PROCEEDINGS OF

UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

(SELECTED PAPERS ON SPECIAL PROBLEMS IN OCEAN ENGINEERING)

COLUMBIA UNIVERSITY

Volume VIII: 1974 - 1975

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COLUMBIA UNIVERSITY

in cooperation with

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INTRODUCTION

In 1970, as a joint effort of the Columbia University School of Engineering - Ocean Engineering Division, the Henry Krumb School of Mines, and the University Seminar on Pollution and Water Resources an additional Seminar was established: Special Problems in Ocean Engineering. This Seminar is devoted to environmental problems of coastal and off-shore areas in such fields as coastal geology, estuarine biology, hydrology, submarine ecology, and thermal pollution.

A collection of selected lectures and papers was to be published in the "Proceedings" of the University Seminar on Pollution and Water Resources. In 1972, it was decided that articles on Ocean Engineering should be made public in separate volumes. Sixteen articles were selected to be published in two volumes.

The Steering Committee of the Seminars gratefully acknowledges the generous participation of the U. S. Bureau of Land Management, Rutgers University Marine Sciences Center, and the Department of Environmental Protection of the State of New Jersey in financing and publishing the seventh and eighth volumes of the "Proceedings." Special thanks are due to the members of the Seminars who participated in preparing and coediting the publication. Only their unselfish dedication made possible the appearance of these volumes. Our appreciation also goes to David J. Bardin, Commissioner of New Jersey Department of Environmental Protection, and Norbert P. Psuty, Director of the Marine Sciences Center of Rutgers University, for their active support and cooperation.

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UNDERSTANDING THE IMPACT OF OUTER CONTINENTAL SHELF DEVELOPMENT; APPROACHES TO DESIGN OF ENVIRONMENTAL STUDIES

by

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Introduction

Offshore development of oil and gas resources in the United States historically has been focused on the Gulf of Mexico, with other relatively small areas developed off Southern California and Alaska. The recent emergence of the "energy crisis" and the search for energy self-sufficiency have resulted in plans for greatly accelerated development of Outer Continental Shelf (OCS) oil and gas reserves, and a multiple increase in the present rate of leasing is anticipated. Much of the new leasing will take place in previously under-developed "frontier areas" extending from the Beaufort Sea in Alaska to the South Atlantic coast. This widescale search for petroleum resources off United States shores is being paralleled world-wide, as for example in recent development of the North Sea.

Along with the thrust towards accelerated development has come a concern about the potential environmental impact of marine and coastal resources, and a recognition of the need to identify and minimize environmental risks. A preliminary assessment of the risks associated with the development in the Atlantic and the Gulf of Alaska was completed by the Council on Environmental Quality in April, 1974.[1/] This report demonstrated that there were many unknowns concerning the environmental consequences of offshore development in these frontier areas, and recommended that, "Carefully designed baseline environmental studies should be initiated immediately in potential leasing areas and should be an essential and continuing part of the OCS management."

The Federal Government, under the sponsorship of the Bureau of Land Management (BLM), the agency responsible for leasing OCS resources, has initiated a program of baseline studies of the frontier lease areas. As of April, 1975, such studies were under way or in advance planning for the Northeast Gulf of Mexico; South Texas; mid-Atlantic; North Atlantic, Southern California; and the Bering and Beaufort Seas and the Gulf of Alaska. Studies of other frontier areas are also planned for the future.

These BLM funded studies are being implemented by various research organizations and Federal agencies with marine environmental research capability. In terms of magnitude of effort involved, these studies collectively will probably represent the greatest single thrust in U.S. marine environmental research over the near future, far surpassing such efforts as the National Science Foundation International Decade of Ocean Exploration's Environmental Quality Program, or the National Oceanic and Atmospheric Administration (NOAA) Marine Ecosystems Analysis Program. Management of this program is described by a BLM scientist in another paper in this Seminar Series.

The Department of the Interior has established an Outer Continental Shelf Research Management Advisory Board to provide scientific advice on design of the study program. Members of the Board represent the coastal States and the principal Federal Agencies involved: NOAA, the U.S. Geological Survey, the U.S. Fish and Wildlife Service, and the Environmental Protection

1/ "OCS Oil and Gas - An Environmental Assessment," A Report to the President by the Council on Environmental Quality, April, 1974.

Agency. Marine environmental investigations, such as those being launched in the OCS frontier areas, are complex, expensive and must address difficult scientific issues. Therefore, as the BLM study program has evolved, there has been continuing debate and discussion concerning the scope and nature of investigations that should be undertaken to address these problems. In connection with these discussions, one of the major Federal participants in the effort, NOAA, has prepared as a working document a report on the design of marine environmental studies.1/

My paper does not discuss the specifics of the ongoing study program, but rather describes broad concepts involved in designing environmental studies of areas subject to Outer Continental Shelf development. It draws heavily and directly from the previously referenced NOAA report, but reflects a number of modifications from the concepts therein. In presenting these views, I would emphasize that the "best approach to design of such studies will undoubtedly remain a matter of continuing debate and evolution. With little modification, the same concepts should apply to studies of other emerging ocean development problems, such as ocean mining, ocean waste disposal and construction of superports and offshore islands.

Scope and Objectives

It is axiomatic that a clear identification of objectives is essential to sound study design. Environmental studies of OCS development areas have the following objectives:

1. To predict the impacts of development. The studies should develop information which will assist in predicting the impacts of OCS development in order to assist in avoiding or minimizing damage in the development program. These studies should provide information which will aid in decisions on whether or not to lease areas for development. Within areas designated for development, they should assist in designating tracts which should not be leased because of environmental sensitivity or vulnerability. They should also provide information which can be used in establishing operating stipulations in leases covering such matters as waste disposal, blow-out controls and contingency provisions to deal with oil spills.

2. To detect damage actually resulting from development. At first glance, it might seem that detection of environmental damage might not require studies prior to development. The impacts of such widely publicized incidents as the Torrey Canyon and Santa Barbara spills seem all too obvious. But even in those cases of sudden and massive discharge, determination of the full extent and duration of damage and recovery has been no simple task. Further, it is anticipated the most important impacts of OCS development may not result from "catastrophic events." The effects may be subtle ones, difficult to detect and assess ini-

1/ "Report of NOAA Scientific and Technical Committee on Marine Environmental Assessment," National Oceanic and Atmospheric Administration, November, 1974.

tially, but potentially very significant over the long run. This highlights the need for OCS environmental studies to provide the basis for an "early-warning" system.

The Council on Environmental Quality report pointed out, as have other analyses of the problem, that the major impacts of OCS development can be expected to result from the onshore development which will accompany marine operations. This onshore development includes such effects as location of secondary industries such as refineries and petrochemical plants, and major changes in population composition and structure in the coastal zone. It can result in major secondary environmental impacts, such as those stemming from increased air and water pollution loadings and from changes in land use. However, the environmental studies needed to address that aspect of OCS development are not the subject of this discussion. My discussion centers around those studies needed to identify and monitor the primary impacts of OCS development - those associated directly with exploration, development and transportation to shore of offshore oil and gas resources.

The environmental studies should be directed towards two classes of issues: information needed to determine the effects of natural environmental conditions on OCS oil and gas development (hazards), and information needed to determine the effects of oil and gas development on the environment (effects).

1. Hazards. Determination of environmental hazards is necessary in order to predict and make provision for those stresses which could increase the likelihood of accidents during OCS development. Examples are as follows:

   a. Sediment Bearing Strength: May not be sufficient to support structures.

   b. Sediment Deposition and Scouring: Transport processes may be energetic enough to pose a threat to structure stability.

   c. Earthquakes: Faulting, bottom displacement and tsunamis may be a considerable threat to offshore structures and pipelines.

   d. Storms: Winds, waves and currents pose a considerable hazard for all operations in the OCS.

   e. Ice: Sea ice and superstructure icing will be a problem in the more northern areas under consideration.

   f. Circulation: Rates of Transport, flushing and mixing may be either too high or too low in some areas to achieve desired effects with regard to control of environmental impacts.

2. Effects. Examples of primary effects of OCS development are as follows:

   a. Release of Hydrocarbons: Consideration must be given to both the large accidental spills and low-level chronic releases. Oil affects living organisms, is incorporated into sediments, and can be washed ashore. The effects may be due to the toxicity of the oil or its other physical-chemical properties.

b. Release of Chemicals and Particulates: Toxic chemicals and metals can affect living organisms directly and can be included in sediments with harmful effects when released at a later time, such as dredging. Drilling muds can increase turbidity and impact benthic organisms and sediment distribution.

c. Dredging and Spoils Disposal: These can have great impacts upon benthic organisms by increacing turbidity and covering productive bottom. Harmful materials in the dredged sediments, either natural accumulations or man-made pollutants, can also be released and spread by dredging.

d. Pipeline Routing: This has the potential for substantial nearshore impact, due to the associated dredging and spoils disposal, changes to bottom topography and the shoreline itself. There is also the risk of nearshore oil spills due to pipeline leaks or breaks.

e. Environmental Enhancement: Offshore structures are known to attract local fish populations by providing shelter and additional substrate for attached organisms.

Determination of each of the above elements may involve an open-ended and potentially bewildering array of scientific studies. Therefore, a major task in study design must be establishment of priorities and areas of emphasis, in relation both to study objectives and to time, financial and scientific resources available for conduct of the study.

Clear identification of the important questions to be addressed is a useful starting point. The following are the types of issues that should be addressed:

1. What is the probable occurrence of earthquakes, storms, ice and other environmental hazards which could result in the accidental discharge of oil or other contaminants to the environment? This information will assist in selection of tracts to be leased, in location of pipeline corridors and in establishment of stipulations and safety requirements.

2. What are the physical transport mechanisms which will govern distribution of contaminants? This information will allow prediction of the trajectory of oil spills and other contaminants, relation of these to the location of environmentally sensitive areas, understanding of the distribution pattern of certain organisms such as plankton, and location of control stations for monitoring.

3. What are the background levels of oil and selected heavy metals in the environment, and the sources and sinks of these materials? This information will provide the basis for monitoring increases in contaminants in various components of the ecosystem, to serve as an "early-warning" system.

4. What is the ultimate fate of oil discharged to the environment? This is an important question, because decomposition of oil is a critical issue in determining environmental impact.

5. What is the natural abundance and distribution of important biota in the study area? This information will enable us to identify environmentally sensitive areas, and to assess the nature of the ecological resources subject to potential risk from oil and gas development. It may also provide a general baseline against which major changes subsequent to oil and gas development can be detected.

6. What are the toxic or other systemic effects of oil and trace metals on important organisms in the study area. Information is required on the following kinds of issues:

   a. Acute mortality to selected marine organisms.

   b. Long-term sublethal effects, such as reduced fecundity or survival, on selected marine organisms.

   c. Other effects, such as interference of oil with olfactory responses in anadromous fish and marine mammals.

7. What are the critical ecological processes in the study area? Public concern about environmental impacts may focus primarily on organisms of commercial values (e.g., commercial fishes) or of high aesthetic or recreational importance (e.g., marine birds), but it is clear that the effects of development may be manifest through the entire ecosyatem. Therefore, it is necessary to delineate to the extent feasible such major processes as food chain relationships.

8. What physical interference with commercial fishing will result from oil and gas development? This will enable us to estimate whether development will result in substantial interference through impeding trawling or fouling nets. This should be determined by describing the extent and nature of fishing operations in the area, and by correlating the findings with results observed in already developed oil and gas areas.

9. What are the effects of dredging and other related construction activities on coastal marshes, estuaries and other environmentally sensitive areas? This is a key aspect of potential environmental impact.

Basic Concepts in Study Design

"Baseline study" is a term which has been widely used to describe investigations required in connection with the current OCS study program. In a strict sense, baseline studies can be defined as studies to describe existing conditions at a point in time, against which later changes can be assessed. However, in actuality a broader range of investigations is needed to address the study objectives outlined above, and use of the term "baseline" has caused and continues to cause confusion.

For purposes of this discussion, the needed investigations will be classified as: 1) Environmental characterization; 2) Baseline and monitoring studies; and 3) Experimental studies.

1. Environmental characterization. Unlike baseline studies in which the principal objective is by definition, to provide a basis against which future change can be detected, characterization is needed to provide a meaningful understanding of the environment which may aid in predicting and understanding future alteration.

   The characterization phase should address both the structure and processes of the system. For example, in the case of sediment studies, the types and surface distribution of sediment on the study area should be determined (structure). In addition, sediment transport mechanisms must be understood (process). In the case of any systems component, different study approaches will be required for determination of structure and process. The former will emphasize static sampling, while the latter will tend to stress dynamics, measurements of rates, development of models, and the like.

   The environmental characterization should identify and describe the important resources and processes comprising the system and provide an understanding of their functional relationships. The concept of formalized environmental characterization involves the following study elements:

   a. The "universe" of resources and dynamic processes (ecosystem) is addressed, rather than a more limited number of selected parameters.

   b. It should draw upon existing information, subject to supplementation with field work as necessary.

   c. It should be quasi-quantitative. That is, population estimates may be approximate and may not be adequate as true "baseline values," because natural variability may be undefined.

   d. All key components should be addressed at approximately the same degree of complexity, to the extent possible. In other words, the emphasis should be on a comprehensive characterization.

   Such a characterization would provide information which can be incorporated into the early planning phase of OCS development. It should be useful in identifying optimum parameters or processes to be included in the baseline/monitoring study phases and in providing an overall context within which such sampling can be evaluated. It should identify areas of significant data deficiency essential to the full understanding of the ecosystem.

2. Baseline and Monitoring Studies. In the strict sense, design of baseline studies must involve selection of those parameters which can best serve as a basis for *post hoc* detection of change. An inherent problem in establishing baselines is statistical definition of natural spatial and temporal variation, against which deviations from the norm can be determined. It must be recognized from the outset that in dealing with marine environment, we are dealing with a very "noisy" background against which signals of environmental change stemming from man-induced impacts may be difficult, if not impossible to detect. The environmental baseline concept probably involves more likelihood of collecting

meaningless or uninterpretable data than any other aspect of the investigations.

In clarifying the distinction between "characterization" and "baseline" it should be pointed out that many of the parameters which should be evaluated in the former case are ones (e.g., severe events) which are not expected to change as a result of human intervention. Therefore, they would not be studied for strict "baseline" purposes, but might be of key importance in characterizing an OCS area.

For these reasons an understanding of baseline concepts should be sharply delineated and rigorously adhered to in study design. It should be distinguished from the scope and purposes of the environmental characterization studies outlined above. For example, in the biology aspects of the program, the characterization phase must identify the important organisms at risk from oil and gas development, such as fish, shellfish, birds and mammals. Importance of the organisms to man is a key determinant in including them in the study program.

In selecting study organisms for the baseline and monitoring phase, other considerations may be involved; such as likelihood of exposure to oil spills (e.g., intertidal organisms) and sensitivity to environmental pollutants (e.g., eggs and larvae). Existing time series data, to which new baseline sampling efforts can be keyed in, may be another important determinant in selecting parameters for baseline efforts. For example, in the North Atlantic area, over 50 years of data on groundfish populations may make it feasible to establish statistically meaningful baselines for that group. Tractability, involving issues of costs, logistics, state-of-the-art sampling methods and natural variability, must also be considered.

From a practical standpoint, it may be impossible to establish baselines that can detect anything other than major or catastrophic changes. Particularly in the case of some biological indicators, variability may be so great that a meaningful baseline cannot be established within available time and resource constraints.

To some extent these inherent limitations in baseline sampling can be offset through:

a. Establishment of representative control areas, against which changes within areas subject to impact can be correlated. In this way difficulty of separating out temporal variability can be minimized.

b. Use of parameters which can assist in separating out the effects of natural temporal variability, e.g., man-induced contaminants, such as levels of petroleum hydrocarbons in organisms.

c. Careful statistical design of sampling programs to delimit spatial and seasonal variation. For this purpose, the characterization phase and planning efforts for the baseline phase should include analyses directed towards defining natural variability, in order to provide a basis for statistical design. This will require the use of historical data and a determination of the extent to which additional field sampling can refine existing understandings or is necessary to fill gaps in the available information. In particular, the extent to which additional sampling will contribute to statistically adequate baselines in both physical and biological phases of the study program must be carefully assessed in program design.

Monitoring is a logical extension of the baseline study phase. In general, monitoring has been defined as sampling to detect changes in the baseline. Put another way, the baseline has been considered to be those conditions existing prior to development of an area, and monitoring to be a program of measurements after the onset of development. However, the line between development of baselines and subsequent monitoring often cannot be defined clearly. In actual practice, continued monitoring can result in improved statistical validity of the baseline. In some instances monitoring programs can proceed to develop time series data which can reveal trends without an initial baseline description of the area in question.

3. Relationship between environmental characterization and baselines. My paper has tended to stress the distinction between characterization and baseline/monitoring studies for several reasons:

   a. First, if properly conceived, they should serve different purposes. For example, characterization should provide a basis for predicting and avoiding certain environmental impacts, whereas the baseline should provide a basis for <u>post hoc</u> detection of change.

   b. Second, reflecting these different purposes, different parameters, concepts and sampling strategies may be appropriate.

   c. Third, is my own conviction that many so-called baseline measurements will prove to be of limited value, if not meaningless, whereas efforts at structured characterization of OCS areas could have major utility.

Having stressed these distinctions, I would now make the point that there is no clear dividing point between characterization and baseline studies. Although the two classes of study are quite different at the extremities, in reality they represent a continuum, with broad areas of overlap.

For example, quasi-quantitative descriptions of marine bird populations will be required for the purpose of characterizing important resources of an OCS area. These descriptions would not support detection of low-level population shifts as a result of environmental impact, but might serve to reveal major or catastrophic impacts. In that sense, then, the measurements can be said to be a baseline.

Further, various parameters may pass from the "characterization: to the "baseline" phase, as the study period progresses and as the extent of natural variation becomes defined.

A failure to recognize these distinctions, however, can result in sampling programs which are neither comprehensive enough to provide a meaningful characterization nor statistically valid enough for baseline purposes.

4. Experimental studies. Given the many gaps in our understanding of marine and coastal processes, and the possibly limited value of baseline measurements in detecting low-level damage, actual experimentation may play a key role in improving predictive capability. A key example relates to the impacts of various marine pollutants. Possible trajectories of pollutants, organisms subject to exposure, and probability of exposure under various assumed conditions can all be estimated as a result of well designed characterization studies. However, in the final analysis, prediction of actual impact may depend upon conduct of toxicity experiments. Such experiments present as many difficulties as do the other study phases. Acute bioassays, of the type conducted in laboratory experiments, may be of limited usefulness in revealing serious chronic effects. Longer-term experiments in controlled environments, such as the International Decade of Ocean Exploration sponsored Controlled Environmental Pollution Experiment (CEPEX) may provide better insights. Experiments involving oil spills in representative areas, under carefully controlled field conditions could also be designed.

   In the final analysis, a careful combination of environmental characterization, addressing both structure and processes of the system, and experimentation may be necessary to improve our capability to predict the environmental impact of OCS development.

Zones of Study

Although development of the OCS frontier areas will take place at distances ranging from three to perhaps one hundred miles offshore, the impacts may be felt well outside the area of actual development. Many observers have suggested that, even considering only primary effects, the greatest impact will be felt not offshore, but in the coastal zone. Therefore, within any given OCS region, the following zones of study should be considered in determining the primary effects of development:

1. Continental Shelf.
2. Littoral (intertidal).
3. Estuarine.
4. In-shore (coastal wetlands, beaches, etc.).

Determination of the nature of sampling and degree of emphasis to be given to each zone should be arrived at by the process of outlining issues as described above.

Study Elements

A wide range of disciplines is involved in OCS environmental studies. It is not my intention to discuss these elements in detail; this is done in the previously referenced NOAA report. The following discussion will only briefly describe those elements. This summary of program elements is presented by discipline. However, in actual practice major efforts at both conceptual and logistic integration will be required, if the individual studies are ultimately to fit within a problem solving matrix.

1. Geology, geophysics and bathymetry. This includes the following study elements:

   a. Sediment Type. Knowledge is required about the types and surface distribution of sediments in the study area, and about the material suspended in the water column. Such information is very desirable in supporting benthic surveys and in assessing the risks associated with the siting of offshore structures, dredging, slope and sediment stability, sediment transport rates including both suspended matter and bed load, chemical and particulate waste assimilation, and sediment pollutant levels.

   In areas where the bottom environment is very dynamic, sediment transport studies may be essential in defining the risk to structures posed by certain conditions of scour, fill, seabed movement or other instability.

   b. Sediment Structure. Sediment structure is the most important geologic element in considering environmental hazards to oil and gas development. Tectonically active areas may experience faulting, earthquakes, and tsunamis that can destroy drilling platforms, pipelines and associated shore structures.

   c. Bathymetry. The bathymetric requirements for oil and gas lease site environmental assessment will, in general, be met by a medium-scale area description. This should be adequate to support correlative geological and oceanographic baseline studies, and should provide sufficient detail to enable follow-up monitoring programs to detect significant bathymetric changes. Detectable bathymetric changes may be sudden, associated with faulting or earthquakes, or long-term, as in the case with subsidence associated with oil and gas extraction and general sediment transport.

2. Chemistry. Chemistry studies should focus on the following aspects:

   a. Petroleum Hydrocarbons. A growing body of data indicates that petroleum hydrocarbons are becoming a serious contaminant in parts of the world's oceans. Their presence may be accounted for by such acute events as an accidental spill during the transportation of petroleum or an oil well blow-out. Other important contributors of petroleum to the sea are industrial and municipal effluents, natural seeps, tanker losses at sea and in port, losses associated with normal oil field production, and particles transported by the atmosphere.

   Petroleum fractions interact with the marine biota at many levels. It is important to emphasize that more subtle interactions with the biota may often be the most serious.

   In order that the effects of petroleum hydrocarbons on the marine environment be assessed, the program should investigate the following:

(1) Differentiation of "recent biogenic" and "other" hydrocarbons and their associated concentrations in water, biota, and sediments should be ascertained for the study area.

(2) An inventory of slicks, tar balls and natural seeps should be undertaken to document the present influx of petroleum hydrocarbons to the area in question.

(3) A general assessment should be made of system inputs, sinks and transport pathways, in order to permit a general assessment of the relative importance of sources other than oil and gas development.

(4) Weathering characteristics of characteristic petroleums should be determined.

b. Trace Elements. A second class of contaminants that may be associated with oil and gas development includes trace elements which could have toxic effects in marine ecosystems. Trace elements considered most important for this assessment program include: Hg, Pd, Cd, Zn, Ni, Cu, Cr, and Ba.

To evaluate those trace elements that are being introduced into the marine environment by man's activities requires:

(1) that the natural abundance of certain trace elements in the biota, water and sediments be determined, and

(2) that the inputs to the system and transport pathways within the system be assessed.

Alterations in trace element concentrations in the marine environment due to oil and gas development may be difficult to establish, inasmuch as natural levels are often poorly known and when known, show variations. Trace element inputs into estuarine or coastal waters from industrial effluents, coastal development and operations, as well as from river runoff, have been observed. In some areas, without knowledge of the makeup of these source materials, it may be difficult to distinguish between a natural and an anthropogenic origin for increased concentrations. In some cases budget estimates may be required as a special study. Similarly, while direct input of pollutants from outfalls, dumping and development of the OCS is of primary importance in coastal areas, atmospheric transport carries large quantities of trace materials to the open oceans. In some cases it may prove necessary to do more detailed assessments of the significance of this pathway.

c. Nutrients. Nutrient analysis (NO_3, NO_2, PO_4, Si and NH_4) should be included as a supporting element to this biological program, specifically as they relate to primary productivity measurement.

3. Physical Oceanography and Meterology. Physical oceanography and meteorology studies should consist of the following study elements:

a. Currents and Circulation. An understanding of all modes of water movements in a given OCS area is required for correlative geological, chemical and biological studies. It is important to integrate studies of these phenomena in the planning phase.

There is no region of the continental shelves off the coasts of the U.S. for which there exists more than a gross description of the tides, and knowledge of the direction (but not the speed) of the average flow on a seasonal basis. Currents are essentially low frequency phenomena and long periods of measurement are required to obtain statistically significant results. Off Southeast Florida, four to six months of observations are required to obtain a stable determination of the mean flow. In deep water just off the U.S. Middle Atlantic continental shelf more than a year of measurements are required.

b. Movement and Dispersion of Properties and Contaminants. In principle, the movement and dispersion of all physical and chemical properties of the water in the study area can be considered to be potential study targets for this category. In practice, however, this study should focus on obtaining answers to direct questions regarding probability and effect of oil spills, particularly in critical areas as determined through the biological study elements.

Operational models for the predictions of oil spill effects exist at present, but are of limited value because the hydrodynamics and dispersion characteristics of the flow are put into the models in only the most elementary fashion; the natural patterns over shelf regimes are unknown in any detail for most regions. The questions that the models purport to answer are basic ones for the environmental assessment of lease site areas; however, because of this, efforts should be made to improve the data input to the models, as well as the accuracy with which the models assess the relevant physical processes.

c. Severe Events. A knowledge of the frequency and intensity of severe environmental events is essential to an environmental characterization; the prime hazards to production-related structures and the greatest impact on the environment will, in general, occur in conjunction with severe events. The primary physical oceanography-related severe events will be related to storms and seismic sea waves. Frequency and effect of earthquakes should be investigated as part of the geology, geophysics and bathymetry program. Potentially severe conditions, such as high or low runoff or changes in current regime, depending on location, might be investigated.

4. Biology. The biology program is particularly critical in all marine environmental assessments because the biological impacts of offshore development will probably be of the greatest concern.

Design of an adequate biological program within the general time and resource constraints likely to be operative, however, will present special difficulties because of:

a. Problems of statistical variability.

b. Lack of understanding of many basic causal relationships associated with environmental impact, particularly at the sublethal or chronic levels.

c. The wide range of biological parameters that could be measured.

This means that careful determination of priorities will be required in outlining the biological investigations for any given area.

The biology program should consist of four main assessment elements:

a. Pelagic and demersal fish.

b. Plankton.

c. Benthos.

d. Marine mammals and birds.

For each of the elements, the marine environmental assessment program should include:

a. Analyses from historical records or surveys of the baseline density distribution (and subsequent changes) of major marine communities with initial emphasis on spawning areas and migration routes for key species, together with such analyses as are possible for the causes for major observed variations.

b. Studies on the systemic effects of pollutants on selected species or communities, including identification of those dynamic processes which are likely to be indicators of impact (e.g., community metabolic rates, bioaccumulation, critical life processes such as maturation, fecundity, larval survival, etc.).

c. Determination of pollutant levels in selected species life stages and/or communities (discussed in the chemistry section).

d. Experimental studies. The most important special studies are those associated with toxicity of oil to selected organisms. These should include studies of the effects of oil upon fish palatability, and physiological effects such as interference with olfactory response in anadromous fish or marine mammals. Studies of interference with migration patterns of important resource species may be of particular significance since migration may be dependent in part on environment variables such as water chemistry which could be subtly altered by oil and gas development.

Summary

It is anticipated that major expenditures will be made in the years ahead for marine environmental studies in connection with OCS and other development programs. Although it appears that substantial funding will be available at the Federal level to support such studies, the magnitude of the scientific problems involved may loom even larger. The range of phenomena that bear further investigation, particularly in the eyes of scientific experts on the phenomena concerned, seems almost limitless. Some of the needed understandings can only be provided by long-term ecosystems research. Yet information will be needed over the short run to assist in decisions related to OCS development.

All this emphasizes that study design concepts must be a matter of continuing concern. Selection of study priorities and the design of studies that are relevant and provide meaningful answers to the issues at hand will continue to be a major challenge to the scientists involved.

THERMAL PLUME FIELD MEASUREMENTS IN THREE DIMENSIONS

by

Dr. James R. Roney*

ABSTRACT

The desirability of measuring thermal plumes in three space dimensions is discussed. Examples are presented of the value of information derived from an extensive field program involving complete three dimensional temperature mapping. The technique used in the field for data collection, reduction and presentation is described. Some of the environmental consequences of the three dimensional nature of real thermal plumes discussed in the paper are illustrated by field results of the survey program.

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Introduction

Thermal plumes resulting from heated effluents, tend to spread in three space dimensions through the receiving water body. Although the physical character of thermal plumes has been recorded on the water surface in many instances, few studies have been conducted in detail in three dimensions including appreciable sub-surface information. Recent experience with an unusually extensive program of thermal plume measurements has developed useful information concerning the character of three dimensional plumes and field techniques for making the measurements.

The three dimensional physical nature of thermal plumes is first discussed from the aspect of the plume shape on the water surface as differentiated from sub-surface characteristics. Second, a discussion is given of the problems and techniques of measuring thermal plumes in the field in three space dimensions. Third, a discussion is given of some of the environmental consequences of the three dimensional nature of thermal plumes.

For the most part, the discussion considers thermal plumes from electric generating power plants which are the most significant source of thermal effluents, and that of most active contemporary concern.

Some Aspects of the Physical Characteristics of Thermal Plumes

Thermal plumes resulting from injections of heated water into receiving water bodies have a behavior dependent on the nature of the injection and on conditions in the receiving water body. There are many discussions in the literature concerning the behavior of the mixing processes and the hydrothermal characteristics of thermal plumes. For the most part one observes both horizontal and vertical mixing which tends to occur in a near-field region where the discharge momentum of the effluent is the principal mechanism for inducing mixing. A transition region is sometimes considered. Often the dominant region of interest is the far-field region in which the character of the thermal plume is dependent primarily on the conditions of the receiving water body and on the atmosphere above the air-water interface.

Some of the difficulty in describing the physical characteristics of a thermal plume in three dimensions centers on some means of adequate physical display, a graphic or numerical format in which to visualize or conceptualize the physical characteristics of the plume. The water surface lends itself to conveniently sensing the physical temperature of the thermal plume and tracing out the shape of the plume in terms of isotherms. There has been a history of the development of regulations and criteria for enforcement of effluent standards which tends to use this framework of description by means of isotherm characteristics on the water surface. To appreciate some of the influence this has had, one might borrow a thought from the educational field: that in education, one tends to quantify not necessarily the best measure of educational progress or educational development, but tends to measure that which is measurable. Correspondingly, in the consideration of thermal plumes, one tends to look at the surface temperature distribution (perhaps overly so) since it lends itself most readily to temperature measurement by several instrumentation techniques. The wide usage of infra-red scanning or similar remote sensing techniques to measuring thermal plumes has contributed to this focus of attention.

As will be discussed further in the paper, the characteristics of a thermal plume as a function of depth can be of great importance. In the near-field region, depending on the type of discharge system, the depth of vertical mixing may be considerable. Outside this region, the plume tends to become quite shallow, perhaps only a few feet below the surface in depth with a horizontal spread of perhaps thousands of feet. The relative shallowness of the thermal plume may then be of great interest in evaluating the environmental consequences of the discharge.

In the display and discussions of thermal plumes with numerical values, it is often necessary to consider a temperature in excess of some baseline temperature. The selection of any given reference temperature is arbitrary from a scientific point of view, although from a regulatory or enforcement point of view, the selection may be exactly specified. In New York State, an existing thermal criterion states, in effect, that a plume should not extend more than two thirds across a river surface with the 4°F. isotherm. This isotherm is defined in terms of an excess temperature above a natural condition without man-made effluent introductions. There is no precise or standardized method for determining the numerical value of a natural receiving water body temperature. This base temperature, therefore will be subject to a certain amount of arbitrariness or interpretation. Consequently, the extent of a reach or area within a given isotherm above this base temperature will be subject to the possible variations in defining this base temperature. Quantifying the sensitivity of the numbers derived from this process to a change in temperature of reference can be beneficial in applying a reasonable judgment to whether or not a thermal plume has met a criterion or not. This is further discussed with the results of field experience.

Techniques of Measuring Thermal Plumes in Three Dimensions

The scanning of a thermal plume with a moving system has certain advantages over a fixed system, in certain circumstances. Usually, a fixed system consists of a number of sensors moored in fixed positions in the water distributed vertically and horizontally. These tend to be more appropriate in water bodies such as lakes, where currents are not of a highly transient nature, as one encounters in tidal estuaries. In tidal estuaries where the direction of water movement changes continuously through a tidal cycle, and where in many cases the tidal component of velocity is much greater than the non-tidal component, fixed systems are not usually practical. The number of stations needed to cover the area of the plume in the up-stream, down-stream, and cross-stream directions would be prohibitively high. In this case, some type of moving or scanning system is preferable.

Airborne infra-red scanning has been used with justifiable success but has inherent limitations. Experience in the field with simultaneous comparisons of plume measurements with very accurate in-water sensors and infra-red overflights have shown the I-R is subject to wider variability in readings, as discussed further, later in this paper.

To develop three dimensional information, one must either scan with a moving boat with temperature sensors such as a thermistor string towed from the boat or by making fixed vertical profiles at selected horizontal locations. From the field experience, it was found that both techniques are desirable. The vertical profiling is time consuming and only a limited number of profiles can be run during a given time segment. One of the major problems of scanning a thermal plume in an estuary is that the run must be completed within a sufficiently short time to avoid time dependent alteration of the plume shape and extent by tidal changes. A total tidal cycle being approximately 12 hours, and the time interval between major phases (such as slack and flood) being about 3 hours, it is found necessary to scan a plume within a time less than one hour and preferably no greater than 30 minutes. A properly rigged-out boat can scan approximately 4 line miles during a 30 minute run time. This allows a boat to scan a plume some two or so miles long in a zig-zag pattern so that isotherm patterns can be constructed with good detail.

Figure 1 is a schematic representation of the system used in the field. Three thermistors are deployed vertically at the surface and at two selected depths. The boat scans through the plume and temperatures are read at three vertical positions continuously. Navigational position is determined by electronic means, specifically a Motorola Mini-Ranger. This information is recorded digitally on an Endeco Type 156 data gathering system which includes a casette tape unit. Readings can be recorded as often as two seconds. Immediately after a run, the data casette can be transferred to a shore station and the data transmitted by telephone line to a central computer system. The computing system processes the data to yield X-Y plots of temperature printed horizontally at the navigational position. Automatic isotherm contouring routines have not proven as acceptable and efficient as hand contouring isotherms from the printed out temperature numbers in the proper X-Y position. Since three vertically spaced thermistors are used in the system, three isotherm plots are generated from each scanning run. In addition, for information about the near field region as influenced by the discharge jet, scans were made at six deeper depths.

A small remote portable computer terminal was used at the shore station to assist in data transmittal and screening. It was possible for the field team to examine data shortly after a run. The data from the casette as logged by the Endeco Type 156 unit contained three temperatures and two navigational ranges for each data frame. This was transmitted by telephone line to the central computer where reduction operations were performed. Sample output could be called back by the field team to verify results or to provide guidance in the following runs. Temperature plots consisting of numbers printed at the proper X-Y location on a large graphic plotter were available from the central computer station within twenty-four hours.

For each plume survey, scans were made over at least a complete tidal cycle, with scans during at least the four major phases: flood, high slack, ebb, and low slack. In order to gain greater detail to meet the requirements of the Indian Point study, two boats configured for scanning were used, one concentrating on the near field and the other on the far field. In addition, a third boat was used for vertical profiling along cross-section transects or in the jet discharge region.

This amount of detailed information, along with river hydraulic data, made it possible to examine the behavior of the thermal plume with great detail.

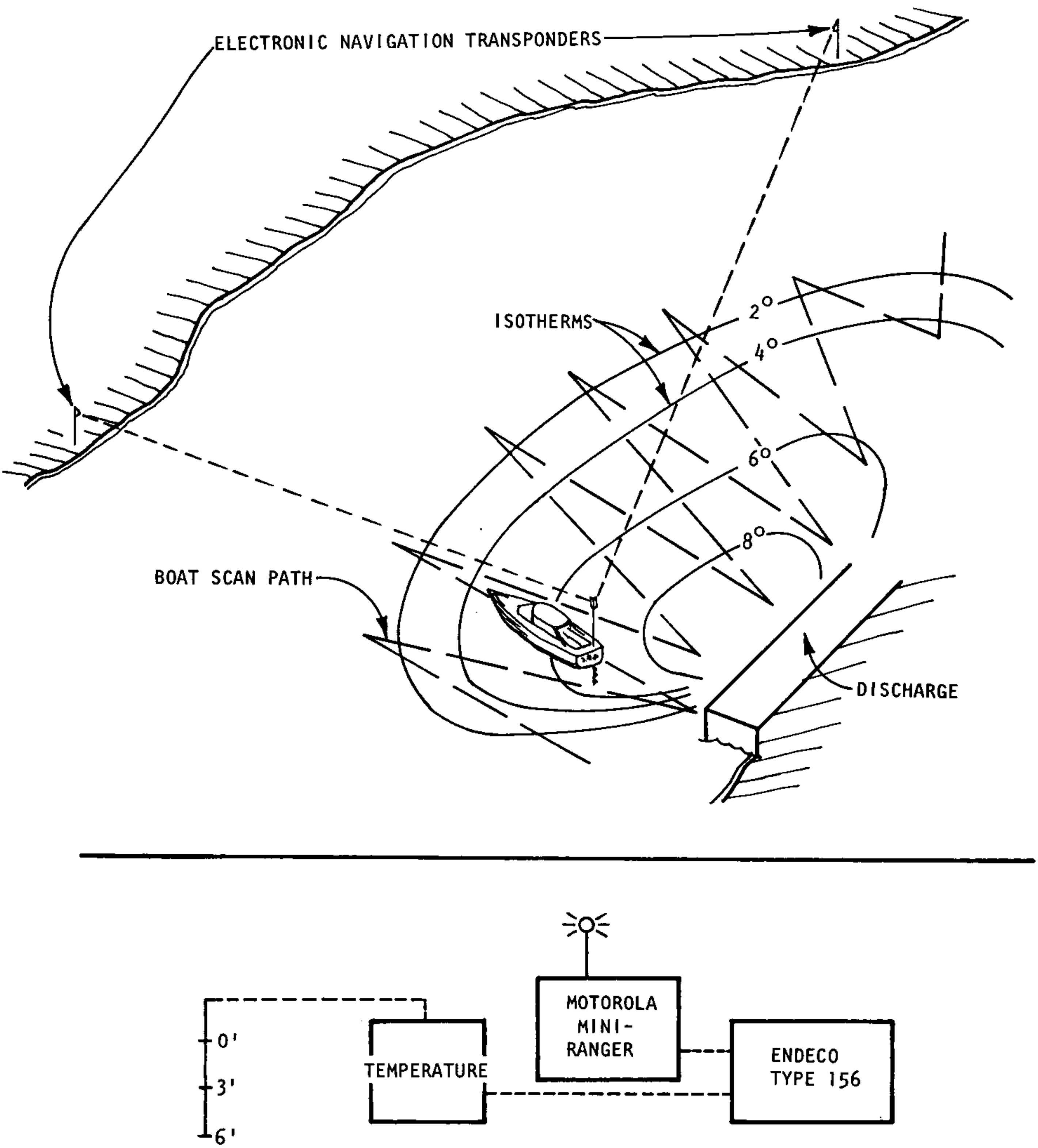

FIGURE: 1

BOAT SCANNING SYSTEM CONCEPT AND INSTRUMENTATION

Discussion of Field Results

The major field program using the plume measurement techniques described mainly consisted of a seven month program at Indian Point on the Hudson River near Peekskill for Consolidated Edison Co. Indian Point Units One and Two were operating during this period. During the period from May to November, 1974, the thermal plumes were mapped at least once each month. During August and October, more intensive measurements were made over a two week period during each month. Over twenty complete mappings of the thermal plume were conducted and several hundred isotherm plots developed. In addition, extensive measurements of river currents, tides, salinity and dissolved oxygen were carried out.

The results presented are either selected for special interest, or are results averaged over numerous observations of a similar nature. They show trends of a recurrent pattern observed over the seven month period. The power plants were producing approximately 1000 megawatts electrical and discharging heated water at about 2000 $ft.^3/sec.$ during the program.

Figure 2 is a typical isotherm reconstruction illustrating the three dimensional character of the discharge in the near field. The temperature of the discharge was about 84°F. and the isotherms are plotted for 74°F. which was 4° above a reasonable baseline temperature well upstream beyond the reach of the plume. The solid lines are the 74° contours at the water depths labeled. Two other surface isotherms are included to indicate the spread into the far field. The plume was tending downstream during an ebb tidal phase. The dotted line isotherms are plotted for a later stage in the tide, low slack turning to flood. Figure 2B is included to show the detail of the isotherms at two of the levels measured.

It is seen that the near field tends to retain its basic shape and extent, tending in stream directions as influenced by the tide. However, the far field patterns were not nearly as consistent. There tended to be two classes of behavior. The first was of a shallow widely spread surface far field plume, and the second was of a more restricted surface area, but with noticeable vertical mixing. The first case tended to exist during ebb tidal phases, and the second case would predominate during flood phases. During an ebb, the surface area within a selected isotherm was typically two or more times that during a flood phase. Figure 3 is a plot of a typical ebb tidal plume with an extended far field (obviously measured during a different month from Figure 2). The 61°F. isotherm was approximately 2° above a reasonable "ambient" baseline temperature. The solid isotherm lines are drawn in from the surface mapping. Also indicated with dashed lines are the isotherms for 60° and 61° at a depth 3 feet below the surface. This strongly illustrates the shallow plume effect. Much of the 61° surface water lies above 59° water as measured at 3 feet. A 2° vertical gradient in 3 feet is quite strong and suggests that much of the far field is a very shallow layer.

By contrast, those plumes which were more restricted in extent on the surface, typically the flood plumes, showed a much lesser vertical gradient temperature and measurable temperature rises at both the 3 and the 6 foot depths, suggesting significant vertical mixing in the far field due to ambient river conditions. Figure 4 shows a typical flood plume in the far field.

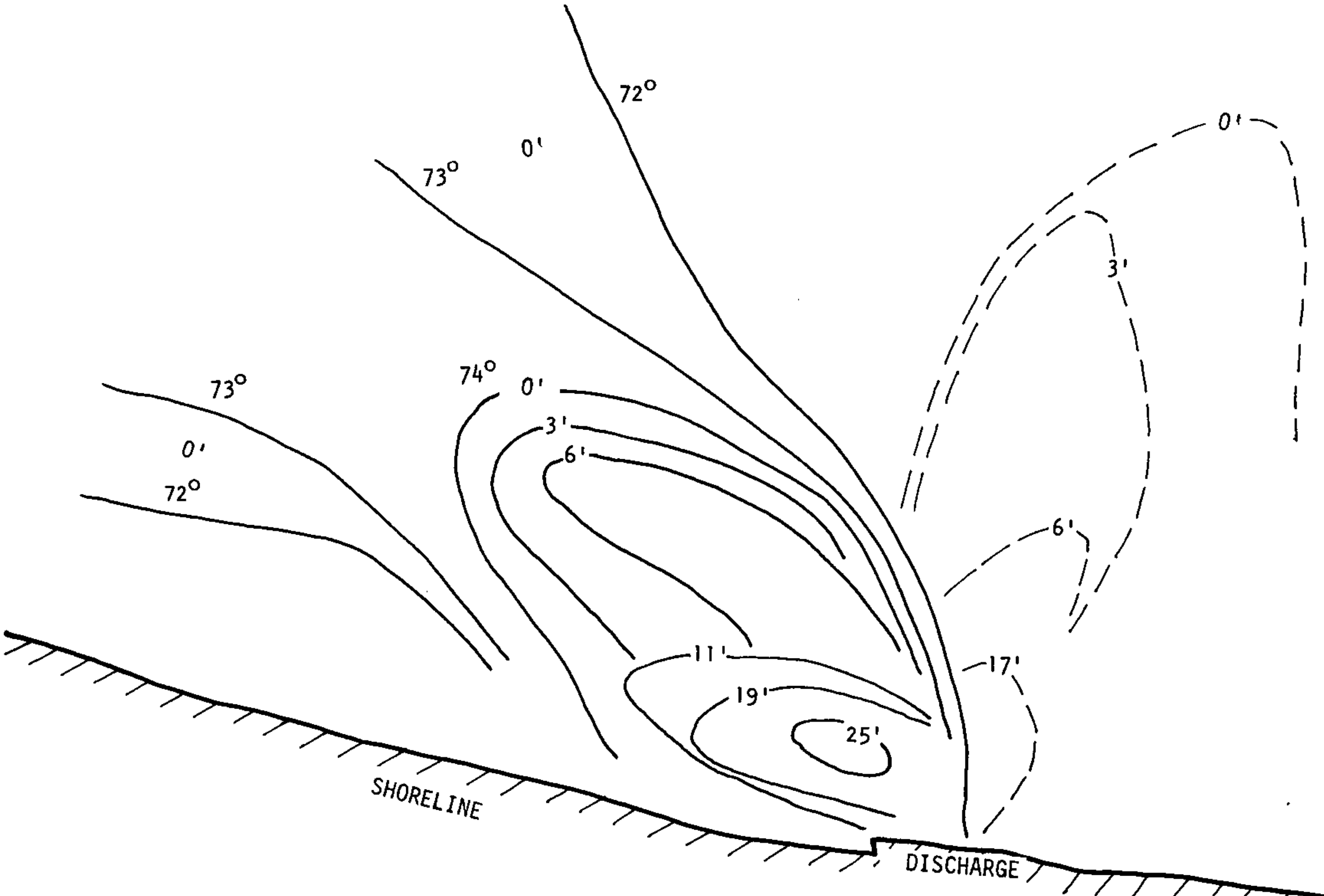

FIGURE: 2

TYPICAL PLUME ISOTHERM PLOTS
NEAR FIELD REGION

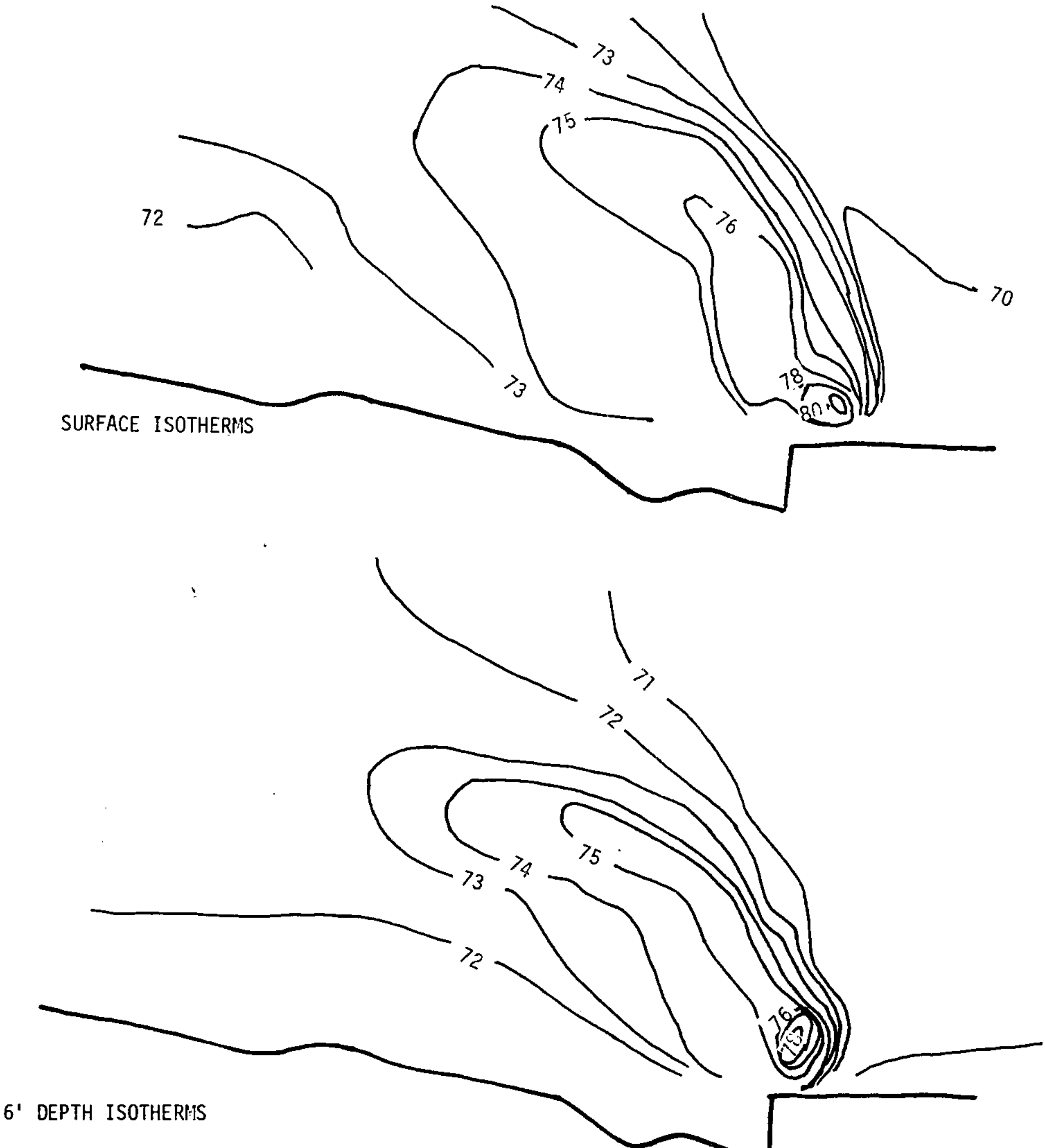

FIGURE 2B: ISOTHERM DETAILS FOR TWO DEPTHS

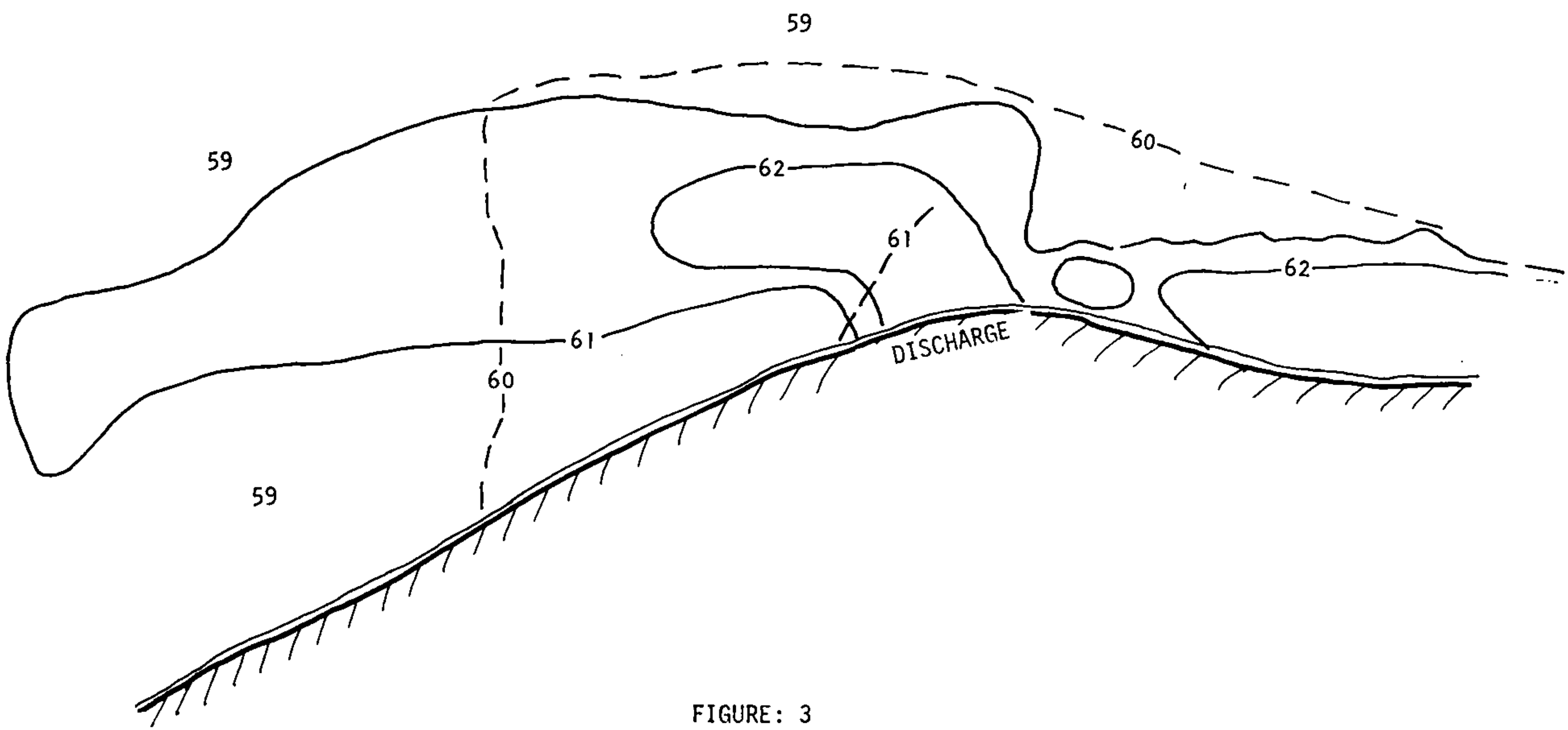

FIGURE: 3

EBB TIDAL PLUME CHARACTERISTICS

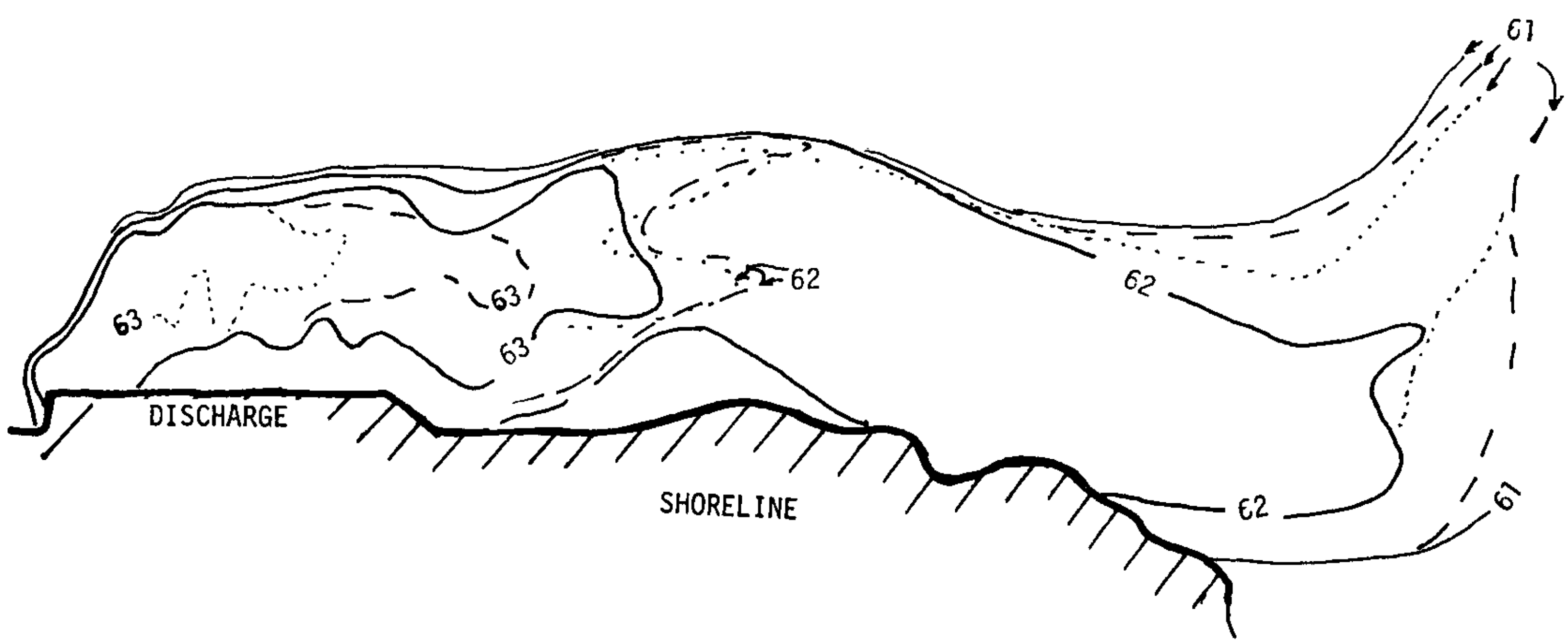

FIGURE: 4

FLOOD TIDAL PLUME CHARACTERISTICS

The solid lines show the surface isotherms as labeled. The dashed lines show isotherms at the level 3 feet below the surface, and the dotted lines show isotherms at the -6 foot level. Note that within the 62° surface isotherm, the majority of the lower water at 3 and 6 feet is 61°. The vertical gradient is no more than 1°F. in 3 feet, indicating good vertical mixing. The results tend to suggest that erroneous conclusions or difficult interpretations can result from examining thermal plumes on the surface of the water only, as opposed to considering them with three dimensional information. The behavior of the plume on the surface displayed wide variability which could be accounted to hydraulic conditions in the receiving water body; that is, ambient water conditions.

These results, repeated in numerous measurements, show a behavior of either a very shallow, widely spread plume, or a confined vertically mixed plume. A perspective only on the surface of the water would make the ebb type plume seem much larger, but in fact, the volume of water raised above ambient would be similar. A far field plume one or two feet deep may be of no greater consequence than one of half the surface area but twice as deep. The three dimensional information makes it possible to better consider the environmental consequences of a thin surface layer with poor vertical mixing, contrasted to a "better" surface area condition, but in which vertical mixing effects are more pronounced. In a deep estuary, the environmental effects may be inconsequential, but in a shallow estuary, the larger surface area, shallower plume may be preferable (to the ecosystem, if not the regulating agency)..

This situation is addressed to some extent by the New York State approach to thermal criteria in which both a surface area extent, as discussed, and a cross-section across the river criterion is specified. This states, in effect, that the area within the 4° isotherm should not occupy more than one half the cros-section area of the river.

A representative cross-section profile is shown in Figure 5 during a slack tidal stage. The natural river temperature was between 68 and 69°F. The temperature of the isotherm drawn for 72° is approximately between 3 and 4° above ambient. The 70° isotherm is barely above the river ambient temperature and is that part of a measurable temperature change which is sufficient to be identifiable with the thermal plume. One can see from the figure that the effect of the plume on the water body, as far as cross-section is concerned, is relatively modest. The 73° isotherm is also drawn in to illustrate the consequences of choosing a proper base of "ambient" temperature for designating an isotherm of interest, its area being considerably less than that of the 72° isotherm.

The determination of a baseline or "ambient" temperature can be difficult and problematic. The natural change in water temperatures in an estuary is highly subject to physical conditions within the water body and in atmospheric conditions at the water surface. In studies of a tidal estuary with a downstream fresh water net flow superimposed on strong tidal cycling, strong variations of temperature as a function of time throughout the tidal cycle can readily be observed without any man-made thermal introductions. This may be seen particularly where effects of solar heating and atmospheric surface cooling can be quite pronounced over a few miles of the estuary where, perhaps, in a deeper upper portion the water can be well mixed and largely uniform,

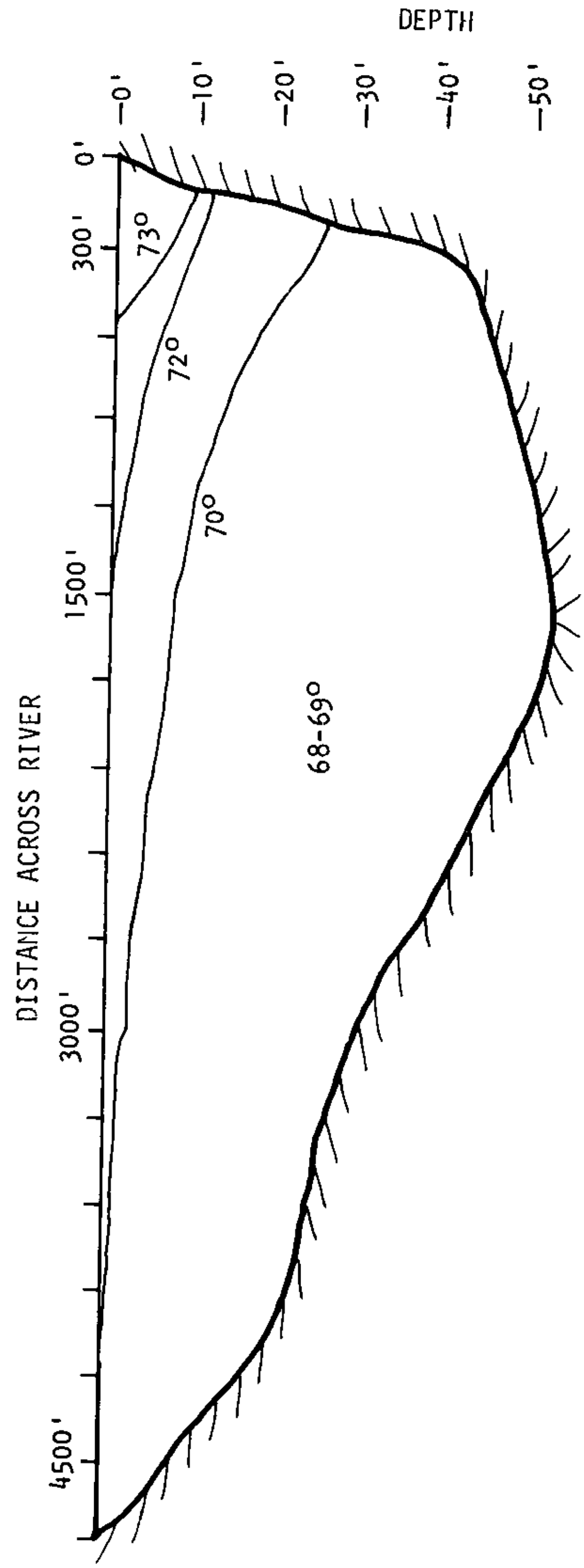

FIGURE 5
CROSS SECTION ISOTHERMS

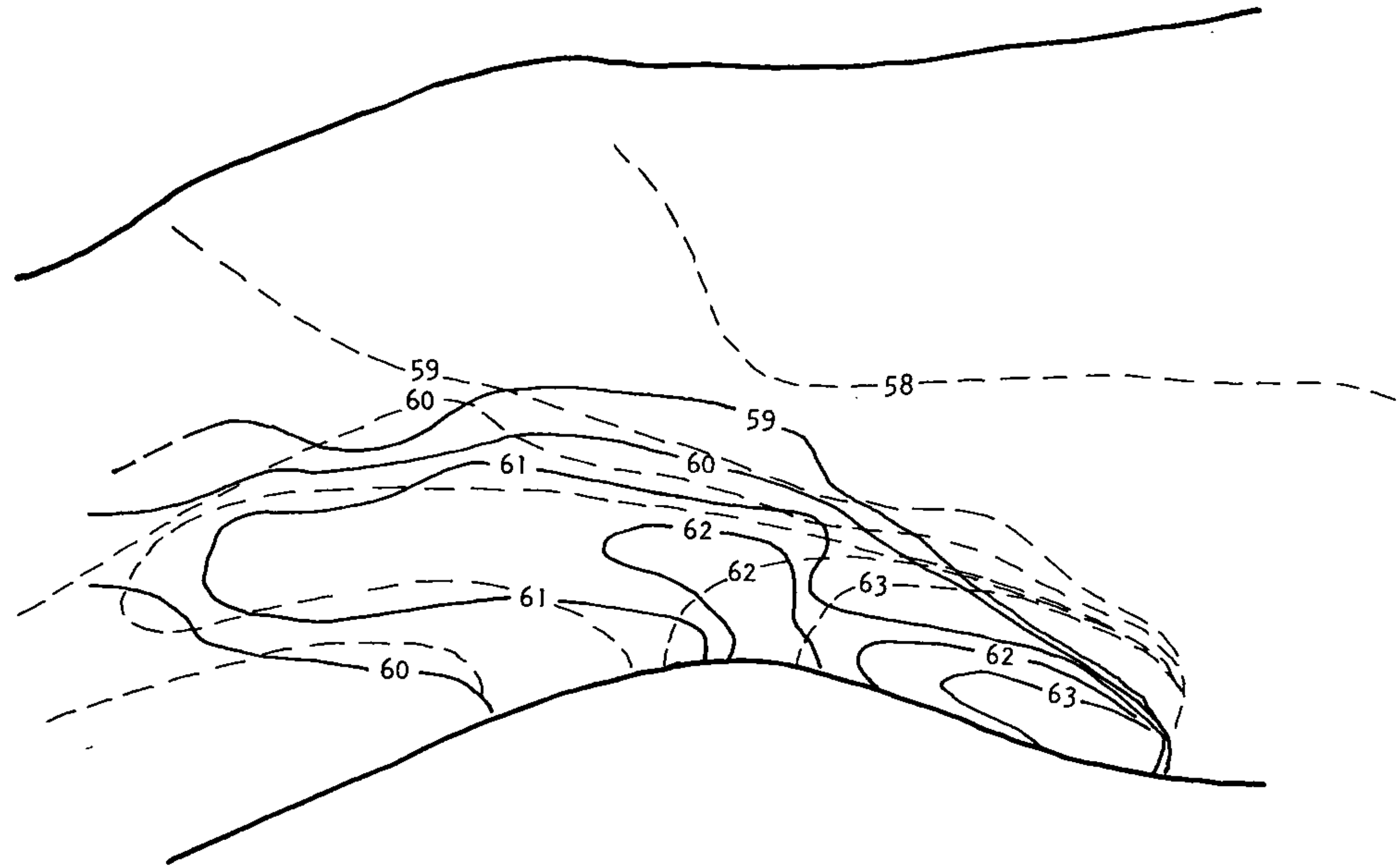

FIGURE 6
COMPARISON OF THERMISTOR AND I-R CONTOURS

while downstream in shallower areas solar heating may cause significant elevations of temperature. During the study observations were made of shore to shore variations of from 3 to 5°F. in some cross stream transects adjacent to shallow water. In one particularly interesting case, which was repeated, observations were made of temperatures several degrees colder downstream of a large thermal effluent during a Fall month, apparently due to more rapid cooling in shallow water.

The consequences of the choice of a base temperature can have significant consequences where regulation or enforcement is involved. One possible solution appears to be that in controversial situations in which the physical characteristics of a plume cannot be displayed and defined with relative ease in terms of excess temperatures above the base, some expression of the sensitivity of the developed numbers to a change in the value of the base temperature may be beneficial. For example:

Base Temperature	Percent Reach Across River
If 72	33
If 71	50
If 73	10

Such a tabulation aids in a more valid evaluation of the numerical results.

The variability of numerical values may also be related to the technique of temperature measurement. As stated previously, some comparative studies were made of simultaneous infra-red scans and moving boat thermistor scans. The thermistors were carefully calibrated and spot checks were made with an accurate mercury thermometer during the run. Figure 6 shows the results of one comparison made. The solid line surface isotherms are reproduced from the boat survey information and the dotted line isotherms from the infra-red developed contours. It can be seen that the overall shape and extent of the two plotted results are reasonably comparable. However the thermistor survey information was more exacting and produced more detail than the I-R. The near field region is appreciably larger in the I-R plots which tended to indicate larger extents of heated areas than the boat surveyed plots.

Conclusion

The value and justification of measuring thermal plumes in three dimensions was discussed, and the techniques used in an extensive field survey described. The results presented are representative of a large number of similar results obtained. It is felt that a proper evaluation of the environmental consequences of a given thermal discharge can be carried out far more satisfactorily with full three dimensional information.

Acknowledgment

The field work and analysis was accomplished under the supervision of Dr. Joseph Cataldo and Tim Janaitis of Dames and Moore.

The Indian Point thermal plume measurements were conducted for the Consolidated Edison Co., and appreciation is expressed to Dr. Han Moy and Dr. Leon Paretsky, Emissions Control Section.

RECENT PROGRESS IN WAVE REFRACTION STUDIES AND ITS APPLICATION IN THE MID-ATLANTIC BIGHT

by

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ABSTRACT

Past research has indicated the possibility of highly complex features for waves refracted on the Mid-Atlantic Continental Shelf. In order to have a better understanding of the refraction phenomenon on the shelf, numerical calculations by means of a high speed digital computer must be made. The effects of the earth's curvature on the refraction of waves must be included in calculations. In addition, a quantitative interpretation of crossing orthogonals and caustics must be made. Also, automation of the depth field preparation including depth digitization and gridding, and the capability of handling a large amount of data are required. Only after adequate refraction studies have been made will it be possible to interpret the available wave data and to understand and predict the wave environment of the Bight.

INTRODUCTION

If one looks out over the sea from a somewhat straight and open beach, one might get the impression that waves incoming from the far reaching horizon gradually change their course. The closer the waves get to the beach, the more the wave crests turn to parallel the beach. This turning or change of wave direction is known as wave refraction.

When a wave runs into shoaling water at depth less than about half of its wavelength, the wave is said to "feel" bottom, and the wave speed is affected by it. The waves will travel more slowly as the water becomes shallower. In water of variable depth, the crests of those portions of waves advancing in shallow water move slower than the crests of those portions of the same waves still advancing in the deep water, causing the wave crests to bend into shallow water.

The physical laws that govern the behavior of waves in water of variable depth are analogous to those governing the behavior of light rays passing through different media. The refraction of waves can be compared to the focusing and defocusing of light rays as they pass through a lens, prism, or for example, glass of water. The refraction focuses the wave energy onto headlands and over shallow regions jutting out from the shore, and it turns the wave away and spreads the wave energy out from channels and bays. Focusing of wave energy results in an increase in wave height, while defocusing of wave energy results in a decrease in height.

Wave refraction plays an important role in understanding and predicting the wave environment over the continental shelf and in coastal areas. Wave refraction may cause a marked change in wave height as well as a change in direction of travel. Thus, a knowledge of wave refraction effects is a prerequisite for adequately siting and designing marine structures, for studying beach erosion and coastal processes, and for investigating water pollution problems in nearshore areas. A ship captain also needs some knowledge of refraction phenomena which may occur on the continental shelf, so that he may choose a safe navigation route and avoid unnecessary damage or loss of his ship.

Kinsman (1965) mentioned a harbor which cannot serve its function efficiently because of refraction effects. The breakwaters which formed this harbor were constructed without considering the bottom configuration and its effect on waves. The entrance of the harbor is located precisely at the point where the bottom topography focused the wave energy for waves from the prevailing winds, so that it is not uncommon to have 10-foot waves in the entrance even though waves outside the harbor are only 4-foot high.

Refraction will concentrate wave energy on areas over shoals or submarine ridges. This is the reason that breaker heights and surf conditions can be so different on beaches that are quite close to each other. This variability may, in turn, affect the pattern and the intensity of the wave-induced nearshore circulation and may therefore affect the movement of sand and pollutants.

Two British fishing trawlers recently sank in the North Sea. Both ships were reported to have been "suddenly overwhelmed by the seas." Based on an analysis of the wave and weather conditions, it has been shown that these ships could have been overturned by an extremely complex pattern of refracted swell (Pierson, 1972). On the other hand, one can make the bottom topography work for him, such as the fishermen who anchor in open water over the Scripps Canyon near San Diego, California. There, the waves are always relatively low since the bottom configuration deflects the wave energy to either side.

The importance of wave refraction to the understanding of surface waves in shoaling water has led to extensive theoretical studies and development of practical applications. Inadequacies and limitations involved in earlier theories have been discussed and solved to some extent. In the recent years, due to the increased demand for the utilization of the continental shelf, many researchers have devoted great efforts to finding better ways of describing refraction phenomena over large areas of complex submarine topography. In this article, a recent development that is applicable to an area with a scale comparable to the width of the continental shelf and to the Mid-Atlantic Bight in particular will be discussed.

BASIC REFRACTION THEORY

The objective of a study in wave refraction is to estimate quantitatively the changes in direction and amplitude of long crested monochromatic waves propagating in shoaling water of varying depth. A physically rather comprehensive way, perhaps, is to introduce a network of curves everywhere perpendicular to the wave crests. These curves are called othogonals or rays, or characteristic curves in the Hamilton-Jacobi theory. The variation of the wave energy is then evaluated basically from the distance of separation between two adjacent rays. The amount of energy between two adjacent rays is assumed to be constant.

The basic equations that are commonly used to calculate the required quantities are those originally derived by Arthur, Munk and Isaacs (1952) and Munk and Arthur (1951). Alternative forms of the original equations are also frequently used (e.g., see Skovgaard, Jonsson, and Bertelsen, 1975). There are various ways to derive the equations for the calculation of the amplitude variation along the ray. A rather formal approach is to derive these equations by employing a perturbation expansion of the solution to the linearized wave equations, based on the assumption that bottom slope is small. The leading term of the expansion provides two primitive equations which are equivalent to the eiconal and to the transport equations for geometrical optics. From these equations, the equations for the rays and for the amplitude variation can be derived (Keller, 1958).

An immediate advantage of this approximate solution is that it gets rid of an early assumption that the sea bed must be locally horizontal. In fact it is a good approximate solution if the local bottom slope, S_b, satisfies the condition

$$S_b \ll kh \tanh kh$$

where h is the water depth, and k is the wave number ($2\pi/L$ where L is the wave length). For example, if the relative depth, h/L_o (L_o is the deep water wavelength) is 0.1, kh = 0.9 and kh tanh kh = 0.6; if h/L_o = 0.05, kh = 0.6 and kh tanh kh = 0.3. If the relative depth is even smaller, say, h/L_o = 0.002 kh = 0.1 and kh tanh kh = 0.01, the bottom slope must be very small in order to satisfy the condition. Since the bottom slope of the continental shelf is in the order of 1/500, the required condition is easily fulfilled for most shoaling water areas except the area close to the shore. The near-shore region in general, is affected by surf, where linear theory is not applicable (the small amplitude wave theory is a good approximation for the full wave equations when the condition $a/h \ll (kh)^2$ is satisfied, where a is the wave amplitude (Peregrine, 1972).

THE CAUSTICS

An early study of wave refraction in the Mid-Atlantic Bight, based on the graphical method (the so-called orthogonal method) derived from the theory described previously, was that of Pierson (1951). It illustrated the complexity of refraction phenomena in the bight and identified the problem of the caustic in the theory.

In order to have a better understanding of the caustic problem, let us begin by considering a simple example. Suppose that the bottom contours are straight and parallel. For this example, the ray equation reduces to the well-known Snell's law, i.e.,

$$\frac{\mathrm{Sin}\theta_r}{\mathrm{Sin}\theta_i} = \frac{C_r}{C_i} \qquad (1)$$

where the subscripts "i" and "r" denote respectively, the quantities corresponding to the incident wave and the refracted wave at a given local depth, and where θ denotes the direction of wave propagation. The quantity C denotes the wave speed which is a function of wave period and depth. The longer the wave period the faster the wave speed. Similarly, the greater the depth in shoaling water the faster the wave speed.

Once the refracted ray pattern is constructed, the wave height in the refraction zone can be calculated from the equation:

$$\frac{H_r^2}{H_i^2} = \frac{b_i V_i}{b_r V_r} \qquad (2)$$

where H denotes the wave height measured from the crest to the trough. The quantity V denotes the speed of energy transmission and b the width between two adjacent rays. The speed of energy propagation, like the wave speed, is a function of the wave period and the depth. But unlike the phase speed, it increases and attains its maximum at the point where the ratio of the water depth to the wave length in deep water is 0.157 and then decreases with decreasing depth. The width of ray separation can be obtained graphically by measuring directly the distance between two adjacent rays, or computing it from the equation:

$$\frac{b_r}{b_i} = \frac{\cos\,\theta_r}{\cos\,\theta_i} \qquad (3)$$

Since the square of the wave height is proportional to the wave energy, Eq. (2) expresses nothing more than the conservation of wave energy between two adjacent rays.

Consider, for example, a straight shoreline from which the bottom drops off gently and evenly. Suppose a uniform wave train travels from deep water toward the beach. And suppose that the wave crests in deep water are at an angle with the beach. Since the wave speed decreases with decreasing depth, the ration C_r/C_i is always less than one and will become smaller as the wave crests approach the beach. Consequently, the refracted angle of incidence also becomes smaller according to Snell's law. This suggests why the wave crests approaching a straight beach tend to be parallel to the beach.

In contrast to the previous example, let us now consider a wave train traveling in a shallow body of water with constant depth but which runs into and evenly increasing depth whose parallel and straight bottom contours are at an angle with the wave train. For this case, Snell's law states that the refracted wave angle will increase because the phase speed increases with increasing depth. As a result, the wave crest tends to be perpendicular to contour lines. For a prescribed bottom condition and wave period, there will be a particular incident angle, say θ_i equals α, so that,

$$\sin\theta_r = \sin\alpha \cdot C_r/C_i = 1, \text{ and } \theta_r = 90 \text{ degrees},$$

and the wave crest is perpendicular to the bottom contours, or in other words, the rays are tangent to a specific contour. The ray after passing this point turns back toward shallow water. If we construct a family of rays for this condition, the family of rays cross successively, and an envelope of the rays is formed. The envelope of the family of rays is called the caustic. At each point on the caustic associated with each ray, cos θ_r equals zero, and therefore the ray separation b also equals zero. This is why, according to the theory, that the wave height increases infinitely at a caustic. This result, of course, is devoid of physical meaning. It implies that the conventional theory fails near this point, and different methods must be used to evaluate the wave height in the vicinity of a caustic.

Based on the assumption that the wave field near a caustic can be expressed by a superposition of many elementary waves (i.e. incident, reflected and diffracted waves) the problem may be solved by the method of stationary phase (e.g. see Kay and Keller, 1954; Brekhovskikh, 1956) or by the method of uniform asymptotic expansion (Ludwig, 1966).

Chao (1971) applied Ludwig's uniform asymptotic expansion to the linearized wave equations to solve the problem for a smooth caustic (see also Shen, 1974). It was found that the wave amplitude increases montonically and reaches a maximum height immediately before reaching a caustic. When waves pass through a caustic, a retardation corresponding to a $\pi/2$ phase shift occurs. A portion of the wave energy is diffracted to the other side of the caustic. The wave amplitude decreases exponentially with increasing distance from the caustic on the far side of the caustic.

The theoretical prediction has been verified in a wave tank experiment (Chao and Pierson, 1972). The wave tank is 14 feet square and 1 foot deep. Figure 1 shows a photograph of the wave pattern in the wave tank. The straight edge located at about the center of this picture separates two different model bottoms. On the right of this edge, the bottom is flat, while on the left, the depth increases linearly. A flat type wave generator can be seen at the lower right hand corner, with an angle of 50 degrees to the edge. Gravity waves are propagated from the shallow water of constant depth up to this edge, then refracted, totally reflected and turned back toward the shallow water. The phenomenon is analogous to the total internal reflection of light in a prism.

For this specific example, the caustic is a straight line parallel to the edge and its location can be determined from Snell's law. Figure 2 shows a comparison of the measured wave amplitude with theoretical curves along the lines perpendicular to the caustic for various wave periods. The x-axis is the distance from the edge. The ordinate is taken as the ratio of the amplitude along the x-axis to its maximum value. In general, the measured wave amplitudes compared favorably with the predicted amplitudes. The discrepancies between the theoretical curves and the experimental results are essentially due to the imperfection of the experiment facilities and the fact that the nonlinear features of the actual wave motion have been neglected in the theoretical development.

The same wave tank has been used to study the refraction of transient wave groups (Chao and Pierson, ibid). This study, perhaps, will provide a better understanding of the refraction phenomena of the actual ocean waves. A transient wave group can be generated by properly turning on and off the toggle switch which controls the wave generator. The transient wave group covers a wide range of frequencies. In constant water depth, a transient is a pure dispersive wave train. The low frequency component waves speed ahead and the high frequency waves lag behind according to their individual phase speed. When the transient travels into water of variable depth, such as the uniform sloping bottom in our model, each wave component refracts according to Snell's law in a similar manner to the monocromatic waves of the same frequencies. For a transient, however, there no longer exists a simple caustic line, instead there exists a caustic zone.

The "critical" wave period is 0.45 sec. in our model basin. Waves of periods shorter than 0.45 sec. proceed into deep water, while waves of periods longer than 0.45 sec. all turn back into the shallow water.

A difficulty and disadvantage in applying the uniform method to solve the caustic problems is that the labor involved increases sharply as the complexity of the problem increases. For example, the solution for a cusped caustic involves a system of cubic algebraic equations. Moreover, the results involved untabulated special functions of several variables (Ludwig, 1966). Studies of the problems involving the cusped shape caustic by numerically solving the wave equations with appropriate boundary conditions or functions have been made by Ito and Tanimoto (1972) and Berkhoff (1972). However, the applicability of their methods to the continental shelf of complex bottom configuration is not warranted from the economical point of view.

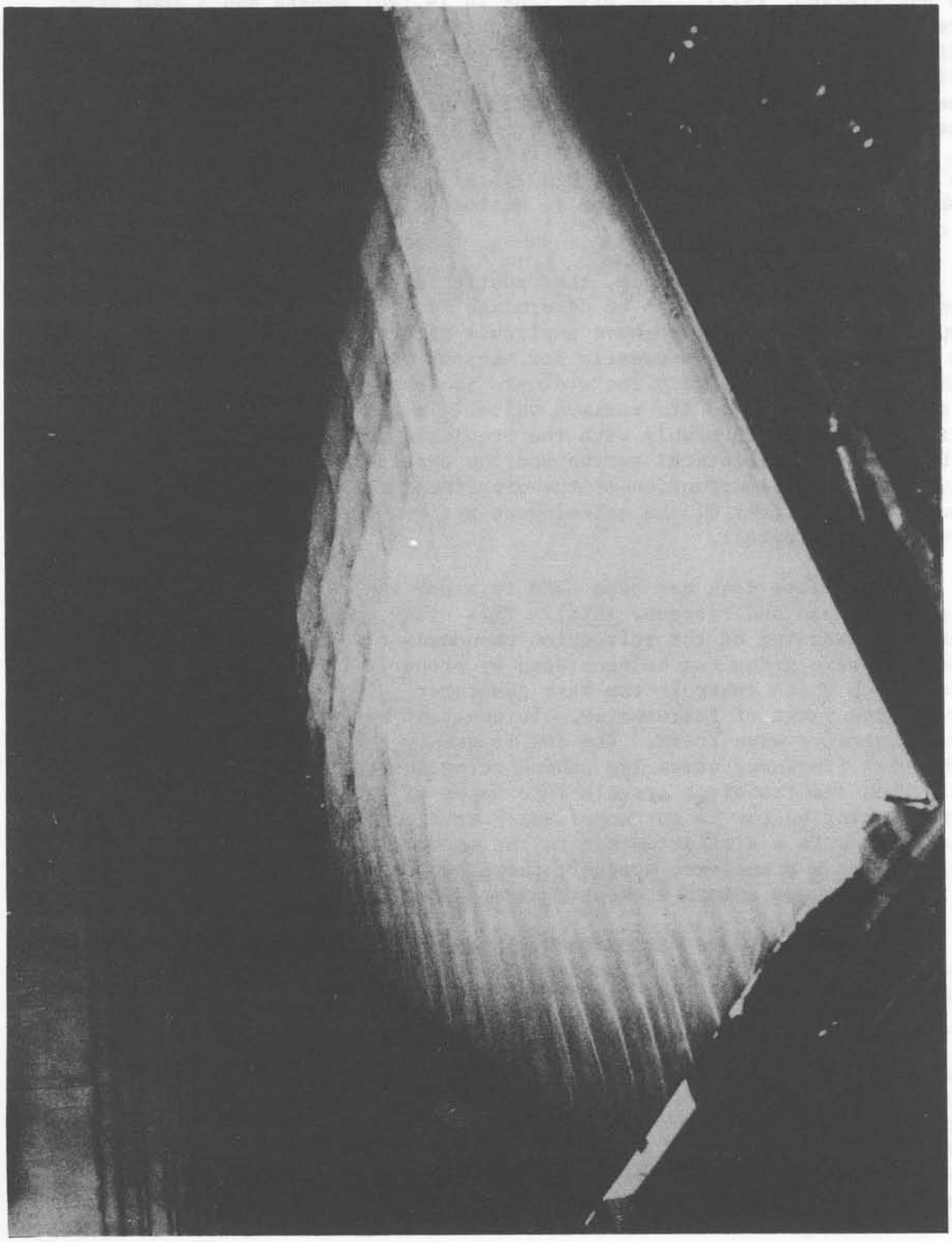

FIGURE 1. A PHOTOGRAPH THAT SHOWS THE WAVE FIELD FOR A WAVE PERIOD OF 0.73 SEC. IN THE WAVE TANK

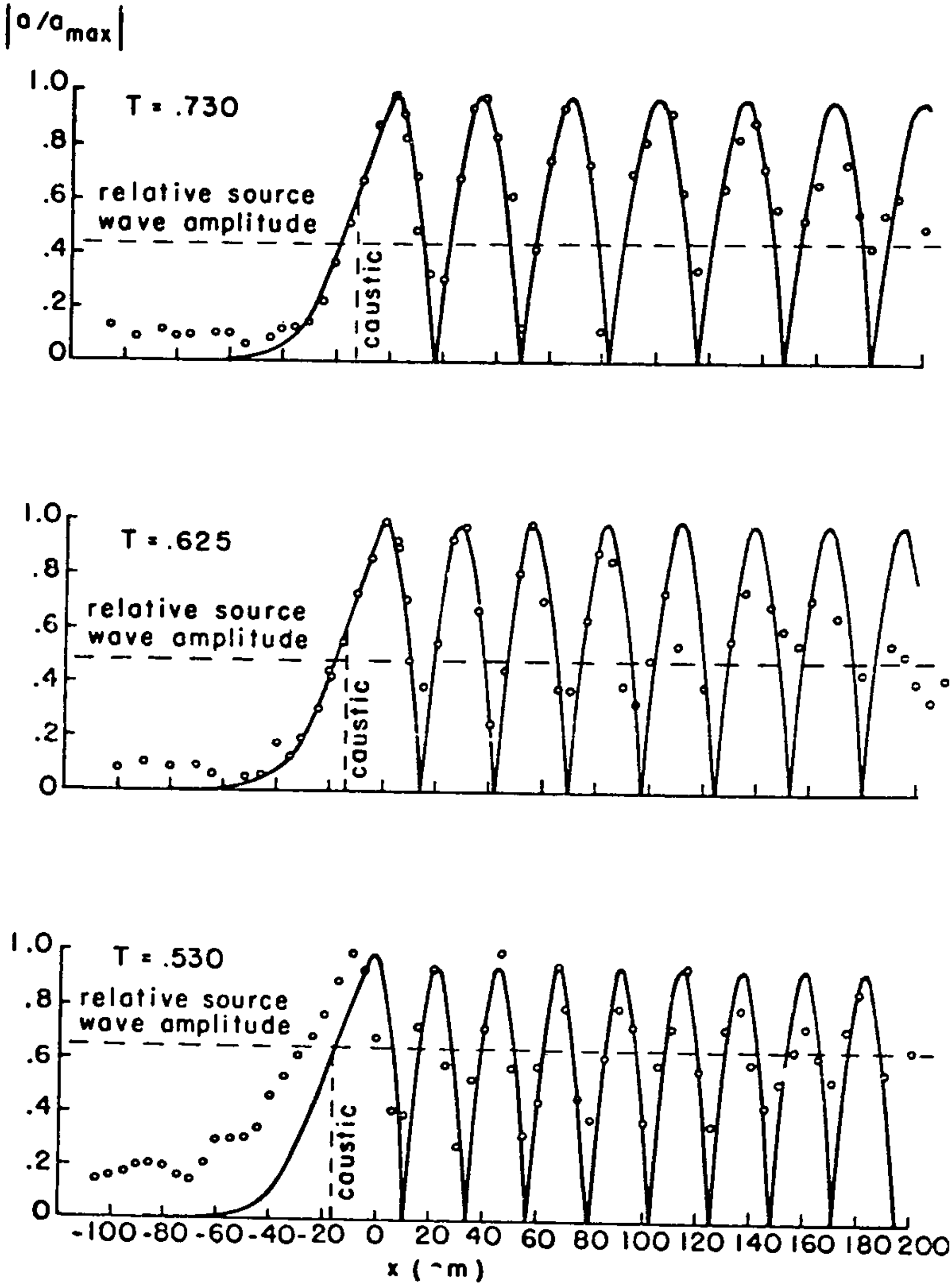

FIGURE 2. COMPARISON OF WAVE DATA WITH THEORETICAL RESULTS

REFRACTION OF ACTUAL WAVES ON THE CONTINENTAL SHELF FOR SPHERICAL EARTH

The refraction phenomena of actual ocean waves are much more complicated than have just been discussed. Waves in nature are neither long-crested simple period regular waves nor purely transients. The complexity of waves in nature, for the first approximation, can be considered as a sum of a great many simple waves with different periods and traveling in different directions, and can best be described by the variance spectrum. Suppose that a directional wave spectrum in deep water off the generation area is given either by actual measurement or by numerical wave prediction procedures. If waves are still traveling in deep water, as time passes, the longer period components will run faster than the shorter components due to dispersion, and the original mixture or interference pattern will begin to sort itself out by length (or period) with the longer, faster components out in front. The direction in which a wave travels is essentially along a great circle track and will not change until it enters shoaling water.

Thus, in order to understand refraction phenomena in a continuous wave spectrum coming from deep water, it is necessary to construct a great many rays to cover all possible frequencies and directions of the spectrum in deep water. (See Pierson, Neumann and James, 1955, or Kinsmann, 1965). An immediate problem is the best way to select representative directions and frequencies for refraction calculations so as to account for a continuous variation in wave frequency and direction. In other words, how large an angular interval and frequency interval may be chosen so that it is possible to interpolate the directions and frequencies in between. The answer is unknown, a priori. It depends on the complexity of the bottom topography in the area where the refraction consideration must be made. The resolutions of direction and frequency depend also on the economic and time limitations imposed on the practical calculations.

The second problem is concerned with the possible distance over which a wave will be subject to the refraction effect. It is well known that swell may propagate over distances of an ocean wide scale. According to an analysis of waves observed off the California coast (Munk <u>et al</u>, 1963) swells may come from storms as far off as Madagascar in the Indian Ocean. Swell with a period of 20 seconds will "feel" bottom and be subjected to refraction effects at a depth of about 400 meters. Swell components with periods longer than 20 seconds are frequently observed. Thus in general, we may expect that the scale of wave refraction may involve the entire width of continental shelves.

The derivation of the conventional refraction theory described previously is based on the assumption that the ocean surface is flat. Therefore, the refraction equations are valid only for a relatively small area of shoaling water which might be considered to have a plane surface.

A ray equation which accounts for both the effects of spherical earth and the bottom configuration has been derived by applying Fermat's principle directly to a spherical polar coordinate system. An equation for ray separation has also been derived (Chao, 1972). The resulting equations, of course, can be transformed onto any map projection in which the depth soundings are available.

A computer program which uses the corrected equations to construct wave rays and computes the separation factor along the ray has been written and applied to a portion of continental shelf near the entrance to the Chesapeake Bay. Figure 3 shows the difference between the rays constructed by programs based on planar and on spherical surface assumptions. For this example, the wave period is 12 seconds and the initial wave direction in deep water is nearly toward west. The distance of travel is about 130 kilometers in an east-west direction. A remarkable difference of the ray paths for the plane level surface and the spherical level surface can be seen in Figure 3. The reason for the discrepancy is that the bottom configuration varies in a complicated manner. A slight change of the ray curvature due to the spherical earth modification will make the ray reach a different water depth.

RESULTS OF A REFRACTION STUDY FOR CHESAPEAKE BIGHT AREA

The main objective of this study was to hindcast the waves in deep water and to compute and compare the refracted wave spectra at the Chesapeake Light Tower with measurements (Chao, 1974).

Using the corrected equations, refraction calculations have been made for seven periods ranged from 6.0 sec. to 12 sec. and for 19 directions with 5 degree increments in the area of interest. Wave rays for each direction are started out normal to an appropriate great circle in deep water.

Figure 4 is a diagram that shows the extreme complexity of ray patterns. The depth field in this area is rather irregular, with small ridges and hollows. The scale of these irregularities is still larger, however, than the scale of the wave lengths. This is why the ray pattern is so complex. Of 21 equally spaced rays in deep water (1 N.M. spacing), it was found that seven pairs of rays straddled the target. These seven pairs of rays, however, are quite far apart from the target. At this scale of ray construction the computed ray separation factors vary substantially for different rays. It is difficult to obtain a reasonable and convincing value of ray separation factor for the target by interpolating the values on each pair of rays. The reason is that the ray separation factor is merely representative for that particular location. Two caustic regions can be observed in the areas marked by square boxes in Figure 4. Because of the scale of construction, however, it is difficult to define the shape of the caustics clearly.

Consequently, in order to obtain the required results, it was necessary to repeat the ray construction for increasingly finer spacings of the rays. However, due to the practical limitations in the use of computers, we were not able to repeat the procedure too many times. We were forced to compute the refraction coefficient by using the conventional method. That is, to determine the refraction coefficient by measuring the distance between two adjacent rays which bracket the target. We have chosen one nautical mile as the principal spacing with which to start the ray construction. Finer spacings were used only when it was absolutely necessary. A total of about 1500 refracted rays were calculated by a UNIVAC 1108 computer.

The results of refraction calculations for a given wave period have been summarized in terms of various wave direction in deep water. A typical example

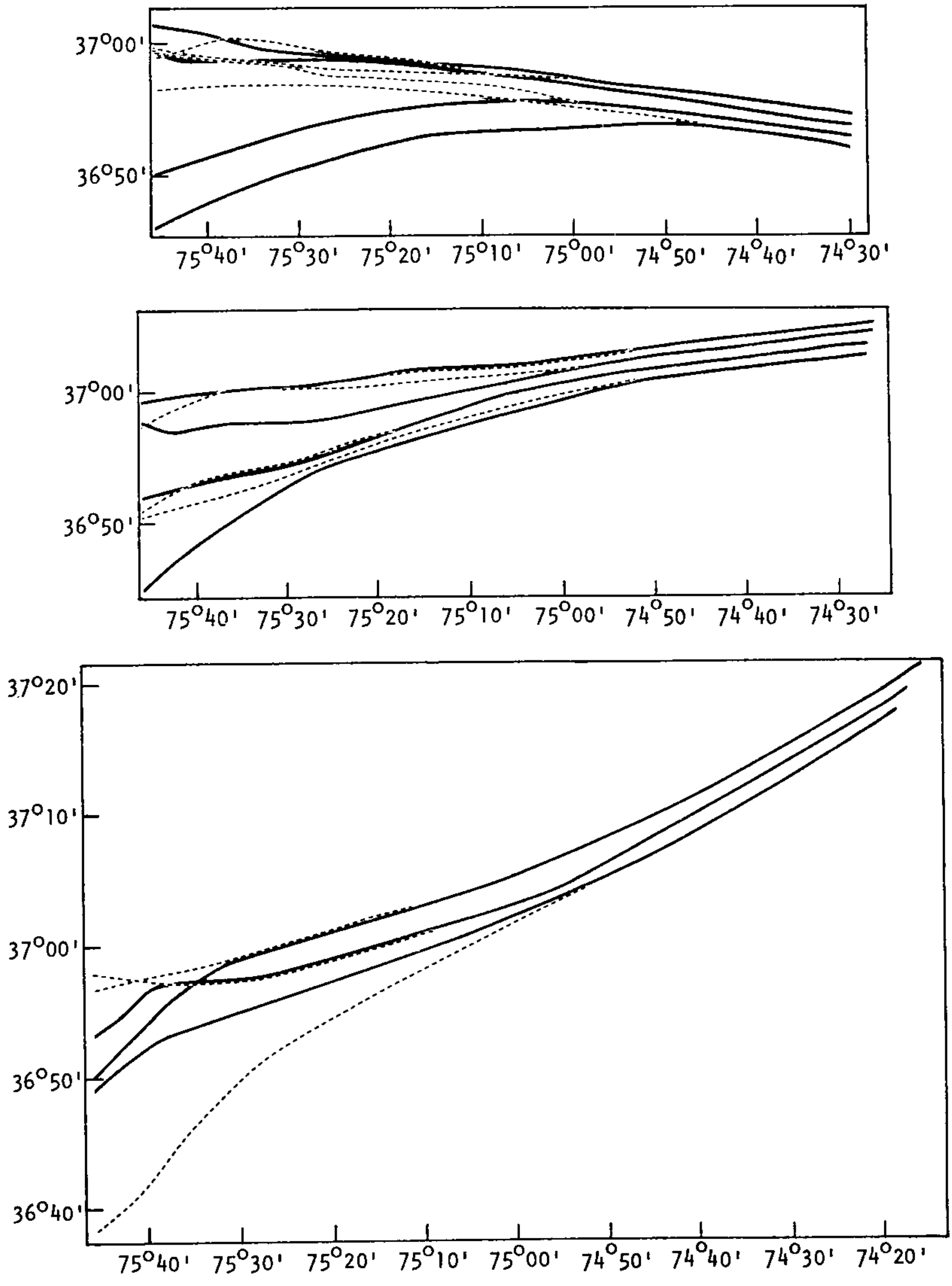

FIGURE 3. EXAMPLES OF RAY PATHS IN THE AREA NEAR THE CHESAPEAKE LIGHT STATION. SOLID LINES ARE CONSTRUCTED FOR A PLANE EARTH AND DASHED LINES FOR THE SPHERICAL EARTH (WAVE PERIOD 12 SEC.)

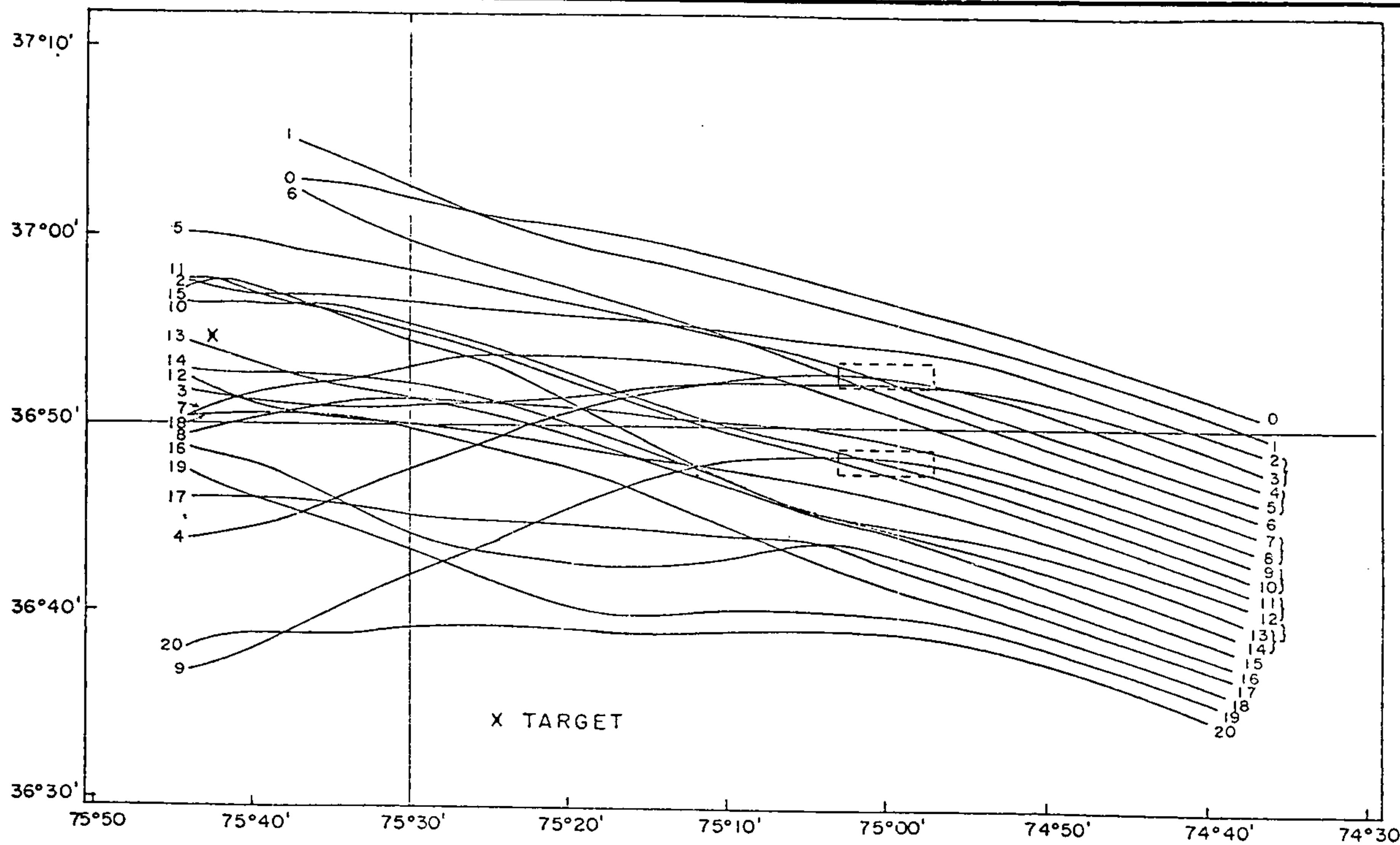

FIGURE 4. THE REFRACTED RAY PATTERN NEAR THE CHESAPEAKE LIGHT TOWER FOR A WAVE PERIOD OF 12 SECONDS AND A DEEP WATER DIRECTION FROM 20° SOUTH OF EAST

is given in Figure 5. Where θ_D and θ_R denotes respectively the wave direction in deep water and at the target after refraction. The refraction coefficient corresponding to a given deep water wave direction and a refracted wave direction at the target is given numerically. There appear to be several refracted coefficients for a given wave direction in deep water. The line $\theta_R = \theta_D$ is to indicate the deviation of the refracted wave direction from the deep water wave direction.

The lower portion of the figure yields the sum of the refraction coefficient multiplied by the square of shoaling factor at the target (38 feet deep). This value was used to calculate the change of the spectral density at the target with respect to this particular period and a particular direction in deep water.

Some well recorded data have been obtained at the Light Station by a resistance type wave staff during August 27 to 28, 1968 and have been analyzed in spectral form. Deep water directional spectra have been predicted for the period from August 18 to 28, using the numerical hindcasting scheme described by Pierson (1971). The hindcasted deep water wave spectra were combined with the calculated refraction parameters to obtain the refracted wave spectra at the target. The time of wave propagation from deep water to the target was considered in the calculations.

The waves were the result of a storm moving up the east coast. This storm was weak and the dominant winds were in the offshore direction. Waves observed at the Light Station were essentially generated by local winds. Only at the end of the hindcasting period did the contribution to the wave spectrum at the Light Station by refracted waves from deep water become significant, especially in the low frequency range. The typical forms of the observed spectra and calculated refracted spectra are shown in Figure 6.

It can be seen from these figures that in order to predict the full pattern of the spectrum at the Light Station, the prediction of a continuous wave spectrum generated by local winds must be made. At the present time, there is no appropriate method to predict the wind generated waves in water of limited depth. This problem has been studied by Collins (1972), Kuo (1973) and Ichiye and Burch (1974) but questions remain. A quick but rough prediction of the full spectrum, however, can be made by applying the forms suggested by Pierson and Moskowitz (1964) for a fully developed spectrum with respect to various wind speeds. The selected, fully developed spectrum corresponding to the local wind speed at each observation time was plotted with a filled-in rectangular mark. Tentatively, the selected fully developed spectrum was added to the refracted wave spectrum to obtain the predicted spectrum at the target. The result is shown by the dashed line. The observed spectra were analyzed from 20 minute wave records with the Nyquist frequency being 1.0 sec. and the lag number being 120. The degree of freedom is around 40. Thus we have 90 percent confidence that the spectral values are between 0.72 and 1.52 times the estimated values. The total degree of freedom is around 400. The 90% confidence interval for the significant wave height determined from the observed spectrum is between 0.89 and 1.13 times the estimated values. For example, the significant height of 6.14 feet is only the best estimate from the observed data, whereas nine times out of ten the true significant height for the waves near this area at the time of observation will be between 5.46 and 6.94 feet. By a similar analysis, the

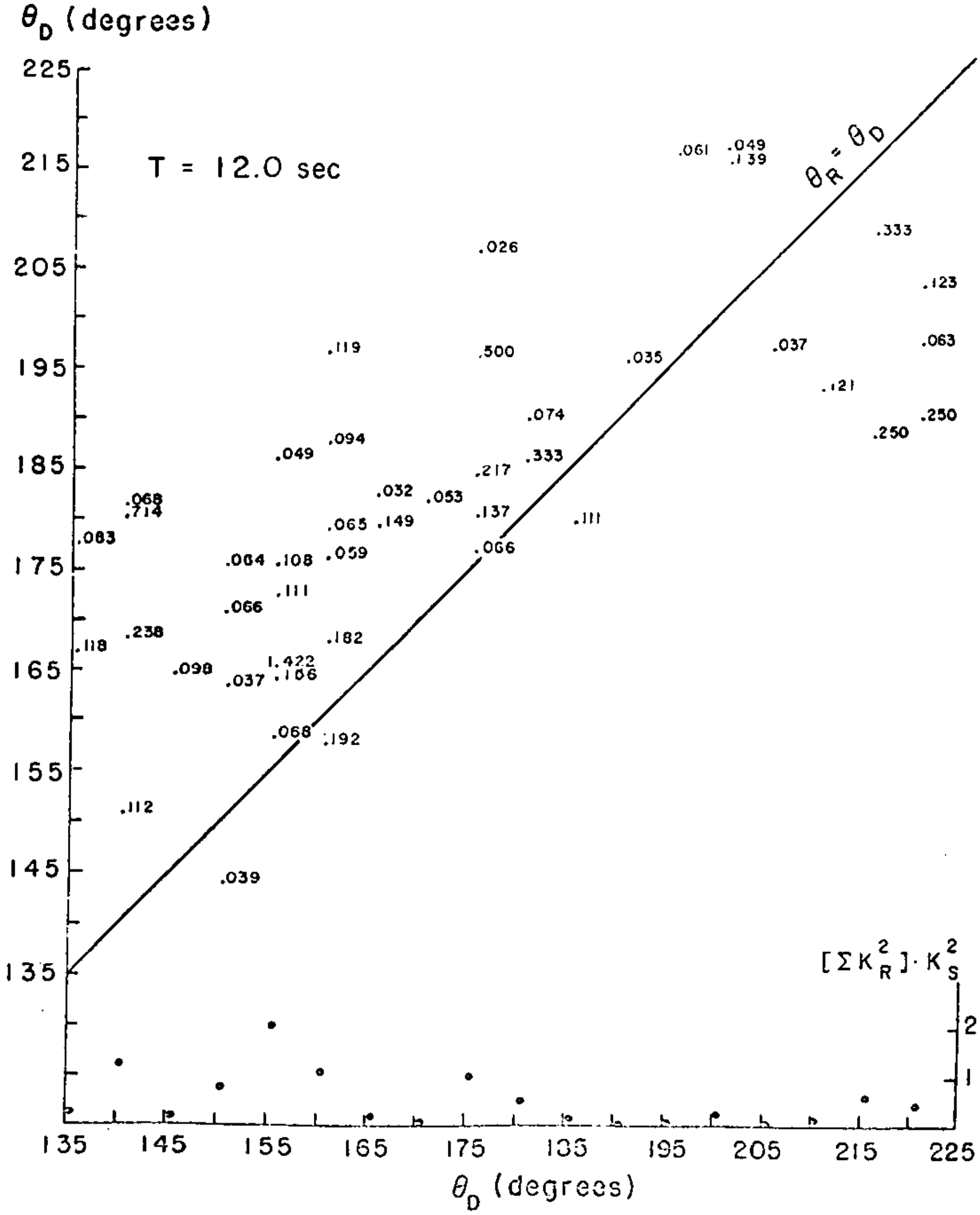

FIGURE 5. VARIATIONS OF THE REFRACTED ANGLE, θ_R, AND THE AMPLIFICATION FACTOR AT THE LIGHT STATION WITH RESPECT TO DEEP WATER WAVE DIRECTION, θ_D, FOR THE WAVE PERIOD OF 12.0 SEC.

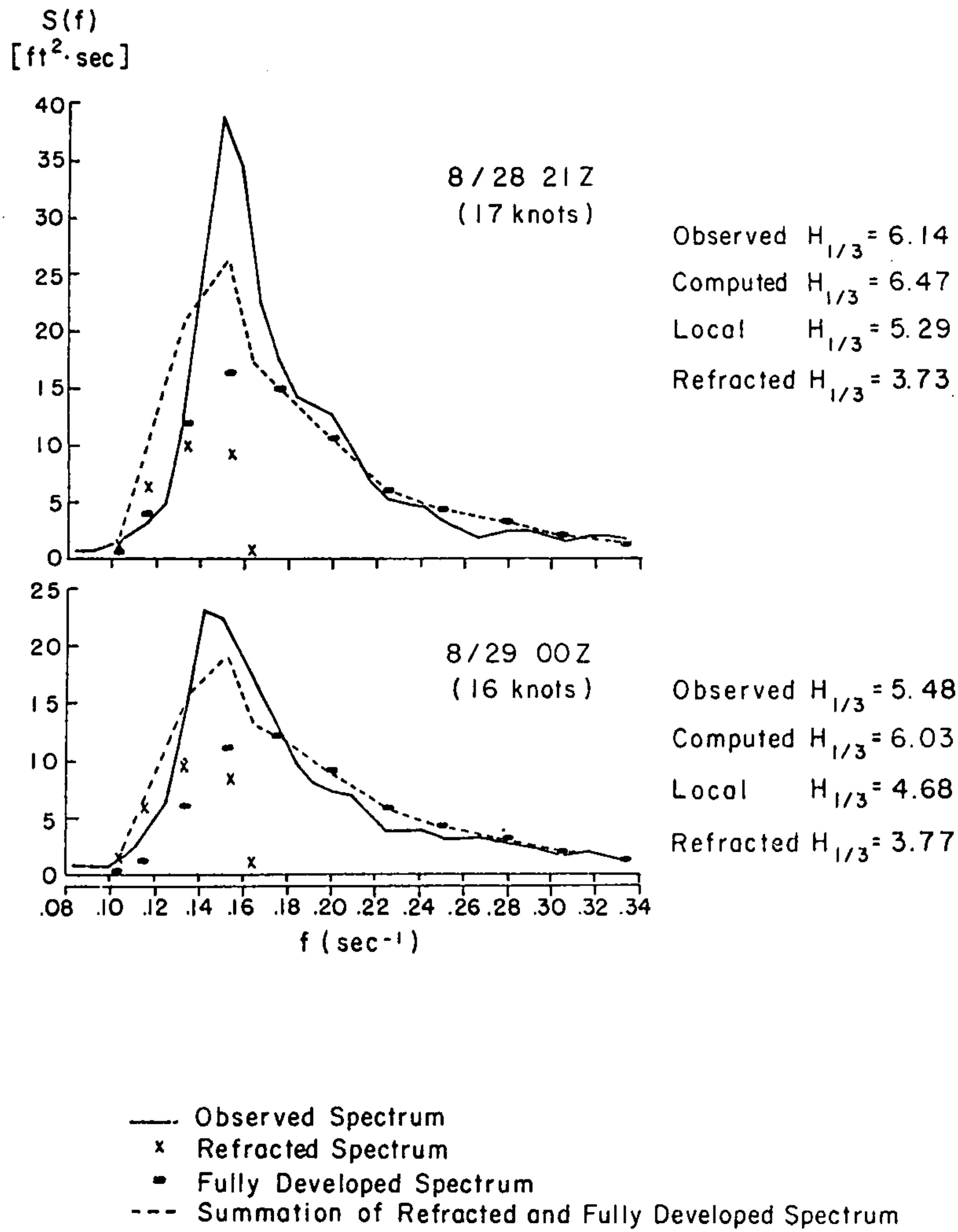

FIGURE 6. EXAMPLES OF FREQUENCY SPECTRA AT THE LIGHT STATION

significant height of 5.48 feet is really bound by a range of 4.88 to 6.19 feet. The results were fairly convincing in that the spectra obtained from the calculations agree with the spectra computed from the measured data.

RESEARCH FOR THE NEW YORK BIGHT

A study of wave refraction for the New York Bight is currently being undertaken as a part of the NOAA MESA program.

For any analysis of wave refraction, it is first necessary to produce the depth field with proper grid coordinates. Particular effort must be made to obtain the gridded depth field because the accuracy of the refraction calculations depends on it.

In the study of wave refraction for the Chesapeake Light Tower area, the input depth data were obtained from bathymetric charts published by the Coast and Geodetic Survey. The charts used for the nearshore portion of the area of interest were C&GS Charts No. 1222 and 1227. For the contiguous offshore region, Chart No. 1109 was used. Since the area under study is fairly large (about two degrees in longitude and one degree in latitude) we divided it into about twenty modules.

A complete module contains 100 x 100 square grids. In the module itself, the grid interval is a constant. For different modules the grid spacing is not necessarily the same. The grid interval for the module in the area where the depth is greater than about 10 fathoms is 1367.7 feet, and for that in the area with depth less than 10 fathoms, it is 333.3 feet.

After the proper grid interval was selected, the depth values at certain grid points were read from the charts. Data preparation became a program in itself as the original depth data was not read at equal intervals. Double cubic spline interpolation was employed to obtain the depth value at each grid point.

To prepare the required depth field as such is very time consuming and tedious. It required built-in human interpolation and analysis of bottom contours from available bathymetric charts, visual extraction, hand tabulation and card punching of the depth values on appropriately distributed points on grids.

We have described the procedure for obtaining the depth field of the Chesapeake Light Tower area here for the convenience of comparison with the new approach which we have taken for producing the depth field of the New York Bight.

The starting point was C&CS bathymetric maps of series 0807N, 0808N and 0708N which yield the most complete and detailed depth information currently available for the New York Bight. In order to correlate the depth field of the Chesapeake Bay area, the depth information for the area south of the New York Bight was obtained from the chart C&CS 1109. The contours were then traced by using a pencil follower, coordinated digitizer to read the coordinates with appropriate resolutions. The coordinates of the contour were automatically punched on IBM cards. In order to identify a particular local bathymetric feature, such as a hollow or a ridge, and also to increase the degree of accuracy of interpolation, additional spot data points were added to the original set of contour data.

The depth value at a given grid was determined from neighboring points. The locations of these points were found by radiating eight lines from the grid until two surrounding digitized contours were intercepted. Using these points a cubic polynomial least square surface fitting procedure was performed to obtain the depth at the grid. The procedure included an appropriate exponential function which weighed the contribution from each point to the grid according to its distance from the center. A comparison of the result of this depth gridding scheme with the depth field shown in the bathymetric chart has indicated that the agreement between the two is remarkably good.

The digitized depth field extends from the shoreline to a depth contour of 250 fathoms, from roughly latitude 37°30'N to 41°00'N and from longitude 69°00'W to 75°00'W. The extent of the boundary enables us to make refraction calculations for wave periods up to 24 seconds (which corresponds to a deep water wavelength of 2948 feet) and for all prevailing incident deep water waves between westward and northward directions. Figure 7 shows the study area involved. Included in the figure is the area for the Chesapeake Light Tower refraction study and the area which is studied jointly by NASA Langley Research Center and the Virginia Institute of Marine Science.

In this study, the global coordinates (i.e. in terms of latitude and longitude) are used throughout. The grid spacing of the depth field is uniformly 0.2 minutes (about 1/5 of a nautical mile. Once the preparation of the required depth grids is completed, refraction calculations will be made using equations which take earth curvature effects into account. In the previous study for the Chesapeake Bay area, the depths were given on a rectangular grid on Mercator Maps and the equations employed were a transformation of the original equations onto a Mercator projection. For the New York Bight Study, the depths are given in spherical coordinates, thus the original equations derived in spherical coordinates can be directly applied.

CONCLUDING REMARKS

The United States is seeking food and other natural resources from the ocean. As a result of the present energy crisis and call for independence from foreign sources of petroleum, the development of the Mid-Atlantic continental shelf becomes a major concern.

There are two types of facilities being considered for installation in the shelf. One type is the offshore oil drilling platform. Another type is the offshore atomic energy power plant. In order to plan and design these facilities and to evaluate the impact of their operations properly, both the understanding and the prediction of the wave environment of the shelf is urgently required.

Much work has to be done in order to achieve this goal. The completion of refraction studies in the shelf will be an important step toward this goal. Only after extensive refraction studies have been made will it be possible to study the applicability of extending the wave generation and dissipation mech-

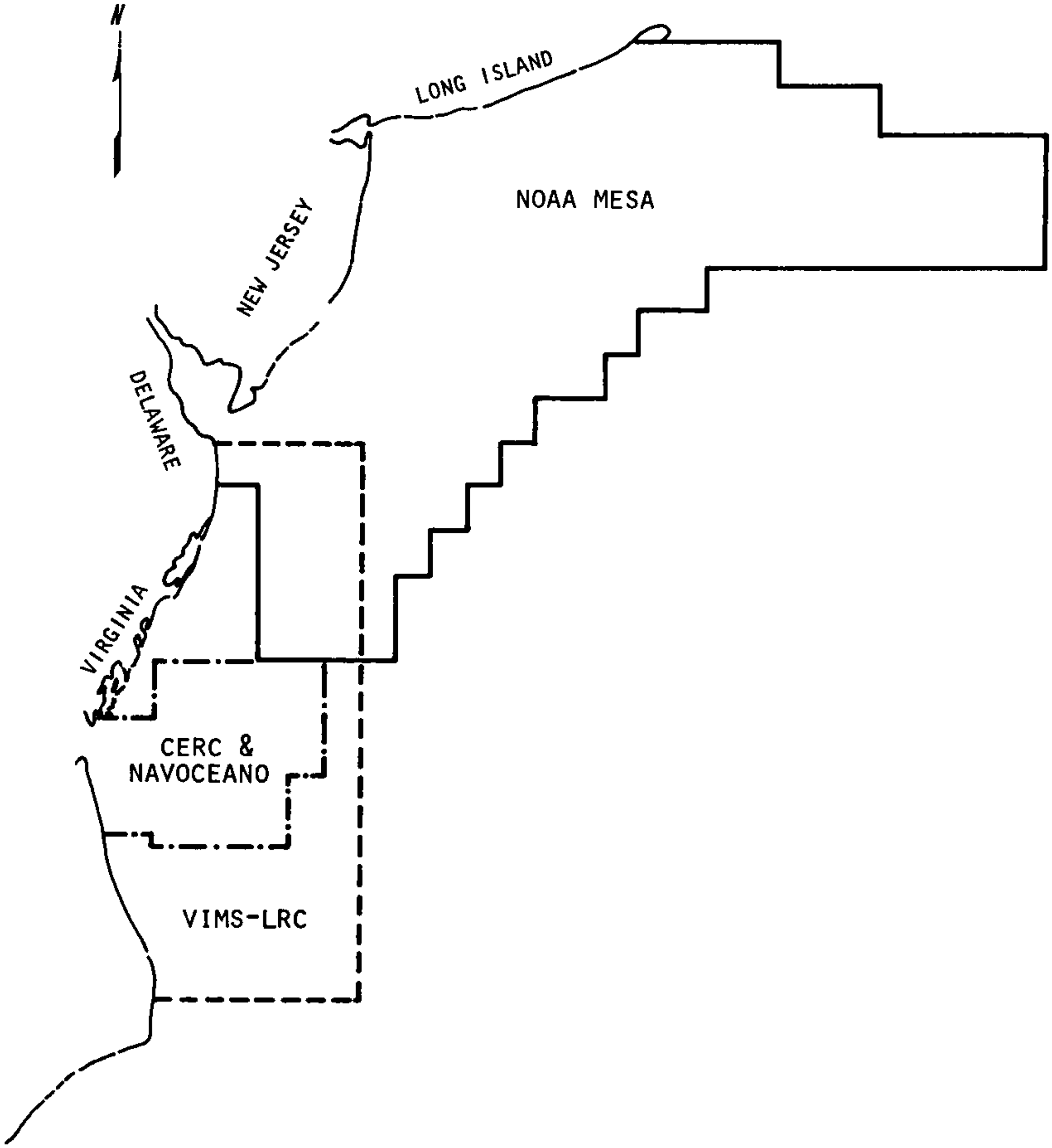

FIGURE 7. REGIONS OF REFRACTION STUDIES

anisms in deep water, which are presently available theoretically and operationally (Pierson 1974, Salfi 1974, and Lazanoff and Stevenson 1974). At that time, a proper modification of theories to suit shoaling water conditions can be made in light of observed data. In addition, only after a careful refraction study may the effect of bottom friction on wave height in water of limited depth be evaluated correctly.

ACKNOWLEDGMENTS

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Mr. Jack A. Koczan suggested that I prepare this paper. His encouragement during the preparation of the manuscript is acknowledged with appreciation. Special thanks are due to Dr. John Cromwell for critically reading the manuscript.

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BEACH DYNAMICS AND SEDIMENT MOBILITY ON SANDY HOOK, NEW JERSEY

by

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INTRODUCTION

Sandy Hook is the manifestation of wave and current processes moving sediment northward into Raritan Bay. The evolution of the Hook causes it to be composed of a series of distinctive beach segments, each experiencing a somewhat different combination of energy and sediment supply. The purpose of this paper is to determine the nature of beach response on the several Sandy Hook beach segments and to identify the degree of interdependence among these segments. This knowledge is required to properly analyze man-induced improvements, such as those suggested by Federal planners for the Gateway National Recreation Area. It is suggested that the relationships among segments may best be studied through general systems theory, where changes in planimetric form (shoreline orientation and position) are the characterizing parameters which describe the conditions of the system. This condition is, in turn, defined as a result of the application of energy (in the form of nearshore processes) acting upon matter (in the form of sediments). Sandy Hook spit may then be viewed as an open system in a steady state. The individual beach segments within the spit system may be viewed as subsystems which, through linkages, define the total system.

The systems approach offers a workable framework for analysis of the effects of implementation of the numerous alternatives available to Federal planners for improvement of Sandy Hook spit as a recreation area under the Gateway project. Once the system and its subsystems are defined, proposed man-induced changes in the energy-sediment budget may be considered as breaks in the steady state conditions and the effects may be studied through the application of strategies available to systems theorists.

SETTING

Sandy Hook is a complex and compound recurved barrier spit located at the northern end of the ocean shoreline of New Jersey (Figure 1). The spit is formed from the northerly transport of beach material derived from the erosion of beaches extending approximately 40 kilometers to the south. Inspection of Figure 1 reveals that the shoreline of Sandy Hook consists of several distinct segments with different rates and forms of development. The spit system may be conveniently broken down for analysis into a set of subsystems, each with differing shoreline orientations to the approach of ocean swell and each experiencing different equilibrium conditions. These subsystems, or beach segments, are identified on Figure 1 as numbers 1 through 7. Certain beach subsystems may be further divided into subunits, identified by lower case letters on Figure 1. Each of these experiences slightly different shoreline development. These smaller subunits are strongly affected by man-made beach protection structures. The effect of these structures in reducing longshore movement of sediment through the spit system is considerable, as revealed in the conspicuous erosion downdrift of the beach protection structures in Segments 1 and 5.

The majority of high energy, deep water waves approach the region from the east-northeast and east (Saville, 1954). However, wave refraction on the inshore portion of the continental shelf causes the shallow water waves to approach from the east-southeast (Fairchild, 1966). This region is also subject to the effects of mid-latitude and tropical cyclones, as well as to

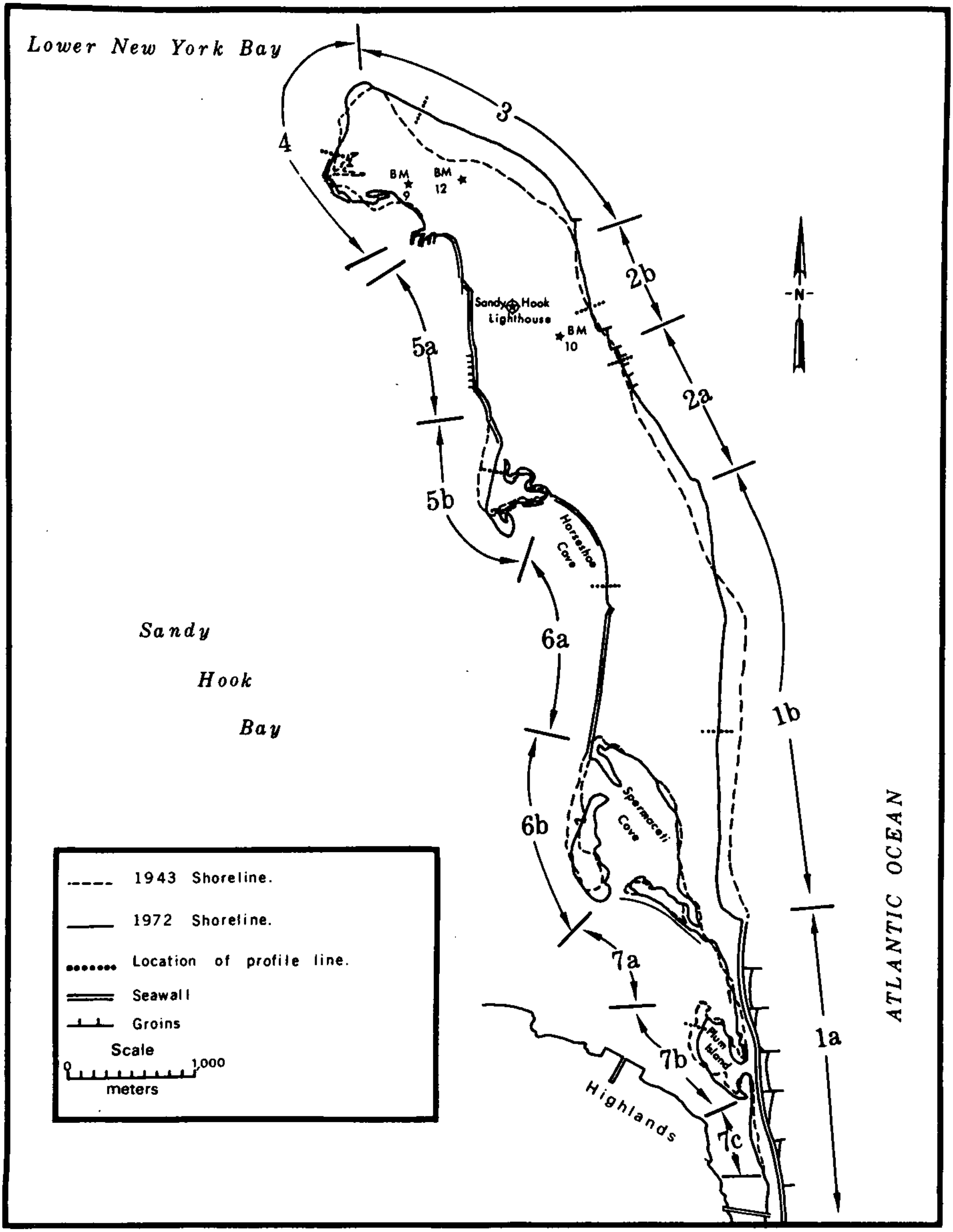

Figure 1. Sandy Hook, New Jersey, showing development of the shoreline from 1943 to 1972.

ocean swell generated by winds far out in the Atlantic Ocean. On the bayside of the spit, the limiting variables of wind speed, duration, and fetch distance favor wave generation from the northwest. Evidence of the importance of these northwest winds is seen in the orientation of bayside beaches perpendicular to this compass direction and also in micro-spit development to the south of these beaches (Figure 1).

Tides at Sandy Hook are semi-diurnal with a 1.4 meter mean range and a 1.7 meter spring range. However, during passage of a storm, strong easterly and northerly winds will pile water against the shore and raise water levels considerably whereas westerly and southerly winds will lower water levels. Foreshore sediments on oceanside and bayside beaches are composed of well sorted sands in the medium size range. The sands consist primarily of quartz particles with less than 5% by weight of potash and sodium-lime feldspars, and less than 1% by weight of heavy minerals concentrated in the size range of fine sand (McMaster, 1954).

Figure 2 identifies the hydrographic features which influence the transport of sediment through the system. The Sandy Hook navigation channel at the distal terminus of the spit is the access route to Raritan Bay and Arthur Kill. It is used by large sea-going vessels and is maintained at a depth of about 10 meters. Periodic dredging of this channel precludes further northward growth of the spit. Channel maintenance, therefore, has a direct influence on the development of Segments 3 and 4. The sediments dredged from the channel are predominately sand and may be used as beach fill.

The spit platform, delineated by the 6-foot, 12-foot, and 18-foot contours, is the subaqueous extension of the headland beach upon which the spit ridge (beach and dune system) has formed.[1] The platform extends out a considerable distance on the bayside and has a filtering effect on the higher bayside waves during low tide. This condition is most pronounced when strong northwest winds occur. These winds generate high energy waves and blow water out of the bay. During such periods, spilling waves may occur across the width of the shelf and a considerable amount of material may be moved alongshore within this broad surf zone. However, the presence of deep coves downdrift of Segments 4 and 5 prevents significant transfers of sediment between segments by this mechanism. False Hook Shoal appears to be the seaward extension of the spit platform formed by ebb tidal currents passing the distal portion of the spit. This shoal affects wave refraction and thus controls shoreline orientation and beach development on Segments 2 and 3.

Table 1 reveals the magnitude of beach processes within each of the subsystems. Table 2 identifies the amount of shoreline change which occurred within each segment from 1943 to 1972. The two tables reveal that bayside beaches are retrograding at surprisingly high rates. This is due to a reduction in the quantity of sediment being passed to downdrift segments, and to higher wave steepnesses.

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[1] A stratigraphic section is given in Minard (1969).

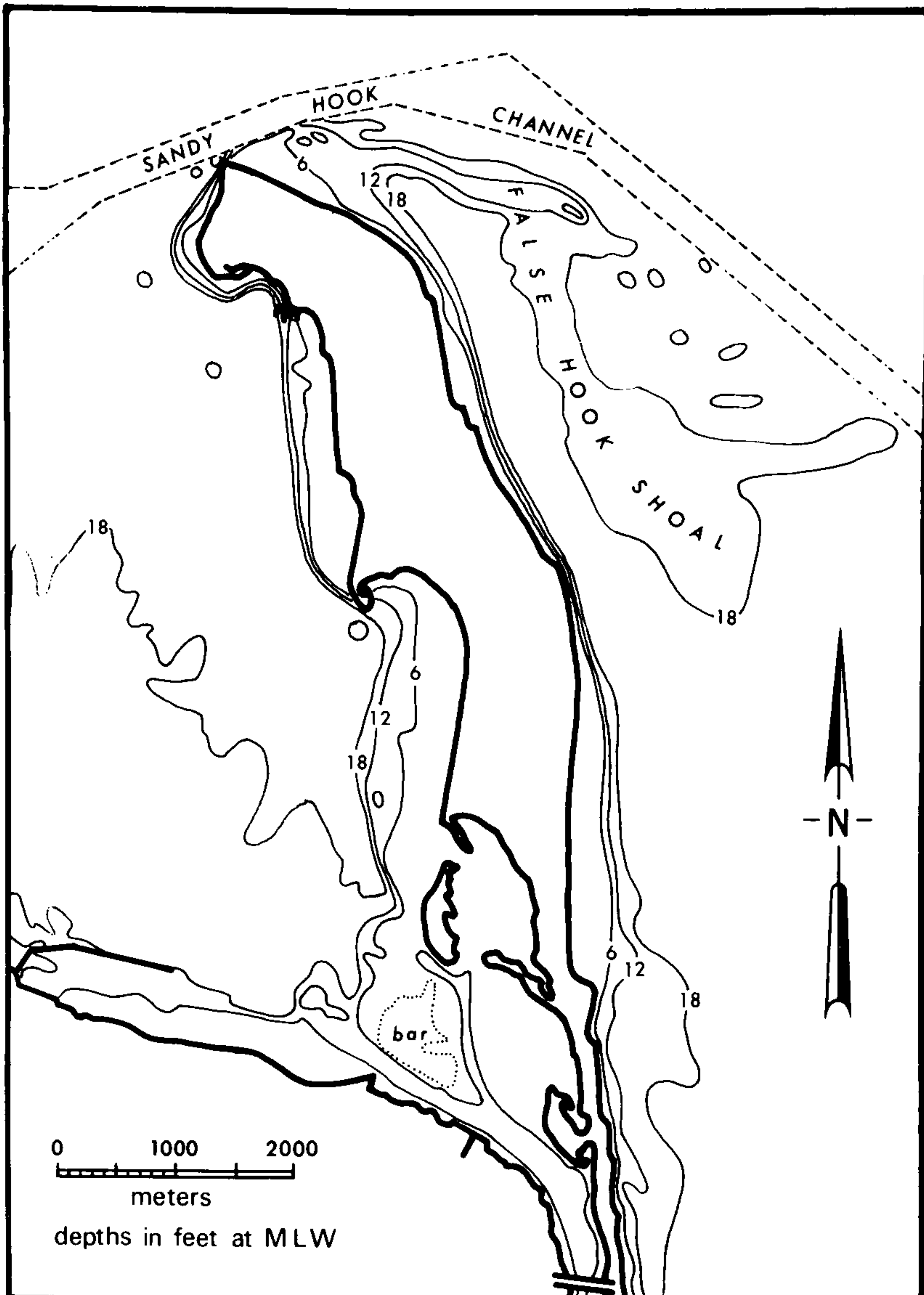

Figure 2. Hydrographic features in the vicinity of Sandy Hook.

Table 1: Averaged breaking wave statistics for sample sites identified in Figure 1. Data for Sites 1b, 2b, and 3 were gathered from July 1971 to April 1973. Data for remainder of sites were gathered from February 1972 to April 1973. No data were gathered on Segments 1a, 5a, and 6b; the data for these segments would be roughly similar to Sites 1b, 5b, and 6a.

	Sites			
Variable (and unit)	1b	2a	2b	3
Days of Observation	121	102	15	25
Breaker period (seconds)	9.7	9.4	9.8	7.6
Breaker height (meters)	0.82	0.58	0.55	0.43
Breaker angle (degrees)	7.9	10.2	9.6	12.2
Breaker steepness (H/L)*	0.006	0.005	0.003	0.005
Total breaker energy (kg.m./m.)**	12,682.3	5,958.5	5,823.8	2,140.9
Alongshore energy (kg.m./m.)**	1,727.3	1,037.9	952.8	493.1
	4	5b	6a	7b
Sample Size	109	106	24	12
Breaker period	3.9	3.6	2.5	2.1
Breaker height	0.21	0.18	0.09	0.06
Breaker angle	11.1	5.7	4.5	9.2
Breaker steepness	0.013	0.013	0.009	0.009
Total breaker energy	134.5	84.2	10.2	3.2
Alongshore energy	25.4	8.4	0.8	0.5

*Breaker height/deep water wave length
**Kilogram meters per meter

Table 2: Change in the location of the Sandy Hook shoreline, by segment, from 1943 to 1972. The values were determined from Figure 1 and represent the change, in meters, along representative lines running perpendicular to the 1973 shoreline.

SHORELINE CHANGE 1943-1972

Site	Along line of maximum change	Average for entire segment	Average for segment per year
1a	+90 meters	+50 meters	+1.7 meters
1b	-190	-153	-5.3
2a	+150	+142	+4.9
2b	+60	+31	+1.1
3	+460	+325	+11.2
4	-90	-20	-0.7
5a	+40	+40	+1.4
5b	-120	-95	-3.2
6a	0	0	0
6b	-170	-104	-3.6
7a	+25	+9	+0.3
7b	-85	-69	-2.4
7c	+100	+43	+1.5

The differences in response to changing wave processes on oceanside and bayside beaches at Sandy Hook have been discussed in detail in Nordstrom (1975). It was concluded that bayside beaches (Segments 4 through 7) appeared to be more in equilibrium with storm conditions than oceanside beaches (Segments 1 through 3). Lower bayside wave energies occurring between storms have little effect on profile development, and foreshore slopes inherited from previous storms undergo minor change. There is little or no deposition between storms. The rate of return is too low to provide adequate protection against dune erosion during the next storm, and dune and foreshore erosion will continue. On the oceanside, in contrast, long, high energy, constructive waves occurring between storms rapidly restore the sediment. These deposits provide a buffer zone to protect the beach and dune against the direct attack of storm waves. The net displacement of the shoreline, therefore, is reduced because of the beach recovery between storm periods.

GENERAL SYSTEMS THEORY

General systems theory offers a conceptual framework for analyzing the diverse processes and forms encompassed in the field of coastal geomorphology. A systems approach to the physical environment focuses on the totality or unity of a defined physical system (in this case Sandy Hook), its internal components (individual beach segments), and its external linkages (related to coastline development). In this sense, Sandy Hook is being studied as a subsystem of the land-sea-air system. The totality of the Sandy Hook system is expressed in energy (wave and current) and matter (sediment) flows that are cycled within the (spit) system or across the interfaces separating this system from other physical systems. The interfaces thus are physical discontinuities, the boundaries of systems. Each system represents the totality or unity of a hierarchy of subsystems each of which has its own internal cycling and external exchanges of energy and matter.

Some subsystems store and slowly use the inputs of matter and energy, whereas in other subsystems there is a continued rapid influx and outflow of energy and matter. This influx and outflow may be periodic or continuous. Each subsystem response is a function of the relative magnitudes of energy and matter that flow through the system and change over time. Storage provides a system with a reservoir of matter and/or energy as a buffer against destruction of system identity. The changing interactions of energy and matter can thus be explained through the use of a time variable. This variable incorporates differing energy applications and matter needs in describing the activity level of the system. Systems analysis thus provides a dynamic, rather than static interpretation of physical environments.

Some physical systems are open systems; they involve the input, transformation, storage, and output of energy and matter across the boundaries of the system. Open systems may take many diverse forms and tend to be highly inter-related. Basic to the concept of open systems is the concept of a steady state. In theory this is an unchanging norm. In reality, however, periodicity in the system creates an oscillating activity level where the resultant of varying inputs of energy and matter defines the equilibrium state toward which the system form develops. Dynamic equilibria may then have upward or downward mean trajectories of activity levels or be constant (the steady state). These are largely maintained by controls referred to as feedback mechanisms and may be of two types: deviation minimizing (negative feedback) or deviation amplifying (positive feedback).

Another type of system is the closed system. In this case, there is no interaction with other systems, no inputs or outputs of energy and matter. The matter may be recycled but the energy diminishes as it performs the work involved in matter flows. In ideal closed systems the dissipation of energy as heat decreases the ability to perform work; this is defined as entropy or how much energy has been lost. All closed systems must eventually run down as their storage of matter and energy reserves are depleted. In nature there are no truly closed systems although it may be convenient to use this framework where matter is being consumed without replenishment even though the amount of available energy is not decreased.

SANDY HOOK AS A SYSTEM

The net sediment migration along Sandy Hook spit is from south to north on the oceanside and from north to south on the bayside. This implies that the movement of sediment from Segment 1 to Segment 7 may be treated as one continuous system with unidirectional flows of energy and matter. Shoreline development within any of the subsystems will then be dependent upon perturbations in the energy-matter relationships in all updrift segments as well as changes in the direct application of energy to the individual subsystem. Perturbations in the system may be man-induced such as the construction or removal of groins and seawalls, dune destruction, or beach fill operations. Natural perturbations, usually associated with storm events, may also occur.

Oceanside beach segments are highly dependent on activity in the updrift segments and yet exhibit distinct differences in form because of variations in wave energy and sediment supply. The ocean beach system is characterized by alternating natural and controlled beaches, and by discrete segmental orientations that differ from the equilibrium logarithmic spiral form.[2] As such, the distinct character of the segments defines complex subsystems within an open ocean system extending around the distal recurve from Segment 1 through Segment 4.

Although the application of an open system model appears suitable for the study of the oceanside segments, it may be argued that the bayside behaves more as a series of closed systems where deep coves and extensive seawalls prevent the transfer of sediment into, or out of, some of the subsystems. This is particularly true of Segment 5. The use of an open system model for the entire spit is not incompatible with bayside beach development, however, since inevitably, such barriers to longshore sediment movement will be bypassed. However, because this paper is intended to establish a model which can be used to solve short-term beach protection problems, Segment 5 will be considered a closed system.

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[2]For a discussion of planimetric curvature as a definition of the state of adjustment of the spit form, see Yasso (1964a, pp. 66-68).

The broad shallow spit platform which extends from Segment 6 to Segment 7 may allow transfers of sediment and this may be considered a separate open system. At present, however, little is known of sediment transfers within this complex region, and this definition is quite tenuous.

Therefore, Sandy Hook spit may be separated conveniently into several units. The highly interrelated ocean beach segments can be considered as an open system. Because of the lack of sediment exchange between the bayside segments, Segments 5, 6, and 7 can be viewed as closed systems.

SEGMENT 1

This portion of Sandy Hook, aligned on a north-south axis, is made up by two distinct subsystems. The southern subunit, 1a, comprises the groin field and seawall protected section. North of this, Segment 1b is a natural unprotected beach whose orientation to storm and swell waves is the same as Segment 1a but the location is offset to the west. The artificially stabilized shore extends south to Long Branch and thus Segment 1a represents an armored barrier spit beach system. Segment 1b can be viewed as being representative of the equilibrium state of the total Segment in the absence of beach protection structures.

Segment 1 is the portion of the spit most exposed to hydrodynamic processes because of the minimal refraction of dominant waves from the eastern quadrant. Energy inputs to this subsystem are therefore higher than to the other subsystems (see Table 1 for wave statistics). Sediment transfers within this high energy subsystem are not correspondingly high because of sediment entrapment in the groin field within Segment 1a. This deficit of particulate matter results in removal of stored sediment from Segment 1b during storms when the energy to sediment disequilibrium exists. Beach profile development in response to erosional and depositional waves is along classic lines and the beach in Segment 1b demonstrates the cyclic form of development noted by Hayes and Boothroyd (1969) on high-energy East Coast beaches (Nordstrom, 1975). Analysis of the sweep zone profiles presented in Figure 3 reveals the beach to be a narrow equilibrium beach with the profile responding to changes in wave energy by sediment migration between the upper limit of swash and the surf zone, with the beach pivoting about an inter-tidal fulcrum.

The cumulative effect of beach processes is the extension of Segment 1b into Segment 2a by both beach and longshore bar drifting processes. In the absence of beach protection structures, high wave and current energies transport a considerable volume of sand alongshore, resulting in conspicuous Segment growth. It is thought that the segmental extension primarily occurs during storm periods when the disequilibrium exists between the alongshore sediment budget and wave energy input. This, in turn, suggests a pulsating sand conveyor system along the oceanside beaches that might be profitably studied through the application of the kinematic wave theory suggested by Leopold, Wolman, and Miller (1964, pp. 212-214).

In the kinematic wave context, the transport rate is minimized when the linear concentration[3] approaches zero. This occurs in low energy states when

[3]Linear concentration at any place is measured by the mean quantity of sediment per unit of distance alongshore.

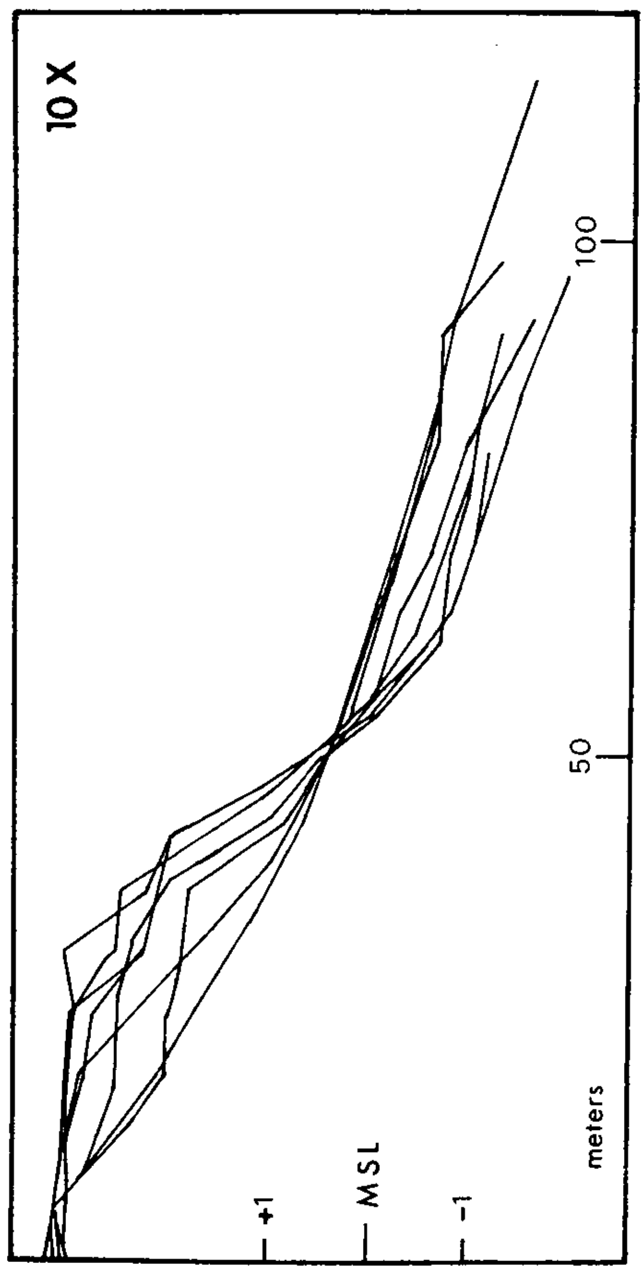

Figure 3. Selected profile lines from Segment 1b. Profile location indicated on Figure 1.

few particles are in motion. The transportation rate is also minimized when linear concentrations are large and sediment concentrations are very dense. This occurs during high energy states when, because of high frictional energy losses, little energy is available for sediment transportation. This condition occurs during the storm stage following the peak erosion of the beach. As storm energy decreases, sedimentation will occur. The location of the deposition will be downdrift of the source area because of sediment movement during the build up of energy prior to maximum concentration. Following sedimentation, the linear concentration is reduced to a point where the transportation rate again is maximized. The kinematic wave theory thus suggests that longshore transport is highest prior to, and just after, the maximum concentration of suspended sediment occurs. This pulsational sediment transport model is much different than the common model of the "conveyor belt" that transports an increasing quantity of sediment with increasing storm intensity and deposits the material when the storm dies out.

The general model of storm-caused sediment pulses can be applied to the segmental extensions along the ocean beaches as the matter linkage between the various subsystems. Allowances must be made, however, for decreasing energy states and man-controlled fluctuations in the alongshore sediment budget and the types of processes that are operative when applying the model to any specific segmental growth. The model also defines the dynamic interfaces across which the subsystems are linked and, thereby, the downdrift limits of each segment.

SEGMENT 2

The orientation and lower energy equilibrium state of Segment 2 has been shown by wave refraction and simulation studies of Sandy Hook (Allen, 1972 and 1973b) to result from the location and northwesterly alignment of False Hook Shoal (Figure 2). This middle shoreline segment is made up of two distinct subsystems. Subsystem 2a consists of a high, steep beach that is planar in form and profile. The beach is sheltered from the major disruptive effects of storms by the offshore bar representing the extension of Segment 1b.

Segment 2a has been studied in some detail by Strahler (1964) and Nordstrom (1975), who noted that the offshore bar favors an equilibrium shoreline configuration. Due to the sheltering effect of the offshore bar, beach erosion does not always occur with the passage of small storms. When erosion does occur on Segment 2a it is not always accompanied by a conspicuous change in foreshore slope as it is on Segment 1. Figure 4 represents selected sweep zone profiles for a sample beach within Segment 2a. The figure reveals considerably less slope variability than is experienced on Segment 1 (Figure 3). The cumulative effect is the deposition of beach material derived from Segment 1b with little change in beach slope and shoreline orientation. The progradation of the foreshore, then, is both parallel and planar.

Segment 2a and Segment 2b are separated by a groin field at the north end of Segment 2a. The groin field prevents beach drift of sand through this portion of the system because the downdrift groins are not quite full. The offshore bar continuation from Segment 1b along Segment 2a terminates at this groin field and therefore does not favor a stable shoreline. The higher wave energies and decreased inputs of sediment to the foreshore result in a readjustment of the equilibrium state of the shoreline from the stable linear form

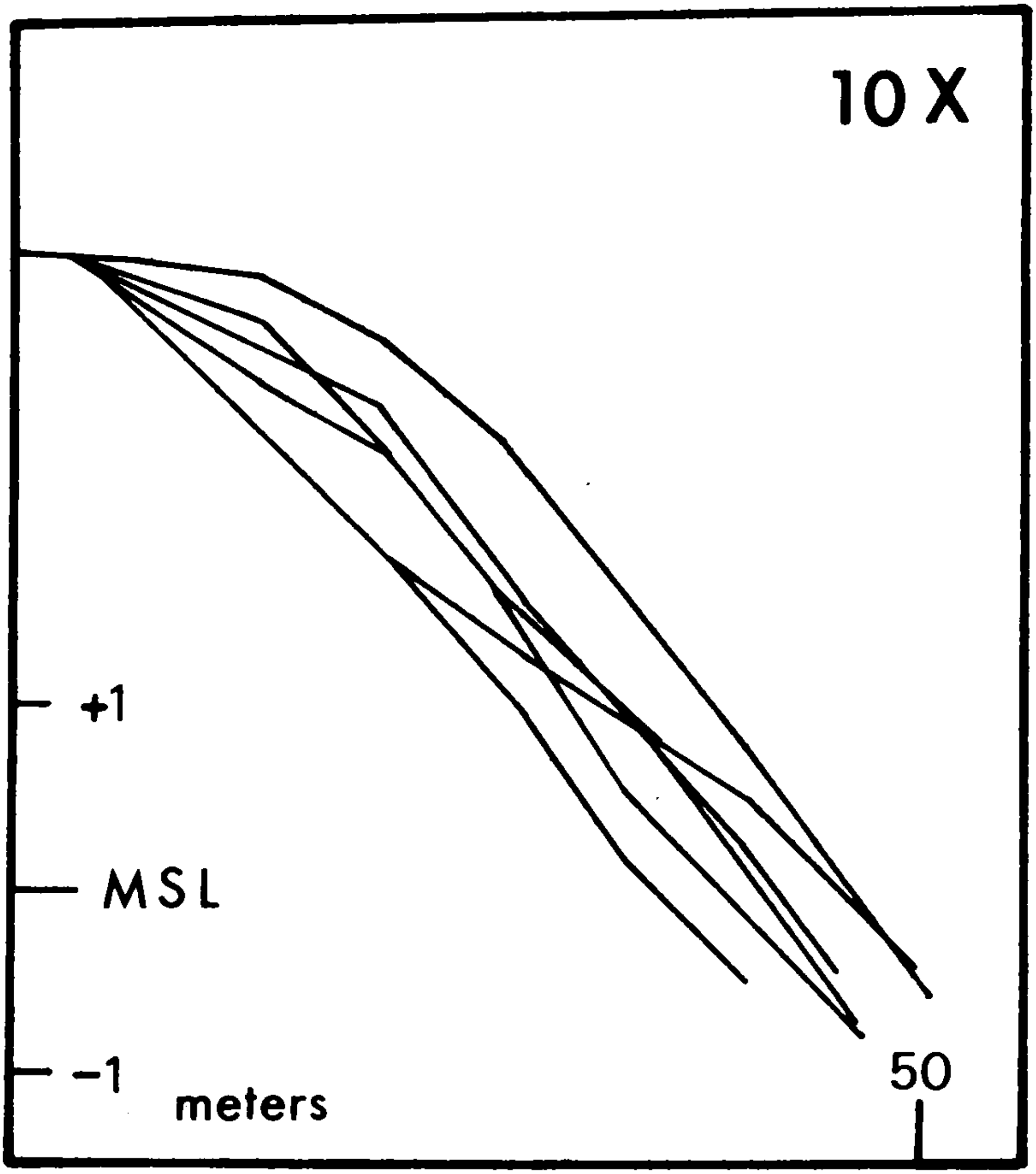

Figure 4. Selected profile lines from Segment 2a. Profile location indicated on Figure 1.

characterizing Segment 2a to the retrograding log-spiral shoreline configuration suggested by Yasso (1964b) for headland-bay beaches. A longshore bar, representing the offshore extension of beach Segment 2a, has recently extended across the reentrant created at Segment 2b. This bar creates a situation similar to that at Segment 2a, and beach response at Site 2b (Figure 5) is similar to Site 2a (Figure 4). The beach has a steep slope with parallel and planar shape dynamics, retreating because of the decreased alongshore sediment supply showing the necessity of the system to maintain itself by drawing on sediment storage within the system. The removal of sand from storage at Segment 2b thus represents the most important source of sediment input into Segment 3.

SEGMENT 3

The northwest extension of Segment 2b has seen the most conspicuous change along Sandy Hook in recent years. Figure 6 reveals a growth of about 360,000 square meters from October, 1969 to September, 1973. In October, 1969 a single micro-spit form is shown arcing from the segmental break. By May, 1970 this had attached onto the shoreline but was breached by lagoon tidal-head energies. Creation of a second spit, curving from the fulcrum of the primary spit is also shown, along with some lagoon infilling from high tide washover. One month later (June, 1970) the size of the lagoon had decreased and the spit had extended. By October, 1970, this second spit had attached its downdrift terminus to the beach of Segment 3. During the 1970-71 winter, the complex lagoon was separated into two parts with connecting flow occurring only at high tide. This was accompanied by further accretion around the distal point of the Hook. The April, 1972 shoreline shows continued lagoonal readjustment from overwash and internal circulation, a general oceanside straightening (with alternate erosion and deposition), and continued growth of the distal lobate beach. Another wedge of sediment, representing a future extension of Segment 2b, also appears to be entering the system. The September, 1973 shoreline shows even further lagoonal infilling and distal accretion. The wedge of sediment from Segment 2b has been greatly enlarged and has resulted in considerable progradation at the arc.

The complex form of the segmental extension is favored by the sharp break in shoreline orientation. Allen (1973a) showed this extreme recurve angle to be a function of extreme wave refraction caused by the very shallow water and the orientation of the north end of False Hook shoal. Field work conducted at this site in the summer of 1970 to determine rates and mechanisms of formation suggested that the primary method was beach drifting. The extreme break in orientation appears to diffuse the longshore component causing general nearshore sedimentation which, in turn, results in spit platform construction. The beach itself shows accretion by swash bar processes and subsequent extension of the spit to close the tidal inlet. Afterwards, the profile development displays continued accretion with little change in foreshore slope (Figure 7). The prograding equilibrium is favored by the low wave energies that, in turn, are constrained by feedback caused by growth of the spit platform. The wide, shallow platform decreases the available ocean swell energy that can be applied to the foreshore. Reversing shallow water currents generated by bay waves and ebb and flood tides also enhance the depositional trend. The general accretion has resulted in a straightening of the shoreline and the promotion of sediment transport through beach drifting in Segment 3. In this sense, the rate of the progradation is lessening with the new shoreline shape, and sediment input for lateral segmental growth along the shoreline axis is increased.

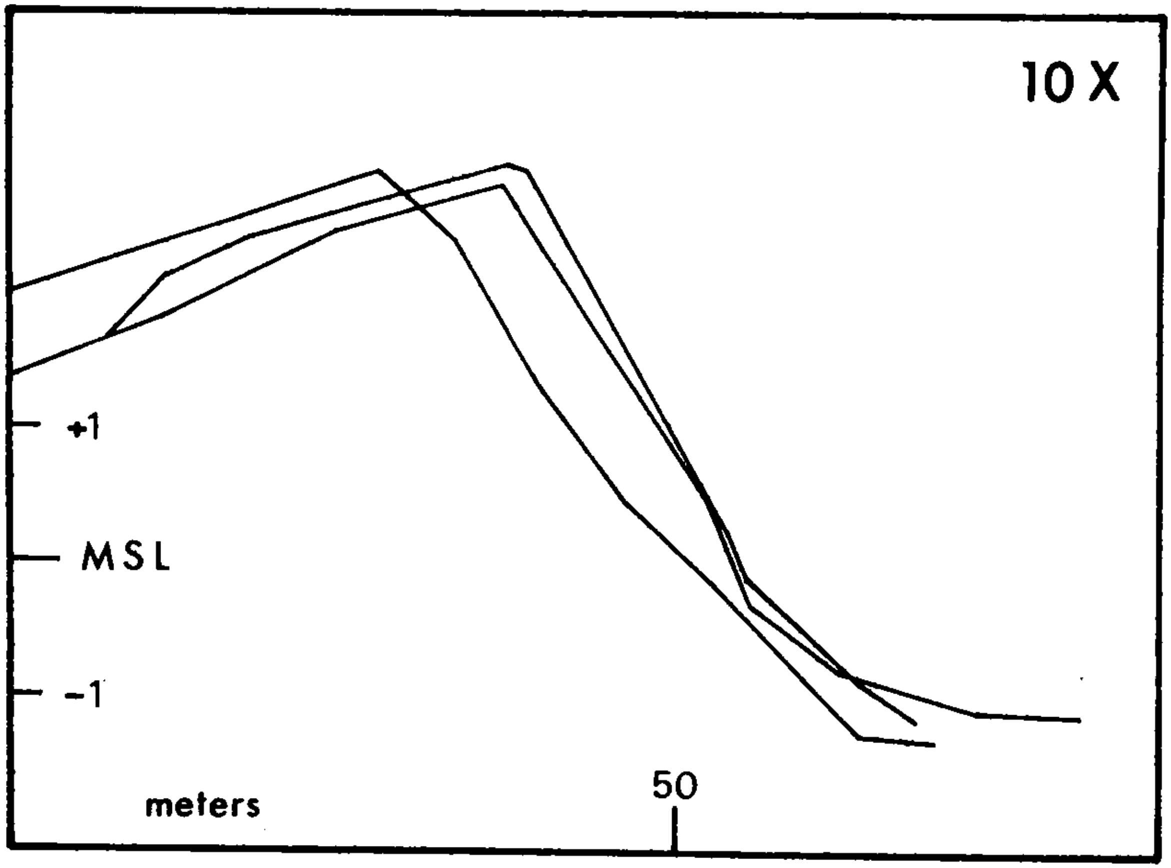

Figure 5. Selected profile lines from Segment 2b. Profile location indicated on Figure 1.

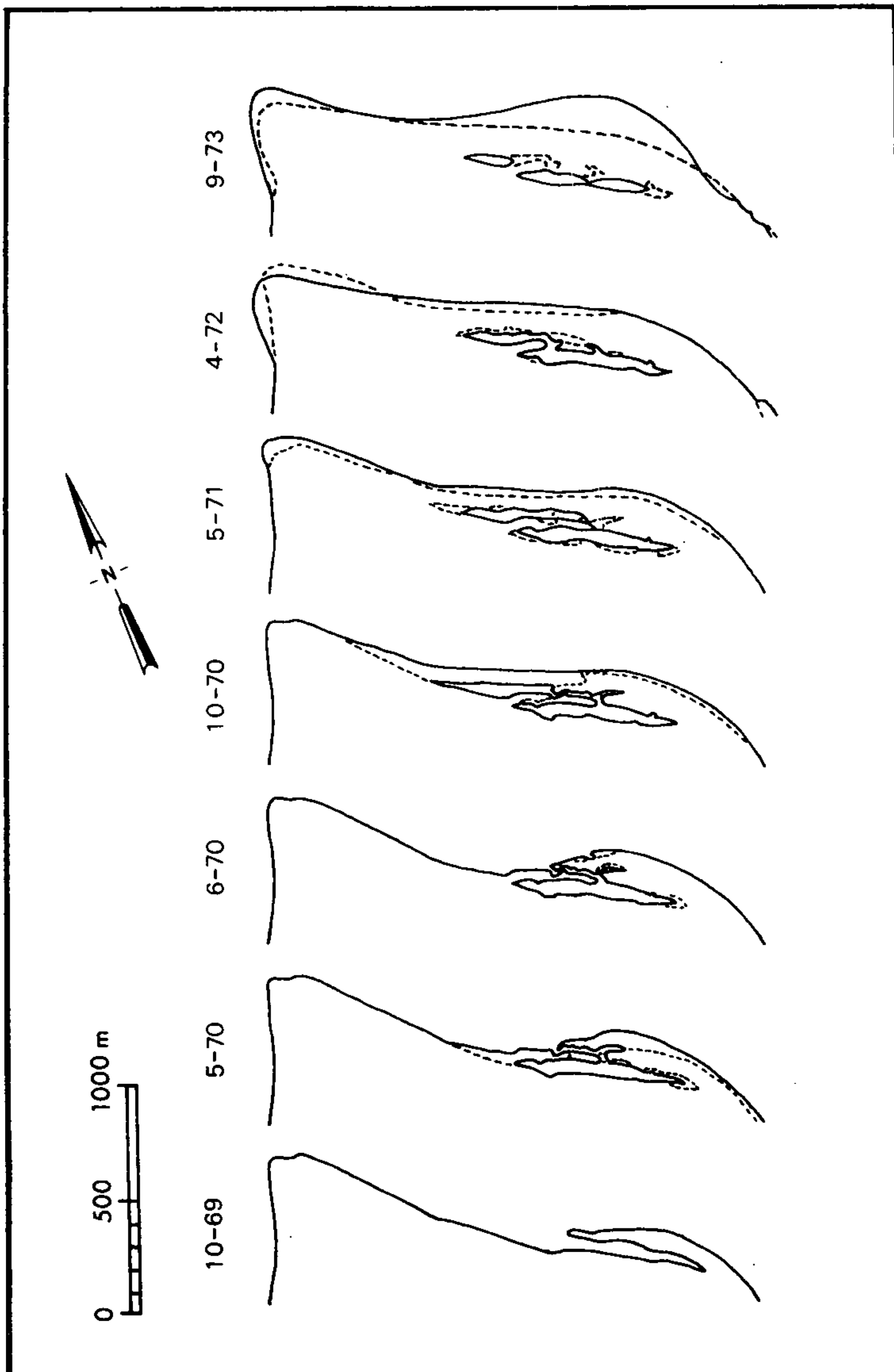

Figure 6. Segmental extension producing accretion in Segment 3, 1969-1973. The dashed line represents the beach outline of the prvious time unit.

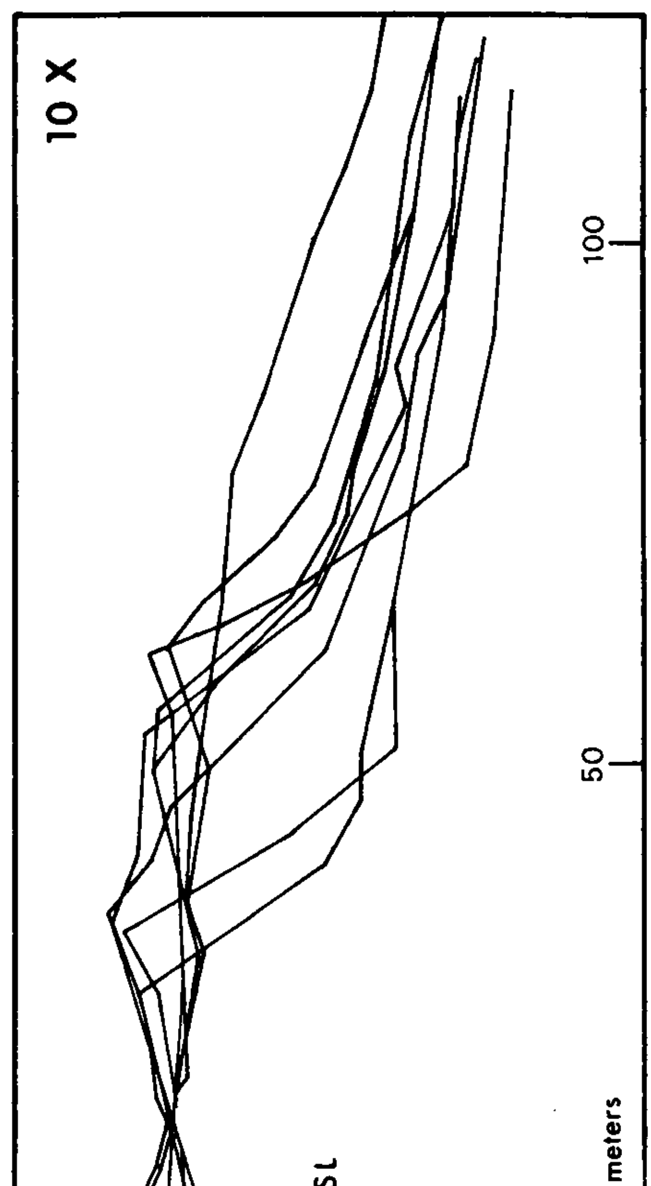

Figure 7. Selected profile lines from Segment 3. Profile location indicated on Figure 1.

The extension of Segment 3 is complicated because of its location at the distal portion of the spit. Not only does it thus represent a partial sediment sink but energy inputs are correspondingly complex. Steep, storm-generated bayside waves may represent higher energy spectra than the filtered ocean swell. NOAA tidal charts reveal high velocity tidal races. All of these in combination appear to modify the segmental extension to a lobate shoal form at the end of this spit recurve. General shoreline advancement appears to result, as in the extension from 2b to 3, predominantly from beach drifting. Spit platform progradation and filling of the Sandy Hook Channel appears to result from nearshore sedimentation from longshore currents. The redistribution of nearshore deposits prevents this area from being termed a true sediment sink in that tidal currents move the outputs of Segment 3 towards False Hook Shoal. This shoal increases the feedback control by filtering ocean swell energy through bottom friction losses and wave refraction. Furthermore, there is evidence that the oceanside system effectively bifurcates at the distal portion of the spit into beach drifting outputs towards Segment 4 and longshore component outputs to the spit platform and eventually towards False Hook Shoal.

The recent extension of Segment 3 is largely associated with recent erosion along Segment 2b (this erosion is not revealed in Table or Figure 2) and, less so, with the erosion at Segment 1b. In future dredging operations in Sandy Hook Channel, much of the dredged spoil may be pumped back to Segments 1 and 2. The implementation of this sediment recycling operation would result in the establishment of a closed exchange of sediment in the ocean beach system.

SEGMENT 4

Despite having the highest bayside wave energies and high wave steepnesses (Table 1), Segment 4 experienced very little erosion over the period from 1943 to 1972 (Figure 1). This is due to the inputs of sediment from Segment 3 offsetting some of the loss through bayside processes. Figure 8 shows selected profiles from Segment 4. The profiles indicate that erosion and deposition occur with little change in foreshore slope, particularly on the lower part of the foreshore. This zone is protected by the shallow spit platform that causes the larger storm waves to break about 150 meters offshore. Considerable quantities of sediment may be moved on the spit platforms during these periods when the surf zone is exceptionally wide. With return to non-storm conditions, the surf zone is limited to a narrow band on the foreshore by low wave heights and the steep foreshore slope.

The cumulative effect of beach processes at this location has been straightening of the shoreline and an increase in the area of the spit platform. The material deposited represents the residual foreshore, dune, and ocean drift sediments. The deep cove, Coast Guard dock complex, and seawall in the northern portion of Segment 5 impede longshore transport out of Segment 4. This segment therefore represents the terminus of the ocean-wave dominated transport system.

CLOSED BAYSIDE SYSTEMS

Along the bayside beaches south of Segment 4, alongshore sediment inputs into each system are insignificant. This is due to both the separation of

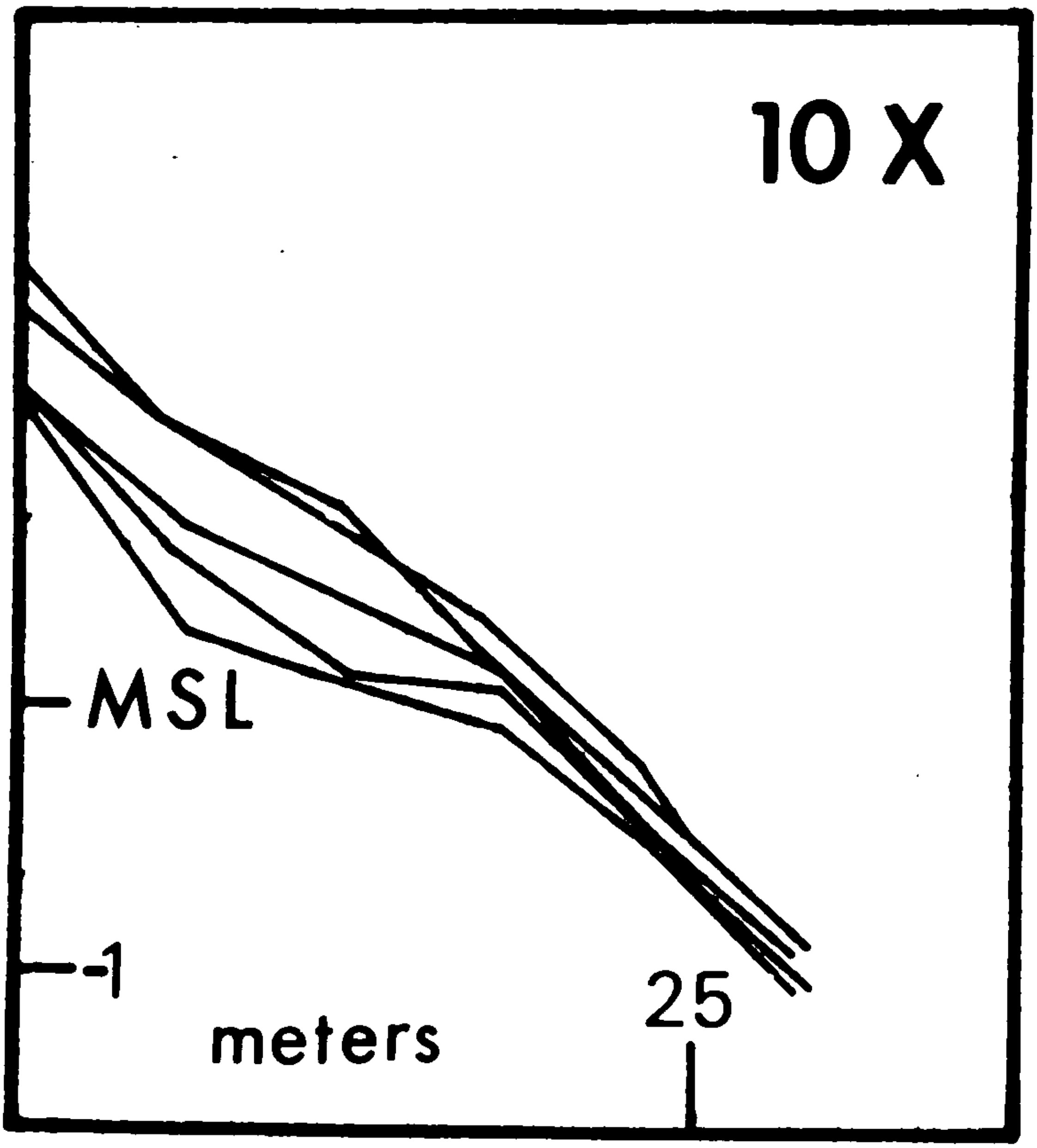

Figure 8. Selected profile lines from Segment 4. Profile location indicated on Figure 1.

each system by protection structures that block beach drifting and the lack of well developed longshore currents. The break in shoreline orientation at the southwest point of each relict recurve also acts as a boundary to each system in the sense that sediment exchange is minimal. Offshore contributions from the spit platform only remain on the foreshore during the summer months and do not offset winter beach losses. The systems 5, 6, and 7 may thus be viewed as closed systems. As such, all matter needs must be satisfied by withdrawal from the beach reservoir.

SEGMENT 5

Segment 5a is protected by a long seawall and there has been no change at this location. At Segment 5b, however, the rate of shoreline retreat is about 3.2 meters per year which is the highest of the bayside beach segments. The erosional imbalance results from seawall construction and is somewhat analogous to that occurring within Segments 1 and 2. Very little beach material passes the seawall to replace that lost in longshore transport and the beach experiences a negative sediment budget. The sediments derived from the eroding shoreline at Segment 5b are forming the prominent spit at the south end of the Segment.[4]

Considering the sharp break in orientation at the tip of this spit and the depth of water in Horseshoe Cove, it is unlikely that much sediment is moved from Segment 5 to Segment 6.

Wave heights on Segment 5b are lower than at Segment 4 (Table 1) and tidal currents are not very well developed on the broad spit platform. The beach accordingly experiences little change as shown in the plotted profiles (Figure 9).

SEGMENT 6

Segment 6 consists of two segments with dissimilar equilibrium conditions as a result of seawall construction. Segment 6a experiences minimal shoreline alteration - largely due to sea wall protection and low wave energies (Table 1). Beach profile development is also minimized through low wave energies and a sheltered position relative to tidal currents. Figure 10 shows selected profiles for Site 6a. The profiles show considerably less change than that which occurs on the unprotected portions of Segments 4 and 5 (Figures 8 and 9) which experience considerably higher wave energies.

Segment 6b has been subjected to extreme shape disruption recently where the bayside spit has been breached (Figure 1). This probably occurred under extreme storm conditions, which, in this case, may be considered cataclysmic. The return to equilibrium conditions is incomplete, pointing out the inability of low energy-low sediment mobility systems to readjust to prior conditions following extreme (low recurrence interval) events. This demonstrates the fragility of the limited oscillatory equilibrium levels of bayside beaches.

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[4]This spit has been described in considerable detail in Antonini (1962), Wright (1962) and Yasso (1964).

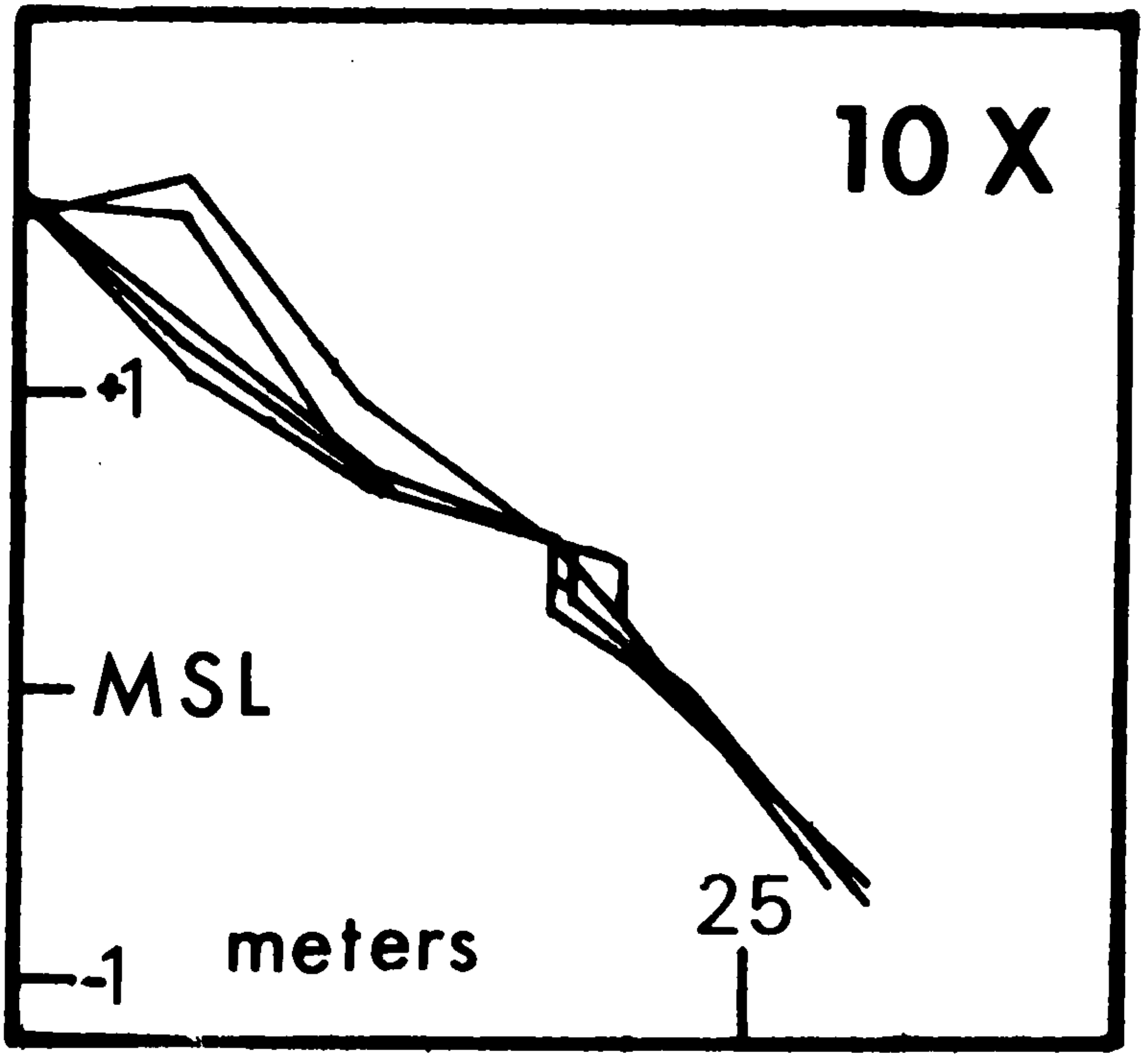

Figure 9. Selected profile lines from Segment 5b. Profile location indicated on Figure 1.

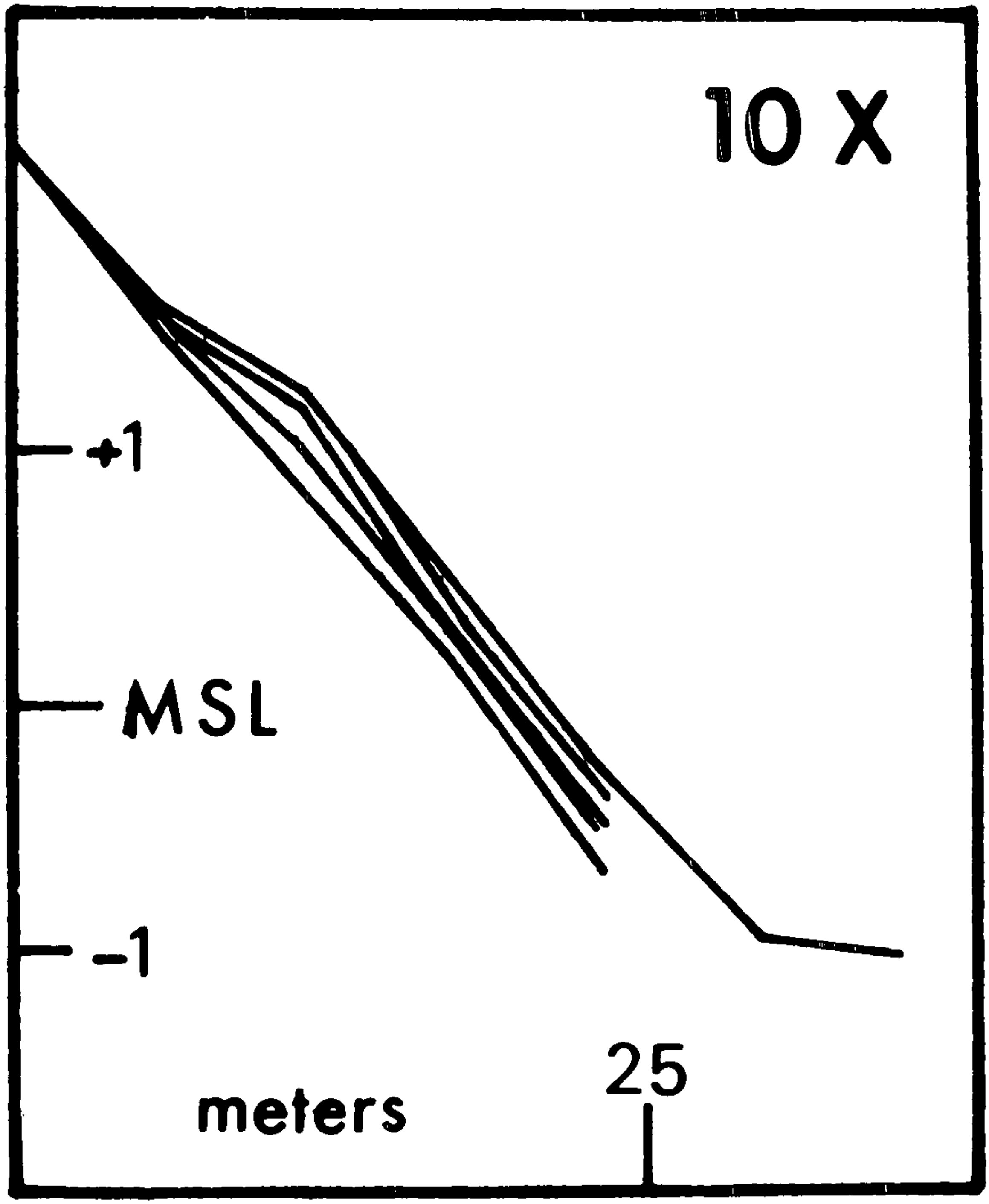

Figure 10. Selected profile lines from Segment 6b. Profile location indicated on Figure 1.

Figure 1 shows some accretion at the breach. This appears to represent storm overwash deposition and subsequent tidal modification with a small contribution from beach drifting. The slight southward extension, however, can be explained by normal wave processes - the shallow inlet would allow for the longshore transport of shelf sediments to the southern terminus of the island.

SEGMENT 7

The shoreline from Segment 6b to 7c represents the interaction of complex tidal and wave processes. Segments 7a and 7c have experienced less change than 7b (Plum Island). This is due to their sheltered position with respect to waves and tidal currents. Plum Island, however, is more exposed to bay waves and, more importantly, to high tidal current velocities. The latter probably account for the rather higher rate of shoreline retreat in this segment compared to the unprotected portions of Segment 6 despite the higher average wave heights on that segment (Table 1). These tidal currents have been observed on the foreshore at 0.28 meters per second during periods when wave action was negligible.

Inspection of beach profiles surveyed at Plum Island (Figure 11) indicates that the beach changes very little in form despite retrogradation. Beach development is, in that sense, similar to Site 5. The cumulative result is shoreline retrogradation with much of the sediment being lost to the spit platform or to spits which have formed to the north and south ends of Plum Island. Spit formation on the north end of the island attests to the importance of ebb tidal currents as mechanisms of sediment transport. The south spit has been shown to be affected by wave and flood tide deposition (Lipman, 1969). Internal tide current gyres also appear to be the mechanism for accretion within Segments 7a and 7c.

BEACH MANAGEMENT PROBLEMS

The value of the application of systems theory in this study of the linkages of Sandy Hook is that information is provided on the sensitivity of the several parts of the spit system. The foundation is laid for an evaluation of many alterations of the spit system proposed for development of the spit into a Federal recreation area. These include:

1. removal or relocation of groins and seawalls;
2. beach fill;
3. dredging of False Hook Shoal;
4. dredging of Sandy Hook Channel;
5. location and character of access roads and park structures.

REMOVAL OR RELOCATION OF GROINS AND SEAWALLS

The removal of groins and seawalls from selected locations along the spit would initiate a return of pre-disturbance shoreline geometry. The removal of the groins in Segment 1a would probably result in a rapid loss of sediment from storage, placing great stress on the sea wall. The system will tend towards establishment of a locational equilibrium in line with Segment 1b. The

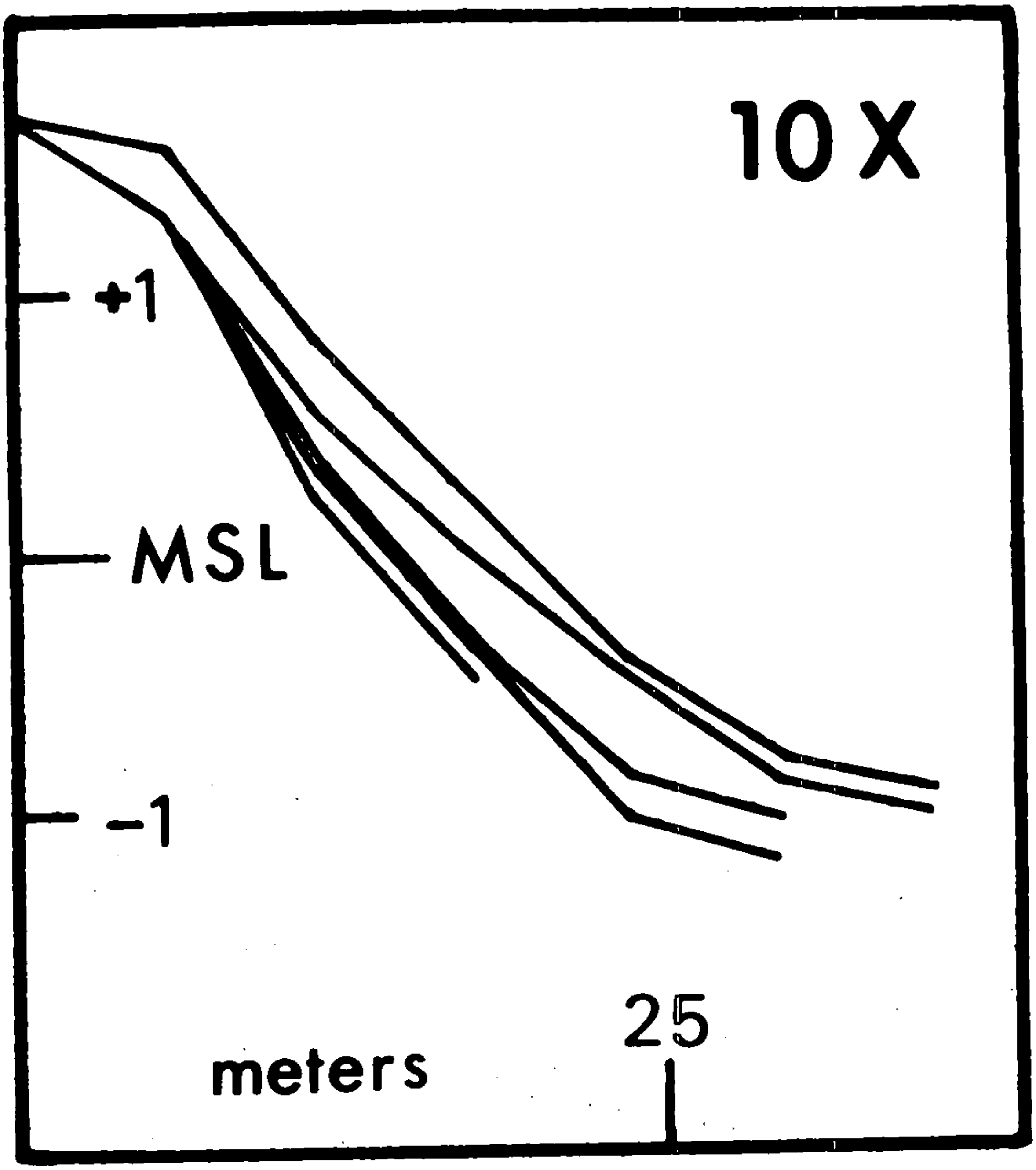

Figure 11. Selected profile lines from Segment 7b. Profile location indicated on Figure 1.

enhancement of alongshore drifting, however, will add to inputs of sediment to Segment 1b and thus buffer Segment 1b from erosion. The inputs from Segment 1a will negate the need for retrieval from storage of sediment at Segment 1b and increase the connectivity between these subsystems. The effects of removal of groins from Segment 2 would be similar to those at Segment 1 with Segment 2b benefiting from increased sediment inputs. Losses from Segment 2a would not be as critical as at Segment 1a however, since the beach would still be protected by the offshore bar discussed earlier. Further, sediment storage is considerably greater here than on Segment 1 which lacks the broad high backshore and prominent dune line.

Some beach protection structures may be necessary for portions of the bayside shoreline where erosion is critical. Each extension of the seawall will lead to a reduction of the erosional zone, but will also reduce the exchange of sediments from one unprotected beach to another. Rock (rip-rap) and other static forms should be viewed as a viable alternative here for protection of buildings and roads. However, the attendant personal safety and aesthetic problems associated with these static forms would limit land use options.

BEACH FILL

Proposals for beach fill in Segments 1a and 1b exist. The result would be that added sediment inputs to Segment 1a will fill the groins (increasing the seawall protection) and enhance beach drifting. Offshore losses, while unknown, might be considerable. Beach fill at Segment 1b, on the other hand, would displace the equilibrium shoreline seaward. Beach fill in Segment 2b would help restore the shoreline of the whole second segment to its pre-disturbance geometry. Beach fill operations at this location are actually planned for the summer of 1975. About 350,000 cubic meters of sediment will be dredged from the navigation channel and pumped to Segment 2b by hydraulic pipeline. Unless the bar and groin field at Segment 2a are altered, however, it is likely that the new sediment will be rapidly removed from Segment 2b as before.

In most cases, bayside retreat does not presently offer a threat to buildings and roads nor does it result in a reduction of bathing space since bayside beaches are, as yet, undeveloped. In some cases (as in Segment 5b where the main road is being undermined), beach protection measures are required, and beach fill offers an alternative. The dominance of erosional conditions on the bayside sites and discontinuity of the closed systems suggest that much of the beach fill would be lost under winter (storm) conditions and not naturally replaced. Sand fill is thus viewed as inefficient.

Beach fill materials may be derived from the navigation channel during maintenance dredging operations or may be derived from any reasonable offshore borrow area. If the dredging operation in the borrow area is carefully controlled, desired changes in the offshore contours may be simultaneously effected. This will introduce changes in wave refraction patterns and thus affect the distribution of wave energy along the coast.

DREDGING OF FALSE HOOK SHOAL

The dredging of False Hook Shoal is attractive in that material which would otherwise be permanently lost to the system could be recycled updrift or passed on to the bayside beaches as beach fill. However, the presence of this shoal is highly associated with the present upper spit shoreline dynamics. Loss of the energy filter would lead to higher energy inputs to System 3 effecting less distal growth. This would appear to reduce sediment transport into the ship channel but with uncertain shoreline displacements. Dredging the northern portion of False Hook Shoal would also theoretically result in a displacement of the distal recurve to the west, thus lessening the problem of channel filling.[5]

DREDGING OF SANDY HOOK CHANNEL

The dredging of the ship channel removes sand from the end of the longshore transport system and provides sand for beach nourishment. However, the spit on the platform and the platform itself will still prograde slowly towards the channel, and dredging offers only a limited solution to channel maintenance. The operation may be integrated, however, into a large scale dredging and recirculation scheme to alter spit system operation to suit the recreational needs of the area.

LOCATION AND CHARACTER OF ACCESS ROADS AND PARK STRUCTURES

As an alternative to permanent coastal facilities which must be protected by standard beach protection measures, limited or temporary facilities (e.g., graded roads rather than black top, removable bath houses) may be constructed which may be dismantled and re-used or "written off." Care should be taken that such structures, when eventually reached following long term erosion, do not form obstacles to sediment transport along the foreshore and introduce undesired perturbations in the natural system.

MATHEMATICAL MODELING

Solutions to the beach management problems discussed above must be tested before implementation. This can be done mathematically through the use of computer models. A mathematical model should dissect the problem into its component parts, analyze the operation of each part and the interactions, and lead to a synthesis of these parts into a working whole. Much of coastal research has shown that exactly predictable relationships of cause and effect are not present in beach activities. Therefore, a simulation of Sandy Hook dynamics must employ a random variable within its component variables. Whereas this inclusion precludes a deterministic prediction of spit behavior, it should add to the general understanding of changes in the form of Sandy Hook.

Simulation of spits is greatly facilitated by the recent development of a spit simulation program, SPITSYM. This program was designed for, and applied

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[5]The displacement of the offshore tidal shoal of a spit towards the proximal portion of the spit has been simulated by computer by King and McCullagh (1972) and Allen (1937b) who point out that the major effect is a tendency for the distal portion of the spit to recurve more sharply bayward.

to, the Hurst Castle spit of the English coast. A discussion of the processes involved in the shaping of the prototype Hurst Castle spit is given in the introduction of SPITSYM in McCullagh and King (1970). Overall, spits around the world result from the longshore deposition of sediments. Therefore, the basic program should be adaptable to simulation of spit activities under a variety of conditions or in any location.

In an existing computer simulation of Sandy Hook (Allen, 1973), the process variables are represented by the program subroutines. Some of the subroutines have been slightly rewritten to account for directional differences in the wave climate of Sandy Hook vis-a-vis Hurst Castle. These gross processes are as follows: (1) spit growth due to alongshore transport (NDRIFT), (2) destructive tropical storm swell from the southeast (HURRIC), (3) erosional "northeaster" waves (NESTRM), and (4) bayside waves (SDRIFT). The effects of submarine hydrography on wave refraction must also be considered.

The present SPITSYM program builds a spit within a 50 x 60 matrix. Each of the subroutines has a probability of occurrence within a total range of one to one hundred. A random number generator provides a number between one and one hundred thus choosing which subroutine (process) will act upon the spit at this stage. The oceanside parameters agree closely with Atlantic wave data frequencies (Fairchild, 1966). Depth and consequent refraction controls further modify the action of a subroutine as to the direction of process operation.

A number of simulation runs are used to refine the subroutine probabilities along with the depth function and refraction control values. Another purpose of iteration is to test spatial responses to changes of process occurrence values, such as a decrease in the littoral drift or refraction changes due to modifications of offshore topography such as shoal migration or dredging. Testing of the effects of subroutine extremes generally coincides with expected results.

The NDRIFT subroutine represents sediment in transit along the oceanside beach system and it produces spit growth. Increasing the probability of HURRIC displaces the spit westward with longer recurves. With a superabundance of steep waves from the southeast, the distal area increases as well. This latter subroutine action provides for backshore deposition through washover fan activity as well as beach erosion. NESTRM simulates the effects of the extra-tropical storms that generate steep waves from the northeast and it aids in the production of the westerly recurved shape. Increasing the frequency of NESTRM slows spit growth at the distal end and enhances recurve activity. Storm action also displaces the spit westward. Bayside erosion and micro-spit accretion typify the SDRIFT subroutine action. The curtailment of recurves and subsequent spits by this activity are brought into the simulation with a probability which represents the smaller energies of the bayside dynamics.

The simulated spit is reproduced in Figure 12. The overall form of the simulated spit compares very well with the form of the real spit (Figure 2) indicating that the subroutine probabilities may be comparable to existing wave energy data for Sandy Hook. Not always do the simulation runs replicate the details of the present outline of Sandy Hook so accurately. Occasional recurves, especially on the proximal portion, intrude far into the bayside. However, this portrayal of recurves may have some validity in the evolution of Sandy Hook. There are several shoal areas on the bayside that might represent remnants of this deposition. The model has another minor distortion because the smoothening of the bayside shoreline by infilling is not duplicated

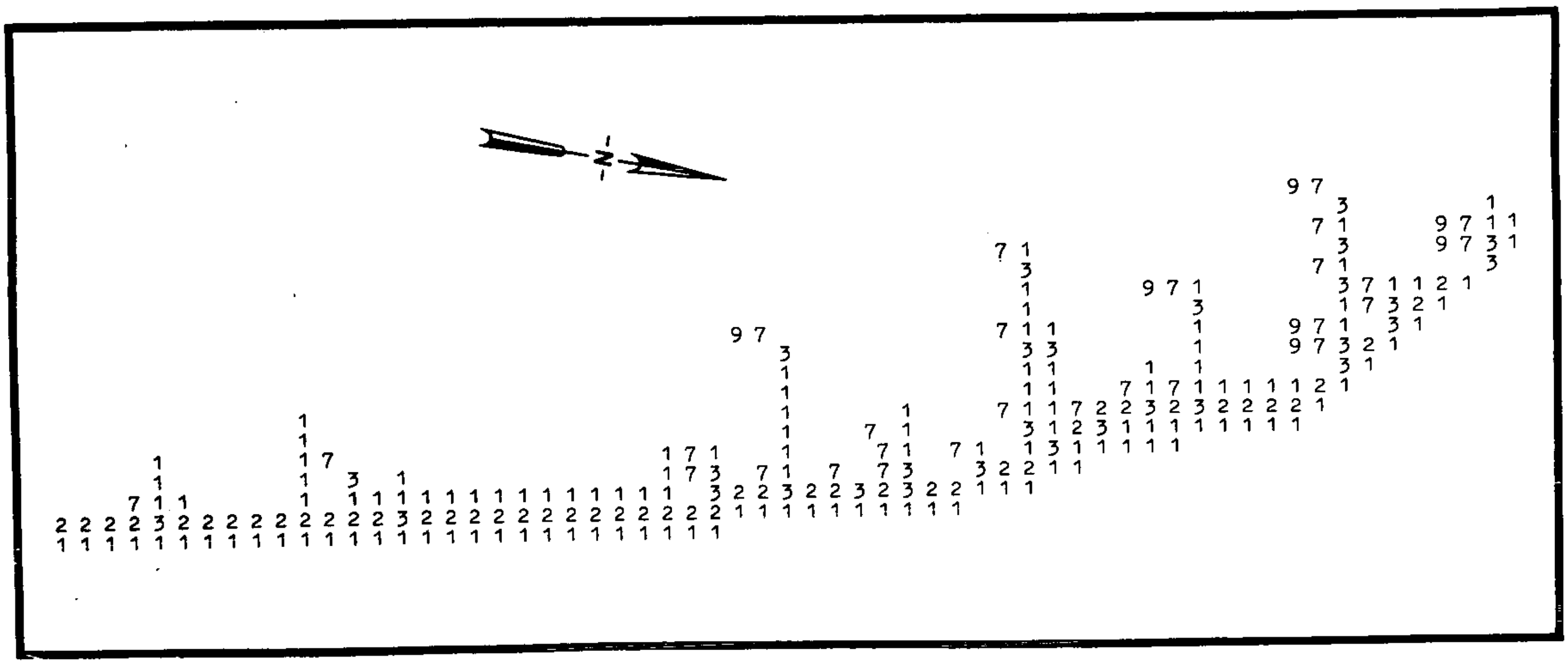

Figure 12. Sample of computer simulation of the development of Sandy Hook. The numbers represent the following: 1 - NDRIFT deposition, 2 - HURRIC displacement of sediment, 3 - spit terminus as base of recurve development from NESTRM and refraction action, 7 - recurve extension by NESTRM and refraction, 9 - bayside sediment movement by SDRIFT.

by the simulation. Hence, some interpolation of the outline is necessary. Notwithstanding these problems, the program seems to accurately replicate the shape and form of the Sandy Hook spit.

Future growth of the spit can be simulated if desired. The program can be altered to simulate the effects of the various beach management alternatives presented earlier, or the program may be replaced by mathematical models which present more detailed information on the subsystems comprising the overall spit system. The success of SPITSYM in reproducing Sandy Hook as a resultant of wave energies acting upon available sediments suggests that, at the generalized level, the stochastic model is a useful tool for spit analysis.

The use of stochastic simulation as a tool of large scale form analysis should also be extended to study individual segments that differ in sensitivity to changes in the processes. The responses of these individual spit segments should indicate the hydrodynamic, morphologic, and sedimentary tendencies towards erosion or deposition that have been noted in the earlier discussion.

SUMMARY AND CONCLUSIONS

The preceding sections have shown how general systems theory offers a conceptual framework for analyzing the diverse processes and forms on Sandy Hook. The spit system is seen to be the result of complex energy (wave and current) and matter (sediment) flows within, and between, several very distinct beach segments. Each of the segments is characterized by different equilibrium conditions resulting from its orientation to ocean swell, winds, and tidal currents. Some of these subsystems, such as Segments 5a and 6a are protected by seawalls and undergo no change. In others, such as 5b and 7b, storage of matter is being rapidly reduced without replenishment. The latter condition shows a tendency toward destruction of system identity, and such segments are considered closed systems. Still other systems, such as 2a and 3 are open systems and there is a continued rapid influx and outflow of energy and matter. Examination of the rate and form of the extension of Segment 2b into Segment 3 indicates that this influx and outflow may be periodic rather than continuous and that accretion and erosion between adjacent segments are highly related, as expected of open systems.

This paper has attempted to define the spit segments and identify the processes and forms which link these subsystems together to form the spit complex. This is viewed as a preliminary step in the development of an applied geomorphological research program to study the specific energy-sediment imbalances and to apply this information to the requirements for the development of recreational beaches on Sandy Hook.

The spit should now be modeled to test each of the beach management strategies discussed above. In the previous section the SPITSYM model was suggested as a possible point of departure. Before such modeling can be accomplished, however, several studies should be undertaken to quantify the contributions made by the several different sediment transport mechanisms to properly describe sediment flows between the subsystems. On bayside beaches, for example, the effect of tidal currents should be isolated from the effects of longshore currents and beach drifting. Contributions of sediment from the spit platform and rates of flow across bayside coves should also be identified, because this would provide considerable information on past processes and would be very useful in calibrating the model of spit growth. On oceanside segments, information is required to identify the relative contribution of longshore currents vis-a-vis beach drifting. Also required is the identification of the critical thresholds within systems, which, when exceeded, result in pulsational transfers of sediment to the downdrift systems.

Once the mechanisms for transport and the quantities of sediment moved are known, recommendations can be made for recycling sediment in the open system of the ocean beaches and for sediment augmentation in the bayside closed systems. Given a calibrated model, it should be possible to predict the effects of different energy levels and different sediment inputs and thus more completely anticipate the future development of the Sandy Hook spit.

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PHYTOPLANKTON BIOASSAYS FOR INDUSTRIAL POLLUTANTS IN THE HACKENSACK MEADOWLANDS *

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INTRODUCTION

If the waters of the Hackensack Meadowlands are to be returned to a more natural and less eutrophic state, the biological effects of each pollutant entering the meadows' waters must be understood. Among the most important living components of the Hackensack Meadowlands that are affected by pollution are the phytoplankton. They serve both directly and indirectly as food sources for fishes and invertebrate aquatic forms such as bivalves and insect larvae along with a host of other aquatic and terrestrial organisms.

An imbalance in the phytoplankton population can result in the destruction of higher forms in the food chain. This occurs because certain types of phytoplankton may not be adequate to satisfy the nutrient requirements of higher trophic levels, and because of the toxic effects of some phytoplankton. Thus, it is essential to a healthy ecosystem that phytoplankton abundance and diversity be maintained.

Phytoplankton can become overly abundant when limiting nutrients are supplied. These nutrients may be by-products of industrial processes (Starr and Carlson, 1968; Lieber, 1970; Lackey, 1950; Wright, 1966), or may be supplied in sewage (Ehrenfeld, 1970) despite passage of the latter through secondary sewage treatment plants. Leachate from sanitary landfills may also supply the limiting factors that produce plankton blooms. The overabundance of phytoplankton adds to the organic burden of an aquatic ecosystem, thereby increasing the biological oxygen demand of the water, a situation which threatens the existence of most aquatic inhabitants.

Some phytoplankton, when present in abundance, produce toxins that are harmful to aquatic life. Examples are the dinoflagellates responsible for the red tide, as well as some green algae, which under certain conditions produce the toxin chlorellin.

Low numbers of phytoplankton, a condition which may be caused by some industrial pollutants (Deubert and Demoranville, 1970; Fonselius, 1970; Parker, 1970; Aoki, 1970; Harris, White and MacFarland, 1970), result in a double threat. First, Those organisms that depend on them for food will be unable to survive. Second, their absence and the absence of their photosynthetic by-products results in a corresponding lowering of oxygen levels in the water. The latter condition discourages the rapid degradation of organic materials and encourages the accumulation of detritus. These organics in turn are acted upon by anaerobic bacteria which produce noxious hydrogen sulfide and methane gases.

In summary, abuse or drastic alterations in the meadowlands' phytoplankton populations will result in a further disordering of the entire salt marsh ecosystem. Conversely, the return of the phytoplankton population to a state of normalcy will enable the meadowlands to become a more natural and productive ecosystem.

The bioassay procedure reported herein has its principal value in serving as a basis for establishing ecologically relevant guidelines for regulating the admission of pollutants into the meadowlands' hydrologic system.

MATERIALS AND METHODS

Chemically defined basal media were used to support the growth of each phytoplankton culture for the purpose of the bioassay. All media were prepared from reagent grade chemicals and were autoclaved at 15 lbs. pressure for 15 minutes. Glassware used in the assay was chemically cleaned.

All effluents tested were collected in the Hackensack Meadowlands:

Effluent E_1 was obtained from the discharge pipe of a metal finishing factory.

Effluent E_2, the landfill leachate, was a water sample taken from a creek adjacent to a sanitary landfill.

Effluent E_5 was obtained from the discharge pipe of a metal plating factory.

Effluents which contained oil as a major or minor fraction were allowed to stand at 5°C. for several days prior to use to assure that compounds which are mutually miscible with oil and water, and which may significantly affect phytoplankton populations (American Petroleum Institute, 1935; Kupzis, 1902; Fonselius, 1970) would have their effects accounted for in the assay procedure.

The temperature for the biassay and an analysis of the effluents dilution effect on phytoplankton growth were determined in preliminary experiments. Proper regulation of these conditions assured that the phytoplankton would respond to the assay in a manner which would closely reflect their response in the natural habitat.

Effluents added to the chemically defined basal media were added in concentrations of 0, 0.1, 1, 5 and 20 ml%. The media were then inoculated with the test organisms and incubated in a Forma B-line growth chamber, with a regulated photo period provided by cool white fluorescent lights. Growth was determined with a Bausch and Lomb Spectronic 20.

SOURCE OF CULTURES

Water samples from which phytoplankton isolates were taken were obtained from several sites which ranged in character from the Hackensack River to various creeks, mosquito and drainage ditches and small ponds and "mud holes." These areas represent a wide variety of habitats and provided us with algal populations representative of the meadowlands.

IDENTIFICATION OF CULTURES

Phytoplankton cultures were identified by Dr. Joseph Cassin as follows:

Culture I
- a) small green forms with 1 flagellum - unable to assign a genus
- b) Biflagellate - green form with cell wall - Chlamydomonas?

Culture	III	Naviculoid diatom, pinnate: Cocconeis?
"	IV	Naviculoid diatom, pinnate: Navicula
"	V	Chlorococcaceae, possibly Chlorella
"	VIII	2 forms present: a) large form fits Chlamydomonas b) small form
"	IX	Chlamydomonas, sp.
"	XIII	Amithitrora
"	XIV	Biddulphia or Cyclotella - probably Cyclotella sp
"	XV	Amphiprora group of the Pinnateae
"	XX	Skeletonema costatum or Leptocylindrus of the Rhizosolenia group. Probably Leptocylindrus

RESULTS AND DISCUSSION

Effluent E_1 - Metal Finishing Factory

E_1 at 0.1% significantly stimulates the growth of Culture V (Fig. 1) but does not increase the growth of any other culture when compared with the control. At this concentration of effluent this chlorococcoid algae is likely to become the dominant phytoplankton. This may result in toxic chlorellin production which can affect the area in terms of reduced bacterial and invertebrate populations. This alone, or in combination with the possibility that the effluent may interfere with respiratory mechanisms (due to clogging of gills by the emulsified lipid that characterized the effluent), could drastically affect the ecosystem in which it is present.

Species diversity is reduced considerably by 1% of E_1 (Fig. 2). When species diversity is reduced, the ecosystem is subject to violent changes from factors that normally would cause only minor alterations in the complexion of the system. Because of the sparcity of primary producers that would occur in the presence of 1% E_1, the selection of food organisms by grazers is limited to few organisms. Further alteration of the phytoplankton populations by any number of normally inconsequential factors may leave the grazing populations with an unpalatable food and, therefore, ensure the destruction of one of the key components of a balanced system, the primary consumer populations.

The 5% and 20% concentrations of E_1 severely limit all the phytoplankton isolated from the meadowlands to growth levels of zero to one quarter that of the control.

It is reasonable to suspect that the detergent component of the effluent is responsible for some of its lethal effects, since surfactants

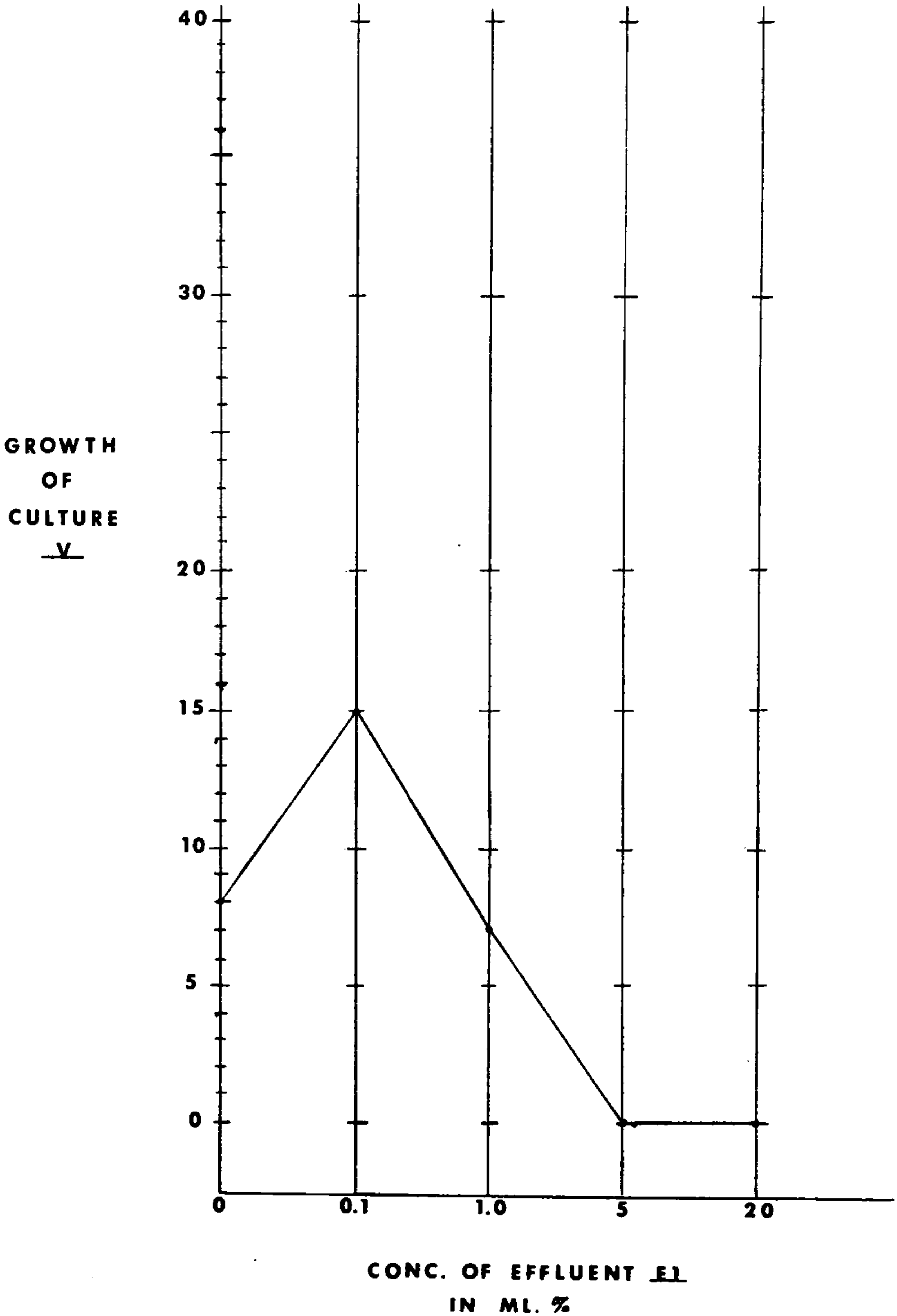
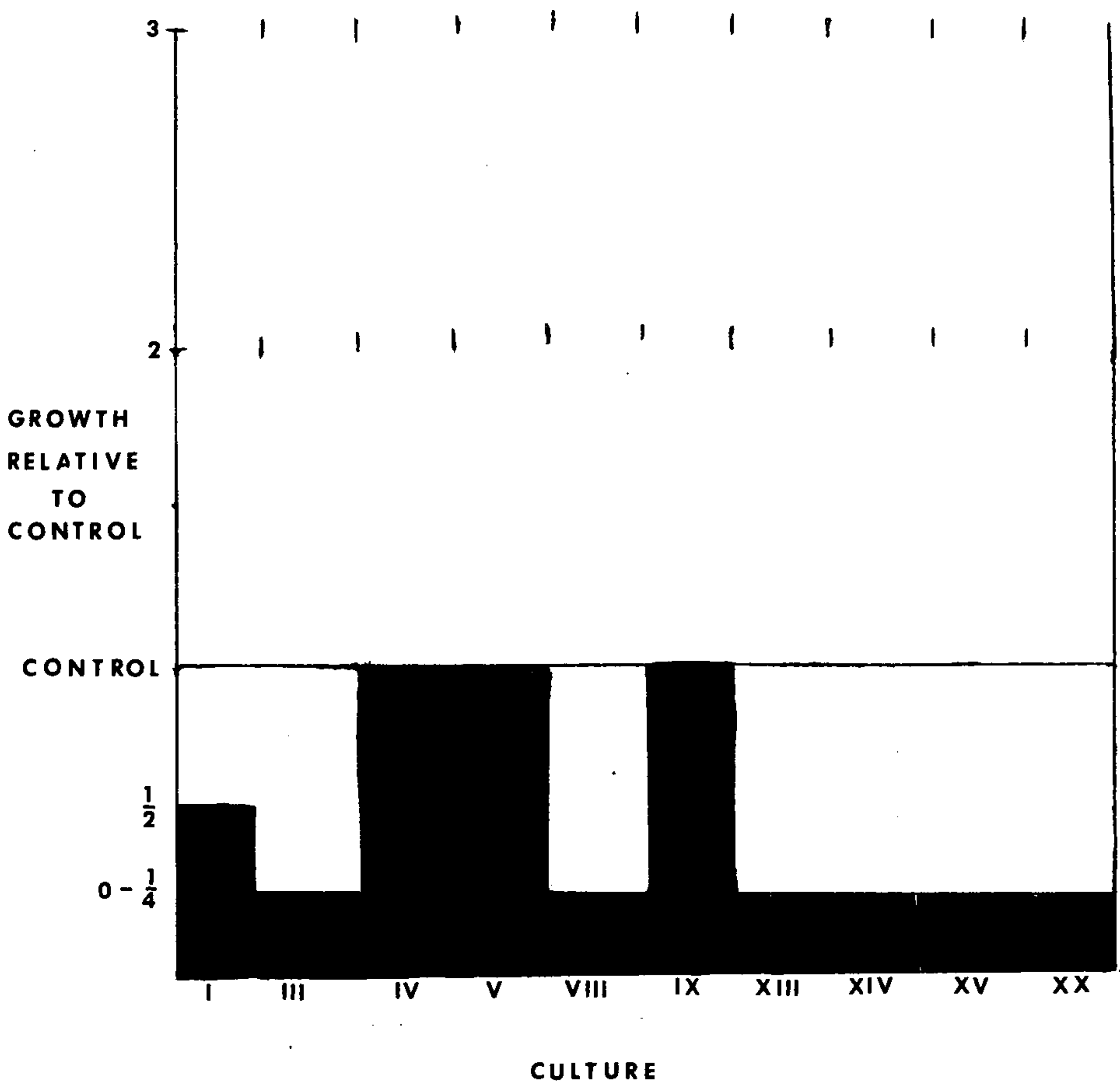

40
30
20
15
10
5
0
GROWTH
OF
CULTURE
V
0
0.1
1.0
5
20
CONC. OF EFFLUENT E1
IN ML. %

FIG. 1



EFF UENT E1
CONCENTRATION 1%

FIG. 2

in very low concentration have been reported to severely inhibit some phytoplankton (Davis and Gloyna, 1969). Whatever is the specific damaging factor, it is evident that all concentrations of the metal finishing factory effluent, considered as a unit, negatively affect the phytoplankton in the meadowlands. Therefore, it would be advisable to prevent this effluent from being released into the meadowlands waterways. If a future bioassay analysis of each component of the total effluent identifies a particular offending component, then neutralization of that component alone will render the effluent's effects ecologically insignificant, and it should then be permitted to enter the meadowlands.

In this manner, large expenditures for disposing of the total effluent would be made unnecessary, a fact which may represent a substantial economic saving when compared with alternate disposal or treatment methods.

Effluent E_2 - Landfill Leachate

In low concentrations, the landfill leachate, E_2, has no gross effect on any of the phytoplankton populations. However, at 5% (Fig. 3) two of the phytoplankton cultures (I and III) indicate a growth response that is two times the growth response seen in the control, and two of the phytoplankton cultures grew three times better than the control.

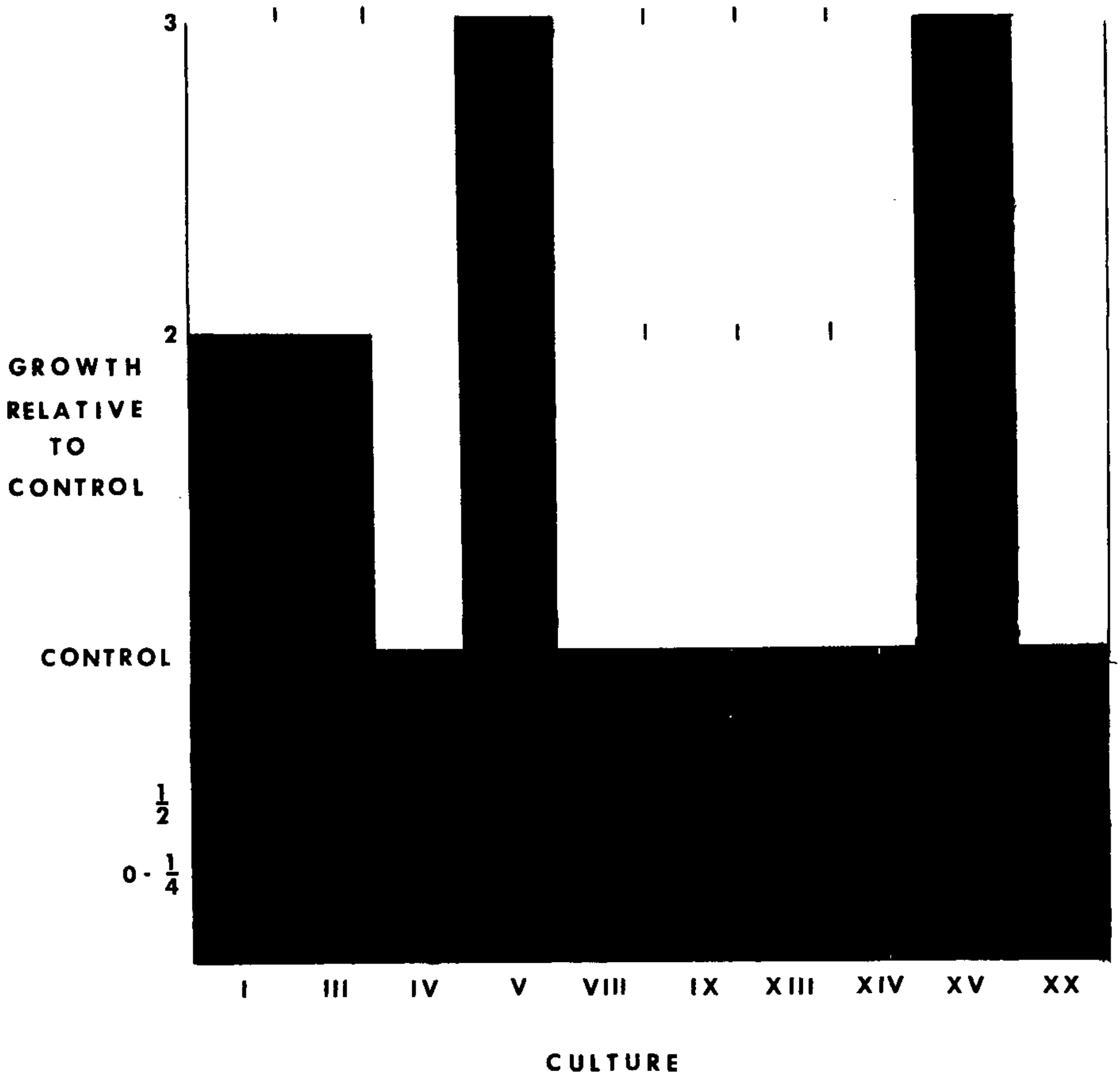
The response to this organically enriched leachate may be due to the heterotrophic potential of these organisms or it may be due to an effect in which the leachate supplies a metabolite ordinarily synthesized by the organism through intermediary metabolism. Similarly, at the 20% concentration of E_2 several of the cultures attain extraordinarily high growth as compared to the controls (Fig. 4).

The stimulation and subsequent return to normalcy of the growth response of Culture XV as the leachate concentration is increased from 5% to 50% (Fig. 5) may be indicative of inhibition at the highest concentration by some component of the leachate such as heavy metals. Similar inhibition occurs with Culture XX.

Cultures subjected to increased concentrations of E_2 respond differently, revealing different physiological preferences. Cultures I (Fig. 6), III, IV, and V show increased growth response with increased concentration of this effluent. On the other hand Cultures VIII (Fig. 7), IX, and XIII are relatively unaffected.

Overall, the phytoplankton response to the higher concentrations (5% and 20%) indicate that species diversity is reduced (Figs. 3-4), a fact which, for reasons already given, is deleterious to the ecosystem. It must be emphasized that the meadowlands probably has less phytoplankton diversity than does a similar estuary which has not been previously subjected to the stresses of pollution. Thus, any further reduction in species diversity carries with it more severe consequences than it otherwise would.

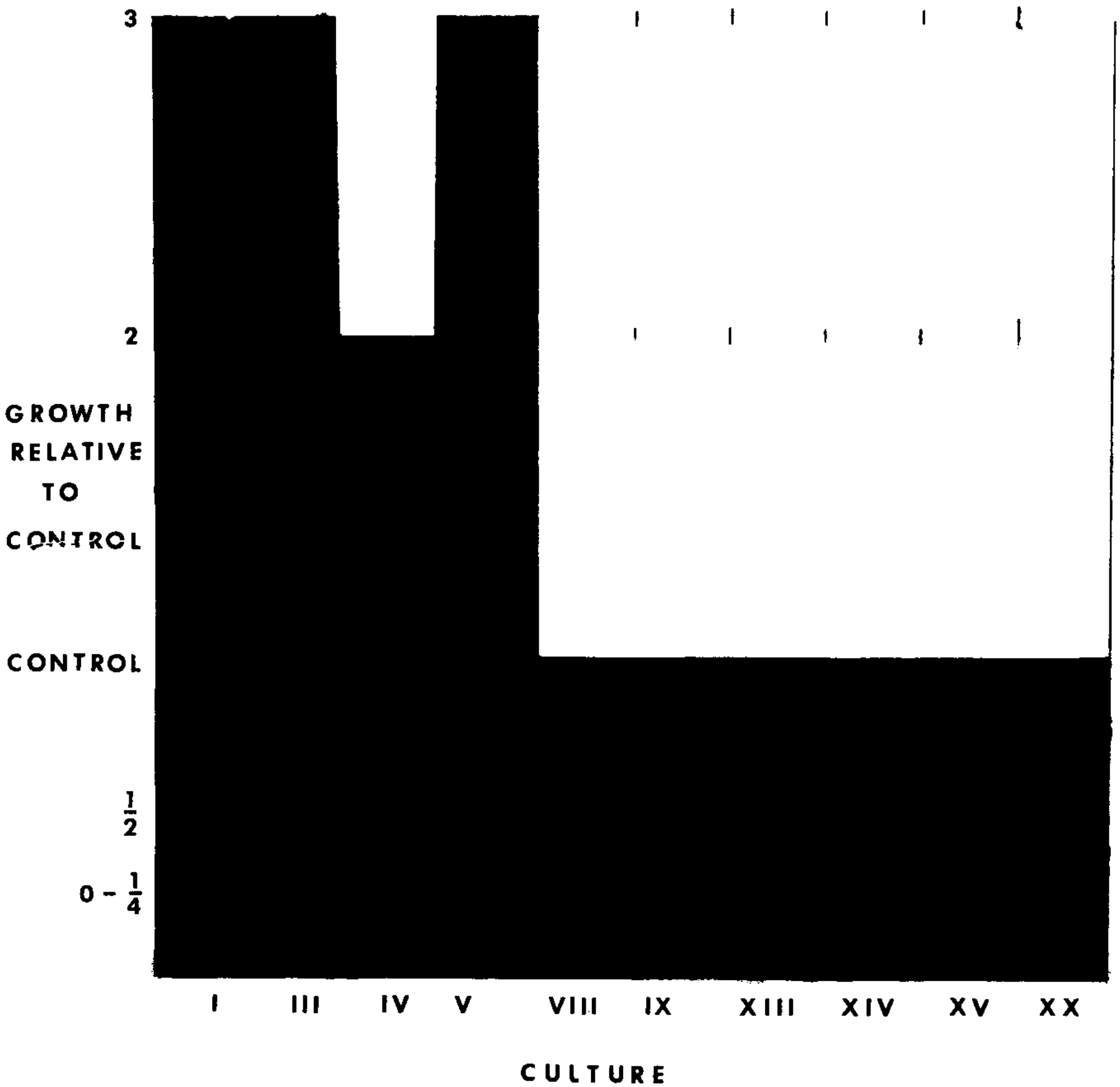
The increase in growth of selected phytoplankton that are favored by the landfill leachate adds to the B.O.D. of the already organically overburdened area surrounding the landfill, and therefore is detrimental to



EFFLUENT E2

CONCENTRATION 5%

FIG. 3



EFFLUENT E2

CONCENTRATION 20%

FIG. 4

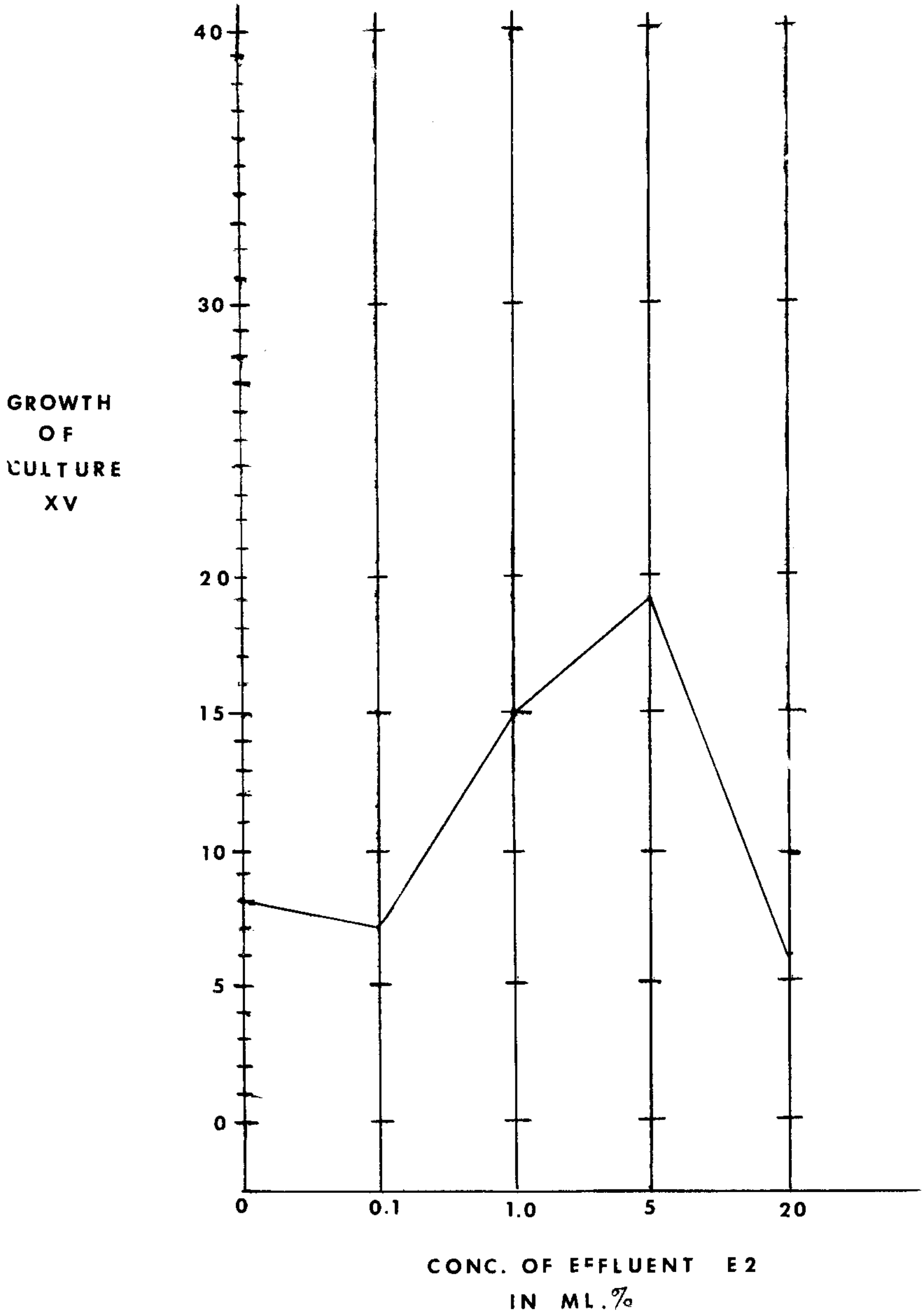

40
30
20
15
10
5
0
GROWTH
OF
CULTURE
XV
0
0.1
1.0
5
20
CONC. OF EFFLUENT E2
IN ML.%

FIG. 5

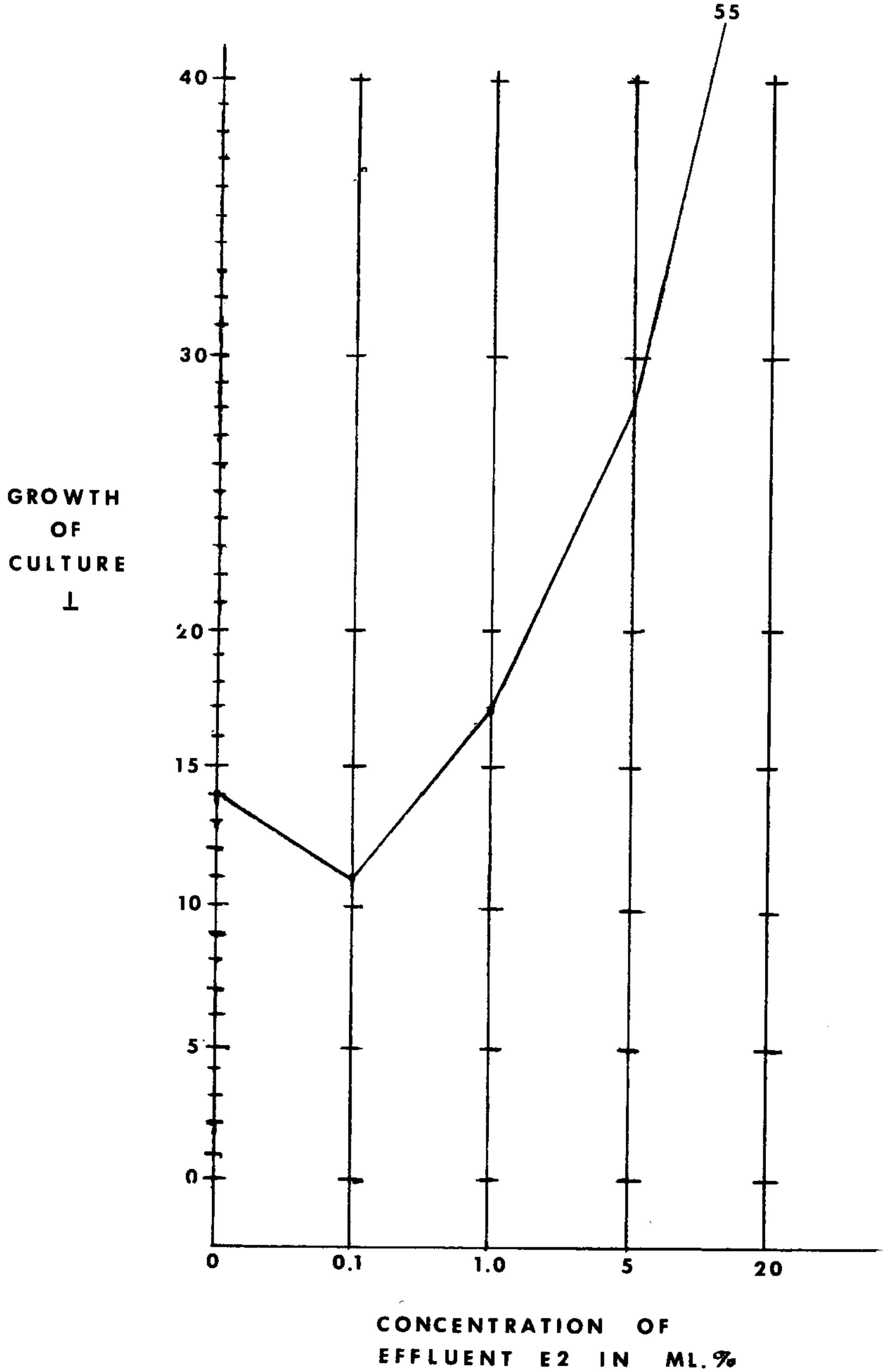

55
40
30
20
15
10
5
0
GROWTH
OF
CULTURE
⊥
0
0.1
1.0
5
20
CONCENTRATION OF
EFFLUENT E2 IN ML.%

FIG. 6

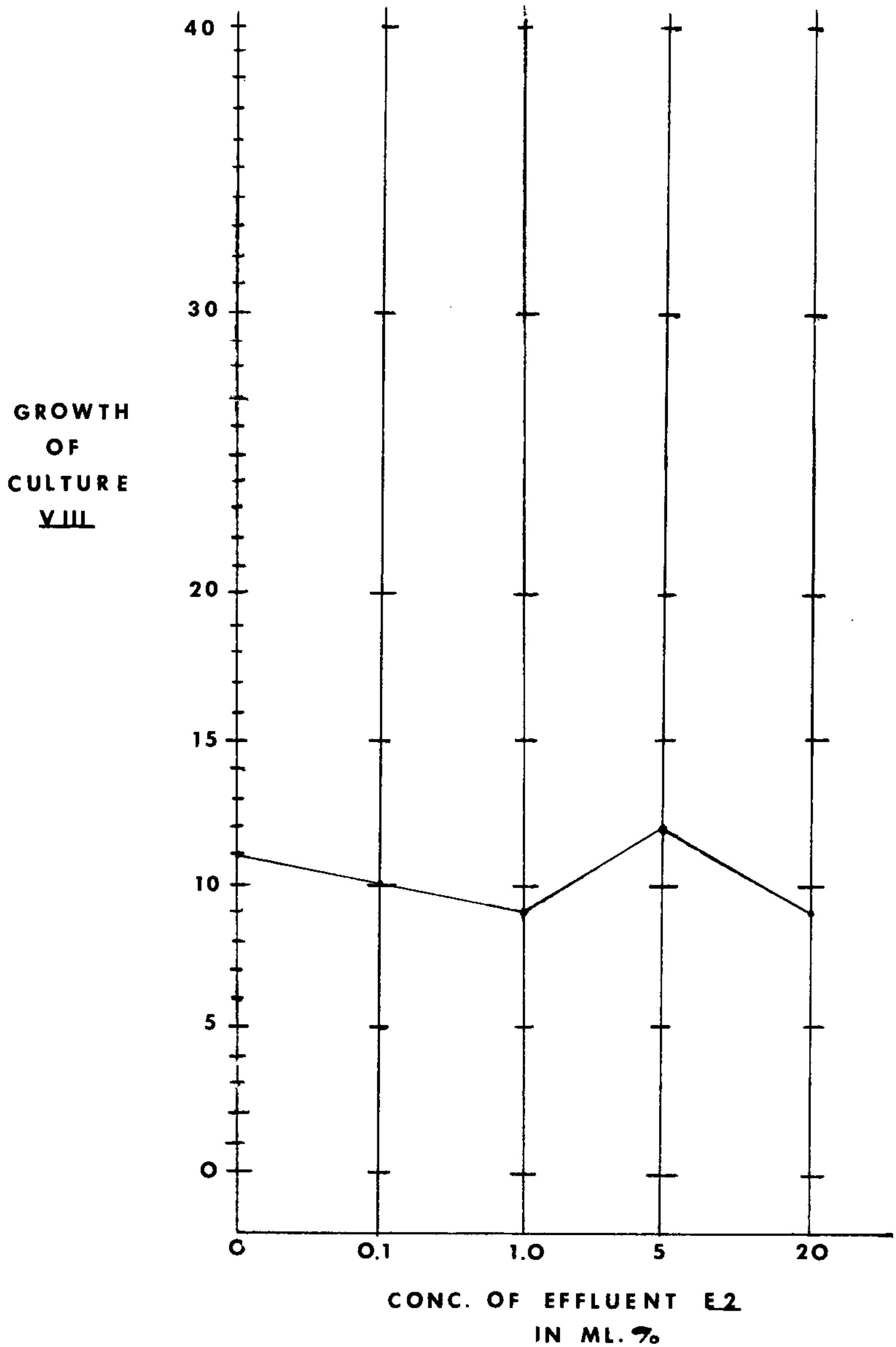

40
30
20
15
10
5
0
GROWTH
OF
CULTURE
VIII
0
0.1
1.0
5
20
CONC. OF EFFLUENT E2
IN ML.%

FIG. 7

this area. This area may also serve as a breeding ground for a dense inoculum of specific undesirable phytoplankton which could enter an adjacent part of the meadowlands during flooding. If this occurs, blooms of toxic or otherwise undesirable organisms may occur in relatively "healthy" areas of the meadowlands. These "toxic blooms" could be detrimental to any attempts to stabilize these adjacent areas by introducing a grazing population.

Because of the effects of the landfill leachate, communication between the landfill leachate and adjacent waters should be minimized or completely prevented.

Effluent E_5 - Metal Plating Factory

Effluent E_5, except in the highest concentration tested (Fig. 8) has little effect on species diversity, permitting all organisms to grow to the same level as the control.

As long as circumstances do not permit undesirable concentrations to be reached, this effluent can safely be released into the water.

CONCLUSION

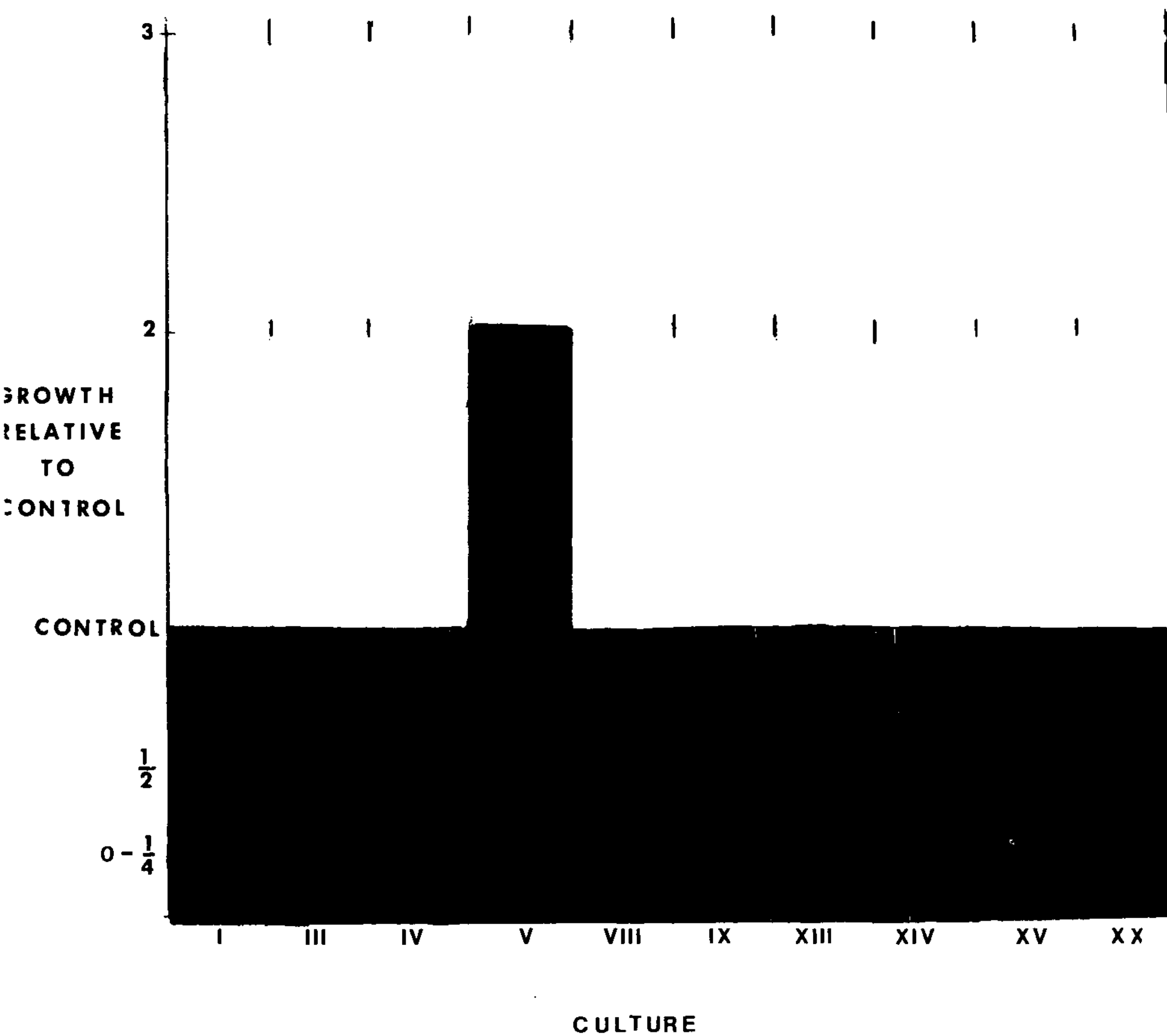
The natural and productive evolution of the Hackensack Meadowlands estuary has been grossly impeded by roadblocks imposed by man. Consequently, the road to the recovery of this estuary must be constructed by man.

One key to the health of any ecosystem is species diversity, that is, the well balanced presence of producers, consumers and decomposers. Balancing the population of producers requires vigilance over the foreign materials that are introduced into the meadowlands waterways. The effect of these materials on phytoplankton stimulation and inhibition must be considered. Should a particular effluent prove deleterious to the photosynthesizing biota, and therefore to the ecosystem as a whole, it must be eliminated. This can be accomplished without the loss of the industry from the area by chemically and physically treating the harmful portion of the individual effluent, or by other methods which would either directly or indirectly reduce the cost of treatment.

It would do well to indicate at this point that perhaps only one component of a particular industry's effluent is responsible for environmental damage. The identification of this component, which can be readily accomplished with bioassay techniques, would substantially reduce the cost of processing the industry's waste and would therefore be of significant economic consequence to the industry in question and to the public it serves.

ACKNOWLEDGMENTS

The author is indebted to Mr. Donald Smith, Mr. John Bolan and the Hackensack Meadowlands Development Commission for providing the invaluable assistance that made this work possible. The author is also indebted to Dr. Joseph Cassin for his identification of the cultures.



EFFLUENT E5
CONCENTRATION 20%

FIG. 8

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SEDIMENTARY DYNAMICS OF A DISTURBED ESTUARY-ENTRANCE SAND SHOAL: THE SHREWSBURY ENTRANCE AREA OF SANDY HOOK BAY, NEW JERSEY

by

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Abstract:

The Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey, consists of sand shoals and man-made navigation channels. The Lower Bar, a prominent shoal, was repeatedly surveyed between 1969 and 1973 in a program to monitor the effects of channel dredging.

Despite seasonal changes of one foot in the average depth to the surface of the Lower Bar, locations on its surface of features having relief of as little as one foot remained stable through the entire five year period of study.

The stability of positions of bathymetric features is explained as the result of a partially closed pattern of sediment transport by tidal currents. Distinct areas of ebb and flood dominance transect the surface of the Lower Bar. Linear ridges of low relief are found between ebb and flood dominated areas and along the margins of the Lower Bar.

The depth to the surface of the bar and the effectiveness with which material finer than 0.063 mm is winnowed from sediments vary seasonally in annual cycles controlled by wave conditions. These cycles were apparently not affected by recent dredging.

Sand deposited on the Lower Bar during seasons of decreasing or low wave intensity is believed to be supplied in part by the return of sand eroded during seasons of higher wave energy and in part by transport of sand into the Shrewsbury Entrance Area from external sources.

Introduction:

Estuary entrances are often areas of strong tidal currents and heavy wave action. The stability of sand shoals in the face of such conditions may be explained at many localities as the result of sediment circulation cells which coexist with mutually evasive ebb and flood tidal currents (Houbolt, 1968; James and Stanley, 1968; Smith, 1969; Klein, 1970; Ludwick, 1972). In other areas patterns of sediment transport resulting from waves and wave induced currents must also be considered (Oertel, 1972).

Sand shoals of the Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey, (Figure 1) are subject not only to waves and currents, but also to the effects of substantial dredging. In a channel maintenance and sand mining operation, more than 1,300,000 cubic yards of sand were dredged from channels between 1968 and 1973 (New Jersey Office of Shore Protection, 1968-1973).

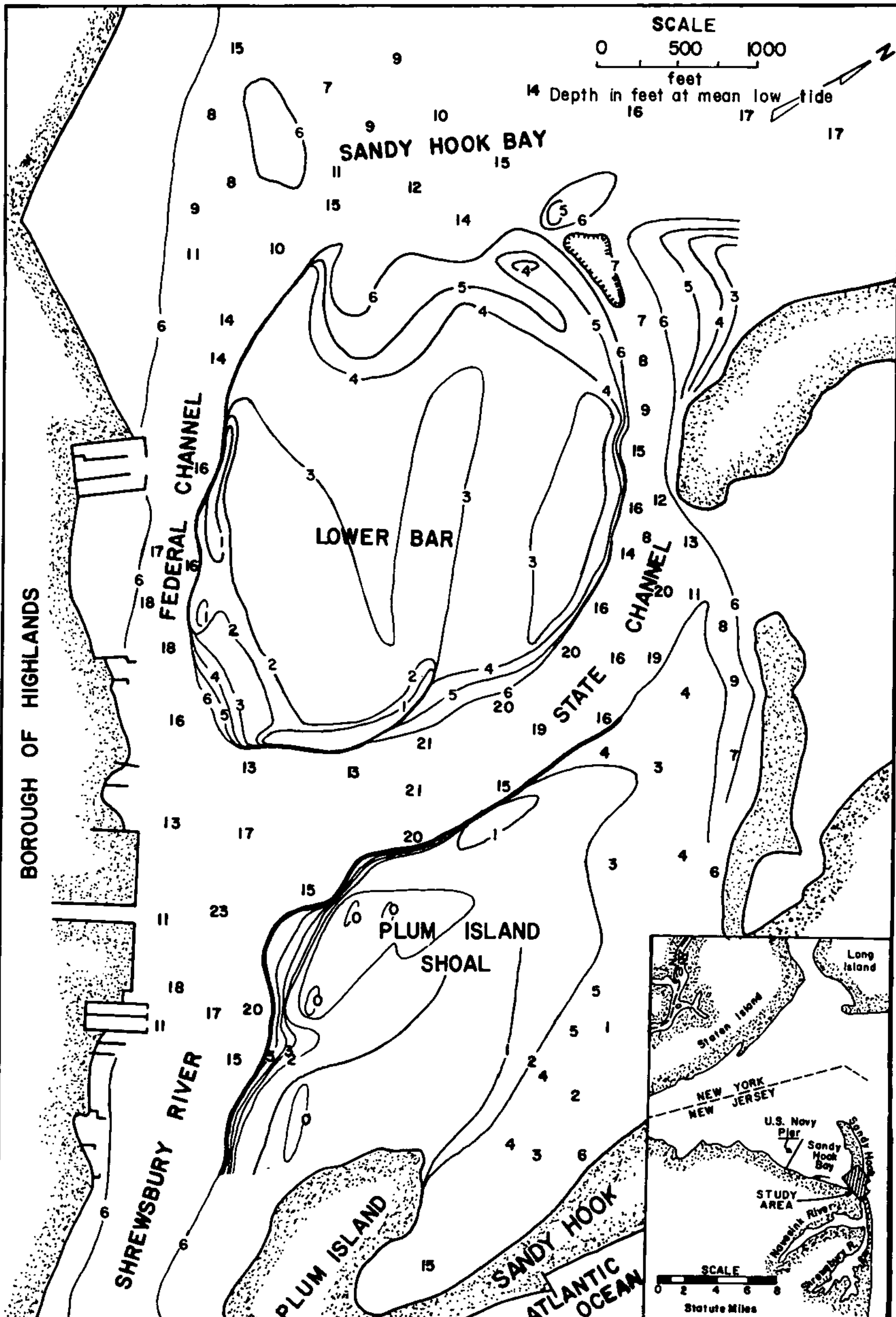

Figure 1. Location and geographic features of the Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey.

This paper attempts to determine whether bathymetric changes observed on the Lower Bar, a prominent shoal in the seaward portion of the Shrewsbury Entrance Area (Figure 1) are naturally occurring fluctuations or the result of dredging in adjacent channels. Measurements of morphology, wave and current conditions, and dates and volumes of dredging are compared to reveal spatial and temporal patterns helpful in this interpretation. Sedimentary conditions are further investigated by comparisons among seasonally collected sediment samples.

Study Area:

The principal channels within the Shrewsbury Entrance Area (Figure 1) are the Federal Channel, following the western shore of Sandy Hook Bay, and the State Channel, trending northward from the Shrewsbury River. Shoals include the Lower Bar, located between the State and Federal Channels, and the Plum Island Shoal, to the north of Plum Island between the State Channel and Sandy Hook.

Sedimentary Conditions Within Channels:

The Federal Channel (Figure 1) is fairly uniform in width (about 400 feet), depth (15 to 18 feet), and sedimentary characteristics. Ebb and flood currents are equally strong, having near-bottom velocities up to two feet per second (H.H. Haskin, Rutgers University, unpublished data). Considerable volumes of sand are moved seaward at ebb tide and towards the Shrewsbury estuary at flood tide (Harper, 1975).

Relatively little dredging has been carried out recently in the Federal Channel. Morphologic changes between nine surveys conducted by the New Jersey Office of Shore Protection from 1969 to 1973 were insignificant.

The State Channel (Figure 1) may be divided into two distinct segments. A relatively narrow, shoaling, seaward section is similar to the Federal Channel in having swift tidal currents and voluminous sediment transport. Near-bottom current velocities reach 2.4 feet per second at ebb and 1.6 feet per second at flood (H.H. Haskin, Rutgers University, unpublished data). Because ebb and flood stages are of roughly equal duration, the greatest potential for sediment transport is seaward at ebb tide.

To the south, the channel is sheltered from intense wave action by the Lower Bar. Recent dredging was concentrated in this sheltered segment of the channel. Between 1969 and 1973 depth was increased from between eight and eleven feet to between twelve and twenty feet. Width was increased from between 400 and 600 feet to between 500 and 1000 feet. Weak tidal currents, having maximum surface velocities of less than one ft./sec., and a bottom sediment of cohesive, silty, fine sand suggest that sediment is more stable than in the seaward portion of the channel.

Sedimentary Conditions on the Lower Bar:

The Lower Bar (Figure 1) is exposed to strong tidal currents and substantial waves. Surface velocities and directions of tidal currents were measured at hourly intervals through a single tidal cycle on a calm day at 9 locations on the surface of the bar.

On the southeastern portion of the bar, peak ebb current is of slightly higher velocity (Figure 2) and occurs in substantially shallower water (Figure 3) than peak flood. The greatest current shear and greatest potential rate of sediment transport, therefore, are at ebb tide. Ebb-oriented ripple marks and dunes are present throughout the tidal cycle and confirm that strong ebb tidal bed shear dominates sediment transport.

To the southwest a topographic rim or ebb shield (Boothroyd, 1969) deflects swift, shallow-water ebb currents from the surface of the bar (Figure 2). While current strength and water depth measurements are insufficient to characterize this area as to dominant tide stage, lunate scour depressions seaward of pieces of concrete debris indicate flood dominance.

Wave action is not believed to change the basic pattern of ebb and flood dominated areas (Figure 2), but is believed to modify sediment transport across these areas.

On rough days waves approach the bar from the north or northwest. At low water stages of the tidal cycle these waves are dissipated at the seaward margin of the bar and carry water by mass transport (King, 1972, p.106-108) onto the ebb and flood dominated sand flat areas. At ebb tide, opposing tidal and wave generated water movements generate strong current flowing southeastward near the seaward margin of the bar (Figure 2). Wind generated currents and southward flowing longshore currents along the western shore of Sandy Hook may also contribute to this flow. Transport of sand from ebb dominated to flood dominated areas by this current even on days of moderate wave intensity is demonstrated by extensive development of southwestward-facing ripples along its path.

At flood tide, water depth is greater (Figure 3) and waves are less effectively dissipated. Repeated sediment suspension by waves contributes to the effectiveness of sediment transport by flood currents, especially on the more exposed flood dominated area. The effect of the change from moderate flood dominance on calm days to strong flood dominance on rough days is to change the direction of sediment transport. On calm days sand is carried northward by ebb currents, then southeastward by flood currents, coming to rest south and east of its initial position. Moved alternately by ebb and flood currents, sand travels southeastward from the Federal Channel across the flood dominated area to the ebb dominated area. On rough days, with strong flood dominance, net transport is towards the Federal Channel (Figure 2).

Bathymetric Change on the Lower Bar:

As part of a program to monitor the effects of channel dredging, the New Jersey Office of Shore Protection (1968-1973) conducted nine surveys of the Shrewsbury Entrance Area between 1969 and 1973.

In the present study bathymetric maps prepared from these surveys revealed fluctuations of nearly one foot in the average depth to the Lower Bar, indicating alternate erosion redeposition of over 100,000 cubic yards of sand (Figure 4).

Despite this, there were no major changes between 1969 and 1973 in the locations of significant bathymetric features (sand flats corresponding to

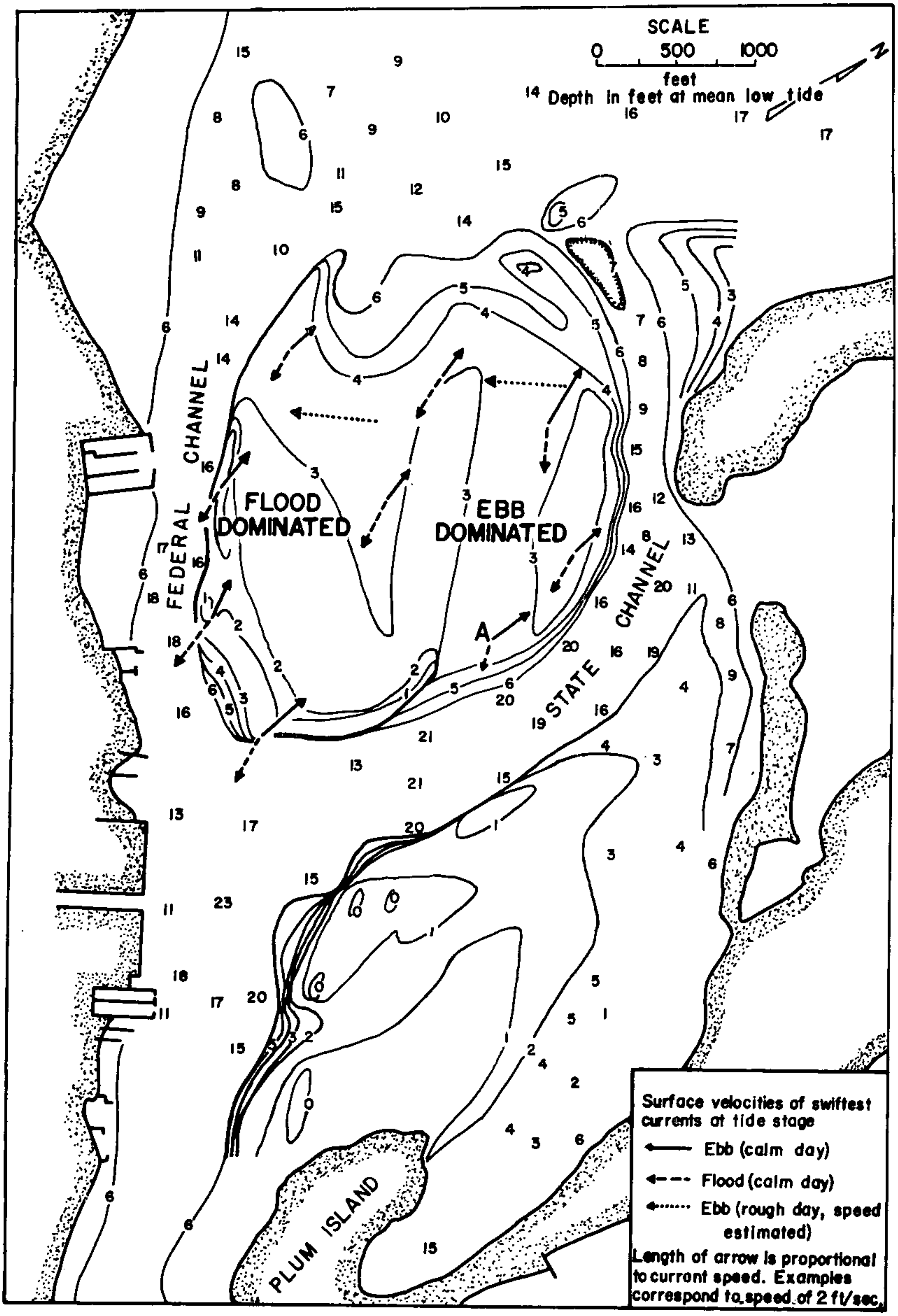

Figure 2. Locations of surface current velocity measurements; ebb and flood dominated areas of the Lower Bar. Arrows indicate direction and magnitude of flow at peak velocity.

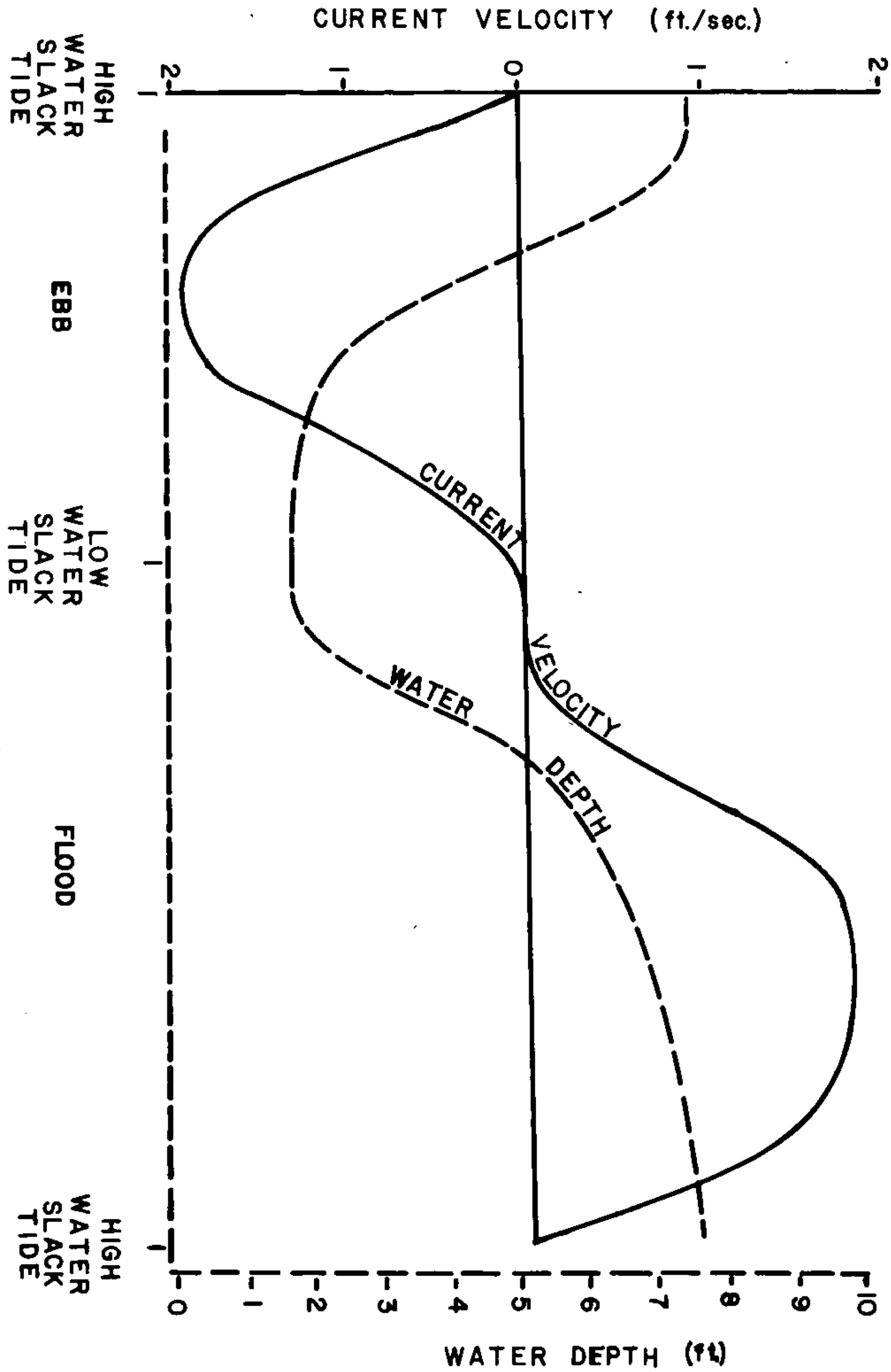

Figure 3. Tidal cycles of water depth and current velocity on the ebb dominated portion of the Lower Bar (point A of Figure 2).

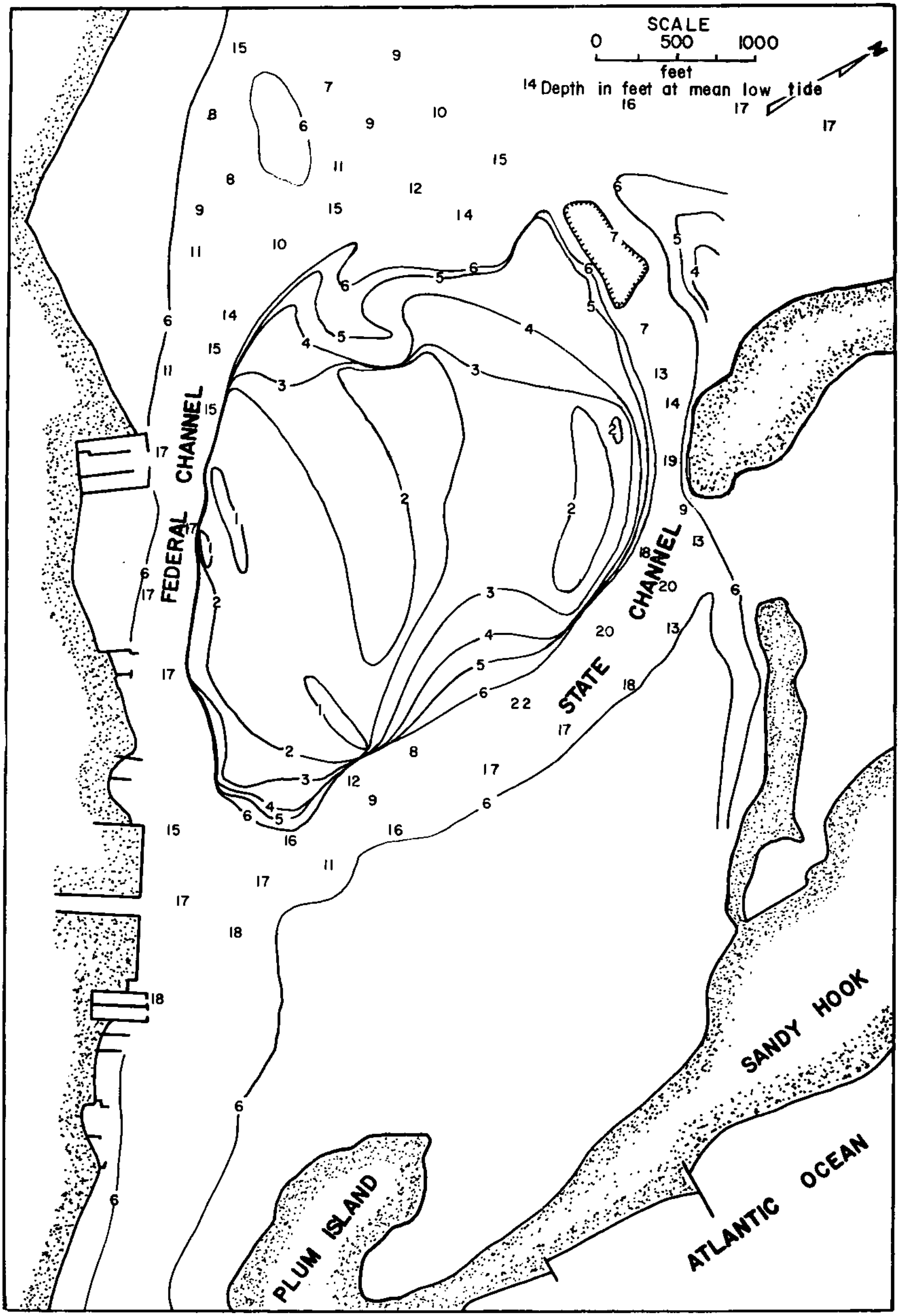

Figure 4a: Bathymetric map of the Shrewsbury Entrance Area, August, 1971.

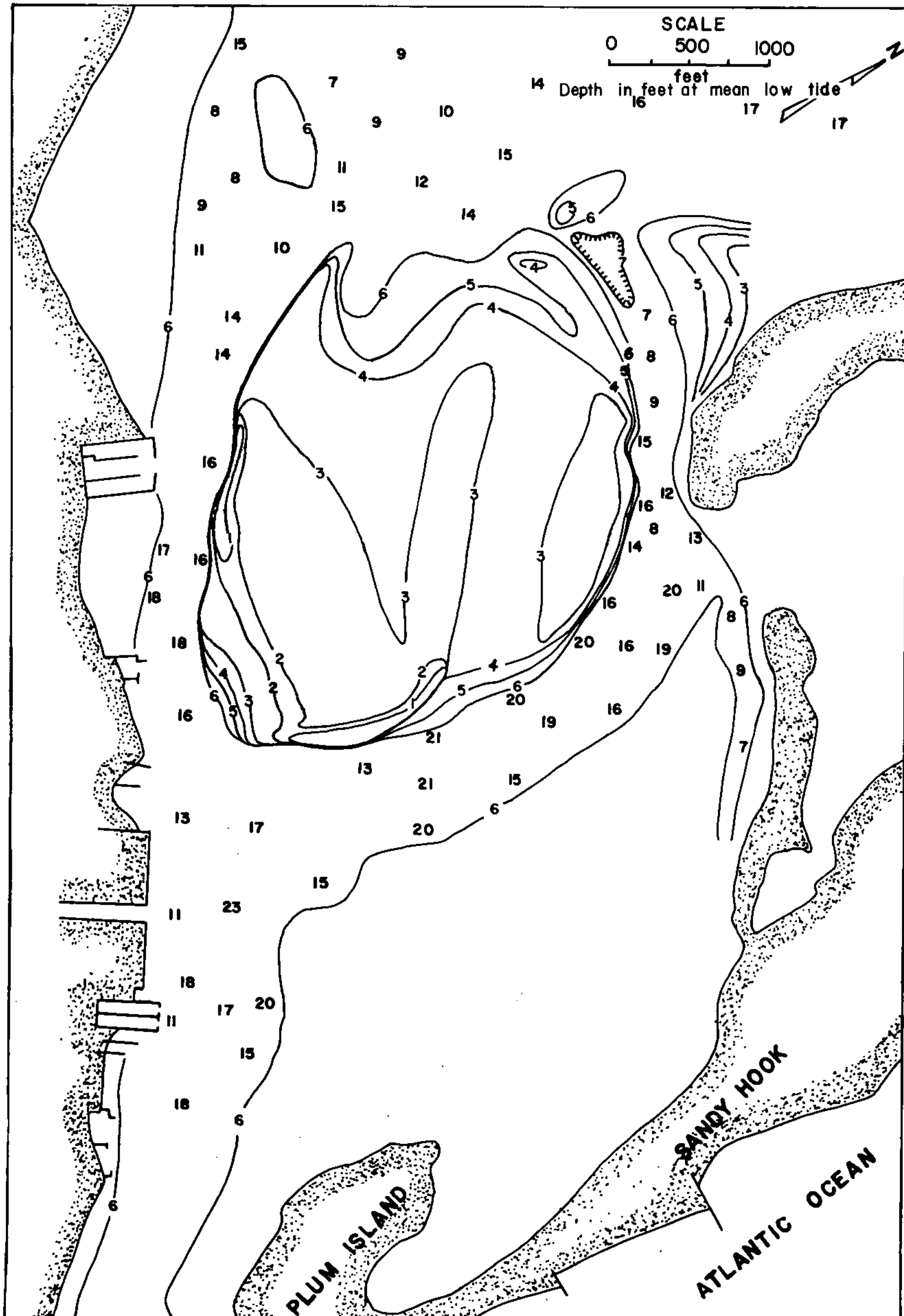

Figure 4b: Bathymetric map of the Shrewsbury Entrance Area, January, 1973.

ebb and flood dominated areas, the ebb shield bordering the flood dominated area, a linear shoal between ebb and flood dominated areas, and a linear shoal between the ebb dominated area and the State Channel).

Nine areas were chosen for a study of the behaviors of these features (Figure 5). For each area average depth was plotted against time to reveal progressive trends and as a function of the month to reveal seasonal changes.

Despite the dredging, none of the areas underwent continuous, progressive, bathymetric change. Depth plotted against time demonstrates bathymetric change, but reveals no unidirectional trends (Figure 6).

Depth plotted as a function of the month (Figure 7) reveals annual cycles in all areas except the western portion of the seaward margin of the bar and near the junction of the State and Federal Channels (areas 1 and 8, Figure 5). Annual cycles involved erosion between early autumn and mid-winter and aggradation between mid-winter and late summer (Figure 8). In area 8 depth appeared to vary randomly whether plotted as a time series or as a function of the month. In area 1 erosional and depositional events are separated by intervals of apparent inactivity lasting as long as two years (Figure 9)

The annual cycle of greatest magnitude, about two feet, occurs at the northern corner of the Lower Bar in the area in which waves are dissipated at low-water stages of the tidal cycle (area 2, Figure 5). On calm days strong ebb currents spread from the shoaling, seaward portion of the State Channel across this area, decelerating as they cover a wider area and enter deeper water. Flood currents in this area are weak and stability of material carried to the seaward limit of competent ebb flow is determined by wave conditions.

Aggradation is coincident with the establishment of low energy wave conditions typical of summer. From June through August weak southerly prevailing winds cross a short fetch and generate little wave action in the southern portion of Sandy Hook Bay (Yasso, 1968). Erosion is coincident with the establishment of higher energy wave conditions. From October through May relatively strong northerly and northwesterly winds cross a fetch of up to 15 miles and generate substantial waves (Yasso, 1968).

Stability of the position of the seaward margin of the bar since at least 1929 (National Ocean Survey, 1929-1973) indicates that sediment is not carried seaward from this area, but predominantly upward onto the surface of the Lower Bar.

Area 1 of Figure 5 is similar to Area 2 in being on the seaward margin of the bar, but differs in being deeper and isolated from sediment sources. Among sediment sources, the State Channel is distant, the Federal Channel is cut off by a prominent sub-aqueous ridge, and the sand flat to the south is flood dominated, net sediment transport being away from area 1.

Area 1 is characterized by periodic erosion or deposition separated by longer intervals of apparent inactivity, rather than by seasonal bathymetric changes (Figure 9). The relationship between storms and this sedimentary activity is unclear. Coastal storms were recorded by Wasserman and Gilhousen (1973). Three storms causing notable erosion on both Long Island and New

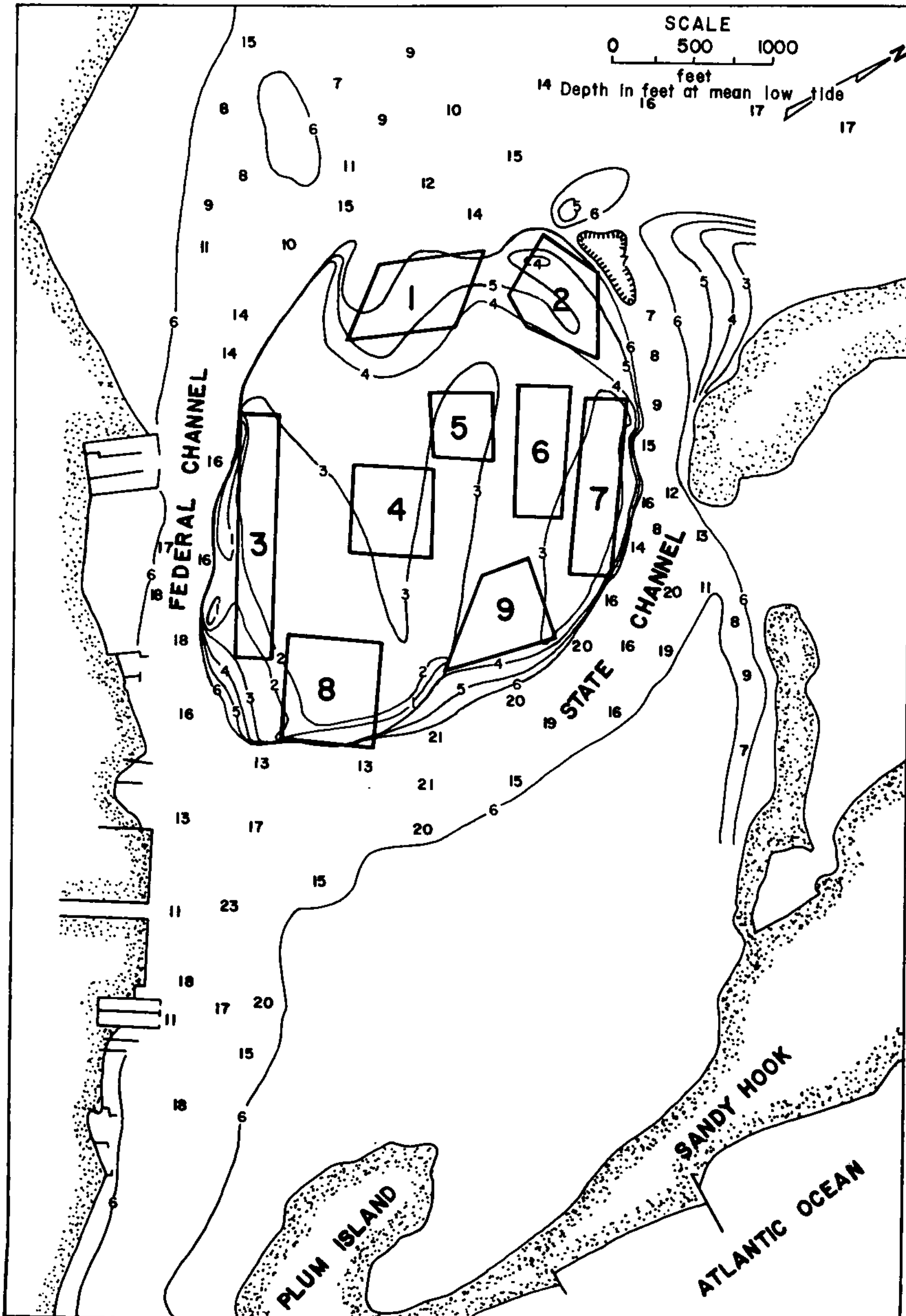

Figure 5. Areas chosen for study of bathymetric change.

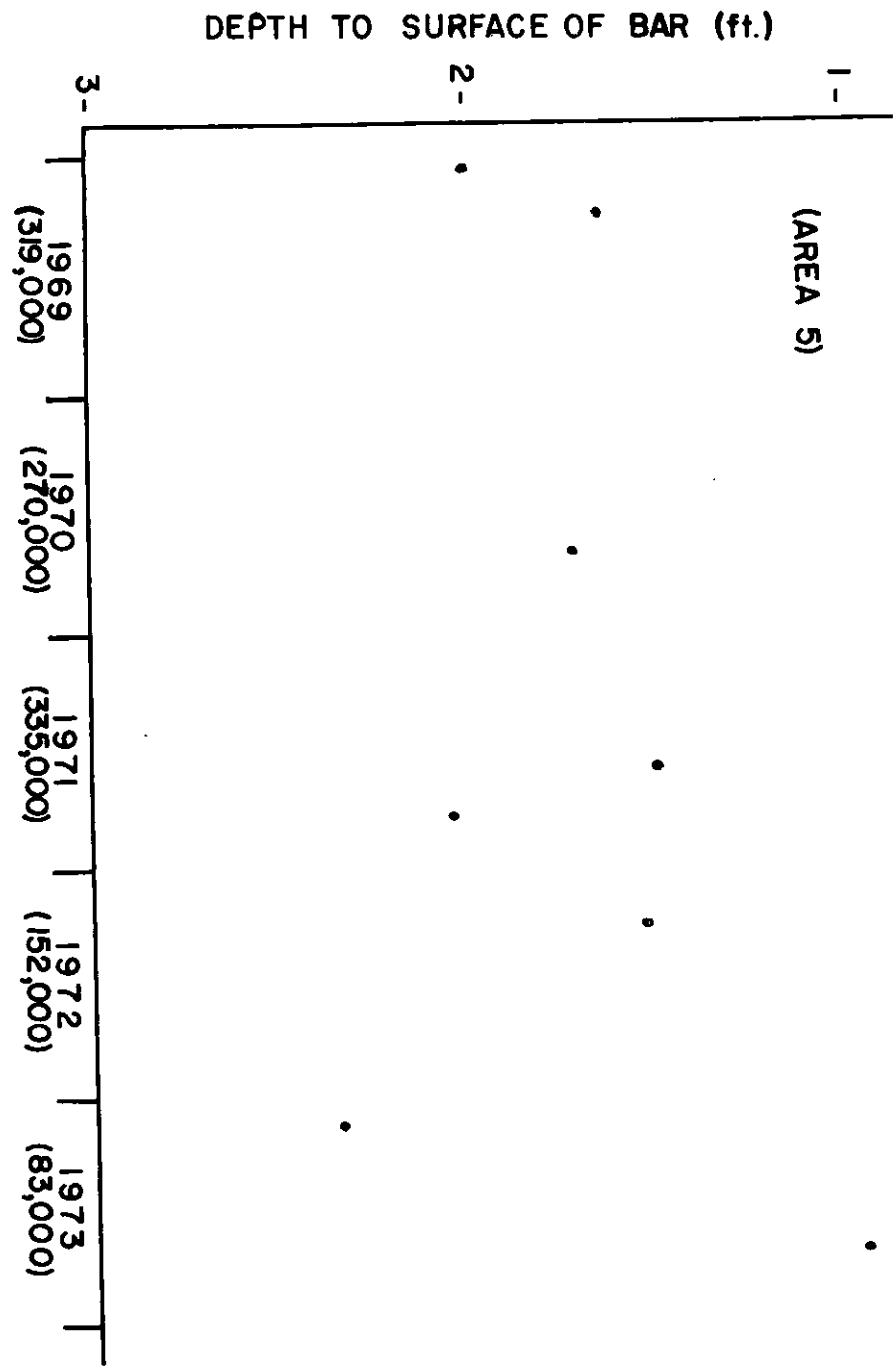

Figure 6. Depth to the surface of the Lower Bar at mean low tide (1969-1973), area 5 of Figure 5.

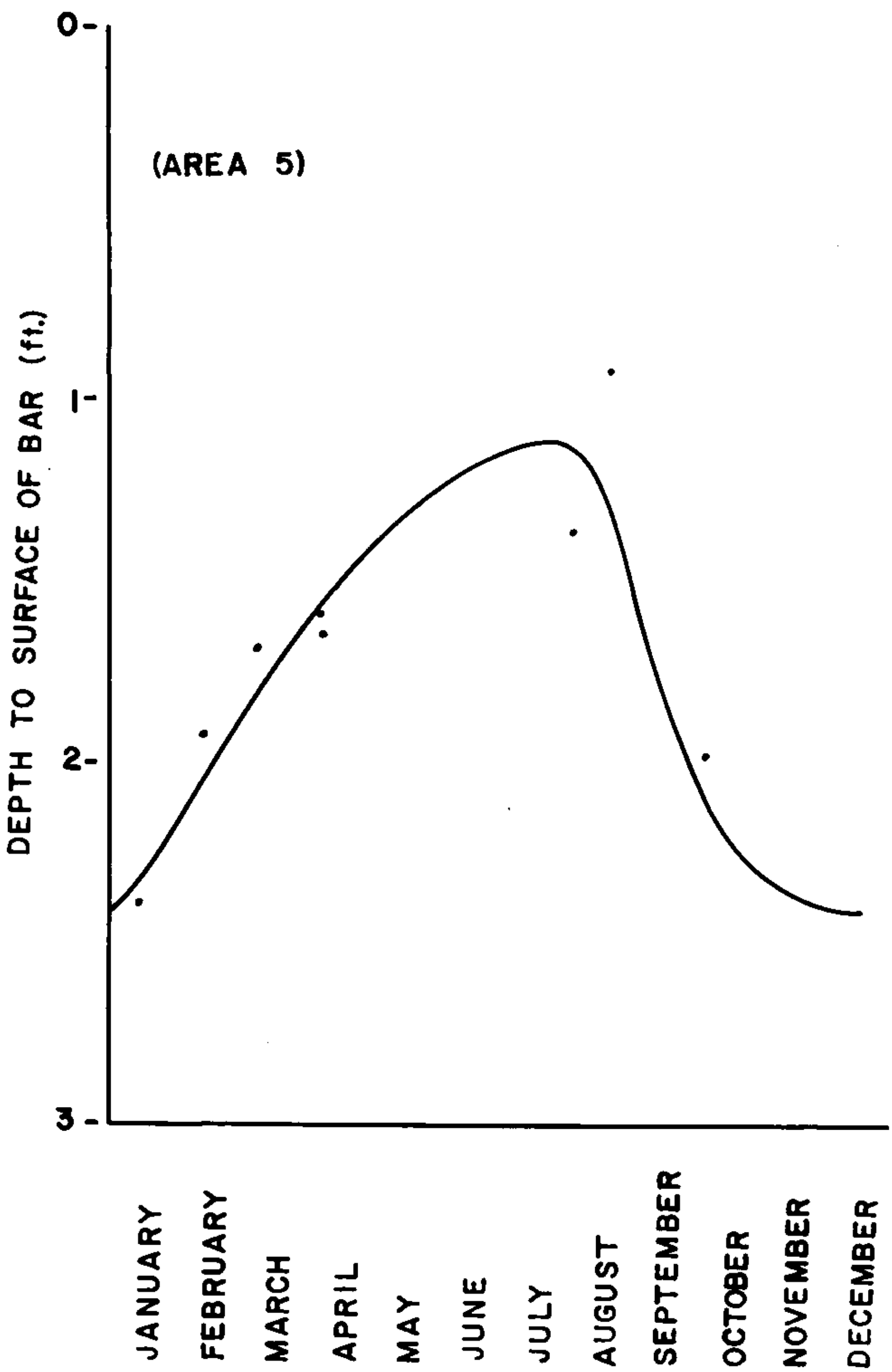

Figure 7. Depth to the surface of the Lower Bar at mean low tide as a function of the month, area 5 of Figure 5.

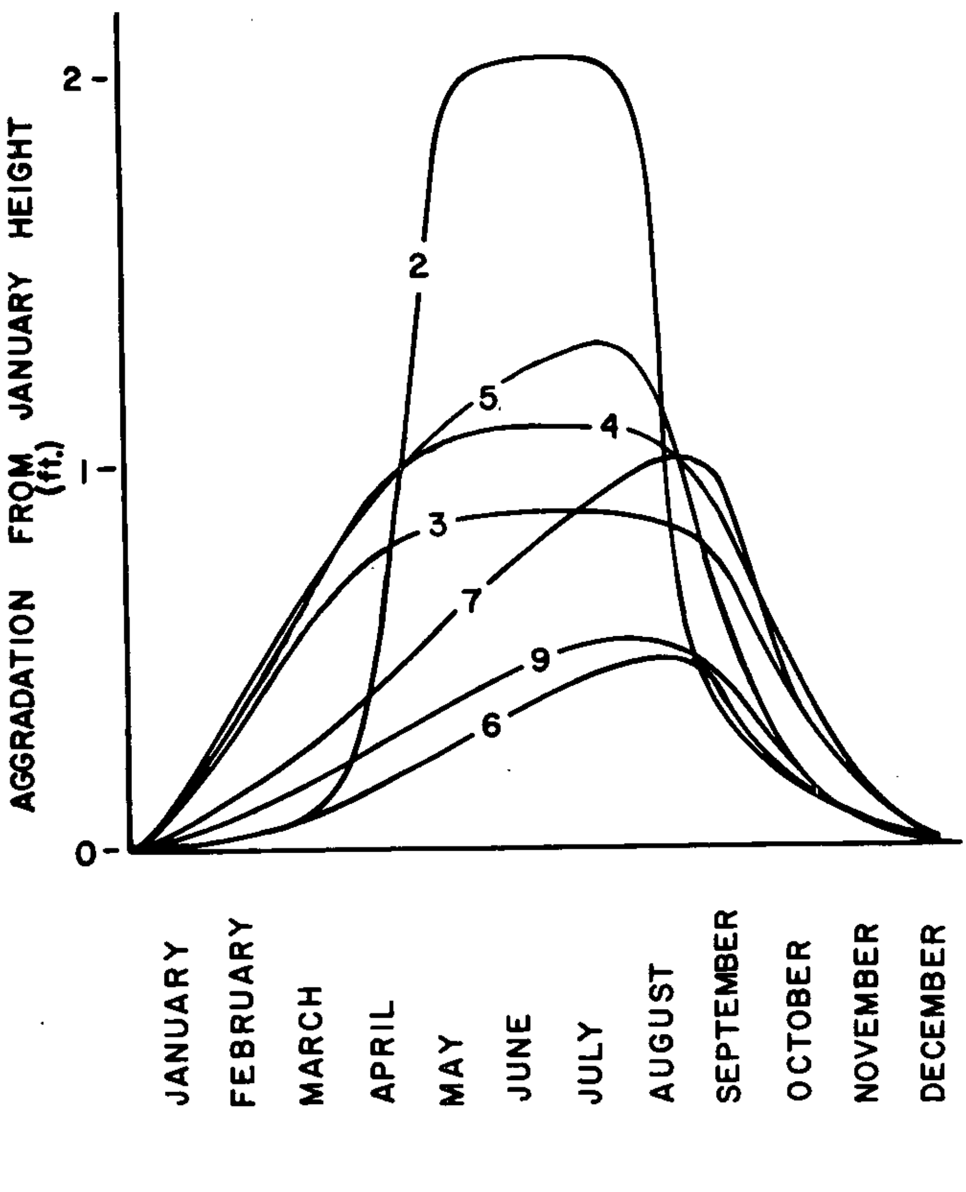

Figure 8. Bathymetric cycles occurring on the Lower Bar.
Numbering corresponds to areas delineated on Figure 5.

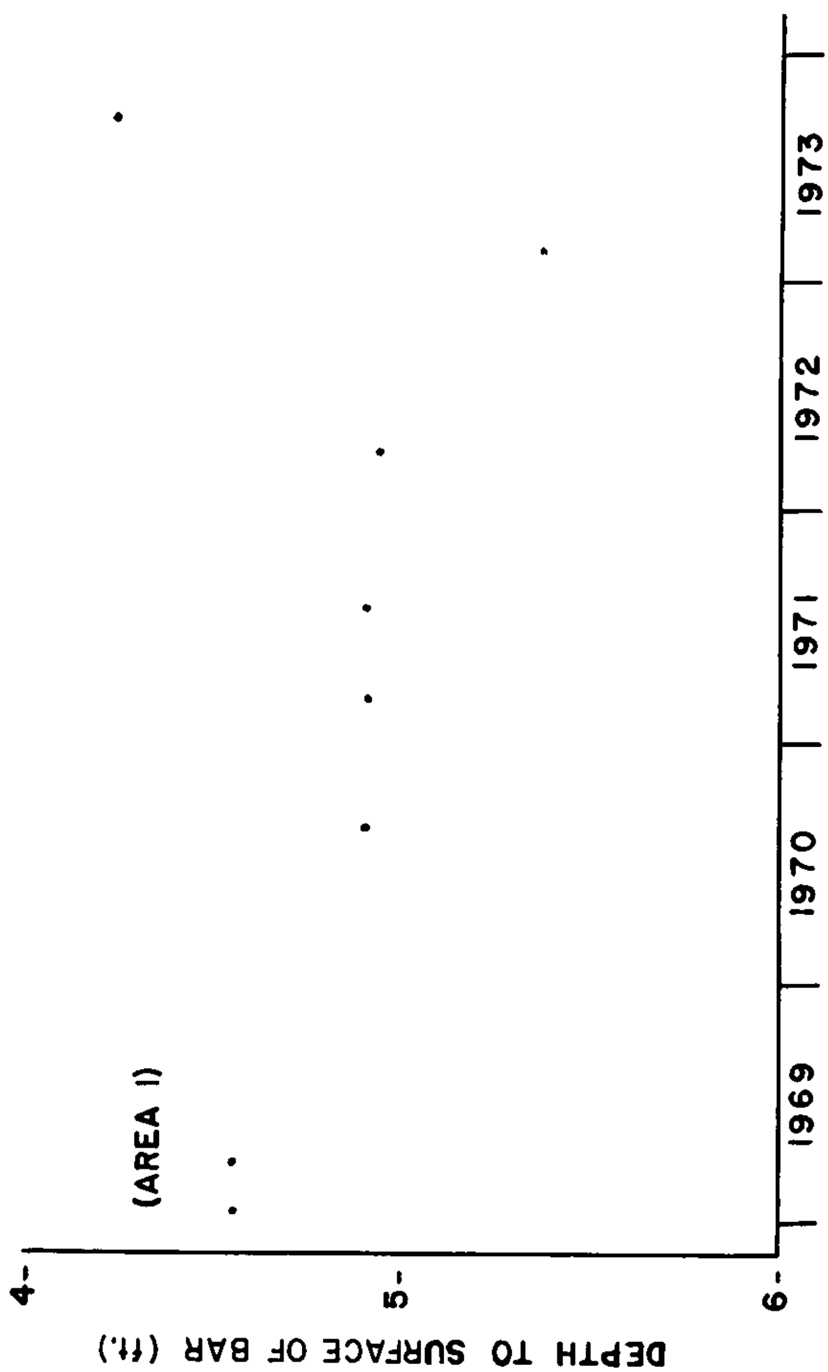

Figure 9. Depth to the surface of the Lower Bar at mean low tide (1969-1973), area 1 of Figure 5.

Jersey shores occurred between autumn and spring of 1971-1972 (Wasserman and Gilhousen, 1973), a period of apparent inactivity in area 1 of Figure 5. The same period of 1972-1973 was without comparable coastal erosion (Wasserman, S.E., National Weather Service, Eastern Regional Headquarters, oral communication), but included an erosional event in area 1.

Away from the seaward margin of the bar bathymetric cycles may be explained as the result of seasonal variation in the effects of wave scour on the directions and relative magnitudes of sediment transport by ebb and flood currents. On rough days, characteristic of autumn and winter, sand is suspended by waves and swept by flood currents into channels. Under calmer conditions sand brought from the Federal Channel to the surface of the bar is entrapped within a closed pattern of sediment transport, being carried southeastward across the flood dominated area (Figure 2), then northwestward across the ebb dominated area, then southwestward along the seaward margin of the bar to the flood dominated area. Accumulation of sand within this cycle is believed to be the cause of aggradation between mid-winter and late summer.

Supporting the interpretation of bathymetric cycles as the result of seasonal variations in wave conditions rather than as an effect of dredging, changes appeared closely related to wave conditions and independent of dredging.

Spatially the annual cycles were most pronounced on the wave-swept seaward portion of the bar distant from heavily dredged sites (Figure 10).

In time, there is no obvious relationship between the volume of sand dredged from channels (Figure 11) and either magnitudes of changes between surveys (Figures 6, 9) or seasonal changes in depth (Figure 8). Dredging was carried out between mid-March and late December. While gradual aggradation in the spring was coincident with both commencement of dredging and decrease in prevailing wave energies, erosion in early autumn preceded shut-down of dredging operations by about two months but was coincident with an increase in wave energies.

Numerous other factors, such as wind driven currents, discharge of the Shrewsbury River, and change in water viscosity with temperature, may affect the annual cycles, but are probably minor in comparison with wave action.

The influence of sporadically occurring weather conditions (storms, periods of strong winds or unusual calm, etc.) on the annual cycles is difficult to evaluate. That the annual cycles are evident from combined data representing years of very different storm conditions indicates that major storms are not responsible for the cycles. Some sensitivity to sporadically occurring conditions is indicated, however, by comparison of the behavior of the surface of the bar with that of area 1, already noted to be responsive to sporadic events rather than seasonal conditions. As in area 1 (Figure 9), the depth to the bar (Figure 6, for example) was unusually great in January, 1973, and unusually small in August, 1973.

Environmental Interpretation of Sediment Samples:

Grain-size compositions of seasonally collected sediment samples were compared to further define sedimentary conditions through annual bathymetric cycles.

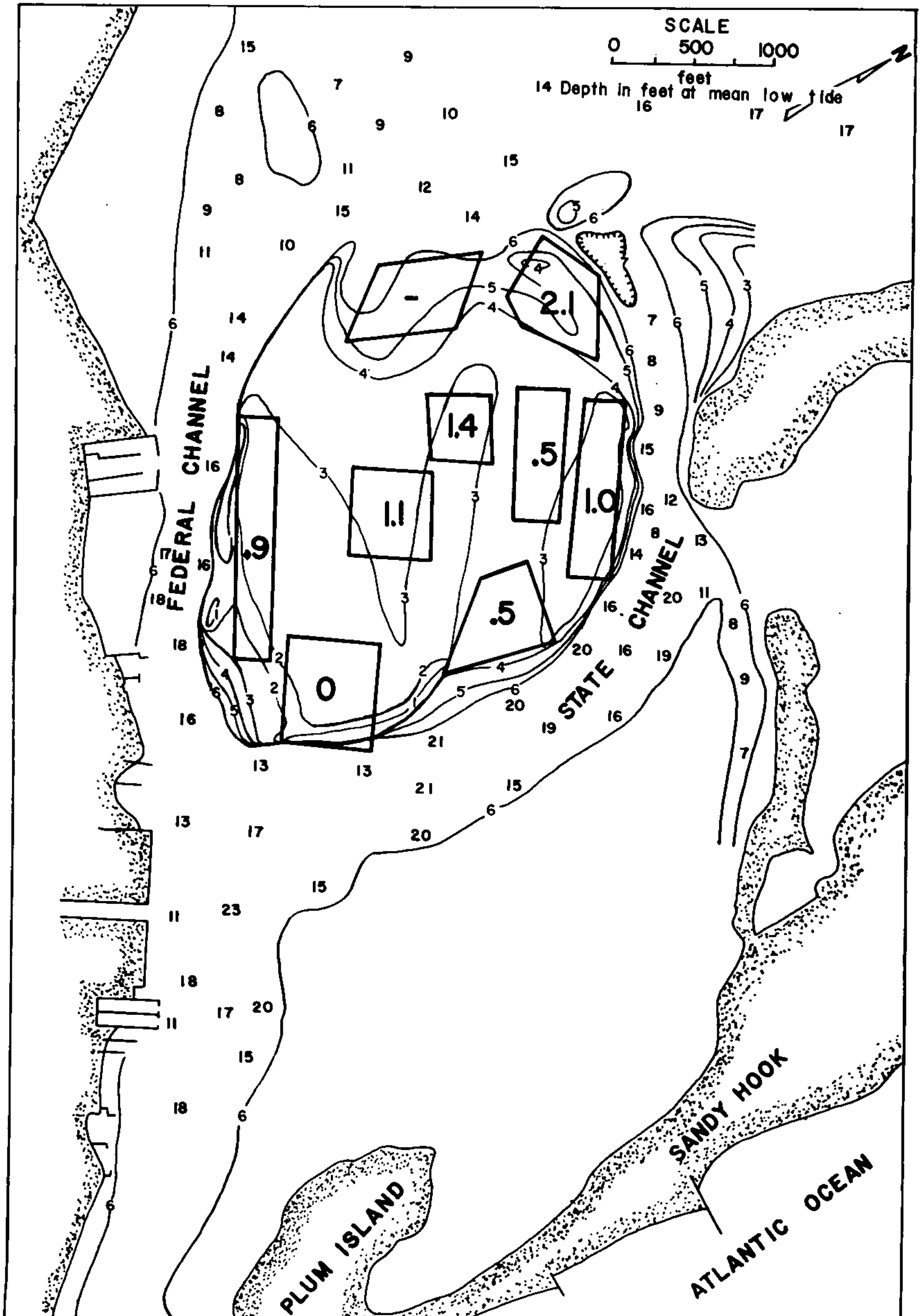

Figure 10. Magnitudes of annual cycles noted on the surface of the Lower Bar.

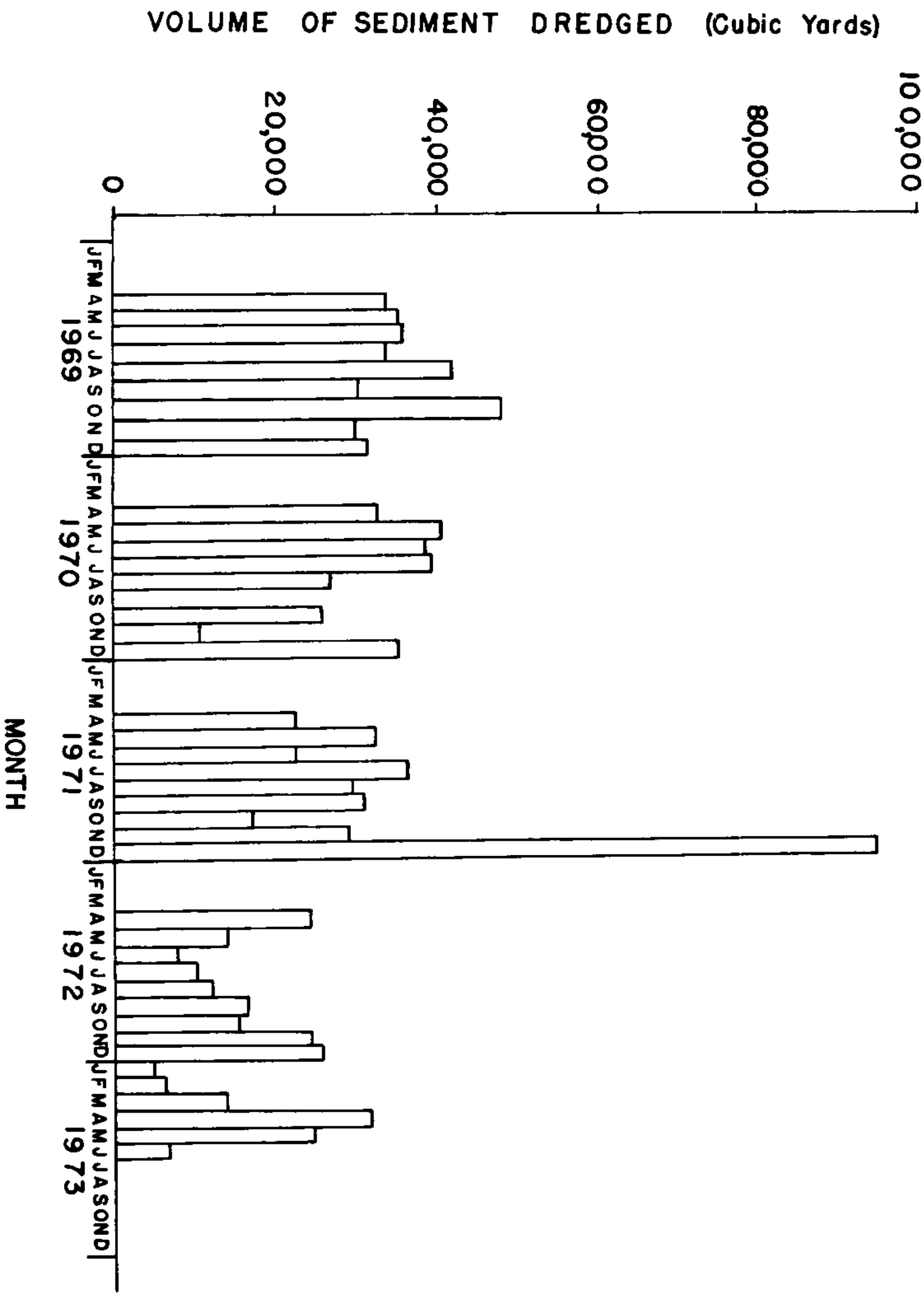

Figure 11. Volumes of sediment removed from channels, 1969-1973.

Numerous studies have confirmed that naturally deposited sands consist of two or more simultaneously deposited grain-size populations. Distinct populations represent tractional, saltational, and suspensional components of the sediment load (Udden, 1914; Moss, 1972; Friedman, 1967; Visher, 1969). Selective deposition of saltational grains on the basis of size and shape characteristics leads to the development of a framework of surface irregularities over which grains of the tractional population are rolled or slid and within which an interstitial population may be deposited from suspension (Moss, 1972). Size ranges of populations, proportions among populations, and distinctness with which populations are separated by sieve analysis vary systematically with environment (Visher, 1969).

Although the conditions governing the composition of sediment deposited from a given flow are complex and incompletely understood, much of the variation among water-laid sands is explicable in terms of hydrodynamic conditions at the bed surface at distinct stages of bed-load sedimentation. Moss (1972) describes the following stages occurring with increasing grain size or sediment transporting power:

1. Fine ripple bed stage. At this stage the framework of surface irregularities formed by grains selectively deposited from saltation (the framework population) is completely enclosed within the viscous sublayer, a thin zone at the base of a moving fluid within which surface irregularities do not generate turbulence. Because strong turbulence is absent at the bed surface, silt and fine sand are able to settle from suspension, becoming concentrated near the bottom of the flow. At most times fluid lift forces raise this material to the top of the viscous sublayer, isolated from the bed surface and unavailable for deposition. Fluctuations in velocity and lift forces within the viscous sublayer, however, periodically allow deposition of fine material within surface irregularities of the bed. This fine-grained interstitial population accounts for a dirty appearance of fine ripple stage sands. This bed stage is developed only if the mean grain size of the framework population is 0.25 mm. or less. Ripples are the characteristic bedform.

2. Coarse ripple bed stage. At this stage, surface irregularities of the framework protrude through the viscous sublayer to create a zone of strong turbulence near the bed surface. Concentrations of fine material cannot be maintained near the top of the viscous sublayer, still active within surface irregularities, in the face of this turbulence. Because little fine material is available for deposition at moments of low flow velocity and low fluid lift in the viscous sublayer, coarse ripple sediments are essentially clean of material finer than 0.25 mm., the maximum particle size generally isolated from the bed surface by lift forces in the viscous sublayer. The coarse ripple bed stage is developed only if mean grain size of the framework population is between 0.25 and 0.92 mm. Ripples are the characteristic bedform.

3. Dune bed stage. At this stage the viscous sublayer is of negligible thickness and turbulence extends deep into surface irregularities of the deposit. Despite the presence of net upward hydrodynamic lift forces, suspended particles are carried by turbulence between framework grains to be deposited as a substantial interstial population. Mean grain size of framework populations of

dune stage sands ranges from 0.25 to 2.2 mm. Dunes (morphologically similar to ripples, but normally differentiated on the basis of size, dunes having wave lengths of two feet or more and heights of 0.2 feet or more) are the characteristic bedform. Packing of sands is loose and bearing strength low.

4. Rheologic bed stage. Whereas in the ripple and dune bed stages particles move as discrete entities propelled by fluid forces, in the rheologic bed stage particles move as a dense carpet of saltational grains held to the bed by gravitational forces and kept in a dispersed state largely by collisions among grains. The energy required to maintain this dispersed state is imparted from fluid shear at the upper surface of the carpet of saltational grains. Flow velocity decreases abruptly at this surface. Observation of the bed surface at the rheologic stage is difficult and the forces influencing particle deposition poorly understood. Bombardment by saltational grains and small-scale turbulence generated by traveling grains are believed to be important. Mean grain size of the framework population for rheologic stage sands ranges from fine sand to gravel. Plane beds are characteristic. Sediments tend to be firmly packed. Isolated pebbles on a sandy bed are considered by Moss (1972) to be diagnostic of rheologic bed stage sedimentation.

Bed stages were established by study of alluvial sediments. The interpretation of estuarine sediments, deposited in the presence of waves and reversing tidal currents, in terms of this sequence must be approached cautiously.

In examples studied by Moss (1972), characteristics of sediments deposited at distinct bed stages were equally well developed whether deposition was from steady flow, where bedforms were prominent, or unsteady flow, where fluctuations in current velocity or direction prevented the formation of ripples and dunes.

Bedforms noted in the Shrewsbury Entrance Area are the result of tidal or wave generated currents, seldom reflecting the oscillatory component of water movement resulting directly from wave action. Within a short period of the tidal cycle it seems reasonable, therefore, to consider sedimentation as the result of unidirectional currents more steady in many places than examples of unsteady alluvial flow studied by Moss (1972). With changing tide stage, flow conditions will, of course, also change. Because bed stage is not self-sustaining, but responds within seconds to changes in flow conditions (Moss, 1972), large volume sediment samples containing material deposited through a number of tidal cycles may be expected to reflect flow conditions at the tide stage dominating sediment deposition.

Collection and Treatment of Sediment Samples:

Grab samples were collected seasonally, without regard to tide stage, in evenly spaced patterns covering the entire Shrewsbury Entrance Area. 145 samples were collected in April, 1973; 47 in July, 1973; 64 in October, 1973; and 62 in January, 1974.

Samples were rinsed through a 0.063 mm. sieve to determine the silt and clay content, then conventionally sieved using wire mesh sieves spaced at 1/2 phi intervals (Krumbein, 1934) from 0.063 to 4 mm. With this sieve interval the linear dimensions of the openings of each sieve are one and one half times those of the next smaller sieve.

Sediment Types Found Within the Shrewsbury Entrance Area:

Grain-size distributions were plotted cumulatively on log-probability graph paper as weight percent per size interval. Straight line segments of the resulting curves may be interpreted as truncated, log-normal grain-size distributions corresponding to sediment populations deposited from traction, saltation, and suspension (Visher, 1969).

Six distinct sediment types were apparent from visual examination of the population compositions of the sand fractions of samples from the Shrewsbury Entrance Area. Within these types the presence or absence of silt and clay appears to be indicative of winnowing. This size material is generally absent in areas of intense wave action and present in amounts greater than 1% of the total sediment weight in areas of weak to moderate wave action.

The six sediment types may be described as follows:

1. Suspensional sediments. Thicknesses of greater than five feet of dark, silty sediment containing less than 1% sand and having very low bearing strength are found to the east of Plum Island in an area dredged to a depth of at least twenty feet at some time between 1900 and 1929 (Figure 12). These silts are believed to have settled from suspension.

2. Fine ripple bed stage sediments. Dirty appearing sands with framework populations having a mean diameter of 0.25 mm. or less (Figure 13) are interpreted as having been deposited at the fine ripple bed stage of Moss (1972). These are found in water depths of greater than 15 feet seaward of the Lower Bar, at similar depths in the broad, quiet southern reach of the State Channel, on a shallow, protected area to the west of the mouth of the Federal Channel, and, in summertime, in the seaward, shoaling portion of the State Channel.

3. Coarse ripple bed stage sediments. Sands interpreted as having been deposited at the coarse ripple bed stage are sharply distinct from fine ripple stage sands in their geographic distribution and clean appearance. The saltational population of coarse ripple stage sands is sharply truncated, usually at 0.25 mm. (Figure 13). Finer sand is minor, averaging about 3% of the total weight of the sediment. Coarse ripple bed stage sands are found on deeper, sheltered areas of the Plum Island Shoal, on the flood dominated portion of the Lower Bar, on seaward areas of the Lower Bar in water depths greater than about three feet, and in the seaward portions of the State and Federal Channels.

4. Dune bed stage sediments. With increasing exposure to currents a gradational sequence of sediment types is noted in going from areas of coarse ripple to dune then to rheologic bed stage sedimentation. Areas of dune bed stage sedimentation identified on the basis of

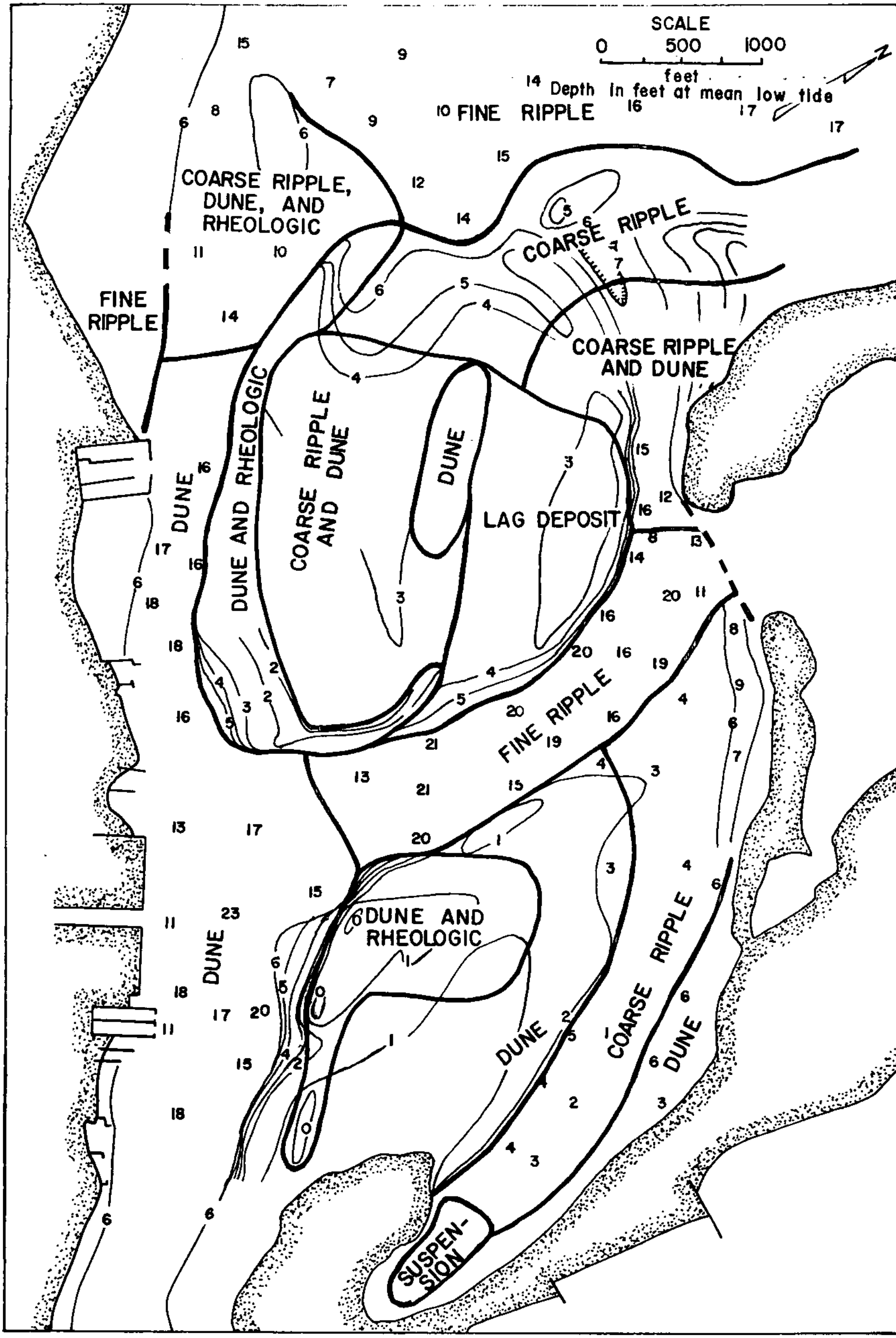

Figure 12a: Distribution of sediment types in the Shrewsbury Entrance Area, autumn, winter and spring.

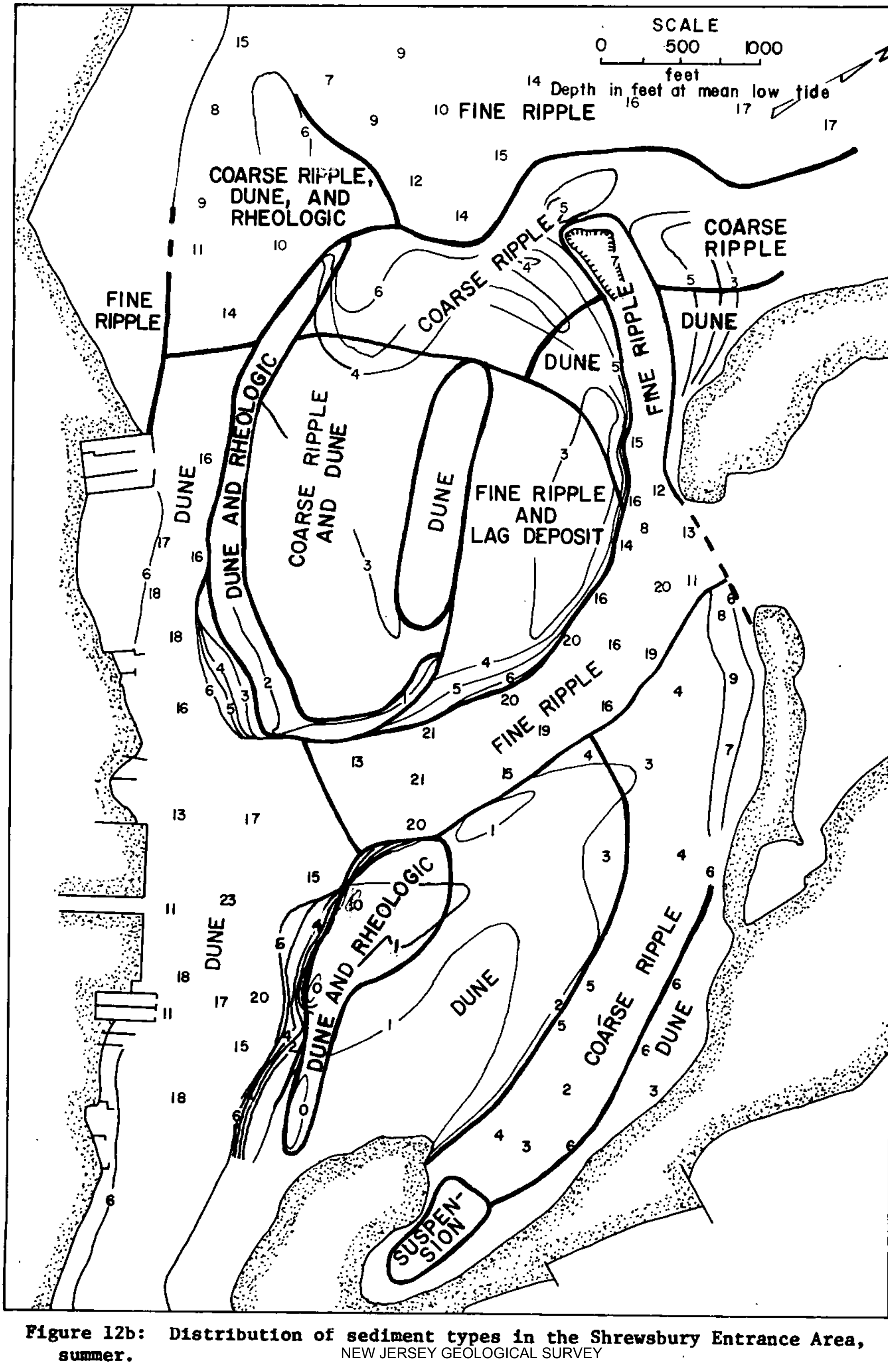

Figure 12b: Distribution of sediment types in the Shrewsbury Entrance Area, summer.

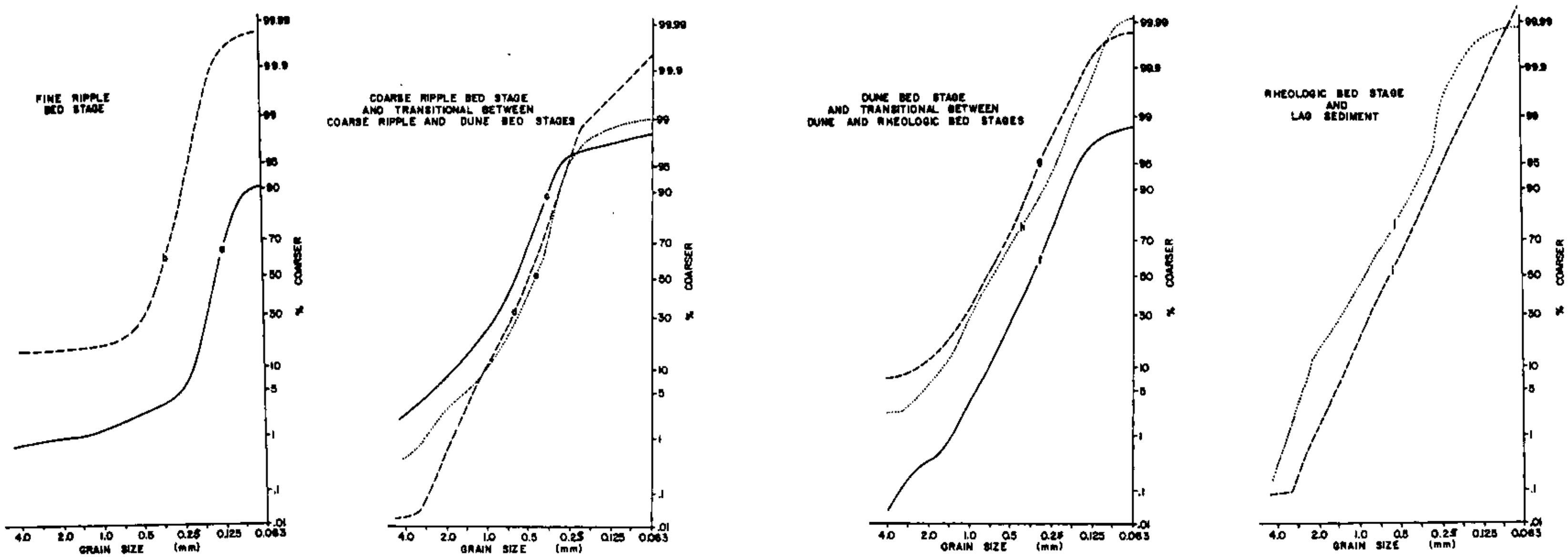

Figure 13. Grain-size distributions typical of sediment types: a. fine ripple, b. fine ripple (winnowed), c. coarse ripple, d. coarse ripple (winnowed), e. transitional between coarse ripple and dune, f. dune, g. dune (winnowed), h. transitional between dune and rheologic, i. rheologic (winnowed), j.lag sediment.

bedforms, low bearing strengths of sands, and moderate current are found within the State Channel, on flood dominated and shallow areas of the Lower Bar, on the shoal at the mouth of the State Channel, and on shallow areas of the Plum Island Shoal (Figure 12). Saltational populations of dune stage deposits, unlike those of coarse ripple stage deposits, are not sharply truncated. From areas of coarse ripple stage sedimentation into areas of dune bed stage sedimentation, the transition on log-probability plots between suspensional and saltational populations becomes increasingly smooth (Figure 13), demonstrating the increasing ability of sand finer than 0.25 mm. in diameter to enter the deposit.

5. Rheologic bed stage sediments. Areas of rheologic stage sedimentation were identified on the basis of transitions from dunes to planed-off dunes to firmly packed, plane bedded sands deposited from strong currents. Firmly packed, plane bedded sands indicate local development of rheologic stage sedimentation during late ebb tidal sheet flow across the ebb shield bordering the flood dominated sand flat and shallow portions of the Plum Island Shoal (Figure 12). Grain-size compositions of samples from these areas consist of a single log-normal grain-size distribution spanning the entire size range of sand (Figure 13). A contact population consisting of gravel or gravel and coarse sand is present in some samples.

   Areas of apparent rheologic bed stage sedimentation near the mouth of the Federal Channel, identified on the basis of grain-size compositions of sediment samples, firm packing, and the presence of isolated pebbles on a sandy bed suggests that, as has been described in the Altamaha Estuary of Georgia (Visher and Howard, 1974) a short period of strong bed shear occurs at flood tide beneath a zone in which dense, saline water intrudes beneath and mixes with less saline water. Velocity cross-sections were not available for this section of the channel.

6. Lag sediments. Sediments from the ebb dominated portion of the Lower Bar (Figure 12) generally contain distinct populations finer than 0.25 mm., between 0.25 and 2.0 mm., and coarser than 2.0 mm. (Figure 13). The coarser than 2.0 mm. population is predominantly a surface veneer of shell and gravel. These are interpreted as lag sediments isolated from sediment supply by their position on an ebb dominated area crossed by ebb currents from a deep, calm section of the State Channel. Stability of large particles on the sediment surface is indicated by dense colonization of their upper surfaces by benthic organisms.

Seasonal Changes in Sediment Type:

Geographic distributions of sediment types in autumn, winter, and spring samples are similar (Figure 12).

Differences in sediment distribution between these seasons and summer are at least partially explained as the result of a lower level of wave activity in the summer. The most striking change is in the greater area in summer of sediments containing appreciable amounts of material finer than 0.063 mm. (Figure 14). This change is ascribed to decreased winnowing.

Deposition of patches of fine ripple bed stage sediment over lag deposits on the ebb dominated sand flat (Figure 12) may be explained as the result of decrease in wave scour, wave generated current, wind generated current, or some combination of these.

A change from coarse ripple, dune, and rheologic bed stage sedimentation in the seaward portion of the State Channel (Figure 12) might be the result of either decrease in wave or wind generated currents or summertime density stratification such that colder or more saline bottom water is unable to flow freely over the shoal at the mouth of the channel.

Elsewhere in the Shrewsbury Entrance Area seasonal changes in sediment texture are minimal.

Discussion:

Morphology of sand shoals of the Shrewsbury Entrance Area is intimately related to patterns of sediment transport. Sediment transport near the mouth of the State Channel (Figure 1) resembles that at the intersection of a littoral drift cell with reversing tidal flow at a narrow inlet (Brunn and Gerritson, 1960). Sediment is carried southward by littoral drift along the western shore of Sandy Hook to an ebb dominated scour trench at the mouth of the channel, then carried seaward by tidal currents onto a shoal concentric about the mouth of the channel. On rough days sand from the crest of this shoal is carried by wave generated currents onto the surface of the Lower Bar.

In contrast to the open cycle at the mouth of the State Channel, sediment transport on the surface of the Lower Bar (Figure 1) follows a partially closed cycle resembling patterns of sediment transport within certain wide inlets (Ludwick, 1972). The surface of the Lower Bar is transected by distinct ebb and flood dominated areas (Figure 2). Sediment transport follows a counter-clockwise path between ebb and flood dominated areas. The rate of gain or loss of sediment to this cycle is controlled by wave scour and reflected in aggradation or erosion of the surface of the bar.

Spring and early summer aggradation of the surface of the bar by deposition of roughly 100,000 cubic yards of sand is believed to require sediment contributions from both an open cycle, in which sediment eroded from the surface of the bar is replaced by sediment entering the Shrewsbury Entrance Area from external sources, and a closed cycle, in which sediment eroded from the bar is stored in deeper areas within the Shrewsbury Entrance Area. Sediment eroded from the Lower Bar might be permanently deposited in dredged areas, on the Plum Island Shoal, seaward of the Lower Bar, in the Shrewsbury Estuary, or on a subtidal shoal which appears to have formed at the mouth of the Federal Channel since 1962 (National Ocean Survey, 1962-1973). Possible external sources of sediment to replace sand deposited in these areas include beaches to the north and west of the Shrewsbury Entrance Area, deep areas seaward of the Lower Bar, and the Shrewsbury Estuary. Sediment storage during seasons of intense wave action in areas other than the Federal Channel, the Shrewsbury Estuary, and the subtidal shoal at the mouth of the Federal Channel seems unlikely. Sediment brought to the southeastern and seaward

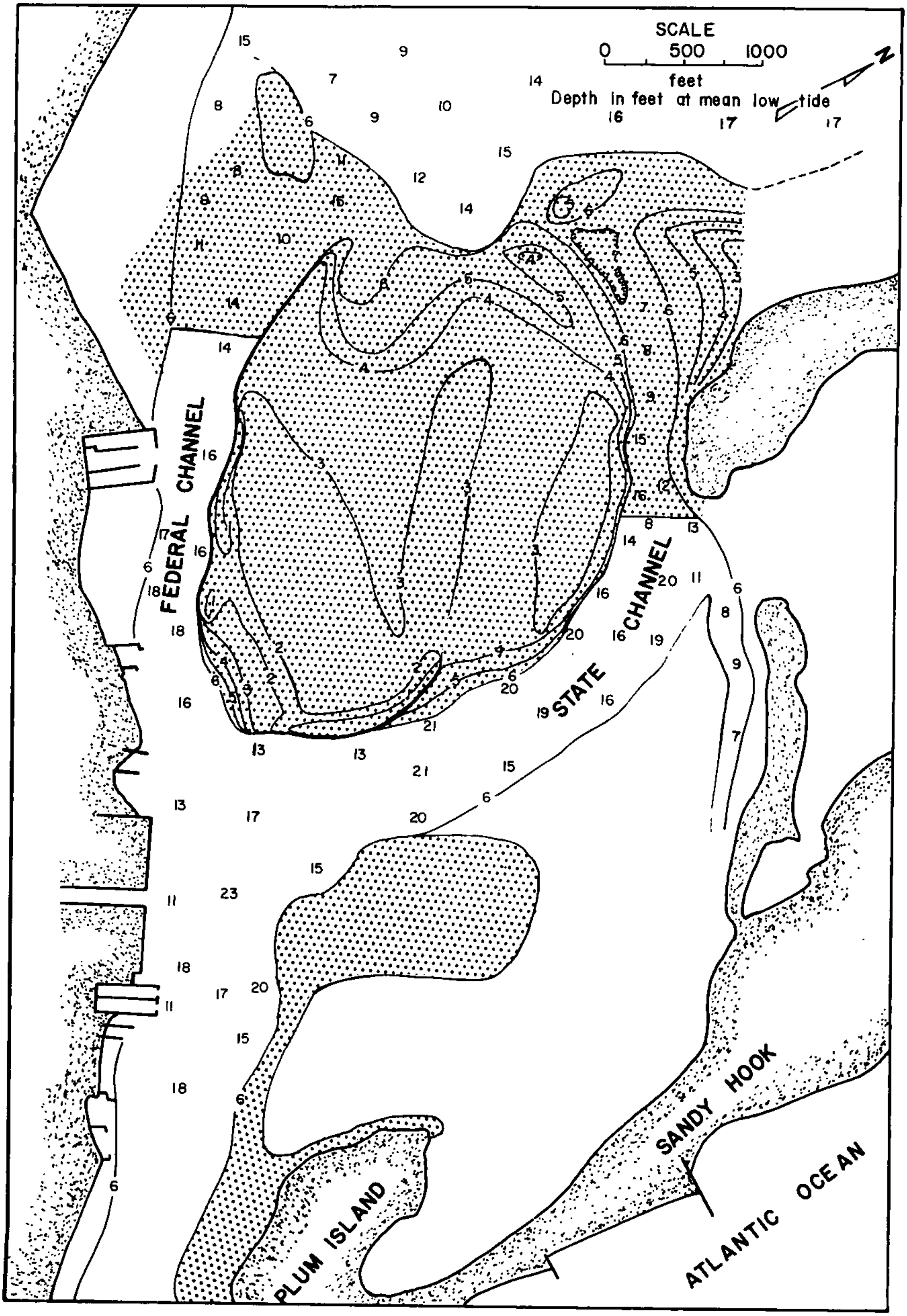

Figure 14a: Areas in which sediment finer than 0.063 mm. is winnowed from sediments, autumn, winter and spring.

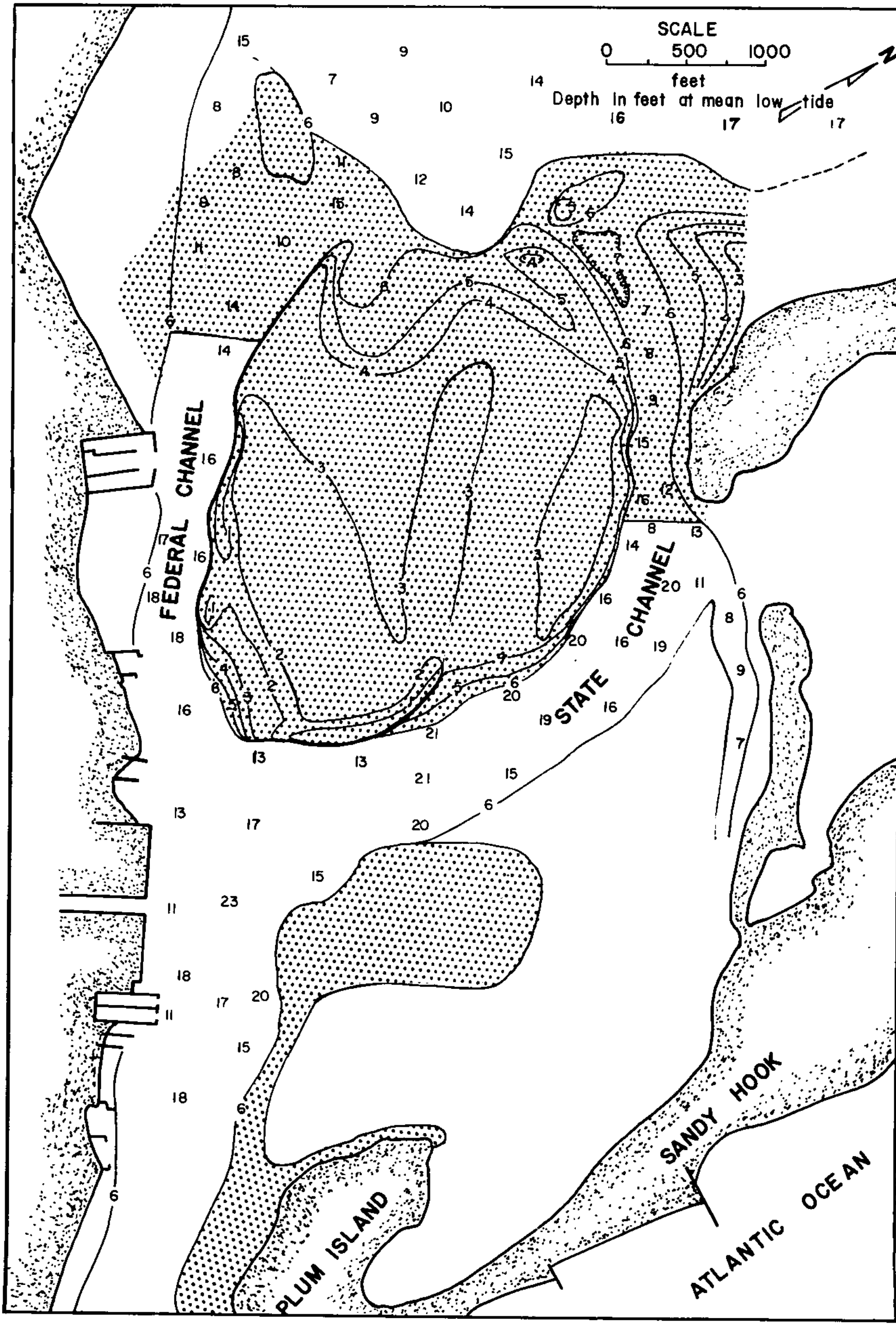

Figure 14a: Areas in which sediment finer than 0.063 mm. is winnowed from sediments, autumn, winter and spring.

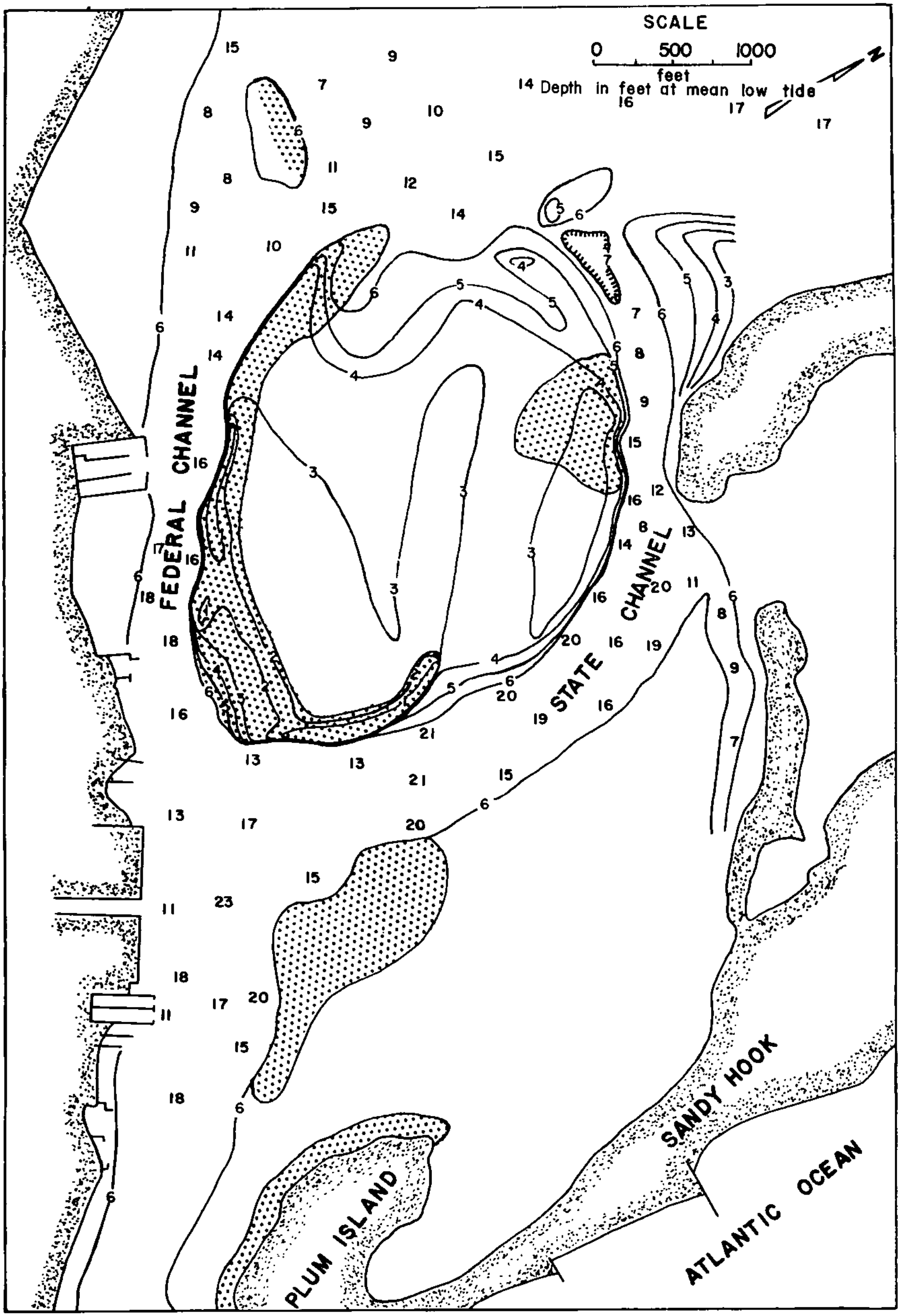

Figure 14b: Areas in which sediment finer than 0.063 mm. is winnowed from sediments, summer.

margins of the Lower Bar is deposited on steep slopes leading to calmer areas. With no obvious mechanism to raise large quantities of sand quickly from these slopes onto the bar surface, this material may be considered permanently lost. Similarly, no mechanism is seen by which sediment could be temporarily deposited on the Plum Island Shoal to be quickly returned to channels, thence to the Lower Bar.

Although the behavior of the surface of the Lower Bar seems to be independent of a recently completed dredging operation, this independence cannot be extended to earlier or future programs. Prior to 1900, a single channel having depths of six to ten feet passed through the Shrewsbury Entrance Area along the western shore of Sandy Hook (Geological Survey of New Jersey, 1901). Voluminous seasonal interchange between shoals and this small, protected channel is difficult to imagine. Subsequent channel development is primarily the result of dredging and has almost certainly affected the behavior of the surface of the Lower Bar.

Regarding future developments, it is important to note that the present annual bathymetric cycle is dependent upon strong currents capable of returning sand from the Federal Channel to the surface of the Lower Bar. Current strength within the Federal Channel might be reduced and the annual cycle disrupted by either substantial widening of the present channel or future growth of the delta at its mouth.

Summary:

The Shrewsbury Entrance Area of Sandy Hook Bay, New Jersey, is an area of sand shoals and man-made, actively maintained channels.

Repeated bathymetric surveys reveal an annual cycle on the Lower Bar, a prominent shoal (Figure 1). Sediment is eroded by higher energy waves between autumn and mid-winter. Net sediment movement is onto the bar at other times of the year.

Seasonally collected sediment samples reveal variations in sediment composition which may be attributed primarily to the greater intensity of winnowing and wave scour in the autumn, winter and spring as compared to the summer.

Annual cycles on the Lower Bar were maintained, apparently unmodified, through a recent, substantial dredging operation carried out in adjacent channels.

Bathymetry of the Shrewsbury Entrance Area and stability of sedimentary cycles on the Lower Bar are the result of patterns of sediment transport by tidal currents. Mutually evasive ebb and flood currents move sediment around the surface of the bar in a partially closed cycle. The depth to the surface of the bar is determined by the balance between entrapment of sediment within this cycle and removal of sediment from the surface of the bar by wave scour and wave generated currents. This depth is seasonally variable and was little, if at all, affected by recent channel dredging.

Sediment eroded from the Lower Bar in autumn and early winter, seasons of intense wave activity, is in part permanently lost, being replaced by sediment from external sources, and in part stored in deeper areas, primarily the Federal Channel (Figure 1). While tidal currents carry sand from the Federal

Channel onto the Lower Bar throughout the year, this sand is able to enter the closed cycle of sediment transport only between mid-winter and late summer, seasons of decreasing or gentle wave activity. During these seasons, sand leaves deeper areas and accumulates on the Lower Bar.

Although the behavior of the Lower Bar seems independent of recent dredging, bathymetric cycles appear dependent on channels created by earlier dredging. Continuation of these cycles in their present form could be disrupted either by further dredging or by natural deposition of sand at the mouth of the Federal Channel.

Acknowledgments:

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FUTURE ENERGY RESOURCES

INCLUDING OUTER CONTINENTAL SHELF DEVELOPMENT

by

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Many forward-looking people have lately come to realize that the nation's environmental problems are inextricably bound up with its energy problems.

They do go together. Large amounts of energy are consumed in meeting today's air and water quality standards. And energy must be supplied -- and used -- with minimal impact on the environment.

This paper will discuss the nation's energy needs between now and 1985, with a brief preview of what might be expected beyond 1985.

First we might look at the current sources of U. S. energy. Chart 1 shows the types and amounts of energy consumed in 1974, in terms of oil equivalents. For example, the volume of natural gas consumed in 1974 was equal in energy content to 10 million barrels of oil a day.

Total energy consumption in 1974 was 36 million daily barrels of oil equivalent. The traditional fossil fuels -- oil, natural gas, and coal -- supplied 95% of our needs.

The hydroelectric contribution was relatively small and the nuclear contribution, despite 20 years of promise, was only about 500,000 barrels of oil equivalent -- roughly 1.5% of the total.

This chart does not mention solar energy, wind power, geothermal energy, tidal power, or any of the other exotic answers to our energy prayers. That's simply because in 1974 they were not significant in relation to other sources of energy.

Imports ran about 7 million barrels a day in 1974. Most of this was crude oil; some was in the form of petroleum products like heavy fuel oil, and some was natural gas. If you take a rough estimate of $10 a barrel, these imports cost the United States more than $25 billion. That's one reason the government would like to reduce them. Another reason, of course, is that they can be cut off at any time for political or economic reasons.

Let's begin our forecast with a look at U. S. oil supply sources.

Chart 2 reflects the optimistic assumption that industry, government, and private citizens will work together to hold down consumption and build up production.

The straight line at the top, running from 1974 to 1985, reflects an annual growth rate for oil consumption of only 2.1%. This optimistic number was obtained simply by cutting in half the growth rate of the decade before the Arab oil embargo. Obviously, it means that most of us will be driving lighter weight cars fewer miles, building more efficient factories and refineries, and generally adopting the ethic of conservation.

That sharp dip at the top of the chart resulted from the oil embargo, the sudden high prices, and the recession. We expect that it will soon turn up again.

If the growth rate should resume its old upward curve, it would run right off the top of the chart. We cannot allow that to happen. The entire increase

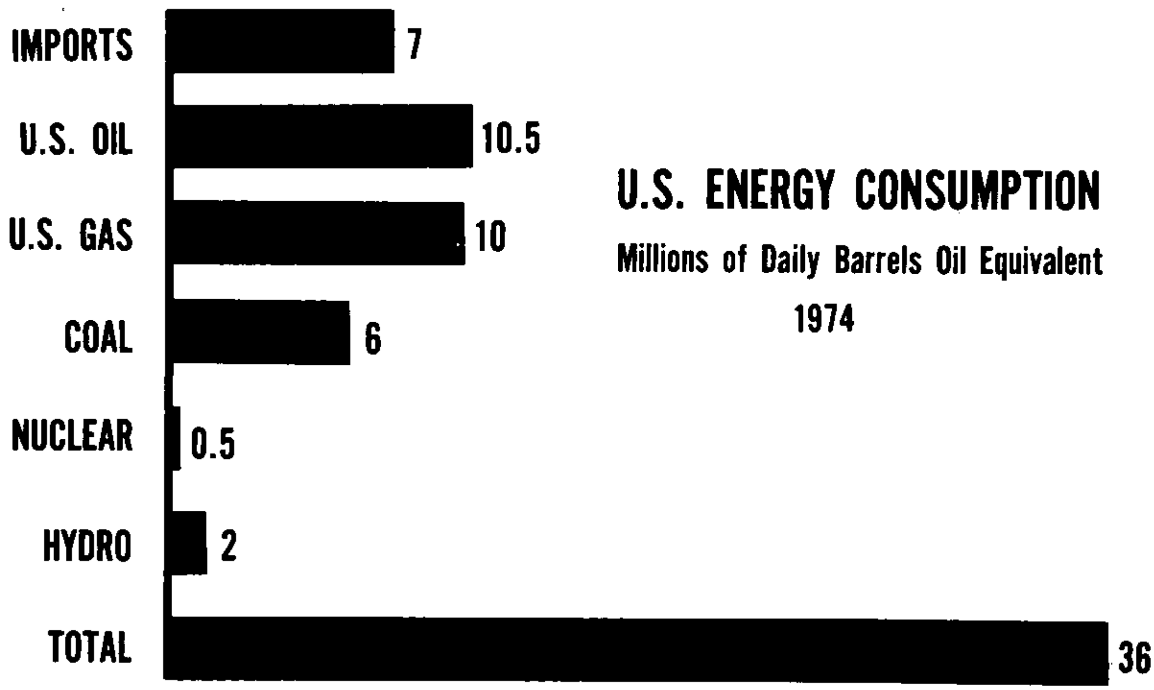
IMPORTS
7
U.S. OIL
10.5
U.S. GAS
10
COAL
6
NUCLEAR
0.5
HYDRO
2
TOTAL
36
U.S. ENERGY CONSUMPTION
Millions of Daily Barrels Oil Equivalent
1974

CHART I

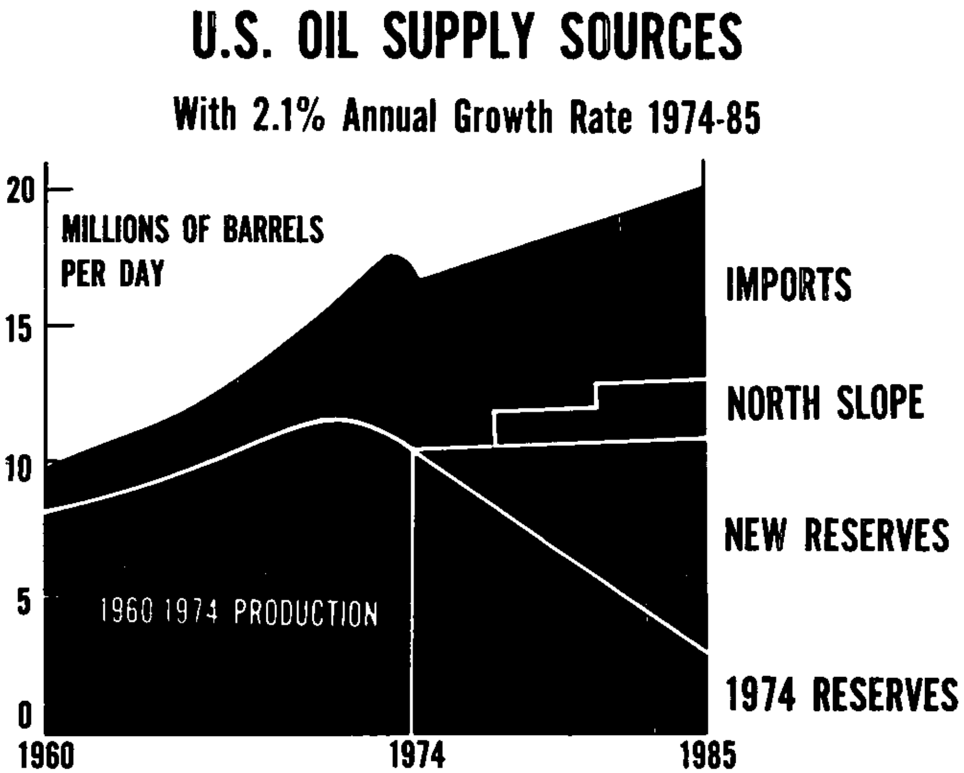

CHART 2

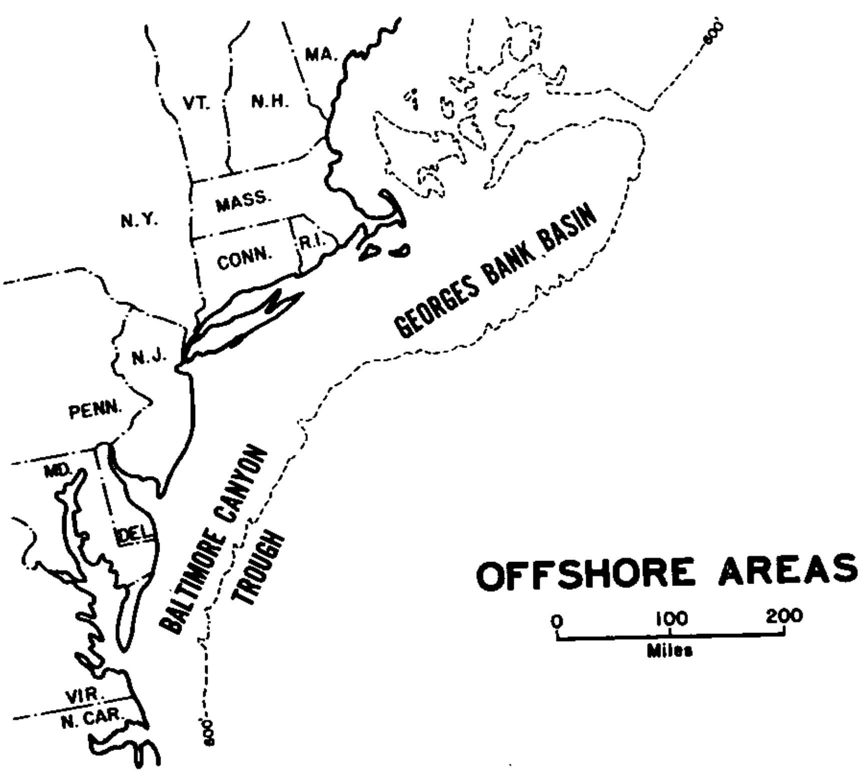

CHART 3

would have to be imported and the economic -- not to mention political -- consequences would be disastrous.

The area at the lower left is the average daily production of U. S. oil from 1960 through 1974. It peaks about 1970. By that time most of the big, low-cost oil fields on land had been found. New discoveries could no longer keep ahead of increasing demand.

The section at the lower right shows how rapidly U. S. oil production would decline between now and 1985, if we did nothing except produce the oil fields. Obviously, we need to find and produce enough new oil to offset -- at the least -- this drastic decline.

The Alaska pipeline will help. Oil should start to flow in 1977, and by 1981 we should be getting 2 million barrels of oil per day from the North Slope.

But the New Reserves area is the critical one. This section shows what could happen with an all-out effort to find new oil fields, drill more wells in the old areas, and use expensive new techniques for getting more oil out of each producing well. Considering the rate at which Congress is constructing an energy policy to encourage this all-out effort, our projection may be too optimistic.

Nevertheless, let's look at the New Reserves that could come on production by 1985.

Offshore Drilling Will Be Essential

We expect that most of the New Reserves of both oil and natural gas wil be found offshore, on the Continental Shelf. The total area of the Continental Shelf is 875,000 square miles, which makes it about the size of all the states east of the Mississippi River. Only 2% of this area has been leased for oil and gas exploration.

The Gulf of Mexico off Louisiana has been the most productive area for both oil and gas for a number of years. Southern California is the second most productive area. A small amount of oil also is produced in Alaska's Cook Inlet.

These are the only active producing areas on the Continental Shelf -- but they supply 16% of our domestic oil and 20% of our gas.

No drilling has yet been permitted along the East Coast of the U. S. Chart 3 shows the most prospective areas: the Georges Bank Basin, some 50 to 100 miles off the coast of New England, and the Baltimore Canyon Trough, 25 to 90 miles off the mid-Atlantic Coast. Another area, off northern Florida and South Carolina, may also be prospective.

All these areas are on the outer continental shelf, meaning they are in federal waters beyond the three-mile limit. The continental shelf extends from the shoreline to a water depth of about 600 feet, which is traced by the dotted line on the map. The depth then begins to increase rather abruptly, and the continental shelf becomes the continental slope. At roughly 6,000 feet the slope grades into the continental rise, and at about 12,000 feet the rise merges into the abyssal plain.

These three zones -- shelf, slope, and rise -- together make up the continental margin. Under the continental margin lie vast amounts of sediments which could contain both oil and natural gas. Exploring these frontier areas will be absolutely essential if the United States hopes to prevent its reserves from declining precipitously.

I'm well aware that every time an oil man mentions offshore drilling, somebody tells his Congressman there ought to be a law against it. I'm also aware, however, that the risk of an oil spill is minimal. The industry has drilled more than 19,000 wells in U.S. waters, with only four accidents that caused major pollution problems. None of these, including Santa Barbara, caused any permanent damage to beaches, marine life or property. Studies also indicate that 30 years of producing both oil and gas in the Gulf of Mexico have not changed the basic biological character of the Gulf to any significant degree.

When the search for petroleum moves into the deeper waters of the continental slope, underwater systems like that shown in Chart 4 will be used for oil production. This type of system will be installed after an oil field is discovered by a floating drillship.

Each SAS unit (SAS is the Seal Atmospheric System, being developed by Mobil and several other companies) is lowered in sections from a ship, and assembled on the ocean floor. Each unit has an airtight control chamber in which three men can work at normal atmospheric pressure, performing maintenance and repair chores.

As many as 18 development wells are drilled through each SAS unit. The flowlines lead to a central gathering station, and from there the oil is pumped through a riser to a storage ship on the surface. The water could be as deep as 6,000 feet.

More Oil from Each Well

Another way to increase new reserves is to produce more oil from each well. In 1960, as Chart 5 indicates, the average U. S. oil field gave up only 25% of its oil over its lifetime. Today the recovery efficiency is about 32%. Most of this improvement is due to waterflooding -- which means pumping vast volumes of water into an oil formation under pressure. The water forces the oil out of the pores in the rock and into the producing well.

New, expensive, but more efficient methods could raise the efficiency to 37% by 1985. This would add 22 billion barrels to the recoverable reserves in the oil fields now on production. Present U. S. reserves are only about 40 billion barrels.

Let's look at one of these improved-recovery processes for crude oil, and then at one for natural gas.

Chart 6 illustrates a process called Low Tension Waterflooding. It involves using chemicals to lower the capillary forces within the reservoir, so more of the oil can be pushed out by the waterflood.

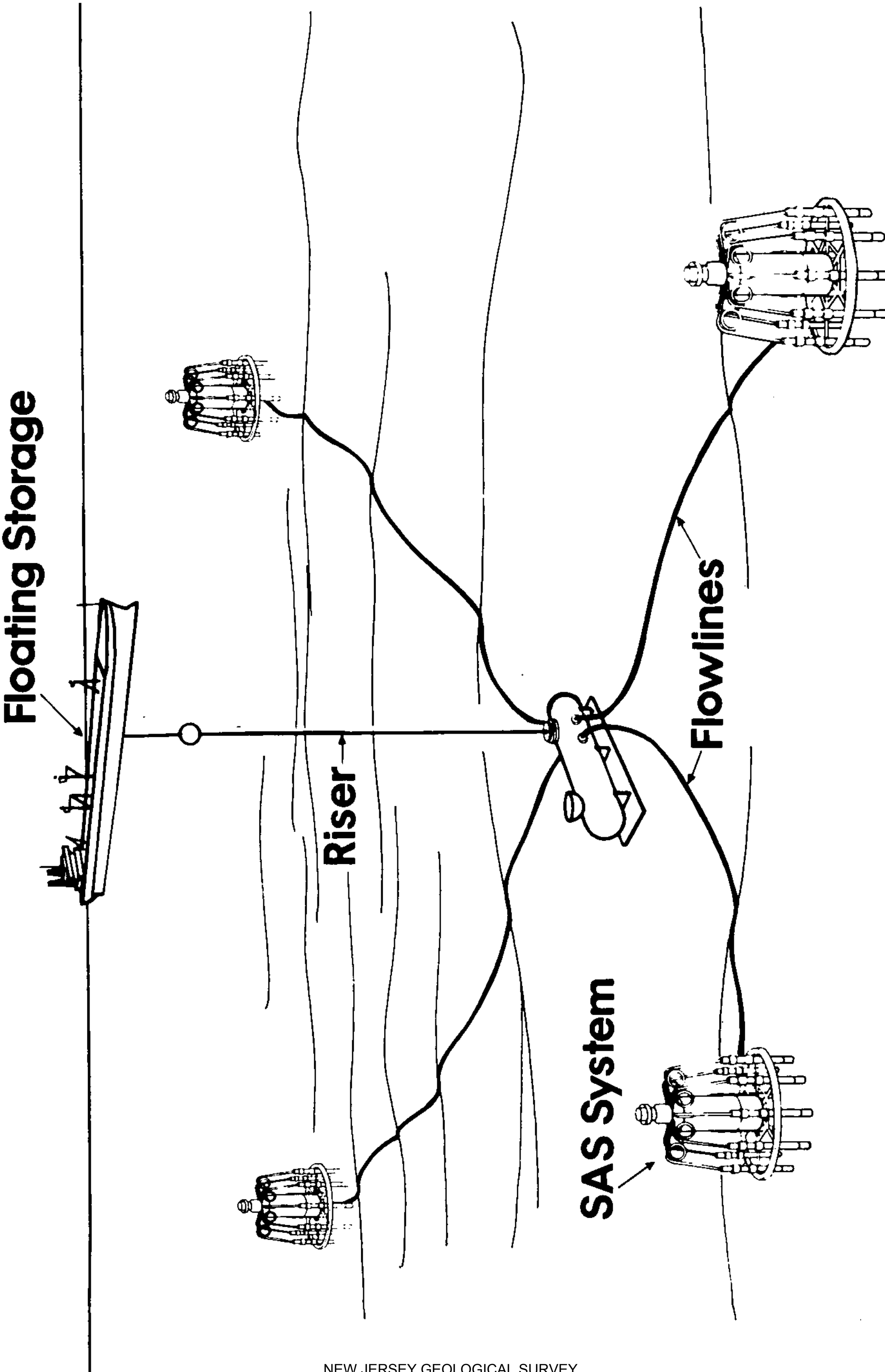

CHART 4

U.S. CRUDE OIL RECOVERY EFFICIENCY

Percent of Original Oil-in-Place Recoverable

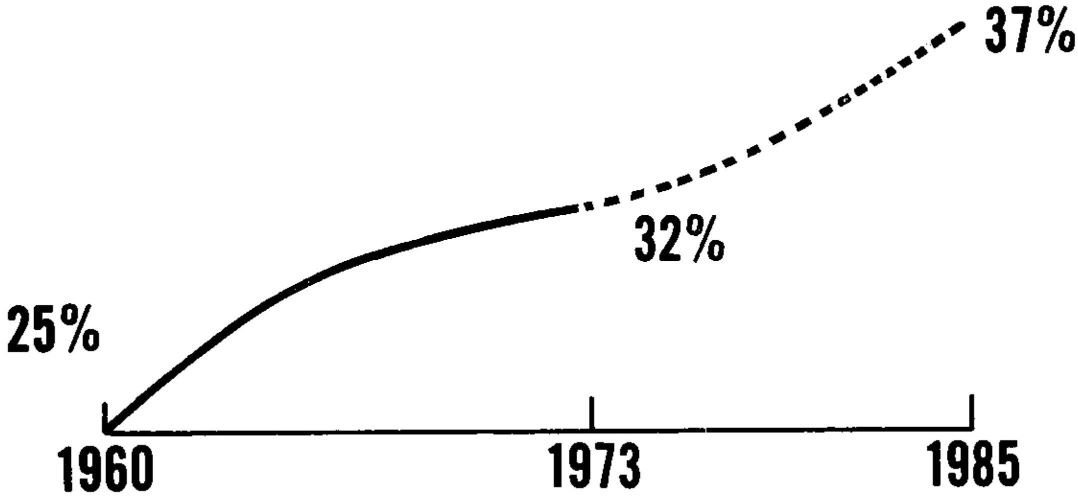

CHART 5

LOW TENSION WATERFLOOD

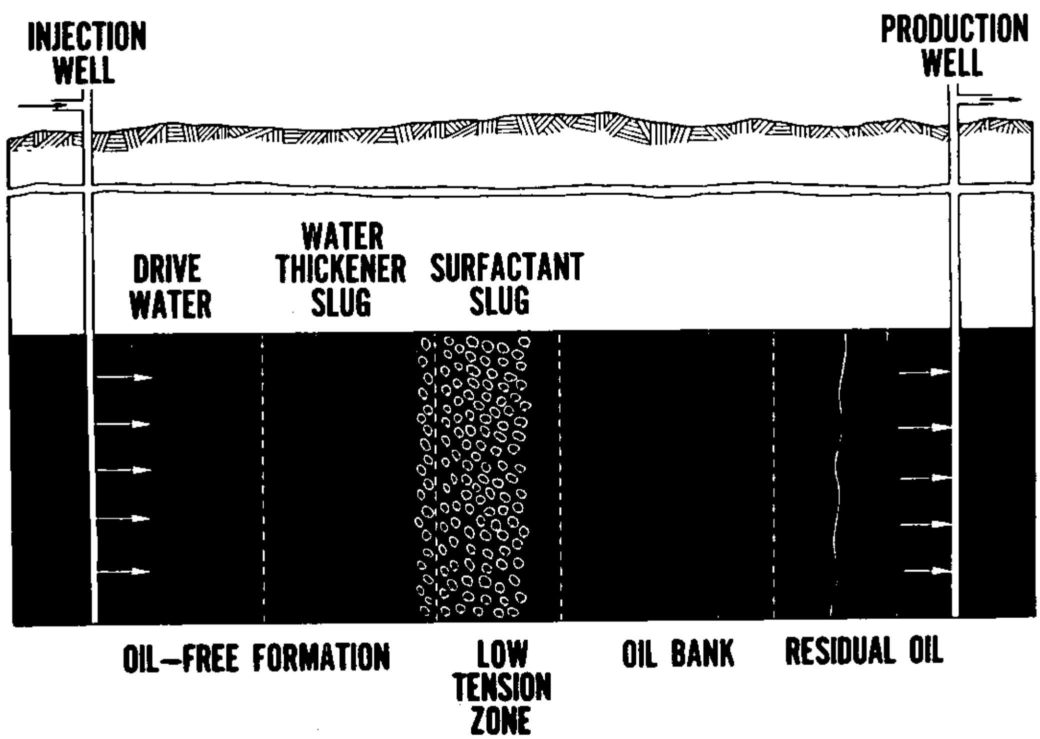

CHART 6

In this diagram, flow is from the injection well at the left to the production well at the right.

⊕ The residual oil at the right represents oil left after ordinary waterflooding.

⊕ Next, an oil bank is being forced toward the production well by the chemical waterflood.

⊕ In the low tension zone, the working chemical -- a surfactant -- creates the very low tension between oil and water which permits the water to carry the oil toward the producing well. It's something like detergent washing the grease out of clothes in your washing machine.

⊕ In the left part of the diagram the rock formation is almost oil-free. The water is thickened with another chemical so it pushes the oil like a piston, instead of "fingering" through the oil.

⊕ Last, in the sequence, is the ordinary drive water.

This is one of a series of chemical processes designed for different crudes, reservoir conditions, and rock formations. In a given field, it may take as long as 20 years to produce all the new oil recoverable by one of these processes, and each new barrel of oil can cost from $4 to $10 to recover.

Heavy oils - oils from 100 to one million times as viscous as water -- need another series of processes. These are generally thermal methods, in which steam or hot water is injected to heat the oil so it will thin out and flow to the producing wells.

Another approach is in situ combustion, in which a portion of the oil in the reservoir is ignited, to produce hot gases which heat the remaining oil and drive it to the producing wells. On the average, 10 barrels of oil -- which otherwise would probably never be recovered -- are produced for each barrel burned in the process.

Improved recovery methods also can increase our production of natural gas. One of the world's great storehouses of energy is in the natural gas basins of Colorado, Utah, and Wyoming. Trouble is, the gas is trapped in low-permeability, low-porosity rock, and cannot be produced in commercial quantities.

Last summer we tested a process called Massive Hydraulic Fracturing in Colorado. We have been using hydraulic fracturing to stimulate gas production in several states, with very good results -- but never on this massive scale or in rock formations as difficult as these. During the test we pumped 400,000 gallons of water and chemicals, plus one million pounds of sand, down an 8,000-foot hole in only two hours.

Chart 7 shows what happened at the bottom of the hole. The water forced open a fissure in the rock about half an inch wide and 200 feet high. As water and sand continued to be forced down the hole, the fissure expanded outward until it reached 3,000 feet tip to tip. Then the water was pumped out, leaving the sand to keep the fracture propped open. We got some gas, but not

MASSIVE HYDRAULIC FRACTURE

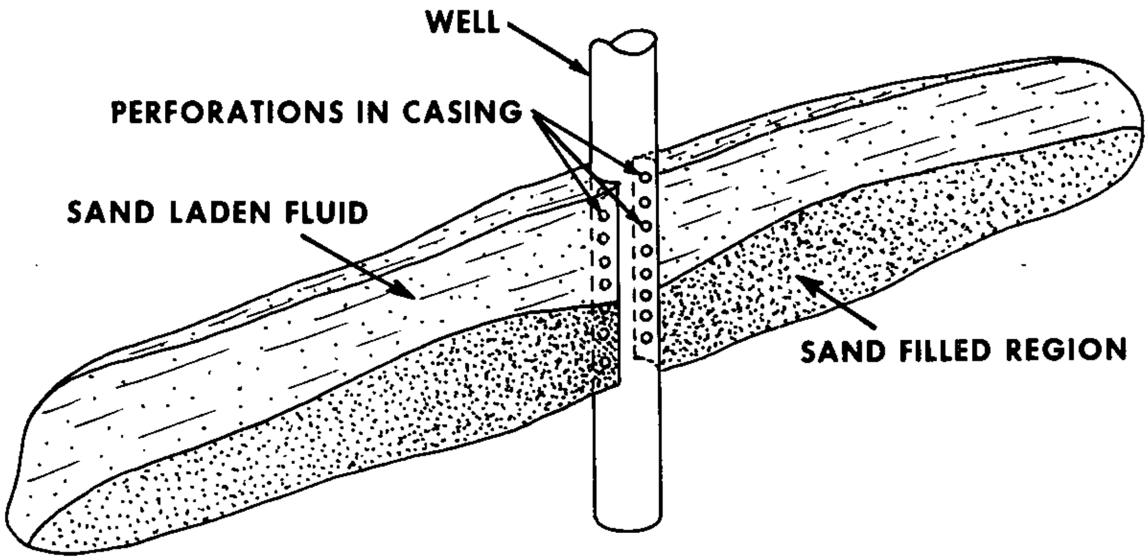

CHART 7

MAKING GASOLINE FROM COAL

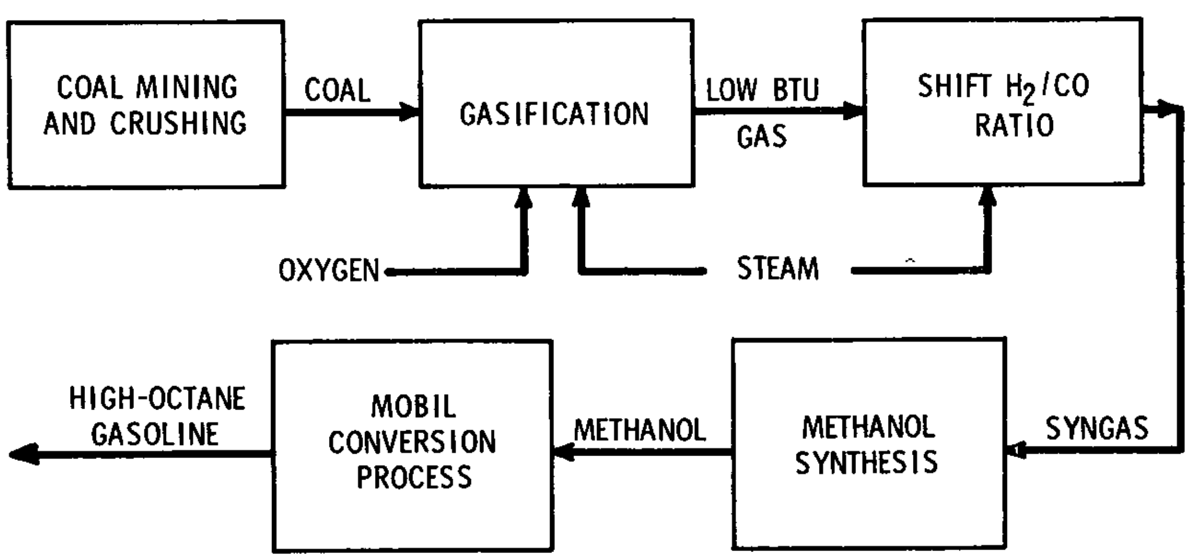

CHART 8

in commercial quantities. The permeability of the rock surrounding the fissure was too low to permit sufficient gas to flow into the producing well.

But such are the risks that must be taken. We plan to drill another well, and try again.

Gas and Oil from Coal

Now let's look at coal -- a fossil fuel, like oil and gas, but many times more abundant. The U.S. has enough coal to supply all the solid, liquid, and gaseous fuel we will need for several hundred years at today's consumption rates. More than half the states, including Alaska, have some coal production.

While power plants are expected to burn most of the increased coal production between now and 1985, a considerable amount of research and development effort will be going into both gasification and liquefaction processes. Most of this work will be done on a cooperative basis with the federal Energy Research and Development Administration (ERDA).

Several gasification pilot plants are already in operation and others are under construction to test processes for making both low-BTU and high-BTU gas. But the cost of high-BTU pipeline-quality gas made from coal will be very high.

Coal can also be liquefied, using either thermal or catalytic hydrogenation methods. Thermal gives a low yield, and hydrogentation poses some difficult technical problems. We expect to see relatively little commercial coal liquefaction before 1985. But it could become a major industry in the years beyond.

As Chart 8 indicates, Mobil is working on a method for converting methanol-- which can be made from coal with existing technology -- into high-octane gasoline. This is a unique new catalytic process.

Under a cost-sharing contract with ERDA, we are now designing a pilot plant to process 100 barrels a day of methanol. More than 95% of the methanol energy content will be converted into hydrocarbons.

At today's prices, gasoline from coal could not compete with gasoline from crude oil. But by the early 1980's, when the first commercial plant could be operating, the economics may be different.

Producing Oil from Shale

Oil shale is another potential raw material for liquid hydrocarbons. Nearly all the U.S. shale reserves are in western Colorado and nearby Utah and Wyoming. It is semi-arid, sparsely populated country. Among the things we have learned about shale is that the problems of environment and sociology are as formidable as the problems of technology and economics.

Oil shale contains kerogen, a solid organic material from which the oil is derived. The shale is crushed and then heated to high temperatures in a retort. The oil is drawn off as a vapor. A rich shale would yield 30 gallons of oil or more per ton of rock.

The process, as shown on Chart 9, looks deceptively simple. But a facility to produce 100,000 barrels of oil a day would require mining 140,000 tons or rock per day. Such a mine would be more than 10 times the size of the largest underground coal mine in the U.S., and the spent shale would occupy more space than the raw rock. The cost would be $1 to $2 billion, depending on the retorting process and the extent to which the oil is upgraded.

Retorting the shale in situ, or in place, would leave less shale for disposal. The technology is not as advanced for in situ methods as for aboveground retorting, but ultimately the investment costs may be lower.

Either way, the environmental and economic problems are difficult -- so difficult, in fact, that we do not expect production to reach as much as 500,000 daily barrels by 1985.

Fission, Breeder, and Fusion

By 1980, uranium will be our largest non-fossil energy source. Today's fission reactors utilize less than 1% of the energy content of uranium. Breeder reactors are expected to achieve an efficiency of 60% or more, but are not likely to be commercially significant before 1990.

Nuclear fusion might be termed one of the two ultimate sources of energy. In a fusion reaction, tremendous amounts of energy are released when the nuclei of hydrogen isotopes combine to form helium. A sustained fusion reaction has not yet been demonstrated. But the theoretical and practical work already accomplished indicates that fusion may be a commercial reality by the year 2000 -- which is not all that far in the future.

Solar Energy for Heat and Electricity

The second ultimate source of energy is the sun. During the next decade we will see hundreds, perhaps thousands, of buildings heated and cooled by solar energy. We also will see progress made in converting solary energy directly into electricity, using a photovoltaic material such as pure silicon.

In one new process for making solar cells, a ribbon of single-crystal silicon is drawn continuously from a crucible of molten polycrystalline silicon. Wire grids are then applied to the ribbons to make complete solar cells. This process is being developed by Mobil Tyco Solar Energy Corporation. The old method is to make cells by slicing thin sections from cylindrical shapes, which is a slow and very expensive procedure.

One day solar cells may compete with nuclear energy in some applications. But like the fusion reactor, the solar cell will not be a significant factor until well after the year we are primarily concerned with here, which is 1985.

Imports to Increase

So now let's focus on 1985. Chart 10 shows how U.S. energy supply and demand could change over the next ten years.

OIL SHALE
Above Ground Retorting Process

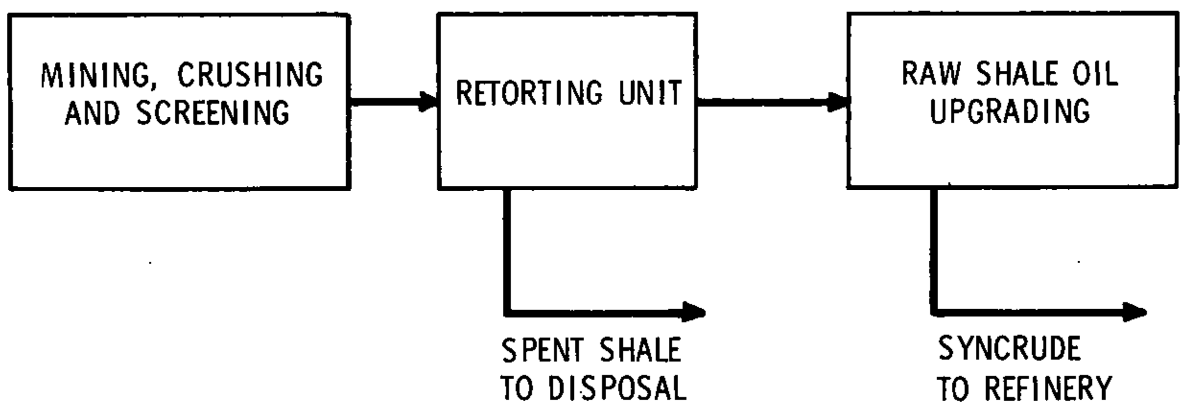

CHART 9

U. S. ENERGY DEMAND & SUPPLY

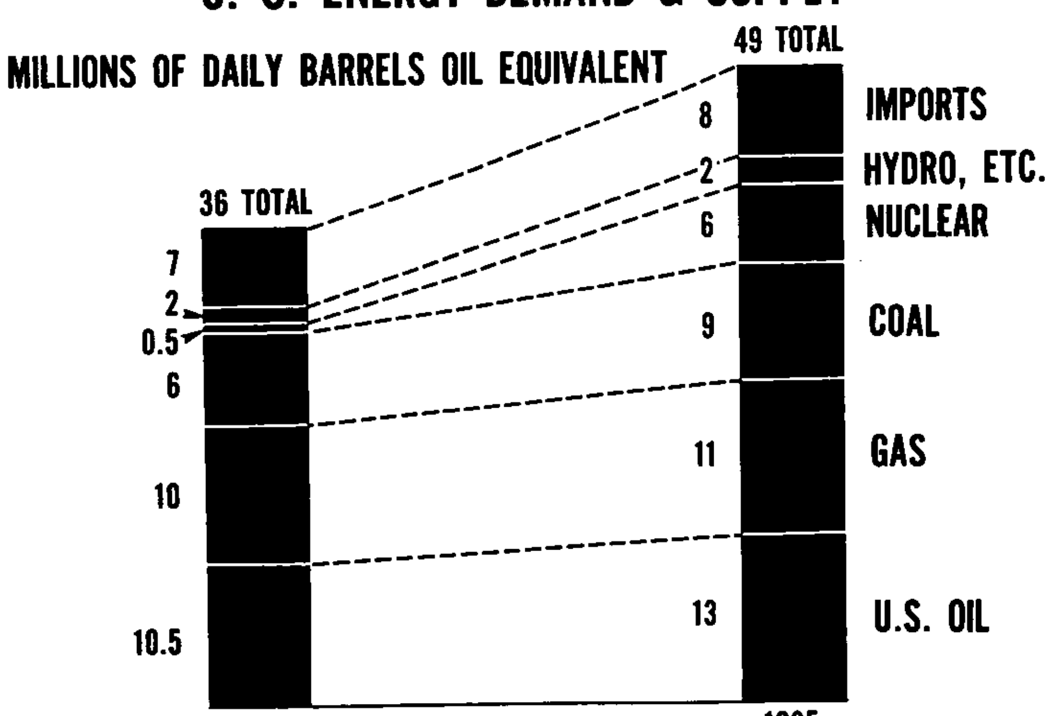

CHART 10

Starting at the bottom of the 1985 column, we see that oil produced in the U.S. will be about 13 million barrels a day. This includes some oil made from shale and coal. Thus the increase over 1974 is not much more than 2 million barrels a day -- which is the capacity of the Alaska pipeline. This means that all the additional oil we can get from drilling new wells, both onshore and offshore, and from using improved recovery processes, will barely offset the decline in production of the older fields

The gas section includes a small amount of gas made from coal. There's a lot more natural gas to be found in this country. But its low prices have led to such high demand that older fields are being depleted as fast as new ones can be found.

Coal shows an increase of 3 million daily barrels of oil equivalent. This is nothing like the doubling and tripling of coal output that many people seem to expect. The lead times involved in getting new mines on production, plus restriction on strip-mining low-sulfur coal and burning high-sulfur coal, will not permit coal to expand as rapidly as some might wish.

Nuclear power shows a spectacular jump, from 0.5 million daily barrels of oil equivalent to 6. We assume that most of the environmental, design and construction woes of the nuclear-power industry will soon be overcome, and that new plants will be built as rapidly as dictated by power needs and capital availability. But note that despite its rapid growth, nuclear in 1985 is still smaller than any of the fossil fuels.

The small section called "Hydro, Etc." is mostly hydroelectric. The "Etcetera" portion is largely geothermal, with some solar energy for heating and cooling.

Now for imports. We see no way in which imports can be reduced by 1985 without a serious detrimental impact on the economy. In fact, it will require a highly hopeful set of conditions to keep the increase to only one million barrels a day.

Conservation Is Not Enough

The U.S. has both the resources and the technology to maintain a reasonable degree of energy independence through 1985. During the following years we can augment our supplies by making oil and gas from coal and shale. And ultimately, we can obtain vast amounts of virtually inexhaustible energy from sunlight and nuclear fusion.

But the early years will be the critical ones, and the U.S. is simply not moving fast enough. Conservation by private citizens and industry will continue to be vital. But conservation is not enough. We cannot maintain any reasonable degree of energy independence without a maximum effort to develop U.S. energy sources.

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RECENT DEVELOPMENTS IN THE LAW OF THE SEA

STATUS AFTER GENEVA 1975

by

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Fordham University
New York

On September 28, 1945 President Truman issued two proclamations. In one concerned with "the Natural Resources of the Subsoil and Sea Bed of the Continental Shelf" the President considered the continental shelf as "an extension of the land-mass of the coastal nation and thus naturally appurtenant to it." He declared effectively that

> [h]aving concern for the urgency of conserving and prudently utilizing its natural resources, the Government of the United States regards the natural resources of the subsoil and sea bed of the continental shelf beneath the high seas but contiguous to the coasts of the United States as appertaining to the United States, subject to its jurisdiction and control.[1]

In the second "Proclamation with Respect to Coastal Fisheries in Certain Areas of the High Seas" the President in a slightly different way declared that

> The Government of the United States regards it as proper to establish conservation zones in those areas of the high seas contiguous to the coasts of the United States wherein fishing activities have been or in the future may be developed and maintained on a substantial scale.[2]

These proclamations represented for the United States a departure from a long cherished main legal principle for establishing and maintaining of territorial sovereignty, namely that of effective occupation through "continuous and peaceful display of the functions of State." Instead the proclamations expressly adopted the principle of contiguity as basis for extension of territorial claims, in the sense that a territorial object should rightfully be under the "jurisdication and control" merely because it is an extension of, or situated nearby to, the established territorial sovereignty of the claiming nation.[4]

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[1]10 Fed. Reg. 12303, as quoted in H. Briggs, The Law of Nations, 1952, Appleton Century Crofts, N.Y., pp.378 f.

[2]10 Fed. Reg. 12304, as quoted in Briggs, op.cit., p.378.

[3]Max Huber, Arbitrator, in The Island of Palmas Case, United States-The Netherlands, Tribunal of the Permanent Court of Arbitration, 1928, 2 U.N. Reports of International Arbitral Awards 829, cited in E. Collins, Jr., ed., International Law in a Changing World: Cases, Documents ..., 1970 : Random House, N.Y., p.134.

[4]In the same Palmas Case, Judge Huber still dismisses the contiguity principle in rather harsh terms: "[A]s a rule establishing ipso jure the presumption of sovereignty in favour of a particular State, this principle [of contiguity] would be in conflict with what has been said as to territorial sovereignty and as to the necessary relation between the right to exclude other states from a region and the duty to display therein the activities of a State. Nor is this principle of contiguity admissible as a legal method of deciding questions of territorial sovereignty; for it is wholly lacking in precision and would in its application lead to arbitrary results." Ibid., p.138.

The presidential proclamation regarding the continental shelf asserted American jurisdiction as established by virtue and at the time of the proclamation itself, while the fisheries proclamation only served notice that jurisdictional claims will be made in the future in areas needing such protection and with certain respect for eventual claims or rights of other nations.

The Truman Proclamations of 1945 started a process of development and growth in the international law of the sea of unprecedented proportions. The thirty years since their publication saw more changes in this body of law than the 300 years before since the time in the seventeenth century when the principle of the freedom of the seas based on writings of the Dutch jurist Hugo Grotius became the predominant rule of maritime law.

Significant was the reception of the American proclamations within the international community. Other nations, instead of protesting to what in physical terms amounted to the largest unilateral extension of territorial jurisdiction in recent history, rather emulated the United States and made similar claims themselves. Within a decade after the Truman Proclamations the continental shelf and, to a lesser degree, the idea to establish exclusive fishery zones became established and recognized legal principles leading to conventional formulations in 1958 at the First United Nations Conference on the Law of the Sea in Geneva.

Two types of early parallel reactions to the Truman Proclamations deserve brief consideration. Both came from American neighbors to the South in Latin America. Neither of the two was as yet officially recognized at Geneva in 1958 but each had important long range implications. Both were from the outset protested by the United States.

The Truman Proclamations presented claims for functional extensions of state jurisdiction in selective areas: total control of natural resources of the sea bed and subsoil on continental shelf, in one case, and control of fishery resources, in the other, while the texts tried carefully to retain the character of high seas of the waters above the continental shelf or within the fishery zones, respectively.

The Latin American approaches were on the other end of the spectrum. One of them, typified by the Argentinian declaration of October 9, 1946, proclaimed full Argentinian sovereignty over both the continental shelf and the overlying epicontinental sea exempting only free navigation in the newly claimed area.[1] The other approach was exemplified by several Pacific Latin American states which, lacking any natural continental shelf proper, began to claim sovereignty over a 200 mile zone from their coasts.[2]

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[1]Cf.Argentina, Declaration Proclaiming Sovereignty over the Epicontinental Sea and the Continental Shelf, Decree No. 14.708, as cited in Briggs, op. cit. pp.379 f.

[2]For a detailed elaboration see F.V. Garcia-Amador, "The Latin American Contribution to the Development of the Law of the Sea," 68 Am. J. of Int. Law, Jan. 74, pp.33-50.

Two sets of developments contributed to the growth of the law of the seas in the 50's and 60's. One was the movement toward the codification of the law of the seas begun in the United Nations by the International Law Commission and culminating in the First and Second United Nations Conference on the Law of the Seas in 1958 and 1960, respectively. The other was an unprecedented increase in scientific, technological and economic activities that brought the world oceans and their actual and potential resources into focus of international attention.

The First United Nations Conference on the Law of the Sea (UNCLOS I) produced four conventions, namely

1. Convention on the Territorial Sea and the Contiguous Zone;

2. Convention on the High Seas;

3. Convention on Fishing and Conservation of the Living Resources of the High Seas; and

4. Convention on the Continental Shelf.[1]

Of these only the high sea convention is according to the preamble "generally declaratory of established principles of international law." The other three conventions recorded many legal rules that could be considered as already accepted customary law[2] though they also formulated some new ones. By 1966 all four conventions were ratified by a sufficient number of states to be valid at least as conventional law between the parties. They are undergoing, however, a process of erosion due to the rapid development of new practices and needs. There may be in several areas already established today new customary rules, especially as evidenced by various more or less authoritative UN resolutions. These changes were initiated in some instances by the new formulations recorded in the 1958 conventions, or because the conventions failed to bring about proper formulations or contained important loopholes. We would like to touch here only on a few, most important such passages particularly from the convention on the territorial sea and from one on the continental shelf.

The Convention on Territorial Sea and the Contiguous Zone, while defining the concept of Territorial Sea in Articles 1 and 2, failed to establish definite seaward limits for the same. The seemingly traditional three mile limit was questioned ever since the 1930 Hague Conference. In Geneva

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[1]The conventions were adopted by the UNCLOS I on April 29, 1958, UN Doc. A/CONF.13/L.52 - L.55, also Ian Brownlie, ed., Basic Documents in International Law, 2nd ed., 1972, Oxford University Press, pp.79 ff.

[2]Thus the Territorial Sea convention specifies in Art. 1(2) "This sovereignty [of the coastal state over the territorial sea] is exercised subject to the provisions of these Articles and to other rules of international law." The remaining two conventions do not contain any reference to an already existing body of law.

a compromise of sorts was reached by adding on top of the traditional territorial sea also a contiguous zone and providing a definite limit for the latter at twelve miles from the baseline. But no agreement could be reached on the limit of the territorial sea itself. Thus the article that attempts to define this limit is a classical example of legal obfuscation:

> Article 6: The outer limit of the territorial sea is the line every point of which is at a distance from the nearest point of the baseline equal to the breadth of the territorial sea.

The second conference convened in Geneva in 1960 for the main purpose to reach an agreement on the limit of the territorial sea. A compromise six mile proposal failed to reach the required majority by one vote, leaving the matters at the 1958 formulation. Afterwards some states claiming three miles, among them the United States and other major Western naval powers, retrenched themselves on their original position and declined to recognize any larger limit as valid against them without their agreement. A greater number of other states, however, began to assert a wider limit for their territorial sea.[1] The indefinite territorial sea limit in the convention thus indirectly contributed to an expansionary trend.

The territorial sea convention also introduced as general conventional law a novel concept of the territorial baseline, that is the line from where the territorial sea is measured. The traditional baseline was the low water line which the convention retains as a general and normal baseline.[2] In addition to this the convention also permits the application of "straight baselines," as this concept was developed by the decision of the International Court of Justice in the Anglo-Norwegian Fisheries Case.[3]

> Article 4. (1) In localities where the coastline is deeply indented and cut into, or if there is a fringe of islands along the coast in its immediate vicinity, the method of straight baselines joining appropriate points may be employed in drawing the baseline from which the breadth of the territorial sea is measured.

One of the justifications offered for this new method were "economic interests pecular to the region concerned."[4] It is important to note that waters shoreward from such straight baselines belong to the internal waters under full sovereignty of the state and cease to be part of the territorial sea.[5]

The logical extension of the principle of straight baselines, not yet, perhaps, envisaged in 1958, is the archipelago doctrine, as it appeared at the third United Nations Conference on the Law of the Sea.

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[1]Cf. Collins, op. cit., p.161 f.; Ian Brownlie, Principles of Public International Law, Oxford: Clarendon Press, 1966, p.178, n.1.

[2]Article 3

[3]I.C.J. Reports (1951), 116, 206.

[4]Article 4(4). [5]Article 5(1).

A coastal state exercises in the territorial sea, according to the convention, full sovereign rights. They extend not only over the surface of the sea and the entire water column but also over the airspace over the territorial sea and to its bed and subsoil.[1] The only exception granted by the convention to ships of all states was the right of innocent passage understood as surface passage as "long as it is not prejudicial to the peace, good order or security of the coastal State."[2] Submarines are specifically required to surface and identify themselves in the territorial sea.[3] The principle of innocent passage is applicable also in international straits narrow enough to fall under the territorial sea of one or more states.

The convention's strong construction of the state sovereignty in the territorial sea is in a way proportional to the extent of this area. In a narrow territorial sea zone a coastal state rightfully may claim and is able to enforce complete control while the general freedoms of the high seas are not much affected. Any appreciable extension of the territorial sea, however, would of necessity imply a more than proportional increase in limitations of the freedoms of the high seas, particularly when applied in straits which may lose the character of high seas with extensions of coastal states' territorial seas, or in much used shipping lanes relatively close to various coasts but outside of territorial seas under the narrow three mile regulation.

The Continental Shelf Convention of 1958 followed basically the ideas of the Truman proclamation in extending the rights of the coastal state to the continental shelf proper, that is to the sea bed and subsoil only and not to the water column above it. The convention uses, however, a much more intensive language describing the rights of the coastal state. Where the Truman proclamation claimed for the United States "jurisdiction and control" the convention allows that "the coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources."[4] The continental shelf was accorded to the coastal state in an exclusive sense, not permitting other states to establish any claims without the former's permission, even if the coastal state does nothing for exploration and exploitation of the area.[5] Nor is any specific act of occupation or proclamation required.[6] The convention thus adopted the contiguity doctrine in its full extent.

The most important flaw of the convention was, however, in the very first article which tried to define the concept of the continental shelf. While the Truman proclamation describes the shelf in its preamble as "an extension of the land mass of the coastal nation and thus naturally appurtenant to it," the convention omits completely any reference to the land

[1]Cf. Arts. 1 and 2. [2]Art. 14(4). [3]Art. 14(6).

[4]The Convention on the Continental Shelf, Art. 2(1).

[5]Art.2(2). [6]Art. 2(3).

area. It defines the continental shelf as

> the sea bed and subsoil of the submarine areas adjacent to the coast but outside the area of the territorial sea, to a depth of 200 metres or, beyond that limit, to where the depth of the superjacent waters admits of the exploitation of the natural resources of the said areas...[1]

It was perhaps not readily apparent in 1958, but the addition of the "exploitation" clause to the definition changed completely the legal meaning of the shelf. Instead of referring to a geological feature along the continents, shelf became "to where the depth of superjacent waters admits of the exploitation." With rapid development of technologies for deep sea exploration and exploitation this definition actually failed to impose any limit to the continental shelf area of a coastal nation save that of the area claimed by the state on the opposite side of a sea or ocean. It was not long that the inexorable logical deduction produced maps of oceans showing how hypothetically the sea bed would be divided between coastal states ringing the ocean basin.[2] After all the ocean sea bed could be regarded as "terra nullius," no man's land which the new understanding of contiguity doctrine awarded to the adjacent coastal state who could be presumed to be able to acquire sooner or later the technological capabilities for its exploitation.

The late fifties and the sixties were decades of unprecedented scientific developments as far as oceans were concerned. For the first time a comprehensive picture of the earth emerged where the oceans or rather the big tectonic plates that make up the ocean bottoms were shown to be the prime movers and creators not only of the seas but also of the continents. Simultaneously there was an unprecedented growth of marine technologies that not only aided in development of scientific knowledge but also began to bring into the realm of economic feasibilities the newly discovered riches of the oceans: the fossilized energy resources suspected to be in the shelves and also the mineral-rich nodules found at the bottom of ocean plains.[3]

The seas also became an increasingly important supplier of food. The concern arose that the seas may not be an inexhaustible source of fish and other living resources, endangered both by overfishing and pollution from evergrowing shipping activities, waste dumping and other uses.

In the strategical competition between the superpowers the seas became the favorite area where nuclear submarine fleets equipped with missiles could navigate undetected by overhead aircraft and satellites, but perhaps traceable by devices implanted on ocean slopes or at other convenient places.

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[1] Art. 1.

[2] Cf. for samples of such maps in W. Friedman, The Future of the Oceans, 1971, Braziller Inc.; J. Andrassy, International Law and the Resources of the Sea, 1970, Columbia U. P., N.Y.

[3] For a survey of these scientific developments cf. the articles collected by Scientific American in The Ocean, 1969, W. H. Freeman & Co., San Francisco.

On November 1, 1967, Dr. Arvid Pardo, a delegate of Malta to the Twenty-Second session of the United Nations General Assembly, delivered a speech in the First Committee of that body. In his address he ably summarized the technological and scientific achievements of the recent decade and pointed out that under the then existing legal framework soon the oceans will be divided between the rich and developed nations to the disadvantage of the developing countries especially those that are either landlocked or are otherwise in a geographically disadvantageous situation.[1]

Pardo's speech was a well reasoned but also emotional appeal to put a stop to the expanding national jurisdiction over ocean floors under the faulty definition of the 1958 continental shelf convention, to declare the ocean bed outside of national jurisdiction as heritage of mankind and to create an international agency that would supervise or direct the exploitation of resources in the international area in the interest of mankind with particular regard to the needs of poor countries, and also to reserve the whole area exclusively for peaceful purposes.

The General Assembly followed the suggestion. A Committee on the Peaceful Uses of the Sea Bed and the Ocean Floor beyond the Limits of National Jurisdiction was created and entrusted with the task. After three years of activities the Committee enabled the Assembly to pass on December 17, 1970, a series of resolutions dealing with the subject. The most important one was the Resolution 2749 (XXV) entitled "Declaration of Principles Governing the Sea Bed and the Ocean Floor, and the Subsoil thereof, beyond the Limits of National Jurisdiction." It declared, inter alia, that this area is the common heritage of mankind, not subject to appropriation by any state or person, where no state shall claim sovereignty, that an international regime shall be established, that the exploitation of the area should be for the benefit of mankind as a whole, taking into consideration particularly the interests and needs of the developing countries, that the area should be reserved for peaceful uses only, etc.[2]

The legal binding quality of the United Nations resolutions is open to dispute and debate. They are basically recommendations. No opposing vote was cast against the Resolution 2749 (XXV) though fourteen states abstained. It appears, however, that this resolution put at least a moral and political

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[1]The text of his speech is reproduced in UN GAOR, XXII session, Documents A/C.1/PV.1515 and 1516. The speech was delivered in general debate on agenda item 92: "Examination of the question of the reservation exclusively for peaceful purposes of the sea bed and the ocean floor, and the subsoil thereof, underlying the high seas beyond the limits of present national jurisdiction, and the use of their resources in the interest of mankind."

[2]For text see Brownlie, Documents ..., pp. 112 ff. Also for general discussion of the development Zdenek Slouka, "UN and the Deep Ocean: From Data to Norms," 1 Syracuse Journal of International Law and Commerce, October, 1972, 33-50; and Proceedings of the ASIL, 8th regional meeting "The UN and Resources of the Deep Ocean Floor," ibid., 91.

brake on unlimited expansion of national sovereignty over ocean floors, confining the national jurisdictional claims to a not yet defined but limited area around the margin of continents.

A separate resolution of the same date called for convening of a Conference on the Law of the Sea in 1973 which would deal with the establishment of a regime for the area and resources of the sea bed, the ocean floor, and a broad range of related issues, including the breadth of the territorial sea and the question of international straits.[1] This was a rather hasty call for the preparation and organization of such an important conference. The Third United Nations Conference on the Law of the Seas (UNCLOS III) nevertheless opened in 1973.

The Third United Nations Conference on the Law of the Sea met so far in three sessions. The first was a brief, mostly procedural meeting in New York, in December, 1973. The second session lasted for eight weeks during Summer, 1974, in Caracas, Venezuela.[2] The third session was held for six weeks in Spring, 1975, in Geneva, Switzerland.[3] Another session is planned for Spring, 1976, in New York, and if necessary one more will be held at a later date.

Almost 150 states gathered for this conference, each with a set of special interests. Altogether they represent a complete panorama of various national interests in security, economic, resource allocation, development, communication and commercial fields. Instead of a well prepared draft text the conference started with a committee report presenting and collating various conflicting views.[4] In spite of all this the feeling prevailed that the conference must convene and try to resolve the problems of the law of the sea as otherwise the developments threatened to upset the insufficient legal framework.

In the case of many large nations it was difficult to define a clear national standpoint. The case of the United States is most illustrative. The large American delegation represented several official, governmental agencies and a number of private group interests, many with conflicting

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[1]Cf. Brownlie, <u>Documents</u>,p. 112.

[2]Third U.N. Conference on the Law of the Sea, <u>Official Records</u>, United Nations, N.Y., 1975: Vol. I. Summary Records of Meetings [UN Publ. Sales No.E.75.V.3]; Vol. II. Summary Records of Meetings, [E.75.V.4]; Vol. III. Documents of the Conference [E.75.V.5]. For an authoritative though "private" analysis of the problems facing the conference see John R.Stevenson and Bernard K.Oxman, "The Preparations for the Law of the Sea Conference," 68 <u>American Journal of International Law</u>, January 1974, pp. 1-32; and by the same authors, "The Third U.N. Conference on the Law of the Sea: The 1974 Caracas Session," 69 <u>AJIL</u>, January 1975, pp. 1-30.

[3]Cf. Stevenson and Oxman, "The Third U.N. Conference on the Law of the Sea, The 1975 Geneva Session," <u>ibid</u>., Oct. 1975, pp. 763-797.

[4]Report of the Committee on the Peaceful Uses of the Sea Bed and the Ocean Floor Beyond the Limits of National Jurisdiction, General Assembly, <u>Official Records</u>, 28th Session, Supplement No. 21, (A/9021), Vols. I - V.

claims and desires. During the years of the Deep Sea Committee proceedings[1] and up to the conference's start itself there were several changes in position. By a process labeled "bureaucratic politics"[2] slowly a national standpoint was hammered out. Below are brief summary surveys of the main official and private interest group positions that provided the "input" for a national policy.

The Department of State, officially representing the United States, was interested primarily in reaching a widely accepted, comprehensive and balanced agreement on the international law of the sea, while it tried to make sure at the same time that, first, the American-Soviet detente would not necessarily suffer, second, that our NATO and other allies would be satisfied, and, lastly, that the third world interests would be generally synchronized with the American point of view. The Department of State officially headed the delegation, but actually had to try constantly to bring together a house divided.[3]

The Department of Defense had very specific views. Traditionally it favored a narrow territorial sea and continental shelf concept, permitting thereby an as great as possible free area of high seas for the deployment of naval forces. Most importantly, the Defense was afraid of any overextension of the traditional three mile territorial sea limit. Up to the beginning of the Conference the United States still officially supported the three mile limit. The major apprehension from any extension of the territorial sea was the effect it would have on passage through various straits. A rigorous application of the innocent passage regulations in a twelve mile or wider territorial sea regime would effectively block most important straits for the free and legal use of submarines and for free overflight.[4] The Yom Kippur war in the Middle East in Fall of 1973 underlined this point. As long as the freedom of transit were assured in some way the Defense would not mind a strong international authority over the ocean bed and a regime of internationally supervised exploitation of resources.

The Department of Interior was looking toward the assumption of jurisdiction over natural resources of the yet to be defined area of expanded national jurisdiction on the continental shelf and in the rumored economic zone.

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[1]For the earlier developments see Edward Wenk, The Politics of the Ocean, U. of Washington Press, Seattle, Washington, 1971

[2]"In this approach the actors or 'makers' of ocean policy are public officials and large bureaucracies engaged in a continuous policy of bargaining which is influenced throughout by domestic as well as foreign interests. The ocean policies that result are a product of contention -- within the government and with domestic and foreign interests -- and not of rational centralized decision-making process." Ann L. Hollick "Bureaucrats at Sea," in A. Hollick and R.E. Osgood, New Era of Ocean Politics, The Johns Hopkins University Press, Baltimore, 1974, p.71

[3]Cf. Hollick, op. cit., passim.

[4]R.E. Osgood "U.S. Security Interests in Ocean Law," in Hollick-Osgood, New Era of Ocean Politics, p. 115 and passim.

The Treasury Department was interested in making sure that leases, royalties and taxes on other incomes generated by the expanded sea ventures properly flow into national coffers and do not escape into fluid international channels. In addition there were other public agencies with specific interests.

On the non-governmental side there were several vociferous and some less well-organized groups.

Some mining interests were primarily interested in the gathering and commercial exploitation of the manganese nodules on deep ocean floor. They were not at all enthusiastic for any strong international authority in this field, in spite of the adopted United Nations' principles. The miners would have actually preferred to operate under a national authority, American or even that of other nations, or at worst, under minimal internation supervision.

The oil industry favored as wide a concept of the continental shelf as possible. All hydrocarbons presumably, on the basis of recent exploratory findings, are in the continental shelf area. By past experience the petroleum industry prefers to deal with national authorities rather than with an uncertain, politically dominated international authority.

The fishing industry was divided. The better organized distant fishing fleet industry, primarily for tuna and shrimp, wanted to retain as much as possible of the old cherished freedom of fishing on the high seas. Hence it was against any appreciable extension of the territorial sea limits and even more against the establishment of the wider 200 mile economic zones with more or less exclusive national jurisdiction.

The less organized domestic coastal fishermen, however, were interested in just the opposite. They wanted to expand the American jurisdiction as far as possible and prevent the overfishing of American North Atlantic and Pacific fishing areas by other, much more efficient factory fleets. To these should be added the interests of fishermen of anadromous species, like salmon, who were apprehensive at the dwindling runs because of overfishing on the deep sea by other nations.

The shipping interests cherished the traditional freedom of navigation on the high seas and would not like to see any appreciable extension of the coastal or even port state's jurisdiction at the expense of the flag state, especially in the fields of pollution, ship design and safety, regulation of shipping lanes, etc.

The scientific community was battling for freedom of research and was afraid that any and all extensions of national jurisdiction might hamper uniform and free efforts to explore the seas.

To all of the above must be added the interests of the environmentalists, airline industry and some others and the result was a melange of claims and counter claims from which it was difficult to formulate a consistent national position.

After several shifts the United States' position crystallized[1] at the outset of the conference in what could be characterized as the "12-200-margin-with-qualifications" formula. The United States would concede that it is impossible to fight the trend for extension of the territorial sea to twelve miles. Hence the American delegation would be willing to accept that provided that the innocent passage rules are modified sufficiently to permit uninhibited passage through straits, including the right of overflight and underwater passage. In addition to that the United States would accept a 200 mile wide economic zone where the coastal state would enjoy more or less exclusive rights over resources and other prerogatives, provided that the rights of other nations particularly in navigation, overflight, and perhaps to some degree in fishing are also respected. Beyond the 200 mile zone the United States would claim sea bottom to the continental margin, but would be willing to pay a share of the proceeds from this area to the international authority, if others do the same. The United States also insisted on an efficient system for settlement of disputes. Within this framework the United States saw it possible to work for a comprehensive all-inclusive law of the sea treaty.

Parenthetically it must be observed here that in all these developments the continental shelf as a term became a victim of its own expansion under the influence of the "exploitation" clause incorporated in the 1958 Geneva Convention. Officially today the references are always to the continental margin where the 1958 Convention talks of the continental shelf. The continental shelf in a narrower sense became, again, what it was originally, a geological term denoting the gently sloping sea floor off the coasts. But the jurisdictional claims now extend beyond, down the steeper continental slope and farther over the continental rise. The continental margin is imagined to be where the continental rise ends and the true abyssal plain of the oceans begins, a line that is properly determined and surveyed with scientific and technical accuracy in just a few areas.[2]

Other nations came to the conference each with their own set of priorities and claims. Many small nations pursued just one single or a small set of particular aims, willing to give support to various interest groups as long as their particular demands were safeguarded.

An international codification conference is usually convoked in order to separate a given issue from general political considerations. A subject matter can be easier dealt with, if the specialists and experts on the matter consider it among themselves and present a finished product for political approval of various national authorities. This was to some degree true of the previous two conferences on the law of the sea held in 1958 and 1960 though even then the clashing national interests at least prevented an agreement on the limits of the territorial sea.

[1] Cf. Hollick, op. cit., pp. 41, 47.

[2] Cf. K.O. Emery "The Continental Shelves," in Scientific American, The Ocean, pp. 39-52, and Edward Wenk, Jr., "The Physical Resources of the Ocean," ibid., pp. 83 - 91; also Hollick, op. cit., p. 19.

Traditionally international codification conferences usually began after a preparatory committee or body, such as the International Law Commission, carefully arranged the conference materials, as a rule crystallizing them into a set of preliminary drafts leaving to the conference only the settlement of a few important points. The Third United Nations Conference on the Law of the Sea started without that. It had at its disposal an exhaustive report of the Sea Bed Committee which listed all documents submitted so far and tried to collate and compare the several sets of draft articles, proposals, working papers and other materials presented by individual nations and groups of nations.[1]

The third Conference on the Law of the Sea is politically more an international congress with general political interests rather than a specialized codification conference on a well defined and limited part of international law.

Procedurally the conference adopted an important innovation that was already used to some extent before by the preparatory Sea Bed Committee and in some other United Nations organs, namely the principle of consensus. This principle was developed in order to steer the work of the conference away from the worst excesses of majoritarianism of the seemingly democratic principle of one state vote. Its aim was to permit the conference to achieve some concrete results before the meetings would become hopelessly deadlocked in opposing votes. In discussing a substantial matter the formal voting should be postponed for as long as possible.

This principle was accepted in a so-called "gentleman's agreement" by the General Assembly before the first session of the conference started[2], and was incorporated eventually in the Rule 37 of the Rules of Procedure.[3]

For working purposes the conference divided itself into, and continues its activities in, three main committees with rather uneven work loads. The First Committee deals with the original problems of the sea bed beyond the limits of national jurisdiction and the eventual international authority

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[1] General Assembly, Official Records, XXVIII Session, Supplement No. 21 (A/9021): Report of the Committee on the Peaceful Uses of the Sea Bed and the Ocean Floor Beyond the Limits of National Jurisdiction, Vols. I - V, United Nations, New York, 1973.

[2] "... bearing in mind that the problems of ocean space are closely interrelated and need to be considered as a whole and the desirability of adopting a Convention on the Law of the Sea which will secure the widest possible acceptance;
"the General Assembly expresses the view that the Conference should make every effort to reach agreement on substantive matters by way of consensus; that there should be no voting on such matters until all efforts at consensus have been exhausted ..." A/CONF.62/L.1 Draft Rules of Procedure, Note by the Secretary General, Appendix; GAOR,2169'Meeting, November 16, 1973 in UNCLOS III, OR, Vol. III, p.80, E.75.V.5.

[3] Cf. H. Gary Knight, "The Potential Use of Reservations," in American Society of International Law, Policy Issues in Ocean Law, Studies in Transnational Legal Policy No. 8, 1975, ASIL, Washington D.C., pp. 38 - 42.

which is to administer this "heritage of mankind." The Second Committee deals with the determination of limits of national jurisdiction and thus with the rights of the coastal states and virtually with all other traditional problems of the law of the sea covered in the 1958 Geneva Conventions. The Third Committee was put in charge of scientific research, transfer of technology and pollution problems. A fourth but informal group worked on the problems of dispute settlement.

The Caracas meeting in Summer, 1974, ended without a final text. Only the Second Committee identified a number of issues for which it edited several possible legal formulations labeling them as "main trends" of discussion.[1]

The Geneva meeting in Spring, 1975, made some substantial, perhaps important advances. In the aftermath of the conference discussions each main committee chairman submitted a document entitled "Informal Single Negotiating Text" covering the subjects entrusted to the committee.[2] The language of the title was carefully qualified in a Note of the President of the Conference on the front page of each document. They are not a negotiated text or accepted compromises. They would not prejudice the position of any delegation.[3] One must admit, however, that a text once reduced to writing, will exercise at least a certain inertial influence on further developments.

From several solutions and proposals presented by various informal discussion groups the committee chairmen produced a version which is not necessarily to the liking of all, or which might to some degree contradict a formulation in another part of the whole document. While the Informal Single Negotiating Texts appears as a single document in three parts, each part was actually the sometimes hurried work of a different group with no overall final cross comparison. No formal voting took place on the wording of individual articles or on the documents as a whole, thus keeping in line with the principle of consensus.[4]

The First Committee's Single Negotiating Text[5] boldly proclaims the sea bed and ocean floor beyond the limits of national jurisdiction as the common heritage of mankind, reserved for the benefit of mankind as a whole and takes in particular consideration the interests and needs of developing countries. In this it carries out the sense of several Resolutions of the General Assembly, especially the 2749.[6]

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[1]UN, Third Conference on the Law of the Sea, A/CONF.62/C.2/WP.1, 15 October 1974: "Main Trends."

[2]A/CONF.62/WP.8/Parts I, II, III, 7 May 1975.

[3]Ibid., Part I, p. 1, Part II, p. 1, Part III, p. 1.

[4]Cf. discussion in the third article by Stevenson and Oxman, in October 1975 issue of the American Journal of International Law, (vide supra, p.16, note 2), referred subsequently as Stevenson-Oxman, Geneva 1975.

[5]The acronyms SNT-I, II, and III will be used as appropriately below.

[6]December 17, 1970. Cf. supra, p. 14.

The whole SNT-I appears to be somehow biased in favor of the developing world and its interests. The negotiating text adopts a language which substantially followed the demands presented by the group of 77 on behalf of the developing nations. Indeed a text taking into account the other views[1] was prepared too late to be included in the SNT-1.

The SNT-I presents a very elaborate set of basic regulations for the establishment of an International Sea Bed Authority. It is only through this Authority that the member states shall administer the Area and all activities shall be conducted directly by the Authority and its organ, the Enterprise.

This formulation really represents a victory of sorts for the interests of the developing nations. The developed and technologically advanced nations, and the private mining interests, favored more an Authority that would primarily "assure guaranteed access to, and production of deep sea minerals by states and their nationals under reasonable conditions with security of tenure."[2] In this view the Authority should only issue and supervise the execution of licenses, collect royalties for distribution and the like.

The developing nations, representing a substantial majority of the conference membership, and many of them with memories of recent colonial exploitative regimes wanted to prevent a universal neo-colonial scheme and tried in a way to internationalize the deep sea activities before any private interests were there established.

A certain degree of accommodation between these two views was achieved at Geneva in consideration of the so-called basic conditions of exploitation. What emerged was a formula that apparently favors a system of joint ventures of a contractual rather than equity type.

The SNT-I Article 22 thus provides:

> (1) Activities in the Area shall be conducted directly by the Authority.
> (2) The Authority may, if it considers it appropriate, and within the limits it may determine, carry out activities in the Area or any stage thereof through States Parties to this Convention, or State enterprises, or persons natural or juridical which possess the nationality of such States or are effectively controlled by them or their nationals, or any group of the foregoing by entering into service contracts, or joint ventures or any other such form of association which ensures this direct and effective control at all times over such activities. ...

The balance between a "direct and effective control" by the Authority and a "guaranteed access" by national developers was much discussed. Several systems of reservations for future uses, when the less developed countries could enter, were weighed one against the other. Among these were

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[1]The so-called "Pinto text," see Stevenson-Oxman, Geneva 1975, p. 767.
[2]*Ibid.*, p. 766.

particularly the banking system, somewhat favored by the United States, where each applicant for a joint venture submits two sites of equal size, one of which the Authority would designate as reserved area at disposal of the Authority, and the parallel system introduced by the Soviet Union under which the Authority would exploit by itself or under contract with private entities one portion, while another portion would be reserved exclusively for individual state access.[1] None of these possibilities appeared in the SNT-I as no real trend for consensus could be established beyond the principle of the contractual joint ventures.

The important decisions for the Authority will be made, according to the SNT-I, by a limited size Council of 36 members, among whom there will be always six nations with substantial investment or possessing advanced technology for the exploitation of the area, another six representing special interests of the developing countries and the rest of twenty-four elected in accordance with the principle of equitable geographical representation.[2] The Council decides by a two-thirds plus one vote majority. While this voting system seems to assure a balance between the developed and developing countries, it is not yet quite certain how much the Council's decisions could not be overruled by the Assembly which has basically the supreme policy making functions but where the one nation one vote system would favor the majority of developing nations.

Looking at this quite elaborate blueprint system for the future International Sea Bed Authority one cannot help having certain second thoughts, or questions that cannot be yet answered at this time.

How effective can be an international enterprise, even if using service contracts and joint ventures with individual nations and private companies, when no such successful prototype ever functioned yet? Will such an Authority be able to cope with the problems of growing bureaucratization, when directed that its functionaries be hired on as wide geographical basis as possible?

The initial capital funds, the technical expertise and the know-how will still have to come from the developed nations directly, or from oil rich nations, and also from multinational companies. The providers of capital and technology will certainly play an important role, even if seemingly completely ignored in the present SNT-I.

Perhaps the whole elaborate scheme of the International Sea Bed Authority, with its Assembly, Council, Enterprise, Secretariat, Tribunal, and several committees, commissions and other organs overconfidently assumes more than will be realized. Optimistic estimates of the potential yields of minerals from ocean floors are minor if compared with the mineral and hydrocarbon resources of the continental shelves and other areas that will come under national jurisdiction.[3]

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1 Cf. Stevenson-Oxman, Geneva 1975, p. 767.

2 SNT-I, Article 27.

3 For general background on this see, <u>passim</u>: A/CONF.62/25 of May 22, 1974: "Economic implication of sea bed mineral development in the international area: report of the Secretary General," UNCLOS III OR, pp.4-40, in E.75.V.5; UN ECOSOC. E/5650, 30 April 1975, "Marine questions: Uses of the Sea, Study prepared by the Secretary General;" E/5648, 8 May 1975, "Marine Questions."

A good deal of genuine ocean floor beyond the continental margins would fall under exclusive national jurisdiction, if the 200 mile economic zone is adopted, as proposed in the Second Committee. Approximations of up to 40% of the total ocean area are mentioned in this connection. Not all continents have everywhere extensive shelves. Islands and archipelagos in middle of oceans have hardly any. Thus the economic zones of the latter would appropriate sizable portions of the ocean sea bed. There appear thus already sufficient geographical loopholes for independent national sea bed mining outside of the proposed ISBA jurisdiction.

Perhaps the whole plan for an ISBA is so elaborate that it will never be put in practice, even if a single comprehensive treaty is adopted. But maybe that is exactly what some mineral rich, landlocked developing countries would like to happen to protect their own national mining interests.

The single negotiating text proposed by the chairman of the Second Committee has a much more restrained and concrete language. The text reflects "actual negotiating progress made under the auspices of the Committee officers and in informal but representative groups."[1] The emphasis of this report is on the coastal states as such. It is the latter that in reality would become the main beneficiaries of the regime of the oceans. There are, however, in appropriate places several provisions in favor of landlocked and geographically disadvantaged states, though these often lack concrete precision. The SNT-II is in reality a thorough updating and revision of the 1958 Geneva Conventions.

The Territorial Sea, according to the SNT-II,[2] would extend as before beyond the internal and the new archipelago waters, and is not to exceed twelve nautical miles, as measured from the baselines, either the natural or the "straight" ones. The coastal state has full sovereignty in this zone except for the innocent passage that must be granted to surface vessels of other nations. Passage is innocent as long as it is not prejudicial to the peace, good order and security of the coastal state. Going beyond the 1958 formulation the SNT-II elaborates in detail what actions may be considered prejudicial. Since the new outer limit of the territorial sea actually covers the old limit of the contiguous zone, the latter is not eliminated but rather doubled to 24 miles from the baselines.[3] This is a true case of creeping territorial jurisdiction, though it is by no means generally accepted yet, as it is simply a SNT-II provision. Within the contiguous zone the states would be permitted, as before, to prevent and punish infringements of their customs, fiscal, immigration and sanitary regulations.

Separately from the territorial sea, the SNT-II deals with straits used for international navigation.[4] There the text does not refer to innocent passage but develops a new concept, that of the right of transit passage conceived as

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[1]E.G. the Evensen group, cf. Stevenson-Oxman, Geneva, 1975, p.769.

[2]SNT-II, Pt. I, Arts. 1 - 32.

[3]SNT-II, Art. 33.

[4]SNT-II Pt. II, Arts. 34 - 43.

> ... the exercise [in accordance with the provisions of this Part] of the freedom of navigation and overflight solely for the purpose of continuous and expeditious transit of the strait between one area of the high seas or an exclusive economic zone and another area of the high seas or an exclusive economic zone.[1]

Freedom of navigation and overflight are presented as extensions of the rights nations have on the high seas. Underwater passage is not mentioned, hence seems not to be forbidden. On the other hand, the SNT-II elaborates in detail the rights of the coastal state and the obligations of the passing vessels and air craft. Yet in sum these regulations should not have "the practical effect of denying, hampering or impairing the right of transit passage."[2]

The Exclusive Economic Zone[3], designed to extend up to 200 nautical miles from the baseline, is one of the major innovations of the newly developing law of the sea. As already mentioned, it is estimated that about 40% of all the sea area would come under this new regime, encompassing virtually all important hydrocarbon and many other mineral deposits, the great majority of commercially important fishing areas, and would also dominate in part most of the normal shipping lanes.

As presented in the SNT-II the economic zone essentially implies several functionally differentiated extensions of the sovereign, jurisdictional and other rights of the coastal state while simultaneously retaining important prerogatives of other states in the same area. Some extremists' demands were simply to expand the territorial sea regime over the economic zone as well. The SNT-II of the Geneva session, while still at variance with some more modest group views[4] distinguishes between the various grades of the rights of the coastal state, namely:

-- sovereign rights over renewable and non-renewable resources;

-- exclusive rights and jurisdiction over artifical islands and structures;

-- exclusive jurisdiction with regard to other activities for the economic exploitation and exploration of the zone (i.e. energy from water, currents and winds), and scientific research;

-- jurisdiction with regard to marine environment, including pollution;

-- and finally other rights and duties.[5]

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[1]Art. 38(2).

[2]Art. 41(2).

[3]SNT-II, Pt. III, Arts. 45 - 61.

[4]Like the Evans draft as reported in Stevenson-Oxman, Geneva 1975.

[5]SNT-II Art. 45(L).

Dovetailed with these rights and duties of the coastal state are the duties and rights of other sea using states, including the thorny questions of the landlocked and geographically disadvantaged states.

Essentially the regime of the exclusive economic zone would entitle on the one end of the spectrum the coastal state to exercise the complete sovereign right over non-renewable sea bed resources, would impose some obligations on the coastal state for optimum utilization and perhaps sharing of living, renewable resources, including the various types of migratory fishing stocks, while on the other end of the spectrum it tries to retain as much as possible of the old international high sea freedoms of navigation, overflight and similar activities. The economic zone concept is basically directed at the control of resources and the consequent elimination of the high sea freedom of fishing in the area. Delatiled elaboration of the coastal state's sovereign rights to regulate, manage and exploit, as well as its duties to conserve living resources of the zone take up a considerable portion of the text.

On the subject of delimitation of the zone between two or more states the SNT-II offers only some basic guiding principles, leaving it primarily to concrete bilateral determination. The subject, however, will be an important one as in the future the economic zones of many states will converge and overlap, requiring some concrete delimitation. The SNT-II adopts as a basis the doctrine of "equitable principles," with the median, or equidistant line as at least a temporary subsidiary principle pending agreement or settlement.

Continental Shelf. The SNT-II gives to the coastal state the authority to exercise sovereign rights for the purpose of exploration and exploitation of the natural resources of the continental shelf.[1] The latter received, however, a new definition, markedly different from the one formulated in the 1958 Geneva Convention.[2]

> SNT-II, Art. 62. The continental shelf of a coastal state comprises the sea bed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance.

The SNT-II thus eliminates the old "exploitation" clause and replaces it with a combination of an objective geological definition, where the shelves are wide, and a strict quantitative-distance definition, where the actual shelves are narrow.

The United States supported by some other states proposed a moderate plan for sharing of resources of the continental shelf beyond the 200 miles

[1]SNT-II, Pt. IV, Arts. 62-72.

[2]Cf. Supra, p. 11.

exclusive economic zone with the International Sea Bed Authority. This provision was incorporated in the SNT-II.[1] This provision can be essentially regarded as one of the inducements on the part of the big coastal states extended to the vast majority of other nations to accept the eventual comprehensive package-deal treaty rather than go on their own or adhere only to a partial treaty or treaties. It is obvious that in case of no treaty the entire continental shelf would remain under the exlusive sovereign jurisdiction of the coastal state as provided in the 1958 Geneva convention rules. While the SNT-II presents this revenue sharing possibility it does not clearly distinguish[2] the extent and the way in which this sharing should be accomplished: either as a percentage of the value of mineral production, or as a contribution in kind as a percentage of the volume of production, or as a profit sharing system after deduction of the costs.

High Seas. According to the SNT-II high seas is the residual area after the internal waters, territorial sea and the exclusive economic zone are deducted.[3] In this remaining high sea area the traditional principles elaborated at Geneva in 1958 were retained. To the original four enumerated freedoms of navigation, fishing, overflight and laying of cables and pipelines the SNT-II adds two more freedoms, that of construction of artificial islands and installations and the freedom of scientific research. Special provisions deal also with management and conservation of the living resources in the high seas.[4]

Archipelagos. A special novel feature of the SNT-II are the provisions relating to archipelagos.[5] They are logical elaborations and combinations of the straight baseline doctrine together with the principles of the territorial sea, continental shelf and economic zone doctrines, applied, instead of to indented and island surrounded coastal area, to groups of islands completely apart from continental land masses. By straight baseline method first a substantial archipelago-waters area is created essentially akin to the internal waters regime save for certain passage rights. On top of that then the territorial sea, contiguous zone, the exclusive economic zone and, if applicable, the continental shelf claims are recognized. Essentially the same process would apply to small individual islands, except that they would not have any appreciable internal waters area, as long as they are inhabitable.[6] The wide expanses of world oceans would thus shrink appreciably because of the expanding ovals of various archipelagos or single island regimes, leaving less to the area that was to remain the "heritage of mankind" and under an international authority, but giving some island ministates and territories yet to attain independence substantial riches in exploitable natural resources thus providing them with means of economic subsistence. While of great interest

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[1]Incorporated in Article 69.

[2]Art. 69(2): "The rate of payment or contribution shall be x% [sic] of the value or volume of production at the site."

[3]SNT-II, Part V, Arts. 73 - 102.

[4]SNT-II, Pt. V, Arts. 103 - 107.

[5]SNT-11, Pt. VII, 117 - 131.

[6]SNT-II, Pt. VIII, Art. 132.

to a few island states the archipelago provisions, even if various safeguards for passage rights are incorporated, nevertheless impose serious limitations on the rights of other states. Too wide archipelago doctrine application might lessen the chances of a widely acceptable treaty.[1]

The informal single negotiated text presented by the Third Committee is much less definite and represents not quite a completed set of negotiated and agreed upon ideas. The first part of the SNT-III deals with the protection and preservation of the marine environment.[2] The language is mostly in terms of rights, duties and legislations yet to be defined and promulgated by states or by future multilateral conventions. The basic opposition at the conference was between the prerogatives of the coastal state and the interests of other states using the sea. The SNT-III displays a trend against exclusive coastal state's standard setting in the economic zone. In general the SNT-III would vest the relevant environmental rights and duties in that state which has jurisdiction over the activity in question,[3] though it is recognized that rights of other states are affected, too, and hence the development and respect for universal international standards would be essential.

The SNT-III is a bit more detailed in discussing the problems resulting from the pollution generated by vessels. The basic rights and duties of enforcement belong to the flag state, while the interests of the port state and of the coastal state are also recognized, though how much actual power the latter two will eventually obtain remains controversial.

Marine research. The SNT-III discusses the problems of marine research primarily as affecting the activities in the exclusive economic zone and on the continental shelf. The basic controversy that the SNT-III tries to settle was between the demand of the Group of 77 that such research should be subject to the consent and control of the coastal state, while the United States and some other developed countries considered that research should be subject to international treaty regulation and compulsory dispute settlement, as the rights of the coastal states were sufficiently protected in other provisions of the law of the sea and of the general international law. The Soviet Union and other socialist countries introduced the distinction between the research related to exploration and exploitation of living and nonliving resources that would require the consent of the coastal state, while other scientific research would fall under general treaty regulations. This distinction was retained with slight variations in the SNT-III.

Scientific research of fundamental nature would be subject to requirements of notification of the coastal state, its participation, data sharing, and other restrictions, while the research related to resources of the economic zone and of the continental shelf would be subject to the coastal

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[1]Johnson-Oxman, Geneva, 1975, p.785.

[2]The official text (A/CONF.62/WP.8/Part III) does not give numbers to the parts of the third committee report. Marine research part is dealt with on pp. 2 - 14.

[3]Cf. Johnson-Oxman, Geneva 1975, p. 790.

state's consent and other limiting conditions, including the obligation not to publish data without prior permission of the coastal state.[1] This curb on the open dissemination of knowledge is rather ominous for the future freedom of research.

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This brief and by no means exhaustive survey of the most important points of the developing law of the sea as reached provisionally at the Geneva session of the third United Nations Conference on the Law of the Sea in Spring, 1975, should at least be helpful for understanding of the complexity of the issues. Officially the United Nations officials and many leading representatives of the participating nations still adhere to, and insist on, the elusive final goal of the conference - a widely acceptable yet comprehensive treaty. Privately the participants are not as sanguine about the chances of success.

The informal single negotiating text formulation of the law of the sea, the main final product of the consensus process at the Geneva session certainly represents a broad outline of an acceptable overall settlement. What remains to be seen is whether in the future unofficial negotiations and at the official sessions of the conference the individual participant nations pay more attention to the overall solutions or will they insist on protection of certain limited interests, regardless of the rest.

A no-treaty solution is a definite possibility. This would open the way for further development of the uncertain customary practices but also for outright conflicts that could culminate in the use of force. A further product would be an increasing creeping territorialization of the seas. The main gainers of a no-treaty solution would be the big maritime nations with extended coasts. They are even now under constant pressure from their domestic interest groups to advance unilaterally their sovereignty claims and protect the national interests especially in such matters as extending fishing zones to full 200 miles. Advances to claim national jurisdiction to mining rights on the ocean bed are similarly possible.

The great losers of such no-treaty situation would be the developing nations in general and the landlocked and the geographically disadvantaged nations in particular. Without a treaty no real international authority for the development of the "heritage of mankind" will ever be instituted.

The New York session of the Conference in 1976 will perhaps provide some answers.

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[1]SNT-III, Art. 18-22, pp. 18 f., also Johnson-Oxman, Geneva, 1975, pp. 793 f.

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