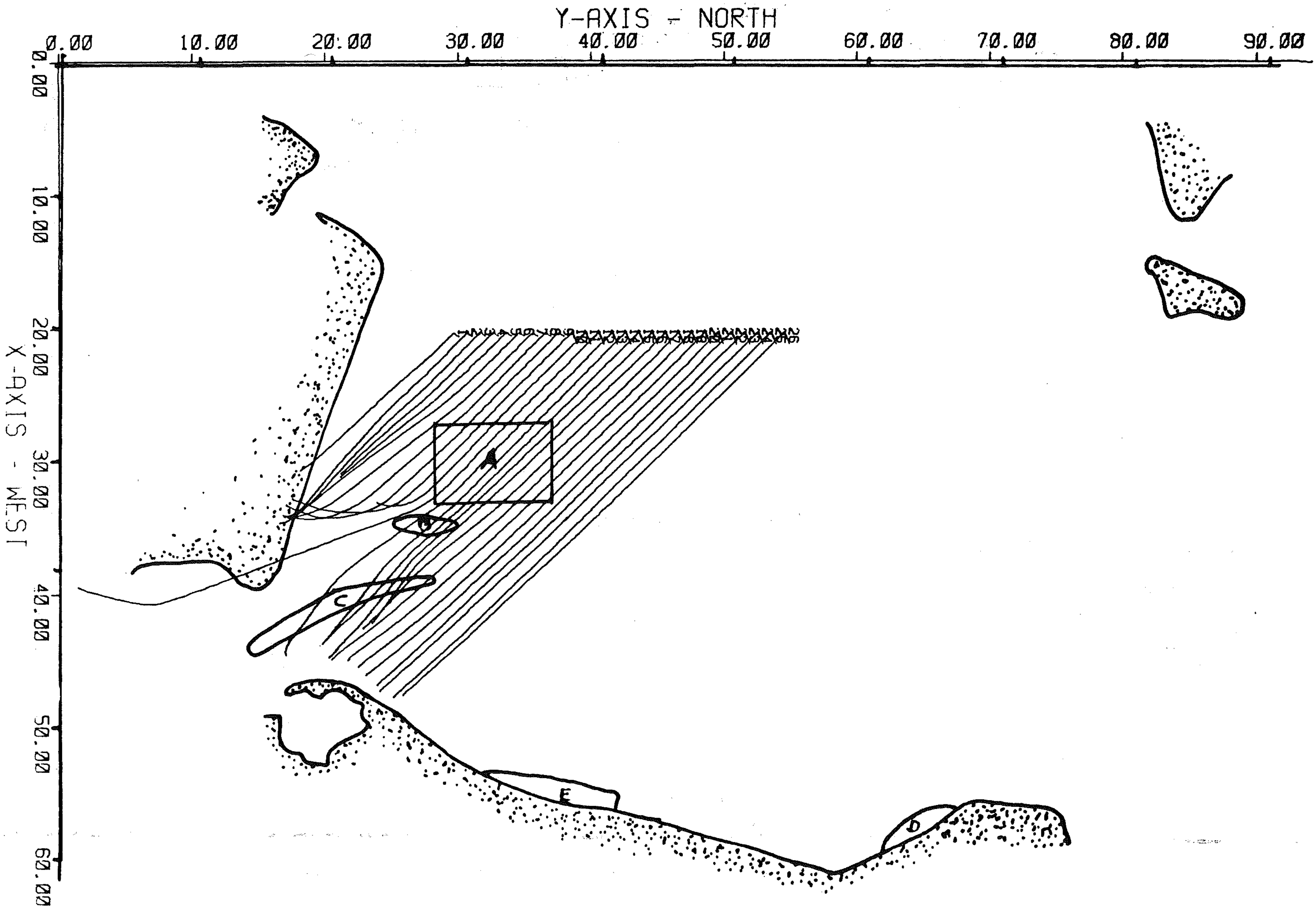

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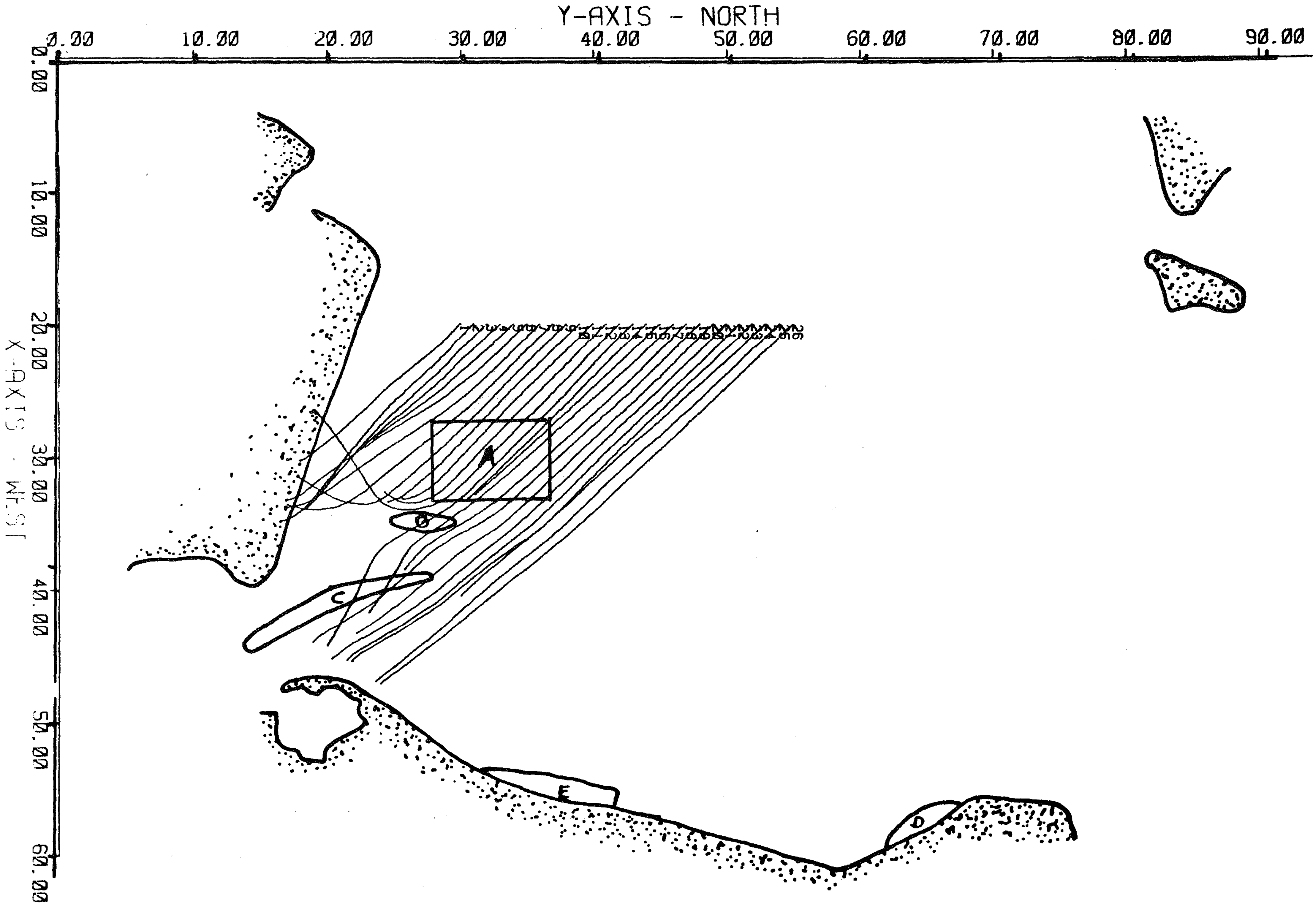

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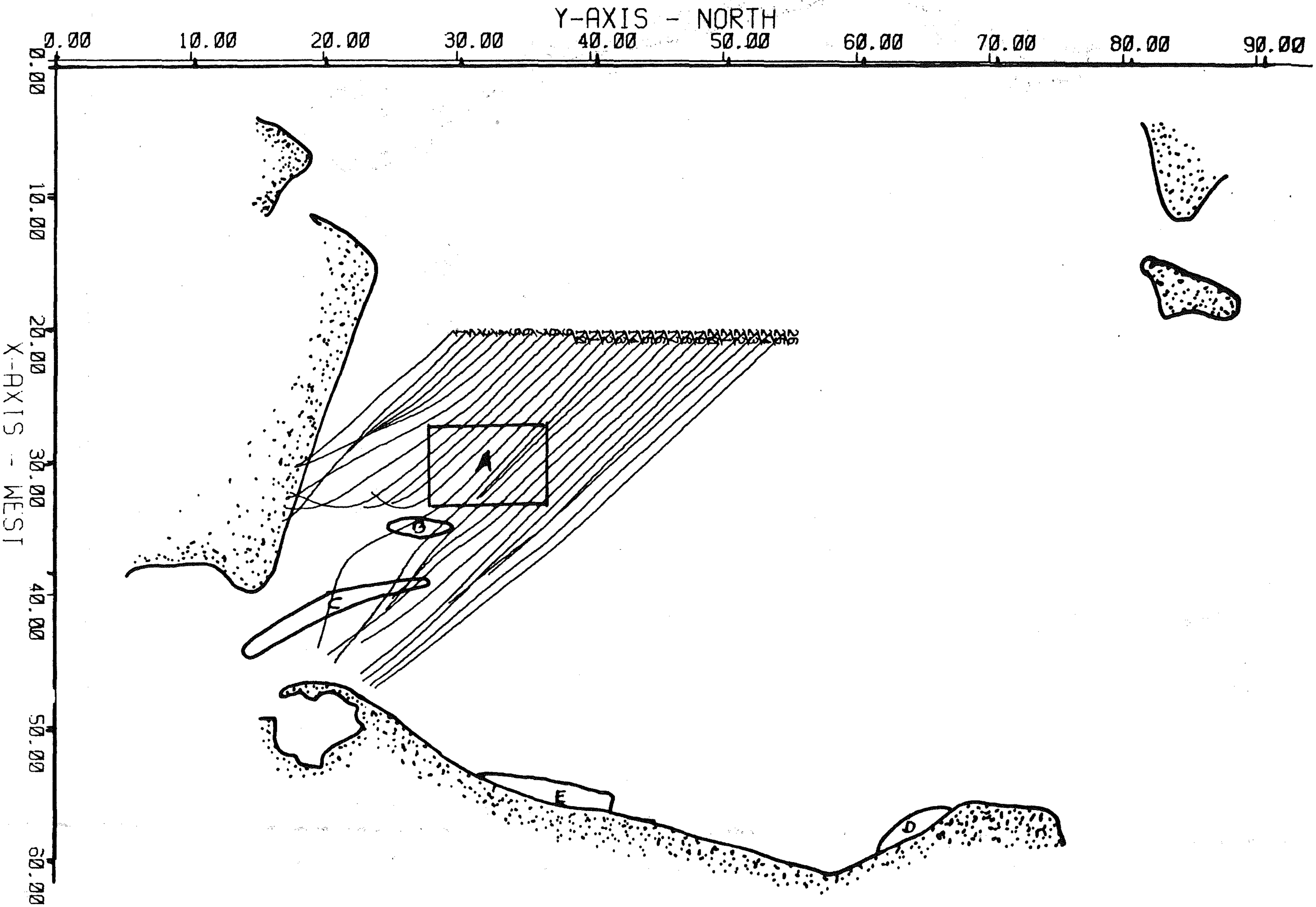

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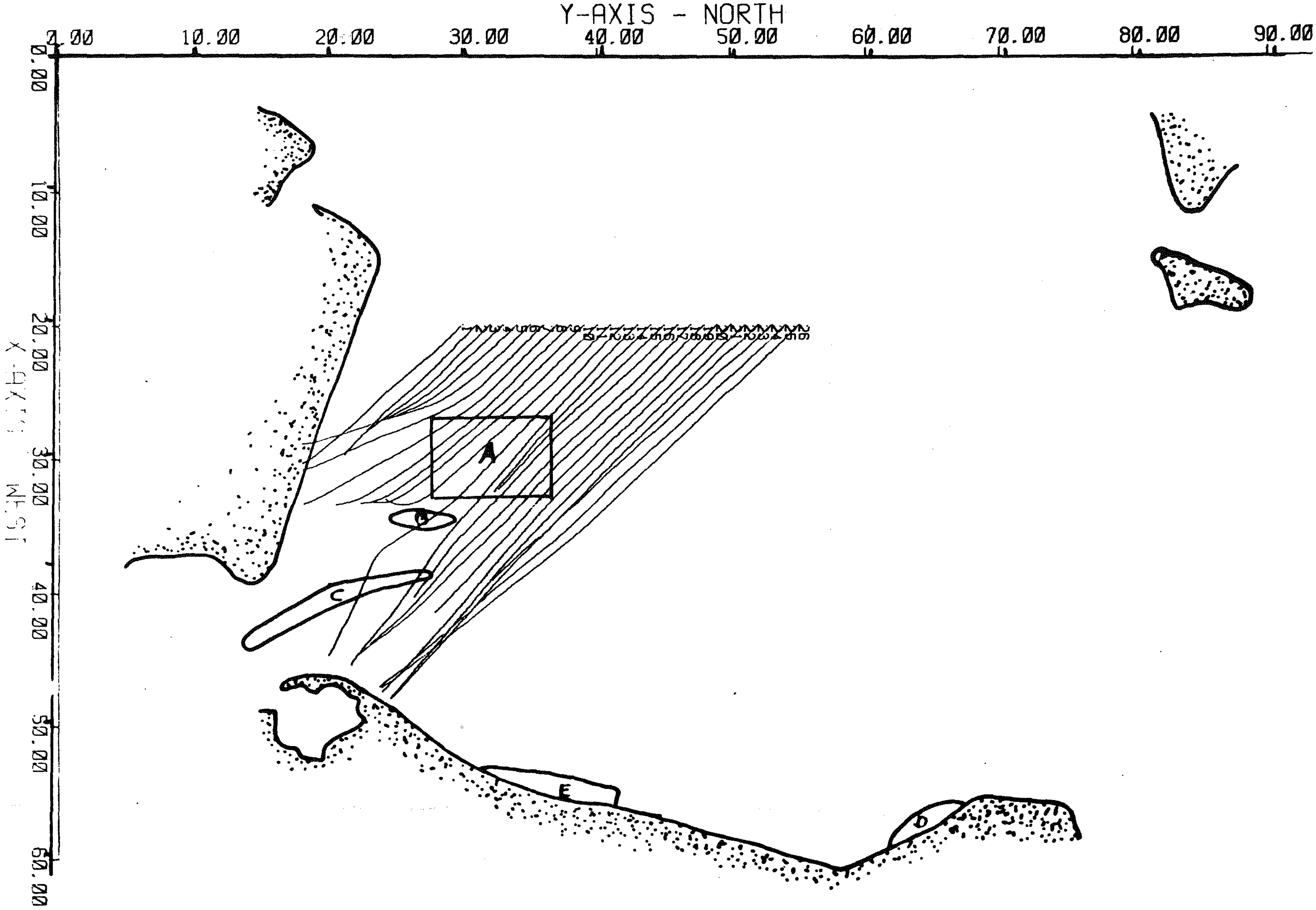

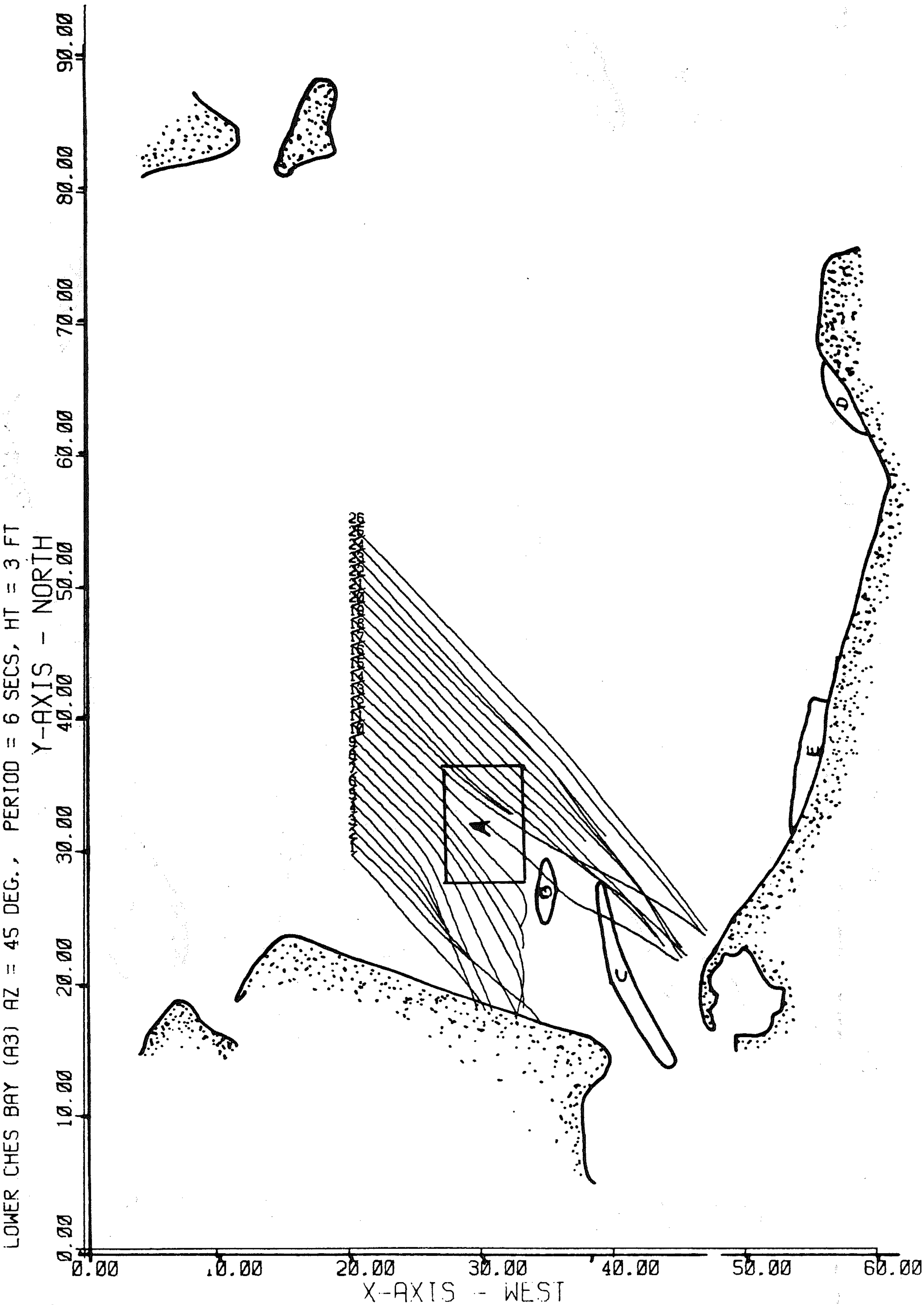

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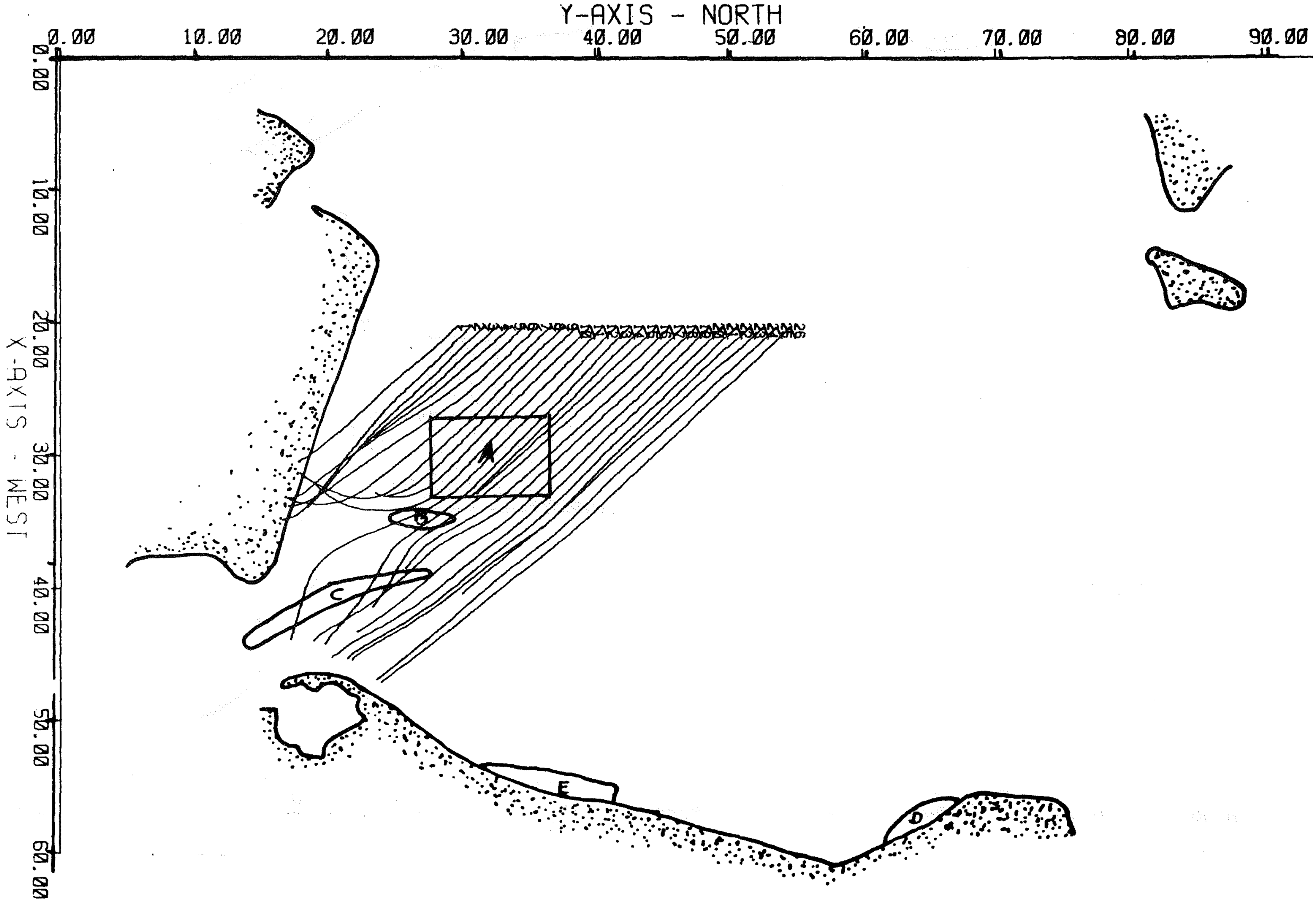

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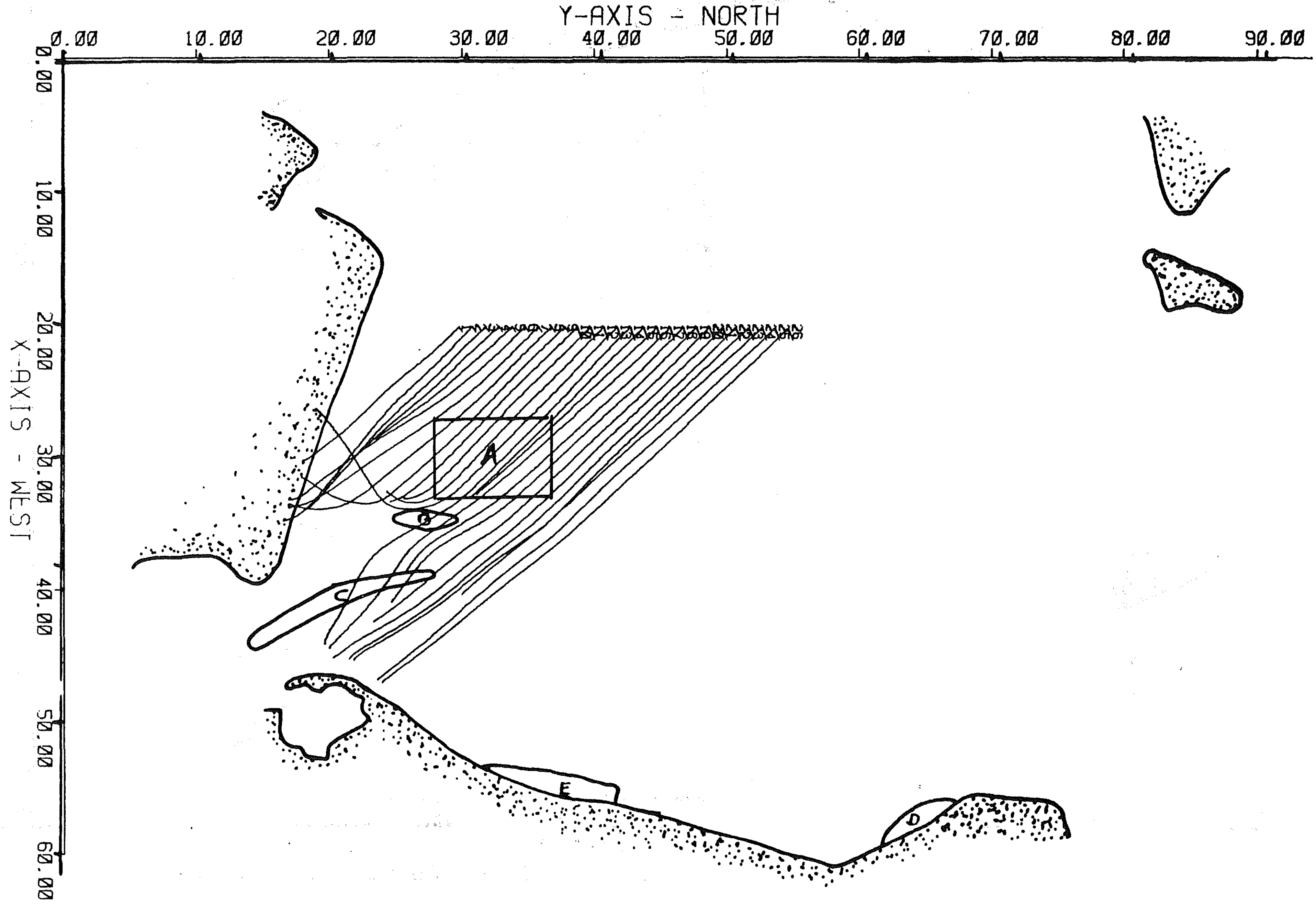

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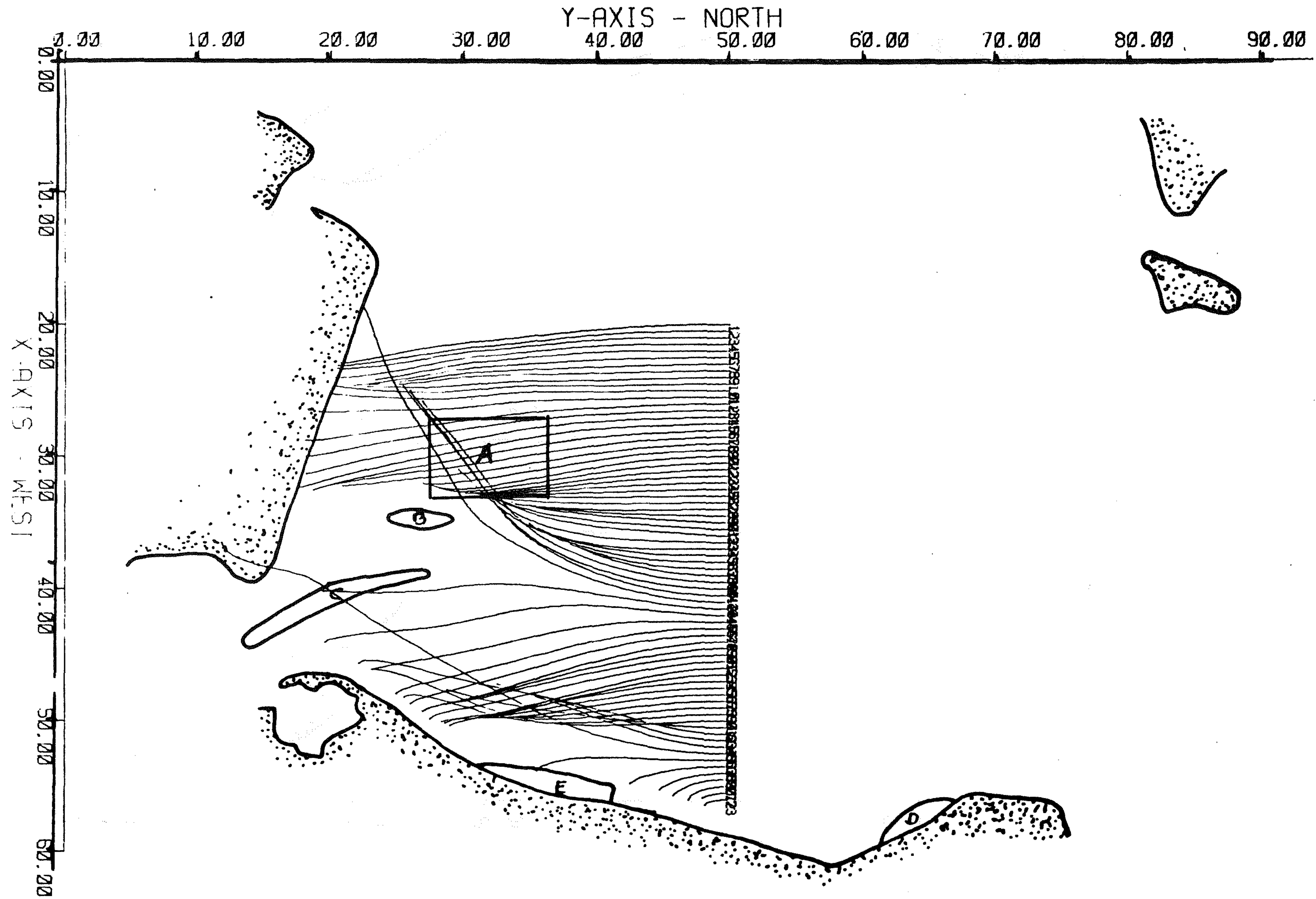

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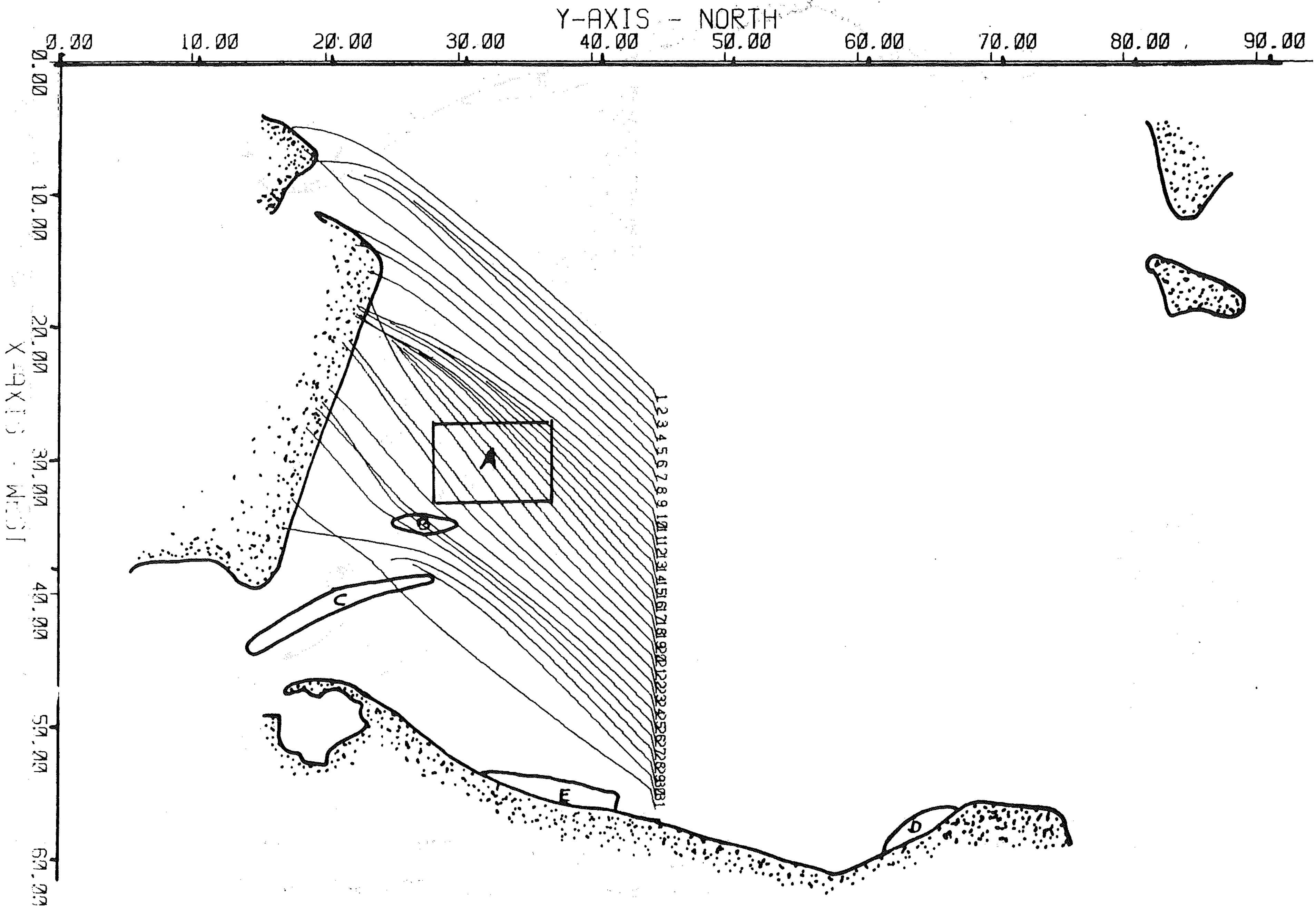

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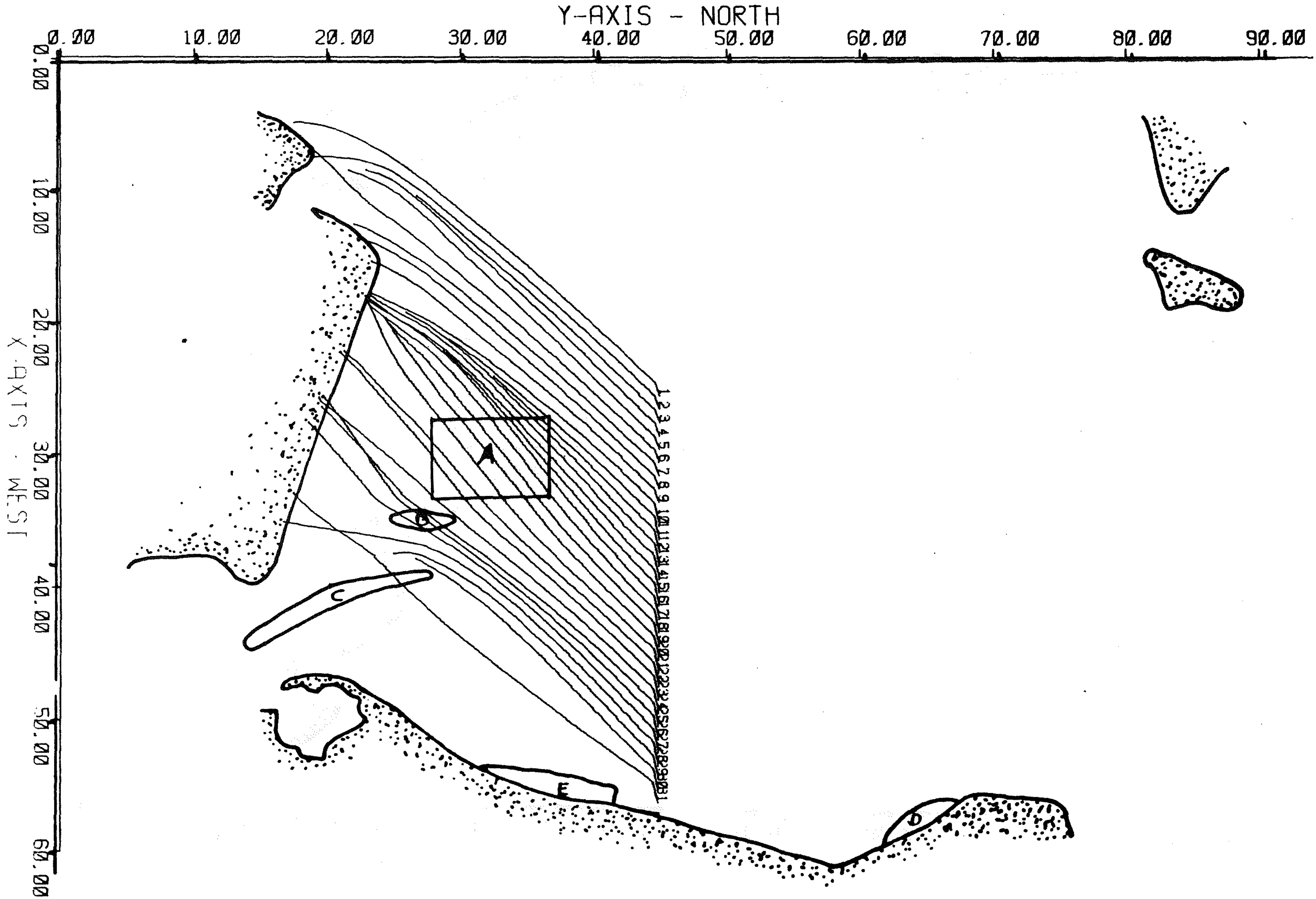

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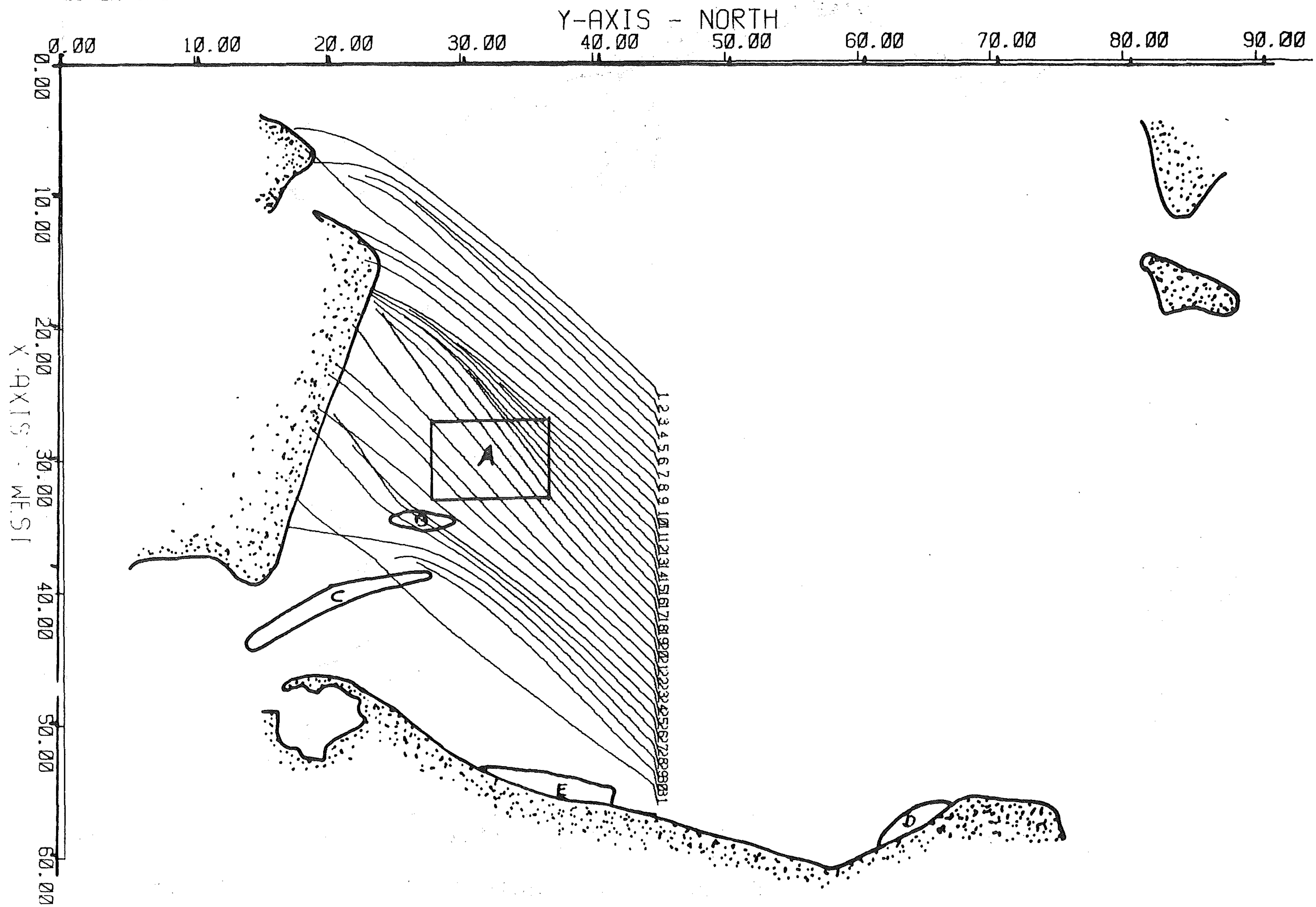

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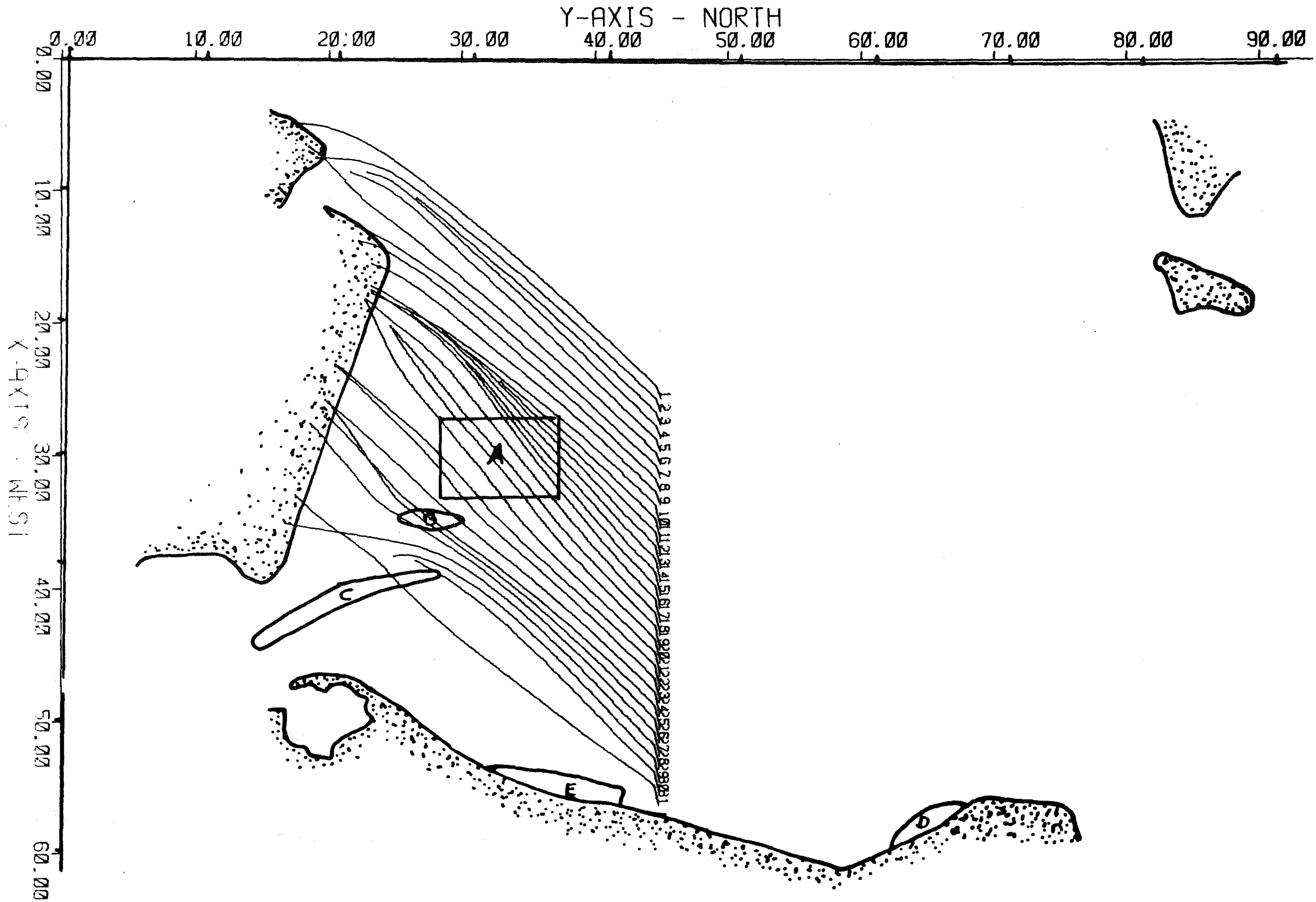

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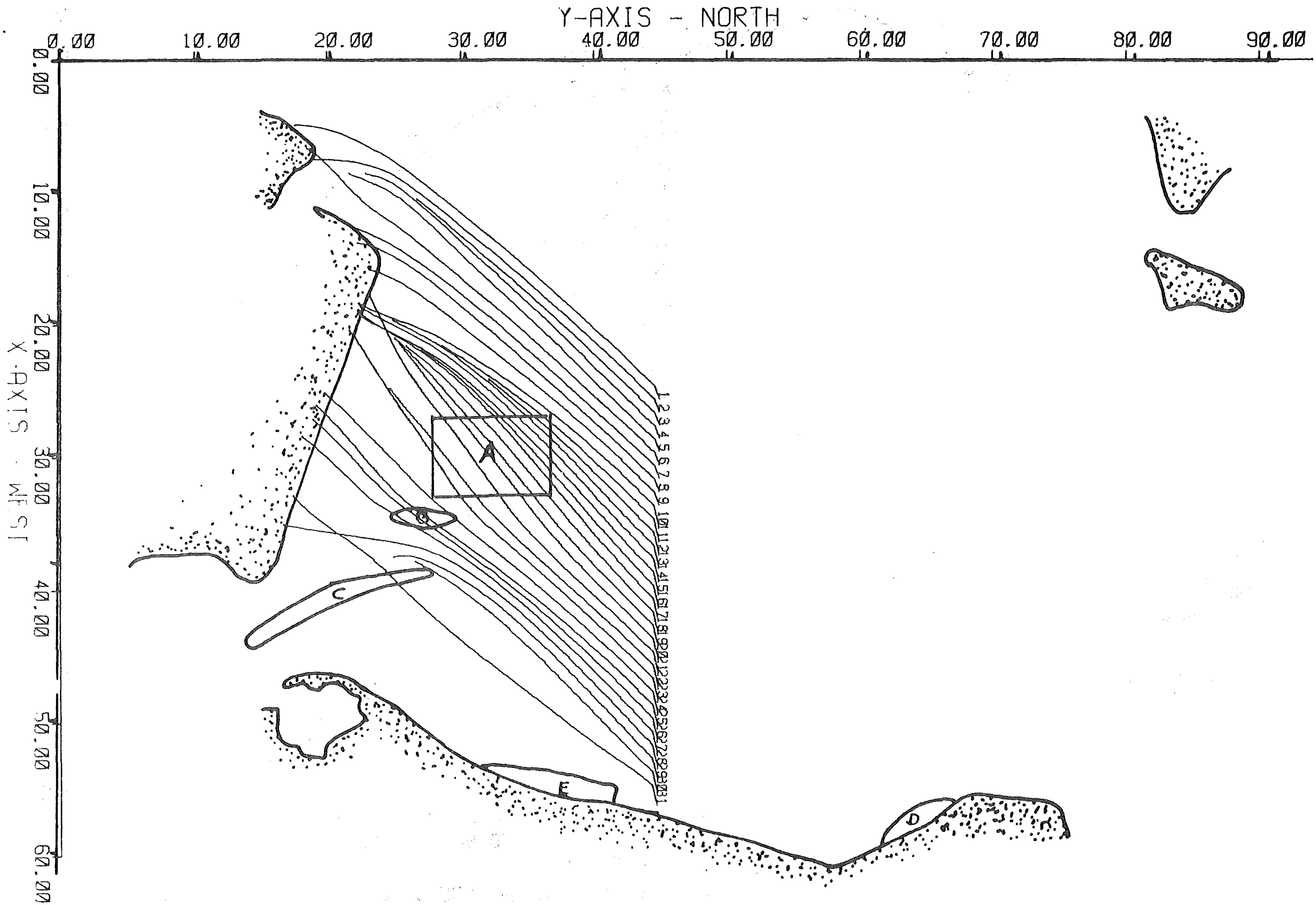

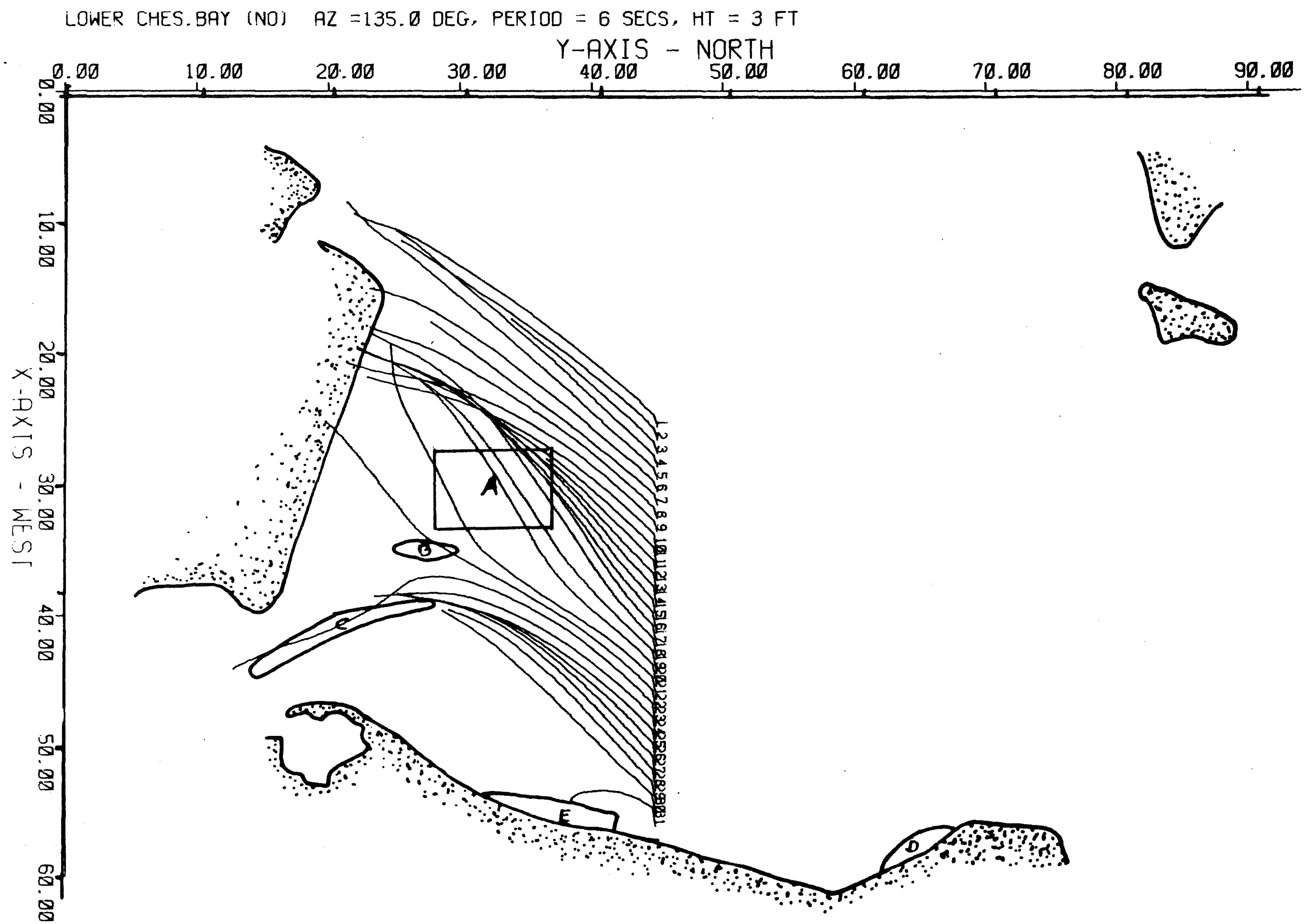

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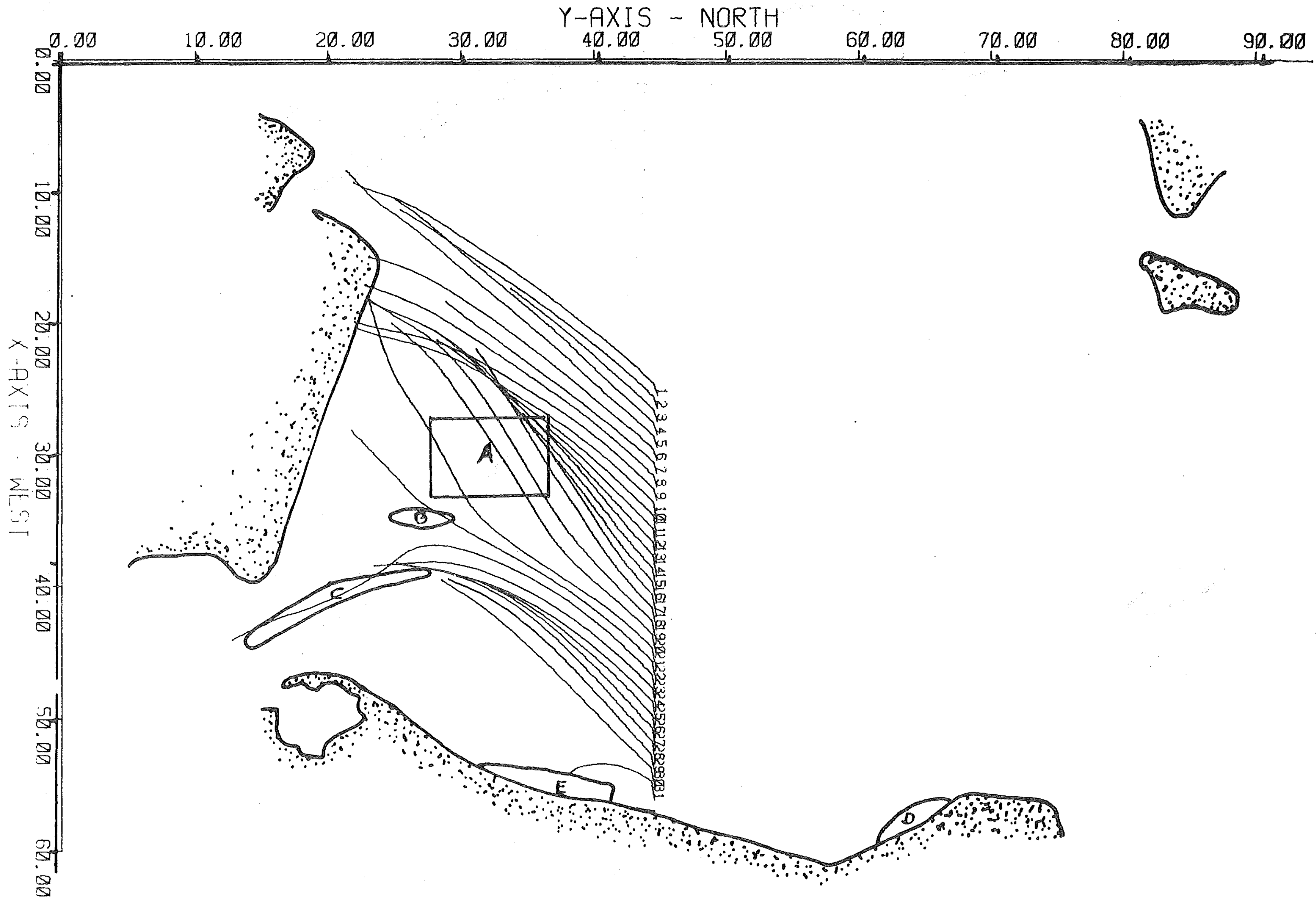

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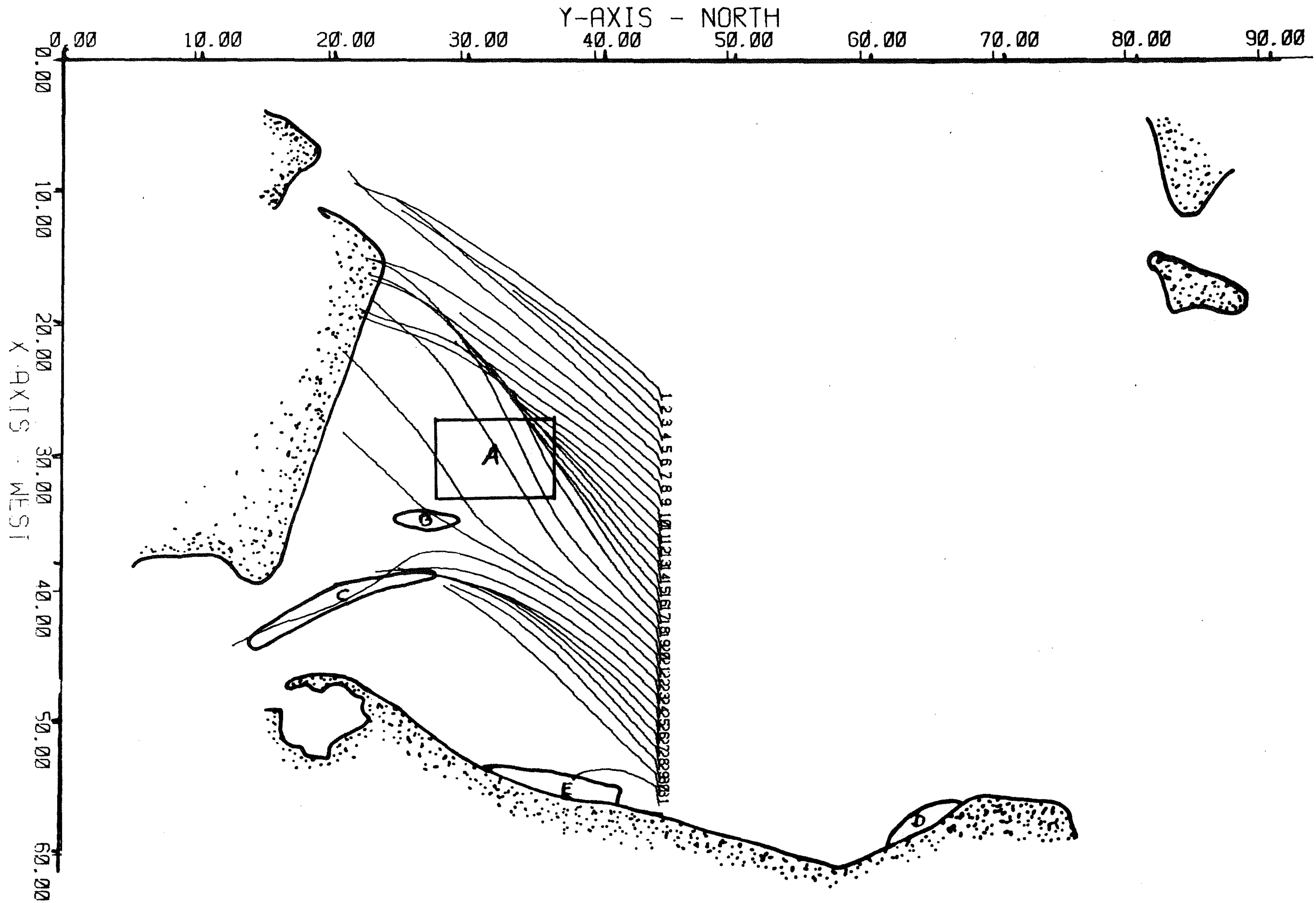

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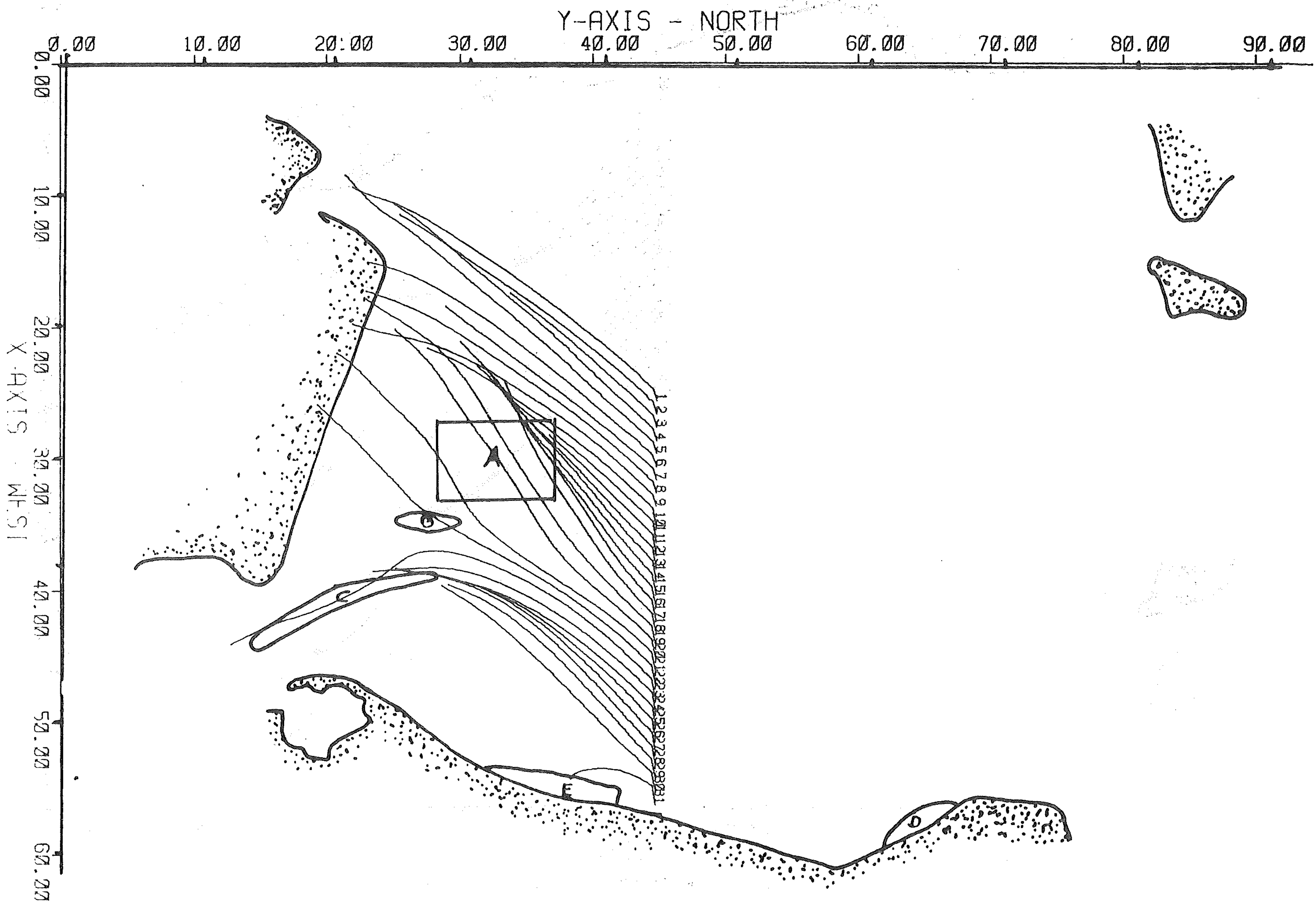

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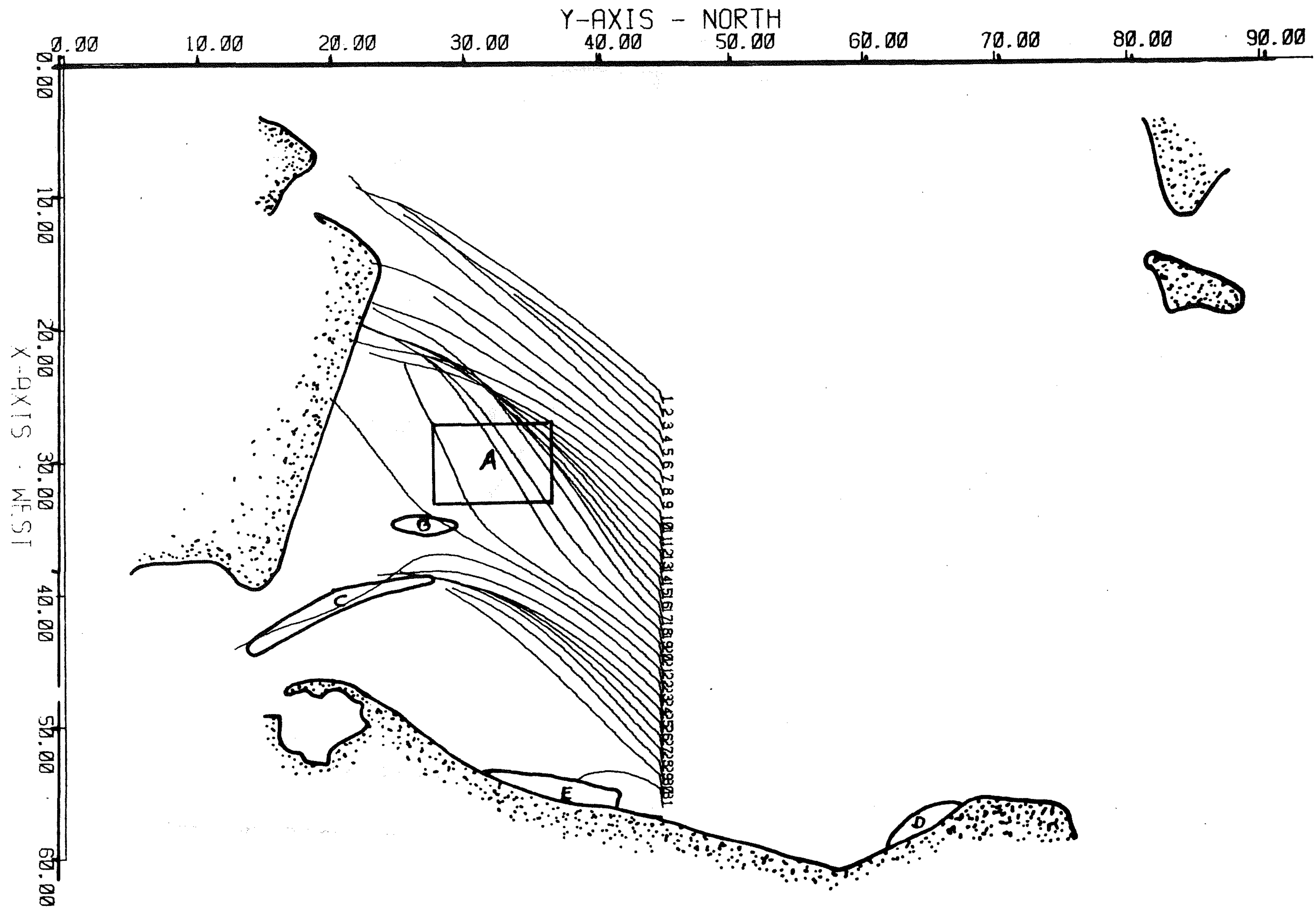

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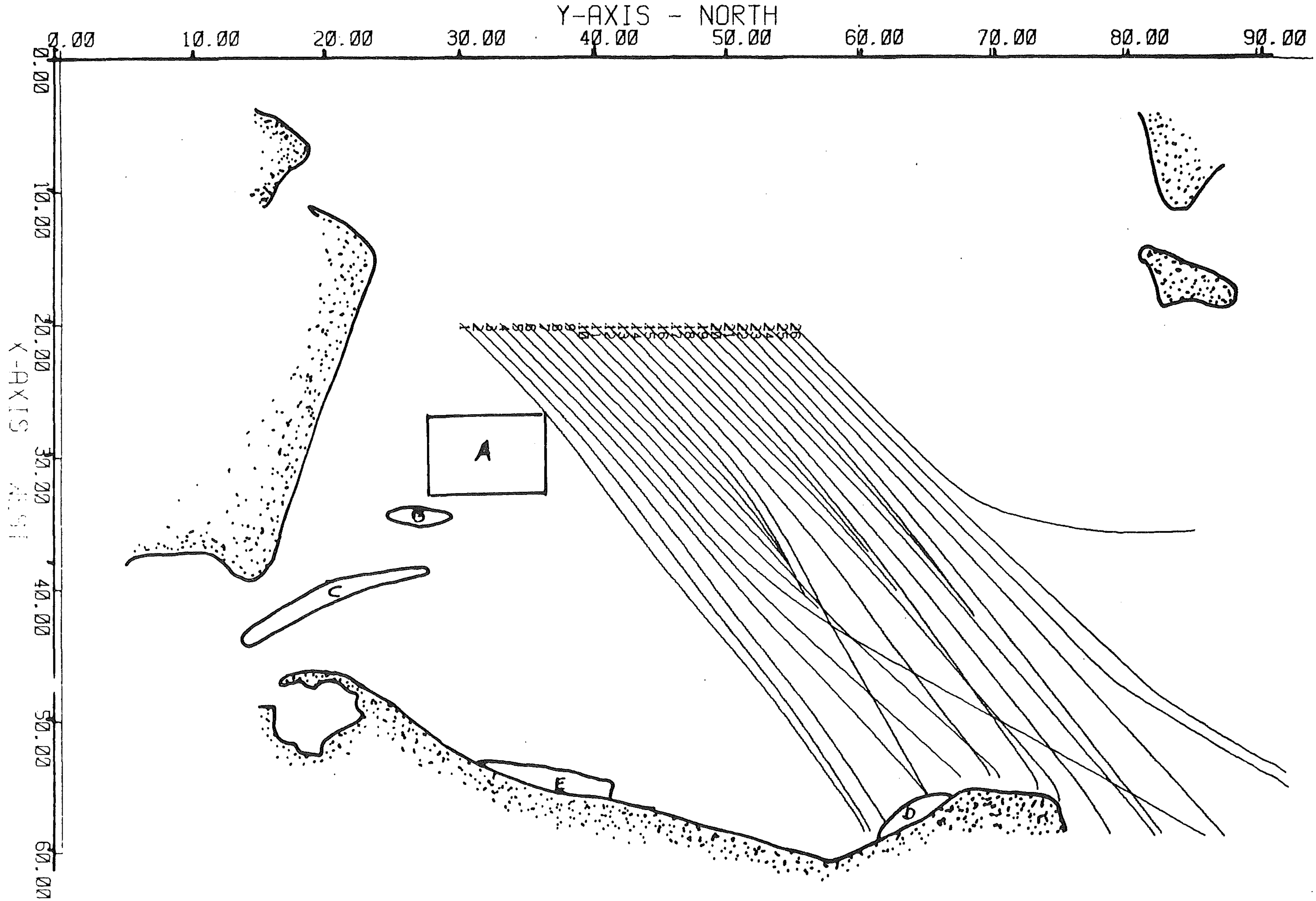


APPENDIX D

ENGINEERING CONSIDERATIONS

The following report was prepared by Drake Engineering Company under a contract for the Virginia Institute of Marine Science.

Color copies of the photographs may be seen at the Department of Geological Oceanography, Virginia Institute of Marine Science, Gloucester Point, Virginia.

SAND DREDGING STUDY FOR BEACH NOURISHMENT SOUTHERN MOST CHESAPEAKE BAY AREA INCLUDING VIRGINIA BEACH, NORFOLK, AND HAMPTON

PREPARED FOR:

VIRGINIA INSTITUTE OF MARINE SCIENCE

COLLEGE OF WILLIAM AND MARY

DEPARTMENT OF GEOLOGICAL OCEANOGRAPHY

BY:

Drake Engineering Co.
512 Strawberry Street
Richmond, Virginia 23220

CONTENTS

1.0 EXECUTIVE SUMMARY

There are sufficient sand resources of satisfactory quality and gradation in the vicinity of the beaches of Hampton, Norfolk and Virginia Beach to satisfy immediate and future requirements for beach nourishment in these areas.

For supplying the 2,500,000 net cubic yards projected as required for each of the beaches at Virginia Beach and Norfolk, it appears that a hopper dredge would be the most efficient and cost effective method of transporting the material to the beaches. The approximate low cost for beach nourishment at Virginia Beach using the Long Island is approximately $4.62 per cy or a total cost of $13,830,000.00. This alternative involves moving the sand from a borrow area offshore of Virginia Beach through a pipeline extending from approximately two miles offshore to the beachfront. The same equipment could be used for the Norfolk project which will also require 2,500,000 cy and involves excavation from the borrow site in the Horseshoe area and pumping from a point just south of the Thimble Shoals Channel. Cost for this Norfolk alternative or approximately $4.56 per cy or $13,680,000.00. The Hampton project, which will require approximately 250,000 cy is estimated to cost $1,697,625.00 or $5.03 per cy. Costs shown above and in the remainder of this report assume 1982 dollars.

Corps of Engineers studies currently underway which relate to beach nourishment should be carefully followed and appropriate input made. The effect of an approved channel and harbor deepening project on beach nourishment projects would be substantial. If deepening projects were undertaken, the total cost to the communities for beach nourishment work would be substantially reduced. It is anticipated that the only cost to be borne by the localities would be the cost for transporting the material from the borrow site to the beach and distributing the sand along the beach front.

There appear to be no environmental conditions that would be substantially affected by the work described.

2.0 INTRODUCTION

The Coastal Erosion Abatements Commission in its report to the Governor and General Assembly of the Commonwealth designated as Senate Document #4, Commonwealth of Virginia, 1979, concluded that "There is a need to locate sources of sand supplies for rebuilding public beaches. Certain bottom areas in the lower Chesapeake Bay should be studied as possible sources of sand supply for public beaches." As a result, there were funds appropriated from the general fund for the purpose of conducting these studies during the 1980--1982 Biennium. The plan of study for this work included requirements to:

A. Determine the extent and quality of sands for beach nourishment purposes in the aforementioned areas (Lynnhaven Inlet, Willoughby Bank, Horseshoe Shoal, Hampton Flats and other areas).

B. Study the most economical means of recovery and transportation of potential sands to the target areas and

C. Assessment of the environmental risk of extraction to the associated marine ecosystem. These requirements resulted in an agreement with The School of Marine Science, Virginia Institute of Marine Science, College of William & Mary to complete the study work described.

VIMS began the study work and in September 1981, published a report to the Coastal Erosion Abatement Commission entitled, "Inventory of Sand Supplies in the Southern Chesapeake Bay." This report was prepared by Robert J. Byrne, Carl H. Hobbs, III and Robert A. Gammish. During February 1982, VIMS developed an agreement with Drake Engineering Company to study the economics of recovery and transportation of sand to the required areas and to examine the environmental concerns related to the construction projects. The contents of this report are Drake Engineering Company's response to these requirements.

Included in Senate Document #4, were comments concerning the needs of the localities. This document reflected that implementation of the Corps of Engineers preliminary plans would require about 2.5 million cubic yards at Virginia Beach and about 2.5 million cubic yards in Norfolk at East Ocean View and Willoughby Spit. It was estimated that about 250,000 cubic yards of material would be required as annual maintenance. It was also estimated that about 250,000 cy would be required at Hampton. The 1972 Corps of Engineers' study indicated favorable deposits of sand in the Thimble Shoals Channel Area and included reconnaissance work offshore of the ocean front of Virginia Beach. Work begun in 1980 by VIMS delineated a number of deposits that were acceptable for beach fill. These are summarized on figure 1, page 27. VIMS has work currently underway to define in more detail the distribution of the sand most suitable for use in beach nourishment.

3.0 CONCLUSIONS

General

The beachfront areas of Virginia Beach, Norfolk and Hampton have a long history of nourishment requirements. These requirements have been met in various ways over the years. Some of these methods have been more successful than others. At this time, there remains a significant need for beach nourishment in the Norfolk area. These conditions and findings have been verified by local needs assessments and conceptionally by the studies underway by the Corps of Engineers.

As evidenced by VIMS' work dealing with the sand inventories, there is more than adequate sand available at each site for any or all of the projects. Each of the sites contain enough sand of satisfactory gradation and quality to satisfy the needs of all three project areas and provide a long-term reservoir of acceptable material. In a recent report to the Norfolk District Corps of Engineers, entitled "Construction Methods and Related Costs for Beach Nourishment from offshore borrow Virginia Beach, Virginia" by the Sand Hen Corporation of Wilmington, North Carolina, information was given that verifies that material available from site 5 is satisfactory for beach nourishment purposes. Although this site has not been as extensively cored as the other sites, the work that has been done verifies the suitability of the sand. Additional cores from this area should be taken if a final decision is made to use site 5 as a primary borrow area.

Because of current significant activity by the Corps of Engineers to study the nourishment needs of the Virginia Beach and Norfolk beaches, this report should be considered as a parallel study of the Corps work. In addition to the Corps activities relating to beach nourishment work, there remains the issue of the proposed channel deepening studies. It is clearly understood that the impact of an authorized and funded project to deepen the approach channels to Norfolk Harbor and to deepen the Harbor would be substantial on any beach nourishment work contemplated. It would unquestionably be in the best interest of the communities to use material dredged to deepen the channels for beach nourishment purposes. The cost savings realized in this approach would most likely be in the range of 60% to 70% of the total cost required if dredging was conducted purely for beach nourishment purposes. Based on current plans, excavation in the site 5 area would only be conducted if a 55 ft. channel project was approved. The approval of a lesser channel depth would only require channel deepening of the Thimble Shoals Channel East to Cape Henry. Therefore, the Virginia Beach nourishment project would be the least project affected by Channel deepening.

To improve the value of this or any other report dealing with dredging of the magnitude proposed for beach nourishmnent, additional information dealing with weather and sea conditions that exist in the Hampton Roads and Virginia Beach areas. There is much available information that relates to previous dredging projects around Hampton Roads and in the Chesapeake Bay; however, since dredging has not previously been conducted offshore of Virginia Beach, the effects of weather and sea conditions on this project can only be vaguely projected. A clear understanding of weather conditions will greatly improve the understanding of the prospective dredgers of the risk factors that may be encountered. For instance, based on previous experience and on information currently available, a bidder will be most reluctant to consider using a pipeline dredge from site 5 to Virginia Beach because of the high risk of damage associated with dredging such a distance with essentially no protection from changing sea conditions. Even with ideal weather, a bidder must consider that projecting production rates is almost pure quess work. Seas in excess of six feet will render even the majority of the nation's most powerful pipeline dredges totally ineffective.

Technical

The first and most important technical conclusion is that the technology, equipment and methodology are available on the East Coast to perform beach nourishment dredging of the magnitude and complexity described by each of the alternatives listed. Each of the dredging units described elsewhere in this report is capable of completing all or a portion of the project requirements. The areas where the highest concentration of large equipment is located are New Jersey, Illinois and Louisiana. It is apparent that since these projects require some of the largest type of equipment available, the bids by the contractors will reflect the location and availability of these selected units.

In reviewing the alternative matrix chart, located at the end of this section, it is clear that certain alternatives of those listed have a decided advantage over other alternatives. In the case of Virginia Beach, Alternative VB-4 which uses the hopper/barge method is the most appealing. This alternative was developed using the hopper/barge "Long Island" which is owned by Great Lake Dredge and Dock Company. The operation of this unit is described elsewhere in this report. This alternative would distribute the sand directly by pump to the required areas of the beach. A review of the chart shows a favorable performance in each of the categories listed. The estimated total cost using this method is $13,830,000 or $4.62 per gross cy of material moved. The total yardage was developed using a loss factor of 20% which resulted in a total of 3,000,000 gross cy to be moved to gain the required 2,500,000 cy on the beach. Loss factors reflect the difference in the volumn of material removed from the borrow area and the amount of the material successfully deposited on the beach. The value of these factors is determined from discussions with dredgers who have experience in the Hampton Roads area. The issue of potential storage of material from Thimble

Shoals Channel may substantially affect dredging options for Virginia Beach. If the previously used Ft. Storysite is unavailable, then it would appear that any alternative considering storage and truck haul would be invalid unless another sizable storage site could be obtained. If this were not possible, then the only alternatives applicable would be those which employed direct discharge to the beach.

The selected N-2 alternative for the Norfolk Project employs the same hopper/barge unit to move a total esimated 3,000,000 cy. Total cost for this alternative is estimated at $13,680,000.00 or $4.56 per gross cy.

The Hampton alternative employs the use of 27 inch hydraulic dredge to move an estimated 337,500 cy. The cost is estimated to be $1,697,625.00 or $5.03 per gross cy.

From the above and considering the matrix chart giving detailed information on these alternatives, it is clear that the hopper/barge unit is productive and economical for moving large quantities of sand. It is expected that this unit would perform better than the pipeline dredge in sea conditions encountered in the Virginia Beach area, and yield higher production rates.

The particular unit "Long Island" used for the purposes of this estimate has been employed previously for anchorage improvements in the Norfolk Harbor. In evaluating the various hopper units, it was estimated that the hopper/barge was slightly more cost effective than the more conventional medium class hoppers which have a useful capacity of approximately 2,500 cy in sand. Based on estimates, these medium class units would increase the cost by approximately 5%-15% of the total project cost. When these projects are ultimately bid, conditions may be such that these medium class units are more competitive. Final engineering will also affect equipment selection since details will be more refined and equipment suitability can be more accurately determined.

4.0 RECOMMENDATIONS

Specific recommendations as a result of this study are as follows:

1. The detailed activities of the Corps of Engineers in regard to their studies concerning hurricane protection and beach nourishment, and channel and harbor deepening should be followed closely. A formal program which allows Commission representatives to make input, review and evaluate Corps information as it is available is desirable. This approach allows Commission and localities to develop intermediate and long-range plans for beach nourishment. Valuable cost information can be derived from these plans and future financial requirements determined.

2. Channel and harbor deepening plans and efforts should be supported as proposed by the Commonwealth and Corps of Engineers. It is obvious that sand made available from channel and harbor improvements will substantially reduce the cost to the localities for beach nourishment.

3. Additional study work should be performed. Information concerning weather and sea conditions as previously indicated of considerable importance. Potential storage sites for sand that would be dredged from Thimble Shoals Channel should be investigated and their capacity

determined. Preliminary agreements on storage sites should be made in anticipation of needs due to channel deepening work.

4. An effort should be made to investigate the possibility of using dredged material that would be generated from the anticipated Baltimore project which will involve deepening of the Chesapeake Channel East of the Chesapeake Bay/Bridge Tunnel.
5. As information is developed concerning channel and harbor deepening a cost analysis should be developed and continually updated to show how deepening plans could reduce beach nourishment costs.

ALTERNATIVES MATRIX--BEACH NOURISHMENT

Virginia Beach 2,500,000 cy, Norfolk 2,500,000 cy, Hampton 250,000 cy

Alternative	Method of Excavation From Borrow Area	Method of Distribution	Costs	Efficiency: Period of OPN 1-5	Reliability 1-5	Equip. Avail.	Impact on Tourist 1-5	Safety 1-5	Noise 1-5	Ecological Effects 1-5	Tot. Score
VB-1	27"Hydraulic From Site 1 to Cape Henry--3,375,000 cy gross	Pump	30,678,750 9.09/cy	Poor 2	Good 4	Yes	Fair 3	Good 4	Good 4	Good 4	21
VB-1A		Haul-off rd.	25,515,000 7.56/cy	Poor 2	Good 4	Yes	Poor 1	Poor 2	Poor 1	Fair 3	13
VB-1B		Haul-On rd.	25,515,000 7.56/cy	Poor 1	Good 4	Yes	Poor 2	Poor 2	Poor 2	Fair 3	14
VB-2	Hopper/Barge From Site 1 to Cape Henry--3,000,000 cy gross	Pump	21,360,000 7.12/cy	Good 4	Good 4	Yes	Fair 3	Good 4	Good 4	Good 4	23
VB-2A		Haul-Off rd.	20,280,000 6.76/cy	2	Good 4	Yes	Poor 1	Poor 2	Poor 1	Fair 3	13
VB-2B		Haul-On rd.	20,280,000 6.76/cy	1	Good 4	Yes	Poor 2	Poor 2	Poor 2	Fair 3	14
VB-3	27"Hydraulic From Site 5 to V.B.--3,375,000 cy gr.	Direct by Pump	23,355,000 6.92/cy	Poor 1	Fair 3	Yes	Fair 3	Good 4	Good 4	Good 5	20
VB-4	Hopper/Barge fr. Site 5 to Mooring Point, then to V.B.--3,000,000 cy gr.	Direct by Pump	13,830,000 4.62/cy	Good 3	Good 3	Yes	Fair 3	Good 4	Good 4	Good 5	22
VB-5	Hopper/Barge fr. Site 1 to V.B.--Pump Barge--3,000,000 cy gross	Direct by Pump	14,970,000 4.99/cy	Good 3	Good 4	Yes	Fair 3	Good 4	Good 4	Good 4	22
N-1	27"Hydraulic from Site 2 to Norfolk--3,375,000 cy gross	Pump	26,493,750 7.85/cy	Good 4	Good 4	Yes	Good 4	Good 4	Good 4	Fair 2	22
N-2	Hopper/Barge from Site 2 to Mooring -- then pump to Norfolk-3,000,000 cy gross	Pump	13,680,000 4.56/cy	Good 4	Good 4	Yes	Good 4	Good 4	Good 4	Fair 3	23
N-3	27"Hydraulic from Site 3 to Norfolk--3,375,000 cy gross	Pump	23,726,250 7.02/cy	Good 5	Good 4	Yes	Good 4	Good 4	Good 4	Fair 2	23
H-1	27"Hydraulic From Site 4 to Hampton--337,500 cy gross	Pump	1,697,625 5.03/cy	Good 5	Good 4	Yes	Good 4	Good 4	Good 4	Fair 2	23

SCORING: Each of the criteria are given a numerical score in the range of 1 to 5. The higher scores reflect more favorable alternatives. The general description of the scores are as follows: Good, 5-4; Fair, 3-2; Poor, 1.

ALTERNATIVE			Total Cost	Cost/cy	Cost/cy Hi/Med. Average	Cost/cy Hi/Low Average
VB-1	Hydraulic from	Hi	$44,540,000	$13.20		
	Site 1 to Ft.	Med	$22,267,231	6.59	$9.90	$9.09
	Story & pump	Low	$16,502,400	4.88		$30,678,750
	to V. B.					
VB-1A	Hydraulic from	Hi	$37,278,750	$11.05		
	Site 1 to Ft.	M	$19,951,315	5.91	$8.48	$7.56
	Story Truckhaul	L	$13,748,113	4.07		$25,515,000
	off Rd. to V.B.					
VB-1B	Hydraulic from	H	$37,278,750	$11.05	$8.48	$7.56
	Site 1 to Ft.	M	$19,951,315	5.91		
	Story Truckhaul	L	$13,748,113	4.07		$25,515,000
	on Rd. to V.B.					
VB-2	Hopper Site 1	H	$24,564,220	8.19		
	to Ft. Story	M	$19,816,751	6.60	$7.40	$7.12
	& pump to V.B.	L	$18,129,251	6.04		$21,360,000
VB-2A	Hopper From	H	$22,487,620	7.49	$6.76	$6.76
	Site 1 to Ft.	L	$18,123,750	6.04		$20,280,000
	Story Truckhaul					
	Off Rd. to V.B.					
VB-2B	Hopper From	H	$22,487,620	7.49	$6.76	$6.76
	Site 1 to Ft.					
	Story Truckhaul	L	$18,123,750	6.04		$20,280,000
	On Rd to V.B.					
VB-3	Hydraulic from	H	$33,200,000	9.84	$6.92	$6.92
	Site 5 to V.B.	L	$13,533,750	4.01		$23,355,000
VB-4	Hopper from	H	$15,976,000	5.32	$4.62	$4.62
	Site 5 to Moor-					
	ing & pump to	L	$11,760,552	3.92		$13,860,000
	V.B.					
VB-5	Hopper From	H	$17,423,680	5.80	$4.99	$4.99
	Site 1 to Moor-					
	ing & Pump to	L	$12,540,000	4.18		$14,970,000
	V.B.					
N-1	Hydraulic from	H	$37,400,000	$10.79	$8.22	$7.85
	Site 2 to Nor-	M	$19,043,505	5.64		
	folk w/boosters	L	$16,577,055	4.91		$26,493,750
N-2	Hopper from S-2	H	$15,952,000	5.31		
	to Mooring &				$4.56	$4.56
	pump to Norfolk	L	$11,441,250	3.81		$13,680,000

ALTERNATIVE			Total Cost	Cost/cy	Cost/cy H/Med. Average	Cost/cy Hi./Low Average
N-3	Hydraulic from Site 3 to Norfolk	H	$29,700,000	$ 9.90		
		M	$16,010,055	4.74	$7.32	$7.02
		L	$14,016,105	4.15		$23,726,250
H-1	Hydraulic from Site 4 to Hampton	H	$1,983,300	5.88		
		M	$1,472,324	4.36	$5.12	$5.03
		L	$1,413,855	4.18		$1,697,625

5.0 FINDINGS AND DISCUSSION

5.1 EXISTING CONDITIONS

Studies Relevant to Beach Restoration

The needs for Norfolk, Virginia Beach and Hampton have been described in various documents that have been produced over the years. The majority of this information has been prepared by the Corps of Engineers. However, periodically the localities have prepared various plans, design documents and assessments which have been directed towards specific restoration efforts.

The City of Norfolk is currently underway with a study including plans and specifications for a project known as the East Ocean View Restoration Project which involves filling a critical need. This project includes filling a portion of the beach from the City Beach area one mile west. Plans and specifications for this project are due to be complete in the Fall of 1982.

The City of Hampton has developed an erosion control plan which primarily involves structural modifications to control beach erosion. The most encompassing documents relevant to beach nourishment are planning documents produced by the Corps of Engineers for restoration and protection of the beaches at Virginia Beach and Norfolk. The most significant studies are: "The Virginia Beach Erosion and Hurricane Protection Study" and the "Willoughby Bank Erosion and Hurricane Protection Study." The Virginia Beach final report including plans and specifications for the selected alternative is due in the Spring of 1983. The project, if authorized would be scheduled for 1988 construction. The Corps expects to have the Norfolk study completed by the Fall of 1982. Initial estimates of the needs of those two projects are that approximately 2,500,000 cy of sand will be required in each area. In Virginia Beach, the placement would befrom Rudee Inlet to Cape Henry and the Norfolk project distribution would be made from the Little Creek Areas through Willoughby Spit. Annual maintenance dredging requirements are placed at approximately 250,000 cy at Virginia Beach and approximately 15,000 cy at Norfolk. This information is also reflected in VIMS' report to the Coastal Erosion Abatement Commission of September 1981.

5.2 Projects Affecting Beach Nourishment

The following is a brief summary of known projects underway at various stages which affect beach nourishment:

5.2.1 Channel and Anchorage Deepening

Deepening of Chesapeake Channel to 55'--The deepening project of the Chesapeake Channel is part of the deepening work for the Baltimore Harbor. At this time, construction funds are being sought by the State of Maryland to start the project. Should those funds be secured, it is anticipated that work would begin within two years in the section of the channel eastward of Chesapeake Bay/ Bridge Tunnel. The mount of material to be removed from this area could be as much as 3,000,000 cy. It is planned at this time that the material would be placed in overboard disposal areas. Since this prospective borrow area is in the same general area that satisfactory sand has been found, it would appear that the material would be suitable for beach nourishment.

- Norfolk Harbor Deepening Project--This much discussed project calls for the deepening of the Norfolk Harbor and approach channels including Thimble Shoals Channel to a depth of 55′ to accommodate large draft vessels. The project is at least three years away from construction. Part of the project encompasses the section of Thimble Shoals inventoried by VIMS and included as possible sand sourcesfor beach nourishment. According to Corps of Engineers estimates, the inventoried area which is the eastern most part of the Thimble Shoals Channel contains about 18,000,000 cy of satisfactory material. About 2,000,000 cy of this material would be removed to meet the 55′ channel depth requirements. Unless otherwise planned, the Corps anticipates that the material would be placed in overboard disposal areas.
- Advanced Channel Maintenance Dredging--This maintenance work is underway at this time. The project includes deepening the Thimble Shoals approach channel and the Harbor area to a 48′ depth. Work should begin this year on the eastern most portion of the Thimble Shoals project. The material from the Thimble Shoals Channel is scheduled to be stored at Ft. Story. Although the quantity of material is unknown at this time, the Corps feels that the quantity will be less than that dredged during 1978 and probably not exceed 250,000 cy. The quality of this material is suitable for beach nourishment purposes. In

the past, this material has been used by Virginia Beach for their annual beach nourishment program which has required an average of approximately 275,000 cy. There appears to be no reason why the material would not be available for use by Virginia Beach or other localities.

- Navy Pier Expansion--The Navy has a project underway to deepen its harbor facilities to 55′. This work involves the removal of approximately 2,000,000 cy of material. The Navy proposes to place approximately half of the material in the marsh area at the southeastern end of the Hampton Roads Bridge Tunnel. This material is unsuitable for beach fill. The Corps feels that the other 1,000,000 cy would be suitable material for beach nourishment but at this time, no plans have been made for use of the material.

5.2.2 Beach Nourishment

- East Ocean View Restoration Project--This is a Norfolk Project currently under design. It involves dredging approximately 300,000 cy of sand from Pretty Lake and filling part of the Norfolk Beach. The area to be filled begins at City Beach and proceeds one mile West. Construction is scheduled for the Fall of 1982 with completion in 1983.
- Virginia Beach Annual Beach Nourishment Program--This nourishment work is a continuing program begun in 1952 for annual maintenance to the beaches of Virginia Beach. According to records from the City compiled since 1952,

the total material placed in recent years has averaged approximately 275,000 cy, part of which is in compliance with federal programs and part in accordance with local requirements. From 1974 to 1979, the program made use of stockpiled material at Ft. Story which was due to dredging in Thimble Shoals Channel. In addition, sand from various sources has been used over the years. The City uses a combination of truck haul from borrow pits, dredging in Rudee Inlet and excavation from the Rudee Inlet sand trap tomeet its annual requirements. A total of 108,000 cy have been taken from the borrow pit on South Birdneck Road, and 150,000 cy from the borrow pit on General Booth Boulevard and Princess Anne Road. The Birdneck Road site is owned by the City and the other two pits are privately owned.

- The City of Hampton has from time to time made efforts to control the erosion of the beaches by sand bagging and groin construction. However, there is no known major restoration work planned at this time.

5.3 Physical Conditions

The Hampton Roads/Virginia Beach area is one of the most unique areas in the United States. Situated at the mouth of the Chesapeake Bay, which is well known for its seafood production, the area is a combination of intense fishing, commerce and recreation. The overall configuration of the land masses are shown on Figure 1. The entrance to the Chesapeake Bay and the Norfolk Harbor are protected by the land mass and Shoal area to the Northeast. The Thimble Shoals and Norfolk Harbor approach areas are relatively protected from wind conditions and therefore are favorable for dredging activities. Since Cape Henry is within 15 miles of the entrance to Hampton Roads, the sites West of the Cape are within easy reach of safe harbor in the event that major storms should occur. If a truck haul option was a favored method of transportation of sand, traffic conditions would have to be considered. As in the case of most commercial/resort type of communities, the waterfront is congested and major arteries feeding the sites experience frequent overloads during peak hours, and depending on the season, generally bear a heavy burden of traffic 15 hours of the day. This condition is a definite drawback to the truck haul alternative and will be discussed later in this report.

The sand resources available for the project are clearly outlined in VIMS' report to the Coastal Erosion Abatement Commission entitled, "Inventory of Sand Supplies in the Southern Chesapeake Bay" dated September 1981. Location of these deposits are detailed on Figure 1. From a review of the document and examination of the chart, it is clear that ample material is available for beach nourishment. The quality of sand in these deposits is satisfactory for nourishment purposes and has been described in detail in the VIMS report. It is evident by review of the chart that there is a substantial advantage to using the borrow areas closest to the beaches for which nourishment is required. Not only is there a direct savings in transportation costs, but hinderances to navigation can be minimized by staying as far as possible away from the shipping and fishing traffic patterns. The only site not extensively examined by VIMS in their report to the Coastal Erosion Abatement Commission is the site offshore of Virginia Beach designated as Site 5 on Figure 1. This site has, however, been studied to some extent by the Corps in their preliminary investigation of channel deepening requirements for the 55′ project. According to their study information, quantities of suitable material lie parallel and inside of what′s commonly called the "CB" line which is the line of buoys ranging from approximately three miles offshore of Cape Henry to six miles ofshore of Rudee Inlet. This borrow area corresponds roughly to the outbound channel line for the proposed 55′ deepening. The material is characterized as well graded fine to medium sand with approximately 10′ of silty overburden. The good material is located at approximately minus 55′ to approximately minus 65′. The Corps has taken some vibracore samples from ths area and has developed gradation curves for the material.

The weather conditions normally encountered in the Hampton Roads area are best described as moderate. Winds as previously mentioned are generally out of the Southwest at 5 to 15 knots. Dredging operations at all areas except for the area offshore of Virginia Beach would receive protection from the land masses from average wind and sea conditions. Unfortunately, there is little documented wave information available for consideration of projects of this nature. Estimates of sea conditions as they relate to dredging are relatively vague and inconclusive. It is safe to say that optimum conditions for dredging are when no wave action exists at all. Each dredge responds to wave action in a different manner and therefore, it is impossible to predict the effectiveness of any particular dredge under varying sea conditions.

Regardless of the limited information, there remains some wave data that is useful for planning purposes. Within the past year, the National Sea Grant Program provided funds for Scripps Institute of Oceanography to establish the wave station off of Croatan just South of Rudee Inlet. The unit was established approximately 2,000 feet offshore and wave data has been recorded since July 1981. This data, which is routinely sent to the City of Virginia Beach, is tabulated and shown on Figure 2. In addition to the above, Coastal Engineering Research Center (CERC) Technical Report #77-1 dated January 1977 shows observations for the Chesapeake Bay/Bridge Tunnel. This information is tabulated on Figure 3. CERC also has information taken from the research

facility at Duck, North Carolina which is less than 50 miles Southof Cape Henry. For the purpose of this report, the wave information at the Chesapeake Bay/Bridge Tunnel and at Croatan is preferred since sea conditions towards Cape Hatteras generally are more severe. The Sand Hen Corporation of Wilmington, North Carolina in its recent report to the Norfolk District Corps of Engineers entitled, "Construction Methods and Related Costs for Beach Nourishment from offshore borrow Virginia Beach, Virginia" relates Virginia wave action to wave action along the East Coast of Florida. The information from that report is duplicated on Figure 4 of this report.
Since there have been no offshore dredging projects in Virginia waters and there has been an abundance of work going on along the East Coast of Florida, it is hopeful that the corelation between the two areas could be made and therefore, provide prospective dredgers with useful information as they relate the capabilities of their equipment to sea conditions. The Sand Hen report shows the average significant wave height of the Chesapeake Bay and Duck Pier Stations compare favorably with readings taken from Lakeworth, Florida. Although most sources consulted say that Florida sea conditions are more severe than those encountered in Virginia waters, the values shown tend to contradict this position.

The effect of sea conditions on dredging equipment varies from dredge to dredge. There are no set rules that describe acceptable conditions; however, there are certain conditions for which conclusions can be made. Although planning is made on average wave heights, it is the maximum wave that causes the most severe problems to dredge equipment. Waves of short period do not cause problems that long waves cause and as the wave length approaches and exceeds the length of the dredge barge, the most severe damage is encountered. Pipeline dredges are more susceptible to wave damage and therefore their efficiency controlled more rigidly by sea conditions than hopper dredges. Many contractors would agree that the pipeline dredge becomes totally ineffective when the maximum wave exceeds five feet.

Waves averaging in excess of three feet seriously reduce the productivity of pipeline dredges. Hopper dredges are more effective in heavier sea conditions. Although it is difficult to interpret the mass of information available concerning sea conditions and its effect on dredging, it is even more difficult to predict the reaction that a dredger has to this data when he prepares a bid for a project. Although he may assign a reasonable factor of safety to wave heights in order to judge the effectiveness of his equipment, the use of these efficiency calculations in determining a bid is dependent on a multitude of factors and conditions. Unfortunately, the times when sea conditions are most favorable for dredging are the times when most localities would least prefer to have dredging operations underway. In the Virginia Beach/Hampton Roads area, the most favorable sea conditions are encountered in the summer months (June through August). Unfortunately, this is a time when tourist season is at a peak and most localities are unlikely to view dredging operations with favor. Perhaps this position is unjustified since operations off the coast of Florida and Virginia Beach maintenance nourishment work have not appeared to stem the tide of sunbathers in the respective areas. Figure 5 shows an estimate of the most probable high production periods for dredging in the Hampton Roads/Virginia Beach area.

FIGURE 1

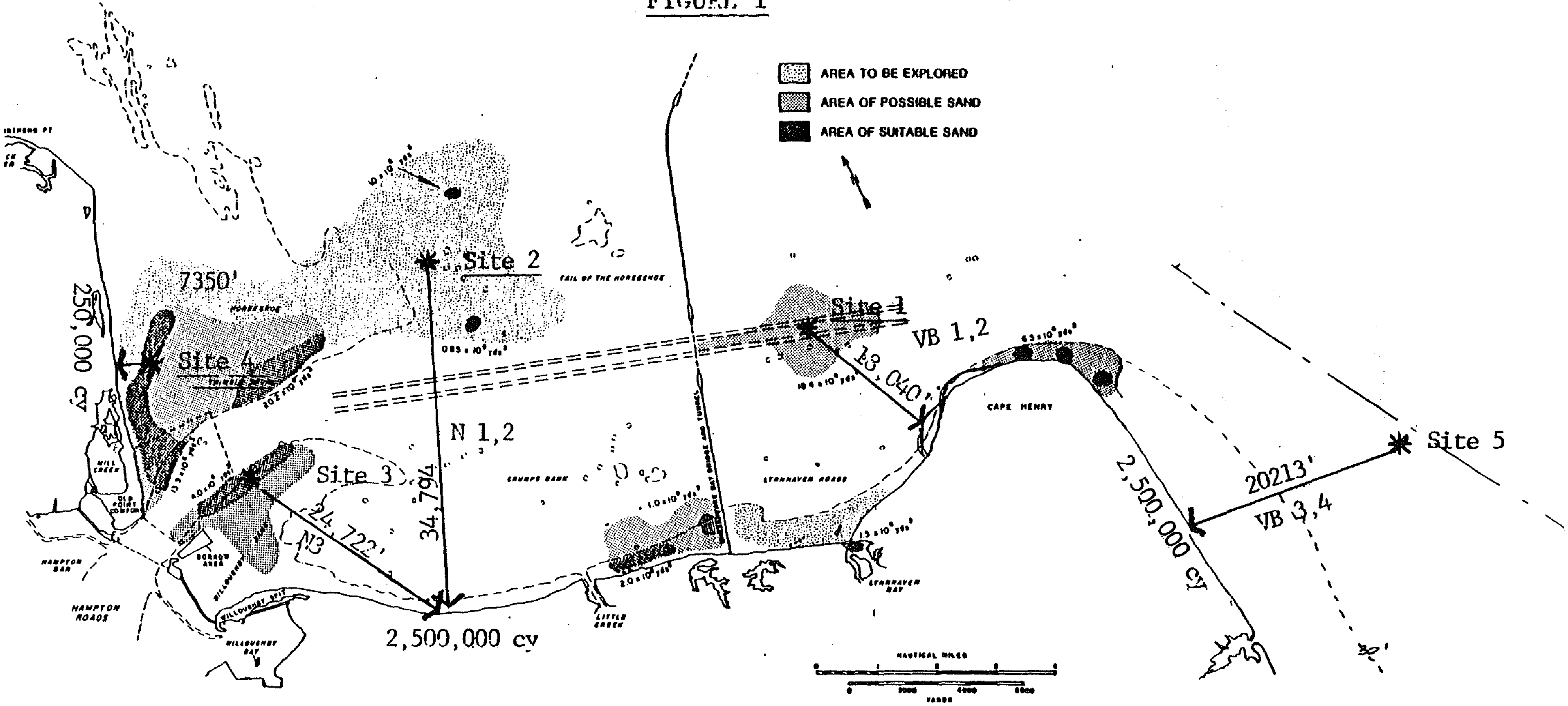

AREA TO BE EXPLORED
AREA OF POSSIBLE SAND
AREA OF SUITABLE SAND
Site 1
Site 2
Site 3
Site 4
Site 5
VB 1,2
13,040'
VB 3,4
20213'
N 1,2
34,794
N3
24,722'
7350'
250,000 cy
2,500,000 cy
2,500,000 cy
TAIL OF THE HORSESHOE
HORSESHOE
CAPE HENRY
LYNNHAVEN ROADS
LYNNHAVEN BAY
CRUMPS BANK
LITTLE CREEK
HAMPTON ROADS
HAMPTON BAR
MILL CREEK
OLD POINT COMFORT
BORROW AREA
WILLOUGHBY BAY
WILLOUGHBY SPIT
NAUTICAL MILES
YARDS

Figure 2

WAVE DATA FROM CROATAN STATION

SOUTH OF RUDEE INLET--APPROX. 2000 FT. OFFSHORE

SIGNIFICANT WAVE HEIGHT

DATE	MAX	AVE
Jul. 1981	2.95	1.64
Aug. 1981	8.86	2.36
Sept. 1981	3.94	1.18
Oct. 1981	6.23	2.85
Nov. 1981	6.56	2.65
Dec. 1981	3.94	2.32
Jan. 1982	6.56	1.99

Figure 3

WAVE CONDITIONS AT

CHESAPEAKE BAY & DUCK PIER

Month	CHESAPEAKE BAY Average Significant Height Feet	DUCK PIER Average Significant Height Feet
January	1.54	2.76
February	2.26	3.68
March	1.79	3.51
April	1.56	2.36
May	1.54	3.25
June	1.15	1.90
July	1.19	1.90
August	1.19	3.18
September	1.82	3.08
October	2.10	3.58
November	1.72	3.31
December	1.69	3.54
Average	1.62	3.00

Figure 4

COMPARISON OF VIRGINIA BEACH AND EAST COAST OF FLORIDA*

The average of the Chesapeake Bay and Duck Pier data is shown below and the published data for Lake Worth, Florida is presented for comparison purposes.

CHART, CHESAPEAKE BAY, LAKE WORTH, FLORIDA

	AVERAGE, CHESAPEAKE BAY AND DUCK PIER DATA			LAKE WORTH, FLORIDA		
Month	Average Significant Height H	Period t.	Approx. Length* l	Average Significant Height H	Period t.	Approx. Length* l
	Feet	sec.	feet	feet	sec.	feet
January	2.5	5.61	161	2.29	6.48	215
February	2.97	7.06	255	2.24	9.94	502
March	2.47	7.04	254	2.61	8.33	355
April	1.96	6.07	188	2.08	5.58	159
May	2.40	5.85	175	2.15	5.59	160
June	1.52	5.84	175	1.72	4.09	86
July	1.55	5.64	160	1.37	4.95	125
August	2.19	6.23	198	1.56	6.71	230
Sept.	2.49	7.18	264	1.95	6.11	191
October	2.84	6.62	224	3.37	6.23	200
November	2.52	6.40	209	2.50	6.51	217
December	2.62	6.00	184	2.06	6.95	247
Average	2.31	6.30	204	2.40	5.82	224

*From Sand Hen Corp.

FIGURE 5

PROBABLE PRODUCTION EFFICIENCY

OFFSHORE VIRGINIA BEACH, VIRGINIA

Month	Expected Efficiency
January	Poor
February	Poor
March	Poor
April	Fair
May	Fair
June	Good
July	Good
August	Good
September	Fair
October	Poor
November	Poor
December	Poor

5.4 ENVIRONMENTAL CONCERNS

The most significant environmental concerns for these dredging projects deal primarily with two areas: Ecological effects and socio-economic effects. Although some thought could be given to additional concerns such as water and air quality, impacts on these criteria are virtually non-existent.

Ecological Effects

The primary cause of concern of adverse impact on any of the aquatic organisms is caused by turbidity, spoil disposal practices and destruction or relocation. Adult finfish are not threatened by any of these conditions since they will simply move away from any hazard imposed by the dredge equipment during operations.

According to the Bureau of Shellfish Sanitation, State Health Department, Site 3 is the only area in which a substantial harvestable shellfish population exists. This agency has monitored the area and has designated the area as a conditional harvest ground for clams. The remaining sites under consideration do not contain a shellfish population that is of concern. The removal and overboard disposal of 3 to 4 feet of overburden will cause some covering of the shellfish. This overburden is only a small percentage of the material to be removed during the entire project and rests on the shoulder of the entrance channel to Hampton Roads. The effect of the dredging of the sand will produce virtually no turbidity.

Dredging at sites 2, 3 and 4 will relocate or eliminate benthic organisms existing in bottom sediments in those areas. There is little or no marine life in the channel areas such as the channel segments in sites 1 and 5. The echo system in these channel segments is constantly disturbed by the effects of shipping traffic.

The outlook of the socio-economic impact of these dredging projects is generally favorable. The primary purpose of beach nourishment is to protect shore construction areas against losses due to erosion or high sea and to improve the recreational quality of the area. There is little question that both of these aims would be achieved through these projects. The only significant concern when performing the work would be the safety of the public to the construction procedure. This concern for safety is focused in two areas. The first area is the safety of the public in regard to the onshore equipment required to complete the work. The pipes and pumping equipment impose some degree of hazard as well as spreading equipment normally employed to help contour the beaches. The other area of concern is similar and deals with loading, off-loading and trucking equipment required to move large quantities of sand if a truck-haul method of distribution was selected as the primary alternative. It appears that the problems associated with truckhaul impose the most significant threat to public safety. However, in both cases, there is substantial experience with similar projects that can verify that these operations can be conducted safely under a variety of conditions and with minimum negative impact on the public.

5.5 Dredging Equipment And Capabilitiesz

Over the past number of years, the drdging industry and the government have made substantial progress in upgrading equipment inventories and improving methods. At this time, there are a number of dredging units being planned or constructed by private industry and the government. The "Comber" and "McFarland", which are government owned medium class trailing suction hopper dredges, have been retired and new equipment is being planned or constructed to replace these units. Upon completion of these new dredges, the Corps expects to have located on the East Coast at least one large hopper dredge (Capacity of approximately 9,000 cy) and two medium class hopper dredges (4-5,000 cy capacity) which could be employed for beach nourishment projects. It is expected that these will be of split hull design and capable of pumping ashore. In addition, the government owns a number of pipeline units that would be applicable for beach nourishment purposes. In addition to the type of equipment listed above, private industry has amassed a substantial inventory of equipment that could be used for dredging in the Hampton Roads Area. A partial list of hopper units includes:

"Atchfalaya" -- Gulf Coast Trailing	1,000 cy
"Long Island" -- Great Lakes D. & Dock	12,000 cy
"Manhattan Island" -- Great Lakes D. & Dock	3,600 cy
"Sugar Island" -- Great Lakes D. & Dock	3,600 cy
"Padre Island" -- Great Lakes D. & Dock	3,600 cy

"Dodge Island" -- Great Lakes D. & Dock	3,600 cy
"Eagle I" -- Eagle Dredging Co.	6,300 cy
"Esperance III" -- Roger Au	4,000 cy

In addition to the hopper dredges listed, a representative list of pipeline dredge plants that are certified for dredging work in ocean waters is as follows:

"American" -- American Dredging Co.	27 inch
"ADCO" -- American Dredging Co.	27 inch
"Alaska" -- Great Lakes Dredge & Dock	27 inch
"Illinois" -- Great Lakes Dredge & Dock	27 inch
"Jim Bean" -- C. F. Bean	27 inch
"Buster Bean" -- C. F. Bean	27 inch
"Diesel" -- Williams, McWilliams	30 inch
"The Fritz Jahneke" -- Williams, McWilliams	27 inch
"Bill James" -- T. L. James	30 inch
"Superdredge" -- Western Pacific	30 inch
"The Papoose" -- Western Pacific	30 inch
"Western Condour" -- Western Contracting Co.	36 inch
"Western Chief" -- Western Contracting	30 inch

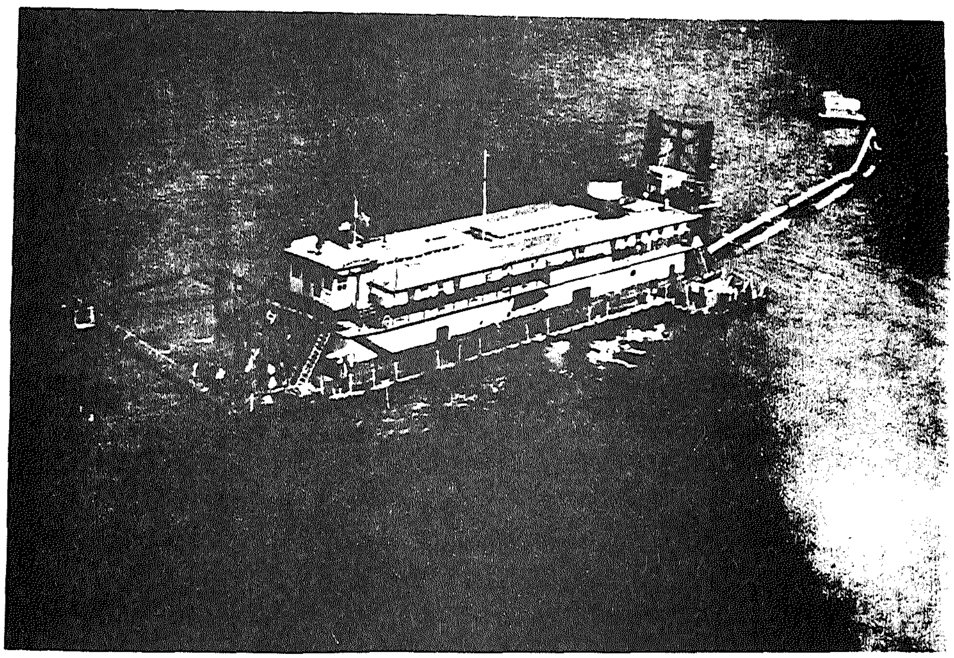
As indicated earlier in this report, the pipeline dredge plants are most effective in calm sea conditions. Judging the overall merits of the pipeline units and considering the alternative dredge sites for beach nourishment, sitesd 2, 3 and 4 are the most applicable sites for the hydraulic plants. Sites 1 and 5 are more susceptible to heavy sea conditions and further away from sheltered areas in the event that severe weather conditions should force the dredge to move out of position. However, the dredging contractors with which contact has been made, would consider submitting proposals to use pipeline equipment at sites 1 and 5. Consequently, this alternative is included in cost estimates presented elsewhere in this report. Unquestionably, the pipeline units would be the best choice and perhaps the only choice at sites 3 and 4. Sizable hopper dredges would be unable to work in the vicinity of 3 and 4 due to minimum draft requirements. Large hopper dredges requiring approximately 25′ of depth would be restricted from coming inside the Thimble Shoals Channel in the Crumps Bank area or closer than approximately 1/2 mile from Cape Henry. Similarly, a large hopper dredge would be restricted from coming closer than the 30′ contour off Virginia Beach which is approximately 2 miles from the beachfront.

The hydraulic dredge equipment will be superior in production to the hopper dredge under conditions where the unit can be located in safe harbor, and pump continuously directly to the beach or through a booster station. Sites 3 and 4 are particularly favorable to the hydraulic dredge. Pumping from site 2 would require at least one booster station to get the material to the Norfolk beach area. Site 1, although close to Cape Henry, may be adversely affected by weather conditions. However, high production rates could be achieved by using a large hydraulic dredge at site 1 and pumping during the summer months of the year. As previously indicated, the use of a hydraulic dredge on lines pumping from site 5 through a booster is marginal at best. Regardless of the site, one of the primary concerns in pumping from a large pipeline unit is maintaining a good connection between the submerged pipeline and the dredge or the booster station. This requires particular care and expertise when dealing with the currents and tides predominant in the Hampton Roads area.

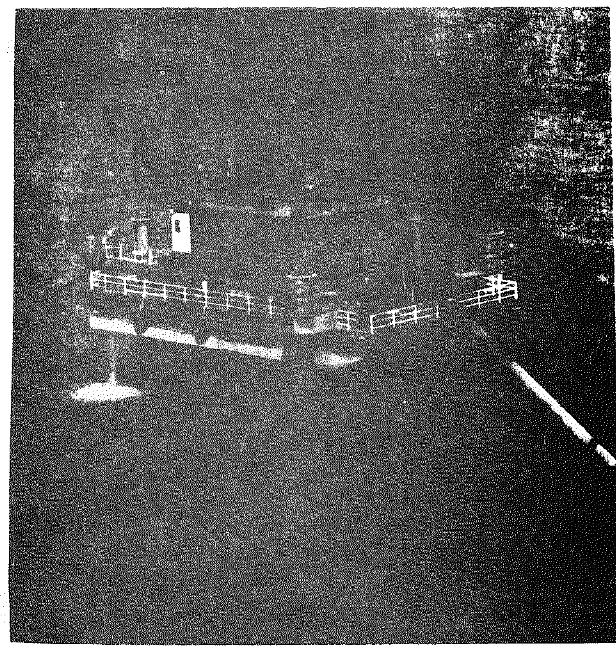
The employment of the hopper dredge presents a number of differences in techniques and procedures from the hydraulic dredge plant. The hopper dredge does not pump continuously but fills from the borrow area, transports the sand in the hull of the vessel and pumps out from a mooring station to the beach. Because of the design of the hopper dredge, the material placed on the beachfront is normally of a better gradation and quality than material pumped from the hydraulic plant. This condition occurs because the dredged material is sorted during pumping operations into the hull of the vessel and the fine fraction is lost during filling and transporting the material. One of the common methods of transferring material from the hopper to the shorefront is to load the hopper, steam to a stationary jackedup barge close to the beach and pump through the jack up rig to the beach. Under sea conditions, this method poses serious drawbacks. It is very difficult to stabilize the moving hopper against the stationary jack up rig, maintain pipeline integrity and effectively discharge the dredged material to land. A more favored method by contractors who are routinely involved in ocean dredging is to secure the floating hopper to a mooring point thus allowing the vessel to swing naturally with wind and sea conditions and use a pipe connection system similar to one used by the oil industry to transmit the material to shore. This flexible system requires less time for hook-up and is much less sensitive to sea conditions. Therefore, production is substantially increased and damage reduced.

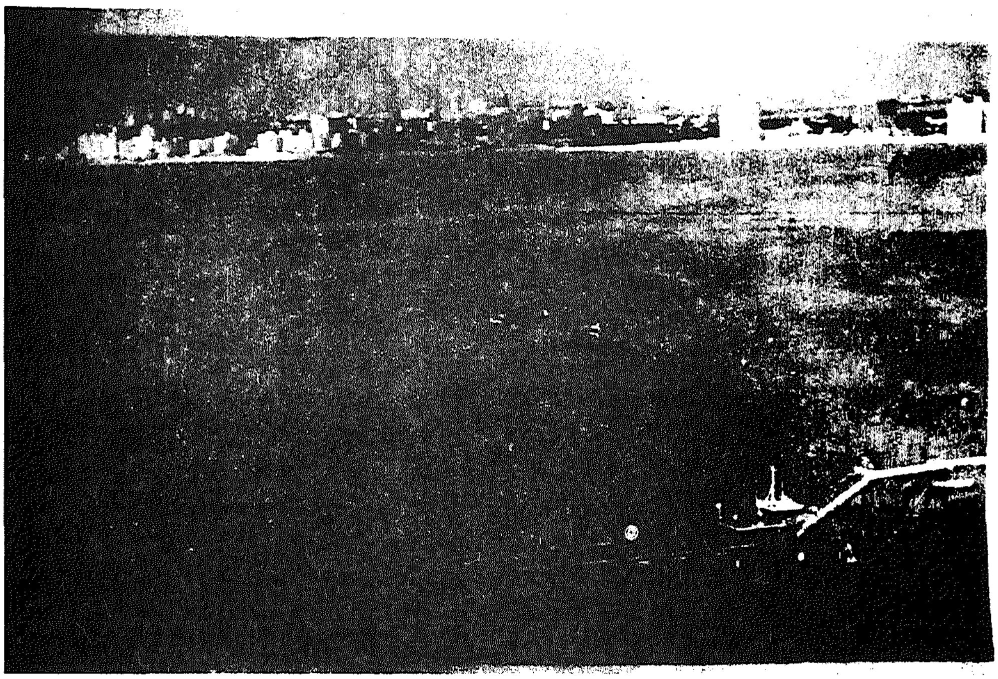
In either case, the importance of the shore crew cannot be overemphasized. With the use of the hydraulic dredge, the shore crew must allow the wasting of fine material into the surf through the effective use of training dikes and ponds, yet control the loss of good material with stabilizing and spreading equipment. Although the material discharged from the hopper is a better quality, the shore crew with the use of the pipeline spreader and with support equipment must keep losses at a minimum and reduce the amount of shore grading required to meet specifications.

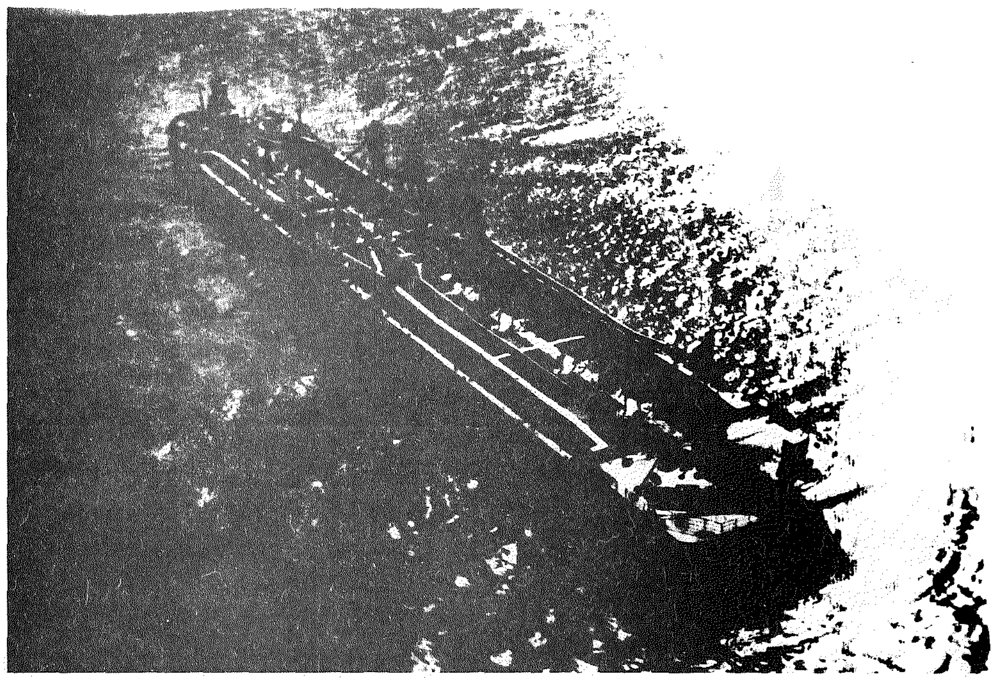
In the event that an alternative is selected that involves pumping to storage areas on the beachfront and then rehandling the sand by trucks, a different set of conditions are imposed. In addition to traffic and safety conditions previously discussed, the truck haul method will involve some lossduring transit and distribution. Losses are not as significant with the direct discharge method. It is difficult to achieve optimum distribution and compaction conditions by transporting the relatively loose material by truck to the beachfront dumping the material and mechanically spreading the sand. Common estimates



DRAKE ENGINEERING CO.







from dredgers and haulers for losses range from between 20 to 30%. This is relatively high when it is considered that loss due to dredge pipe placement from a hopper unit would not exceed 20%. Theloss ratios are a subject of much debate and are generally a matter of opinion by each dredging contractor. The factors involved are understandably complex and involve plant efficiency, wind and sea conditions and the character of the dredged material.

5.6 Alternatives For Beach Nourishment

The borrow sites selected for beach nourishment are those sites indicated by VIMS as having particularly suitable sand deposits. Those have been shown as sites 1 through 4 on Figure 1. Site 5 is at a location identified by the Corps of Engineers as having satisfactory quality sand for beach nourishment. Figure 1 also shows that there is an adequate amount of material available at each site to satisfy all or a large portion of the demand. The ultimate choice for the borrow site or sites may be heavily influenced by other proposed dredging activities. Previously mentioned projects involving the deepening of the Norfolk Harbor and approach channels may result in such a favorable cost sharing condition that the localities would be unable to turn down the opportunity to secure sand at a reduced cost. For instance, it is clear that if a substantial deepening of the Thimble Shoals Channel was approved and undertaken, several million yards of sand would be excavated for disposition. If this situation arose, the immediate use of the other sites would become academic. However, no definite plans have been made and for the purposes of this report, all 5 sites are considered as candidates and examined, and rated accordingly. There are basically only two equipment alternatives: The hopper dredge and the pipeline dredge. Other possibilities are simply not capable of competing with these two methods from a cost and schedule standpoint. As previously mentioned, each of these particular units has its own operational characteristics and site specific advantages and disadvantages.

Once the sand is dredged, there are essentially two alternatives for transporting and placing the material. The sand can be pumped into place or truck hauled and spread into place. The pumping alternative includes direct pump from the dredge unit or transmission by way of booster stations. The truck haul alternative would require that the material be pumped to a beach storage and staging area, rehandled by loaders and trucked to the beachfront. At the beachfront, the sand would be dumped and spread by mechanical equipment.

For estimating purposes, and for purposes of refining the alternatives, the equipment selection has been narrowed to specific sizes and units. In deciding on a representative hopper dredge for the purposes of calculations, a number of factors were considered. It is felt that because of potential sea conditions, the size of the project and the time frame for completing the work, the largest and most stable of dredges available would be an advantage.

Preliminary costs show that the hopper/barge is more cost effective than the more conventional hopper dredges. Depending on the site, the hopper/barge savings ranged from 5% to 15% over conventional hopper units. Therefore, the hopper/barge "Long Island" owned by Great Lakes Dredging & Dock Company was used as the basis for costing in the matrix. This unit's large capacity (12,000 cubic yards), stability and sea conditions and past performance in the Hampton Roads area give it definite operational advantages. An examination of the efficiency and costs of the "Long Island" appears to make the use of this particular piece of equipment favorable.

Unfortunately, "Long Island" is a one-of-a-kind dredge and therefore, its availability and ultimate cost will be questionable until final plans for beach nourishment work can be formulated and the dredge projects distributed for competitive bids.

Because of the predominance of 27 inch pipeline dredges, it was decided to use this size unit for typical costing. Although this unit may be somewhat lightweight for the task of moving large quantities of material from site 5 to Virginia Beach, it is very applicable for use at the other sites. Therefore, for the purposes of developing average costs, the 27 inch plan was considered most appropriate.

For alternatives involving truck hauling, calculations were based on road trucks hauling 10 cubic yards of material. For the off-road option, such as a haul from a stockpile area at Ft. Story around to the beachfront of the commerical district of Virginia Beach, a 30 cy unit is anticipated. It should be pointed out that there is no guarantee that the Ft. Story site would be available for sand storage.

The presentation of the alternatives is best shown on the alternatives matrix which is designated as chart 2. Comments regarding this information are as follows:

- VB-1, VB-1a, VB-1b, VB-2, VB-2a, VB-2b--These alternatives use the concept of pumping either by hydraulic or hopper dredge from site 1 to a storage area at Ft. Story and distributing the sand by booster pumps or truck haul. Because of the variation in consolidation of material during the dredging operation, the hydraulic dredge alternative shows a total of 3,375,000 cy to be dredged which reflects a maximum of 30% loss and the hopper, a total of 3,000,000 cy which reflects a 20% loss to obtain a net of 2,500,000 cy on the beachfront. No additional loss was factored for truck haul. It should be understood that the storage capacity at Ft. Story based on past experience and the overall geography allows for only a maximum of 750,000 cy of storage. This would mean that if the truck haul alternatives were employed, stockpiling could only proceed at a reduced rate since it would be impractical to haul the sand away by truck as fast as it could be stockpiled by the dredge. This condition is reflected in the column designated as efficiency on the matrix chart.

- VB-3--This alternative is an all-pumping option from site 5, offshore Virginia Beach through booster stations to direct beach application. This alternative would require the use of one of the largest and most powerful pipeline plants that is available in the United States.
- VB-4--This option considers using the hopper/barge "Long Island" to excavate material, run into a mooring point and pump to the beachfront. Since the 30′ contour varies substantially from North/South between Cape Henry and Rudee Inlet, a booster station may be required to implement this alternative.
- VB-5--A variation on the hopper alternative would be to hopper from Site 1 around Cape Henry to a mooring point and discharge directly onto the beach.
- N-1--The alternative of pumping out of Site 2 directly to the Norfolk beach area involves crossing shipping lanes with an extended submerged pipe and installing the necessary booster stations. The characteristics and quantity of the sand at Site 2 is particularly good for beach nourishment purposes.
- N-2--This alternative would require that the hopper run from borrow Site 2 to a position just South of the outbound line of Thimble Shoals Channel, moor and pump from that position to the bveach. The controlling factor

in this case is the relatively shallow water depth of Crumps Bank which prevents the dredge from mooring at a closer point to shore.

- N-3--The only method available for excavation from Site 3 is the use of the hydraulic pipeline dredge. The area is tooshallow for employment of a large hopper dredge and therefore, it would be anticipated that the pipeline plant with boosters would supply sand to the Norfolk beaches.

- H-1--Pumping onto the Hampton beaches is similar to the N-3 alternative at Norfolk. It is strictly a hydraulic pipeline project and particularly so in this case since the estimated quantity to be moved is only 250,000 cy.

5.7 <u>Cost Estimates</u>

The method of developing the cost estimates for each of the alternatives listed was influenced by a number of conditions and factors. The basic approach was to use cost data derived from previously completed or current projects in the area.

However, it should be recognized that there have been no projects or are there any currently underway that duplicate the conditions and reflect the magnitude of effort anticipated by these projects. This historical cost information was modified using past trends, information gained from interviews with dredgers and cost information from the Corps of Engineers. After these values were determined, three distinct estimates were made for each alternative using cost data that would result in a high low and medium estimate for each of the alternatives. The end result was an estimate using an average of the three basic estimates. There were no engineering, construction management administration or contingency costs included in the estimates.

In developing these estimates, which must be considered as preliminary at best, various factors and assumptions were integrated into the final costs shown. A number of these factors are as follows:

- Defined detailed plans and specifications for the projects are unavailable and therefore, the lack of information on actual quantities, survey information, loss factors, the suitability of material and probable schedule for the work affected the estimates.

- The effects of weather on the ultimate cost of the work can only be assumed and the degree to which weather conditions in the area may affect biding by the contractors is unknown. The final costs of dredging projects in other areas for similar quantities was considered.

- Actual routes and conditions involved in the potential road and beach hauling of sand was not evaluated in detail; however, past experience by the City of Virginia Beach with this practice would be helpful in the event detailed analysis is required.

- Cost factors that relate to the projected activities of prospective contractors are most difficult to assess. These factors relate to the overall business climate during the time in which the project is actually bid, projected workload of the dredgers, the availability of particular equipment and the method of contracting all have a substantial bearing on the final cost of the project.

- The size of the project and the relationship of beach nourishment work to channel deepening work will affect the cost.

- The proximity of the equipment that would be selected for completion of the work to the location of project substantially affects mobilization costs.

The impact of a number of these factors can be reduced once the projects become more defined. Efforts by the Corps of Engineers to complete their study work will clear up a number of potential scheduling questions and support some of the overall conclusions of this report.