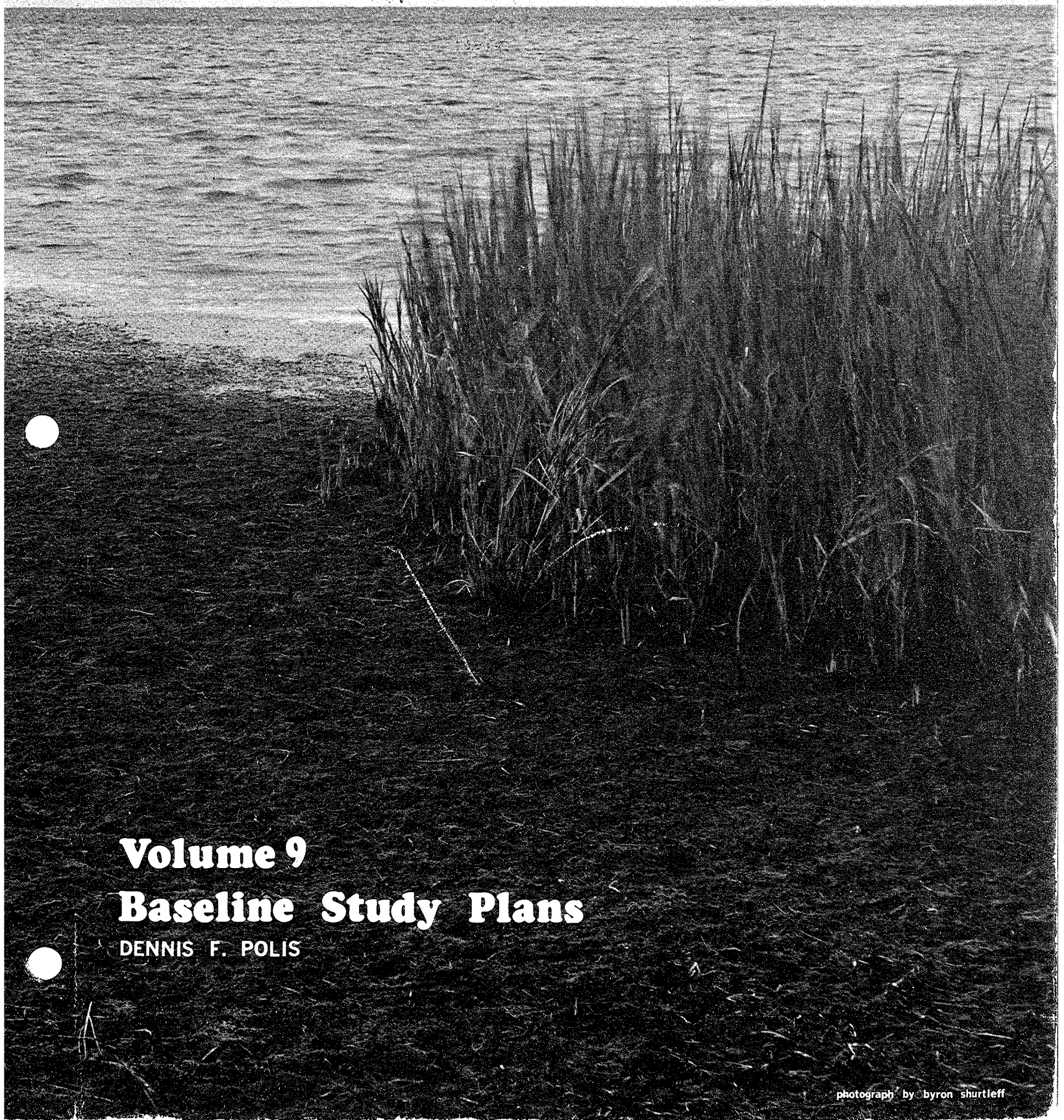
DELAWARE BAY REPORT SERIES



Volume 9
Baseline Study Plans

DENNIS F. POLIS

photograph by byron shurtleff

DELAWARE BAY REPORT SERIES

Volume 9

BASELINE STUDY PLANS

Dennis F. Polis

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Dennis F. Polis

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College of Marine Studies
University of Delaware
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PREFACE

In the spring of 1970, Dr. James Wakelin, then Chairman of the newly organized Governor's Task Force on Marine and Coastal Affairs, and Dr. William S. Gaither, a member of the Task Force and later Dean of the College of Marine Studies, identified the need for an integrated environmental baseline study of the Delaware Bay. The author was approached to coordinate the planning of this study and on July 1, 1970 became the first faculty member of the new College. A proposal was written to the National Geographic Society for the purpose of funding the planning effort. While approval of the proposal was pending a team from the University of Delaware was assembled and work began. The members of that team were:

Dr. James C. Albrecht, Geography Department, Climatologist

Dr. Harold C. Beachell, Chemistry Department

Dr. Robert B. Biggs, Assistant Dean, College of Marine Studies, Geologist

Dean William S. Gaither, College of Marine Studies, Engineer

Dr. Robert R. Jordan, State Geologist

Dr. Blair Kinsman, College of Marine Studies, Physical Oceanographer

Dr. John C. Kraft, Chairman, Geology Department

Mrs. Marjorie Kraus, Senior Research Associate, Department of Chemistry, Biochemist

Dr. John R. Mather, Geography Department, Climatologist

Dr. Don Maurer, College of Marine Studies, Biologist

Dr. Wallace H. McCurdy, Jr., Chemistry Department

Dr. Frank J. Murphy, Entomology and Applied Ecology Department

Dr. Kent S. Price, Assistant Dean, College of Marine Studies and Director, Lewes Field Station, Biologist

Dr. T. W. Fraser Russell, Department of Chemical Engineering

Dr. Jon E. Taylor, College of Marine Studies, Botanist, Systems Ecologist

Dr. Conrad N. Trumbore, Department of Chemistry

Dr. Robert Varrin, Director, Water Resources Center, Civil Engineer and Hydrologist

Dr. Hsiang Wang, Department of Civil Engineering

In addition, the following contributed in some measure to the effort:

Mr. William H. Amos, St. Andrews School, Biologist

Mr. James T. Broom, Assistant Director, Bureau of Sport Fisheries and Wildlife, Fish and Wildlife Service

Dr. Franklin C. Daiber, College of Marine Studies and Department of Biological Sciences

Mr. William S. Davis, Acting Chief, Estuarine & Oceanographic Section, FWQA

Dr. Robert Fothergill, Chemist, College of Marine Studies Counselor

Mr. Joel M. Goodman, Director, Coastal Zone Resource Planning

Dr. H. Haskin, Rutgers University, College of Agriculture and Environmental Science, Biologist

Mr. Austin N. Heller, Secretary, Department of Natural Resources and Environmental Control, State of Delaware

Mrs. Carman Johnson, Acquisitions Branch, National Oceanographic Data Center

Mr. Amor L. Lane, Special Assistant to the Chairman of the Governor's Task Force on Marine and Coastal Affairs

Mr. Charles Lesser, Manager, Technical Service, Division of Fish and Wildlife, Department of Natural Resources and Environmental Control

Dr. Gordon Lill, Deputy Director, National Ocean Survey

Mrs. A. H. Longenbach, Librarian, College of Marine Studies

Mr. Robert E. Loveland, Rutgers University, Department of Zoology

Dr. Thomas D. Myers, College of Marine Studies and Biological Sciences

Mr. Robert H. Mayer, graduate student, Civil Engineering, University of Delaware

Dr. Ruth Patrick, Department of Limnology, The Academy of Natural Sciences

Mr. Robert F. Smith, National Marine Fisheries Service, U. S. Department of the Interior

Dr. Frederick M. Swain, Department of Geology

Mr. Gerald Vaughn, Coordinator, Communications and Resource Development, Agricultural and Food Economics, University of Delaware

Dr. James H. Wakelin, Secretary of Commerce for Science and Technology, U. S. Department of Commerce

Mr. Briton W. Whitall, Secretary, Delaware River Basin Commission

Mr. Norman Wilder, Fish & Wildlife Division, Department of Natural Resources and Environmental Control

The planning involved many meetings, both general and private, as well as the exchange of much written material. As a result of the extensive interaction of the planning group, it is difficult or impossible to trace to its originator each contribution to the plan. Where a section has been largely based on written material submitted by an individual planner, this has been noted in the text.

Generally, where such an identification has not been made, the work of many has been brought together. In some instances it was necessary for the coordinator to sketch the general outlines of subprojects in areas not well represented in the planning group.

The plan was largely complete in January of 1971. On February 18, 1971 the Task Force recommended the implementation of the plan in its Preliminary Report. In May of 1971 a draft of the present report was circulated for comment. One of the copies of that draft found its way to the offices of the National Ocean Survey. In negotiations with the Deputy Director of the Survey, Dr. Gordon Lill, it was decided to use the draft as the basis of an environmental quality initiative being considered by the National Oceanic and Atmospheric Administration (NOAA). The basic plan, augmented to include other NOAA concerns, was approved by the NOAA and the Department of Commerce; however, it was not approved by the Office for the Management of the Budget.

In the early summer of 1971, it was decided to submit certain subprojects of the plan as part of a proposal to the National Science Foundation's Research Applicable to National Needs Program. This proposal was funded and is presently being executed. The subprojects being executed are the hydrodynamical-numerical modeling project and some preliminary biological surveying.

CONTENTS

INTRODUCTION

The Baseline Study (BLS) is a systematic attempt to understand the environmental factors influencing the structures and processes of the Delaware Bay. This includes not only an investigation of the ecology of the bay, but also an evaluation of its other resources. The requirement for such a study to answer the needs of users and regulators, as well as investigators, can be grasped once the bay is seen as an interrelated system. When this thesis is accepted, the need to understand the whole in order properly to understand any part will become apparent. It also follows that, though the objectives of the practical man and the speculative scientist participating in the BLS are diverse, the means for obtaining these objectives are identical. Let us consider to what degree the Delaware Bay is an interrelated whole.

Despite its political division, the bay is a geographical unit. This spatial unity is the basis for the interdependencies that make it a single system. The components of the core system are the water in the bay, the contents of the water, and the basin which holds it. This core system has interfaces with the Delaware River, the Atlantic Ocean, the C&D Canal, the land areas and streams of Delaware and New Jersey, and the atmosphere. Each of these interfaces interacts so strongly with the core system that it is impossible to neglect them in a study of the bay.

In order to illustrate how one is forced into an investigation of the system as a whole, let us consider some of the questions in-

volved in making a practical decision, such as whether and where to place an oil terminal in the bay:

1. Where are the likely locations from an engineering point of view?

This requires a knowledge of the hydrography of the bay; of the types, mechanical properties, and thicknesses of the sediments and substrates that may require dredging; of the sea state under normal and storm conditions; of the presence of ice in the bay; of surface currents through the tidal cycle and of the proximity of acceptable spoils disposal areas. An estimate of the amount of maintenance a dredged channel might require would also be of assistance.

In support of these data requirements, the scientists supplying the information would need to know the prevailing and storm winds, details of the tidal cycle, temperature and salinity profiles, and the details of sediment transport processes in the vicinity.

2. Given these proposed locations, what would be the inescapable economic consequences to others (externalities) of building a terminal?

In order to answer this question, we would have to know the uses to which the area is currently put, as well as its potential alternate uses. Are there shellfisheries in the area? Could there be? Finfisheries? What would be the effects on these of the existence of the terminal? Of building it? Are there mineable deposits of sand, gravel, clay, or oyster shells? Are there subaqueous aquifers? How would the structure affect transport processes in the vicinity?

Wave propagation and focusing?

Again, additional information is required to answer these questions. A survey of the area from biological, geological and physical oceanographic points of view is a beginning, but this alone is insufficient. More data is required to say whether the fin-fisheries, for example, would move or become extinct. This depends on factors such as the distribution of food species throughout the bay, which in turn depends on the nutrient influx from the Delaware River, as well as production in the Bay and in the adjacent marsh lands.

3. Given the proposed locations, what would be the effects of a catastrophe such as an oil spill? (This question has two aspects: one designed to aid in the original placement of the terminal, the other to aid in the control of a disaster should it occur.)

To respond to this question requires a cognizance of the current and wind-stress combinations possible through the year, as well as data on the space-time distribution of the structures and organisms that might be adversely affected by the oil. To fully understand the consequences, however, requires in addition a comprehension of the function of each of these structures and organisms in the entire ecosystem.

We see in this one example the need for investigations to be carried out in the disciplines of marine biology, marsh ecology, hydrology, climatology, physical oceanography, marine geology, and civil engineering. Numerous other practical questions, such as

"What is the fate of heavy metals?" involve marine chemistry and geochemistry and possibly other disciplines as well.

Even though there is an evident need, the questions we have raised will not have been answered before a decision is made on the proposed oil terminal project. The reasons are obvious: such a scientific program is too expensive and time-consuming to charge to the preliminary design of a single project such as the terminal. There are, however, many projects which may have profound ecological effects on the bay -- some only contemplated, others already under way. Among these are a number of off-shore developments associated with deep-draft vessels, the Tocks Island Reservoir, the enlargement of the Chesapeake & Delaware Canal, the installation of waste treatment plants at Philadelphia and in Kent and lower Sussex Counties, the Salem Nuclear Generating Station, and the whole issue of off-shore dumping. The advantage of the BLS is that once it is done, the rough outlines of a unified view of the bay will be in hand for the systematic review of all such projects. This will not necessarily relieve individual projects of the need for intensive local studies, but it will provide a context in which these local evaluations can be seen in relation to the Bay as a whole.

The reason that the same BLS data can be used in the analysis of many diverse projects is that the bay is an interrelated whole. It is an ecosystem, that is to say a complex of interacting organisms and structures with associated functions. The system is so cross-linked that following out the logic of almost any substantive question

will involve a consideration of most of the aspects of the bay. Further, the system is homeostatic, which is to say that it is constantly adjusting itself in response to external changes. These adjustments in search of new equilibria can be so complex as to profoundly alter processes which on cursory examination appear to be totally unrelated to the original change. Unless these processes are thoroughly understood, it is impossible to make a completely rational evaluation of any proposal for the Bay and adjacent lands.

Some examples will show the consequences of an inadequate understanding of an ecosystem. Dredging in Delaware Bay has caused salt water to infiltrate aquifers as far inland as Smyrna. When the Aswan Dam was built in Egypt, two consequences were that the sardine catch in the Mediterranean Sea dropped drastically (the nutrient flow was stopped by the dam), and the incidence of human blindness rose in the delta region (the ecology of a snail, which hosted schistomiasis parasites, was altered.) To foresee this kind of consequence may not require a computer model, but it does require an effective overview of the entire ecosystem. The BLS would provide the basis for such an overview.

Specific Interests

This discussion of the BLS as a systematic approach to the bay should not be taken to mean that the individual investigations which it encompasses are not important in their own right, for certainly they are. Each of them approaches the fundamental aspects of some

practical problem. This is substantiated by the interest of various individuals, companies, and agencies in portions of the proposed BLS data:

Group	Interests
U. S. Geological Survey	Estuarine dynamics, sediment transport, geological structures, aquifer definition
National Weather Service	Meteorological data, air-sea interactions
Corps of Engineers	Pollution data, sediment transport, shoaling, etc.
National Ocean Survey	Currents, tides, and circulation
Federal Water Quality Administration	All water quality data, ecological effects of pollution, overall methodology
National Marine Fisheries Service	Biological survey and general ecology
Delaware River Basin Commission	Entire study
Bureau of Mines	Water resources (especially in relation to the mineral industry), chemical analysis, effects of waste discharges
Environmental Data Service	Meterological, hydrological, and oceanographic data
Delaware Public Health Department	Water quality, bacterial survey
Delaware Department of Natural Resources & Environmental Control	Entire study
Recreational Fishing Boat Operators	Changes in sand bars, shoals and river currents

Barcroft Company (extractive processing)	Bacteria, primarily gram-negative (can cause deposits on equipment and contaminate product) Heavy metals (lead, mercury, etc.) Oil spills (critical to process) Insecticides & other industrial wastes Calcium Content (ppm) Magnesium content (ppm) pH
Doxsee Company (seafood processor)	Metal deposits in clams Clam reproduction
Ferry operators	Driftwood Sand deposits in shallows Ice Corrosiveness
Bombay Hook (wildlife refuge)	Oil spills

The preceding list does not include the interests of the scientific community which span the entire set of parameters to be investigated.

Past Work

It would be wrong to create the impression that the BLS would have to start from total ignorance. In September 1959, Carl N. Shuster, Jr., of the University of Delaware Marine Laboratories, published A Biological Evaluation of the Delaware River Estuary, which did a creditable job of summarizing the biological knowledge of the estuary and bay to that time. It was not, however, the result of a comprehensive and integrated survey of the biota, let alone of the other factors required to gain a comprehension of the ecosystem.

The Preliminary Report and Findings of the $1.2 million Delaware

Estuary Comprehensive Study was published in July 1966. (The final report appears never to have been published.) It outlined the work that had been carried on since 1951 to establish a water quality plan for the upper estuary. While it was systematic in concept, it was limited in scope to the question of water quality in the region of the river between Trenton, New Jersey, and Liston Point, Delaware. The report contains little information of direct use to the BLS, but among its conclusions was this one: "Additional effort should now be directed towards a comprehensive study of the bay to insure, for the future, the commercial and recreational uses now enjoyed in the bay".[1]

Since the mid-fifties the State of Delaware has intermittently carried on an extensive water quality survey of the Delaware River at seventy-eight stations between Reedy Island and Trenton, New Jersey. These data have apparently never been summarized in report form, nor with rare exceptions, have they ever been subjected to statistical analysis beyond the computation of overall averages.

The early work on tides and currents in the bay was summarized in 1926 by Zeskind and Le Lacheur in Coast and Geodetic Survey special publication No. 123. Since then the Survey has been in the

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[1] Delaware Estuary Comprehensive Study: Preliminary Report and Findings (Department of the Interior, Frederal Water Pollution Control Administration; Philadelphia, Pa., July 1966) p. 91.

[2] The interested reader is referred to Volume I of this series where the data base for the bay is reviewed as well as to Volume X, the bibliography.

bay twice for the purpose of observing the currents -- once in 1947 and again in 1953. Some physical oceanography was done in the bay in the 1940's in connection with the establishment and verification of the Corps of Engineers' hydraulic model at Vicksburg. In addition to this, much work has been done on specific biological and geological problems of the bay.

All that has been done, however good it may be in its own right, suffers from a common inadequacy, namely that it is not coordinated with investigations in other disciplines. Thus, while there is much that can be used, we have no synoptic view of the bay at a single time, and in the case of many parameters, we have no data at all. It is the considered opinion of the planners of the BLS that an integrated, synchronized, multidisciplinary study of the bay is an absolute essential to a comprehension of its ecology and resources.

Beyond the intrinsic difficulty that the past investigations represent a fragmented approach to understanding the system, two extrinsic difficulties beset them. First, they are not readily accessible to the decision-maker, the scientist, or the engineer interested in the bay. The articles, reports, and raw data must be gleaned from scattered journals, files, and data banks literally scattered over hundreds of miles. There is as yet no central publication, library, or data bank where one can go for information on past work. The planning of scientific investigations and engineering works proceeds in partial or total ignorance of previous work. The

result is costly duplication or a less than optimal perception of the situation. The second extrinsic difficulty is that as time goes on scientific awareness of the importance of various parameters grows. Mercury pollution is a case in point. No one knows what the levels of mercury contamination were in the bay five or ten years ago because no one thought it was an important thing to observe. The BLS plan has attempted to remedy these extrinsic difficulties insofar as possible.

Goals

Granted that the comprehension of the bay as a total system is a sine qua non for those concerned with it, how is this to be acquired? Clearly, two processes are required to obtain this objective: (1) the information must be gathered, and (2) it must be presented in a comprehensible format. Let us consider each of these processes in turn.

The gathering of information is clearly the backbone of the study. This requires a detailed examination of the present state of the system, as well as an attempt to find its current rate of change. The minimum time in which this could possibly be done is two years. If possible anomalies are to be averaged out, five years would be required.

If we are to be able to assess the effects wrought by new projects, such as the Philadelphia waste treatment plant, the Tocks Island Reservoir and so on, we must be able to distinguish between new changes and the continuation of on-going trends. This implies

that the BLS must concern itself with the present rates of change of selected parameters. Once this information is in hand, the job of interpretation is by no means an easy one, for even discounting the very real possibility of interference effects, one must recognize the existence of long and short period cyclic processes as well as secular changes. This points once again to the need for solid scientific insight as opposed to the rote manipulation of statistical information.

An aspect of the bay deserving to be singled out because of the discontinuitiesit entails is its human utilization. If this is to be foreseen so that planners, decision makers, and users will have adequate warning of the discontinuities, the BLS must make a special effort to survey the resources of the bay which are likely to be exploited in the future. If the knowledge gained by the BLS is not to be quickly out-dated, there must also be a tail of continuous monitoring following the completion of the BLS.

One particular type of information that the BLS will be seeking is the location of possible control or trigger points within the ecosystem. These are the sensitive structures or processes, a small modification of which can drastically change the entire estuarine complex. They are of obvious importance for two reasons: first, an ignorant interference with them could set off a major disaster; second, they represent the potential for an economical means of corrective action in the estuary.

If information gathering is the backbone of an ecological study,

the format in which it is presented is the skin and clothing which make it acceptable in polite company. It is thus worthy of particular care. First, the results of individual investigations must be presented at many levels and with different emphases to a variety of information users. Thus a collection of technical papers would be an inadequate format for the BLS results. There must be technical presentations of the data, but in addition there should be presentations for small boat operators, oystermen, conservationists, regulatory agencies, and so forth.

Another aspect of information presentation is the construction of models, i.e., of structures combining information in formats that allow it to be more readily grasped or used. These may be simple maps or complex computer programs. A wide spectrum of alternatives successively more ambitious, presents itself. The following examples will illustrate the spectrum:

1. Dictionary of raw data in tabular form.
2. Dictionary of data compiled to satisfy known long term needs, and presented in more easily grasped formats, e.g., hydrographic charts.
3. Dictionary of data, some presented as in 2 above, and some incorporated into independent analytic models.
4. A single, or very few, complex and sophisticated general models which attempt to handle all problems.

It is our judgement that at the end of the first three years of the BLS it will be possible to provide a few independent mathematical

models together with maps depicting the distribution of various parameters. This is level 3 in our spectrum. At the end of five years, some progress will be made in the production of a crude predictive model for the entire estuarine system.

On the basis of this discussion, we can establish more particular goals for the BLS, to wit:

1. Establishment of an ecological baseline to gain an understanding of the present state of the bay and to aid in assessing the effect of changes in the biological and physical condition of the bay at some future time.
2. Determination of the present rate of change of certain key variables of practical importance. This will allow us to distinguish changes already under way from those resulting from future human activities.
3. A determination of the resources of the bay, so that the possible uses of it may be foreseen in the period up to the planning horizon.
4. Determination of parameters to be continuously monitored after the termination of the BLS, and design and installation of a monitoring system so that the state of the bay may be known in real time.
5. Identification of problems warranting further specialized scientific research. Among these, the identification of control or trigger points is of special interest.
6. Establishment of a Delaware Bay Reference Collection where col-

lected materials will be available for future research. The specimens will be preserved in different ways so that many parameters not measured in the BLS may be ascertained at some future time.

7. Establishment of a Delaware Bay Data Library and computerized information system to provide a central location for the storage and use of past data as well as BLS and any other data that may be generated in the future.
8. Publication of the information collected in formats oriented to the needs of various users. This will be a continuing function of a marine services program.
9. Establishment of independent, analytical models for selected subsystems of the bay by the end of three years.
10. The establishment after five years of a crude predictive model for the entire Delaware Bay ecosystem, so that short-range changes, resulting from a proposed action, may be predicted.
11. The entire study will be performed with a view to developing a methodology applicable to other estuarine systems.

Program Integration

The goals of the preceding section serve to outline the requirements for the BLS, but do not suffice to insure that the outcome will be an integrated study as opposed to a miscellany of unrelated projects. In order to do this, we must take positive steps to coordinate the work of the sundry disciplines. In a

program as sweeping as the BLS, this cannot be accomplished merely by pointing to the program objective, viz., understanding the estuarine ecosystem in its relation to human activity, but this coordinated effort must be built into the structure of the entire program and embodied in the specifications of each subproject.

The principle of unity in the overall program is the culmination of the project in an ecosystem model incorporating most of the data, and submodels generated during the study. This model is the one called for in subproject SA-IV.

At a level below that of the overall project, the project is unified by a number of themes which can be shared by large subsets of investigators and will serve to bring about closer communication as the project proceeds. To ensure this communication, semi-annual conferences will be organized around these themes. They are:

1) Energy in the Bay

2) Resources of the Bay

3) Natural Transport in the Bay

Our first theme is "Energy in the Bay." This is a notion around which most of the study can be organized. Let us go back to our original description of the bay as a core system with interfaces, and see how it relates to this theme. The core system is composed of the water, its basin, and its contents. A description of the thermal and mechanical energy of the water requires an

investigation of its physical oceanography including currents, tides, waves, temperature, and salinity. Energy in relation to the basin includes transport processes such as shoaling and erosion, as well as energy stored as fossil fuels. The water's contents include chemical energy in organic and inorganic nutrients and in the various organisms of the bay.[1]

The main subsystems interfacing with the core system are the Delaware River, the Atlantic Ocean, the C&D Canal, the land areas and streams of Delaware and New Jersey, and the atmosphere. Each of these has an important energy exchange with the core system. The currents of the Delaware River and the C&D Canal play a role in driving the currents of the bay. The River is also loaded with pollutants rich in chemical energy. The Atlantic exchanges energy in the form of waves, tides, and currents. The land areas of Delaware and New Jersey provide energy in the form of nutrients from their marshes, and absorb energy from storm and sediment transport processes. Finally, the atmosphere is involved in numerous energy-exchange processes with the bay through evaporation, wave generation, the transmission of radiant energy, and so forth.

One of the great advantages of energy as a theme is that it is

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[1]The tracing of energy through the food chain is widely recognized as one of the keys to comprehending the ecosystem. Vide, e.g., Eugene P. Odum, "Relationships Between Structure and Function in the Ecosystem", Japanese Journal of Ecology 12 (3): 108-118. Reprinted in George W. Cox, ed., Readings in Conservation Ecology (N.Y.: Appleton Century Crofts, 1969) pp. 6-20.

subject to a conservation law: The total amount of energy entering the bay must equal that leaving the bay plus what is stored there. While the striking of an exact total energy balance is not currently within the state-of-the-art, the energy flows in various subsystems can be dealt with quantitatively, and the results used to investigate the interaction between the subsystems.

The second theme is "The Resources of the Bay." It is the explicit concern with the resources of the bay that will allow the BLS to key easily into collateral investigations of the socio-economic aspects of the coastal zone resource management problem. It ties together such aspects of the study as those involving the engineering properties of the bottom and the commercial fisheries, and will provide a basis from which we can foresee the future utilization of the bay.

The "Natural Transport" theme is one that will aid in the development of predictive ecological models of the bay. It concerns itself with the question of what goes where. This involves not only sediment transport and the distribution patterns of pollutants and other chemicals, but also the movements of the various populations of the bay from nurseries to feeding grounds. The correlation of these transport patterns with tide stage and river flow is the necessary condition for any overall model of the Delaware Bay ecosystem. As will be seen in the detailed discussion of the BLS projects below, this is accomplished by having the model of the currents of the bay (PO-I) form the framework on which the other models are built.

Beyond this, the study is integrated by the multiple utilization of boat time, common sample collection, and the pooling of information in a common data bank (SA-I).

Further Description

The geographical limits of the Baseline Study will be flexible and dependent on the requirements of the specific discipline involved. The most intensive efforts of all disciplines will be in the portion of the estuary from the C&D Canal to the line between the capes; however, extensions will be undertaken, where necessary, to make that data meaningful. In general, the landward extent will include the areas subject to tidal influences and the bay's tributaries. The seaward extent will be 25 miles off the line between the Capes (May and Henlopen) for biology; the edge of the continental shelf for physical oceanography; and possibly the base of the shelf for geology. Up river, biological and physical oceanographic effort will extend to Trenton.

The schedule will begin with a Phase I BLS consisting mainly of two years of intensive surveying, starting in the summer following program funding. This will be followed by automatic monitoring of indefinite duration, and a Phase II effort of three years duration. The BLS has been divided into two phases in order that: (1) the experience gained in Phase I may be applied to a Phase II, which will eliminate a majority of the errors detected from Phase I effort and its modeling results; and (2) some results will be available to decision makers and other interested parties

at the earliest possible date.

The general scheme of the study may be gathered from Figure 1. There are three types of projects involved which may be broadly classed as survey, modeling, and support. The survey projects are mainly field studies designed to gather basic information on the present state and rate of change of the Delaware Bay system. These projects will have an initial phase of two years of intensive data gathering, followed by a less intense "monitoring" phase of three years' duration. In the fifth year, there will be a biological resurvey for a better perspective on this most variable aspect of the bay system.

The information gathered by the survey projects will be incorporated into a series of computer models by the various modeling projects. The models will be designed from the beginning to allow them to be fitted together in a successively more comprehensive hierarchy. The so-called "current model" will be a hydrodynamic-numerical one which will serve as a framework for most of the other models. As is shown in the diagram, the BLS plan calls for the incorporation of the various special purpose models into two general models during the fourth year, viz., a biosystem model and a physical system model. During the fifth year, these two models will be worked into a comprehensive model of the entire natural system of Delaware Bay.

The support projects form the final broad class of studies in the BLS. These are intended to support the acquisition and

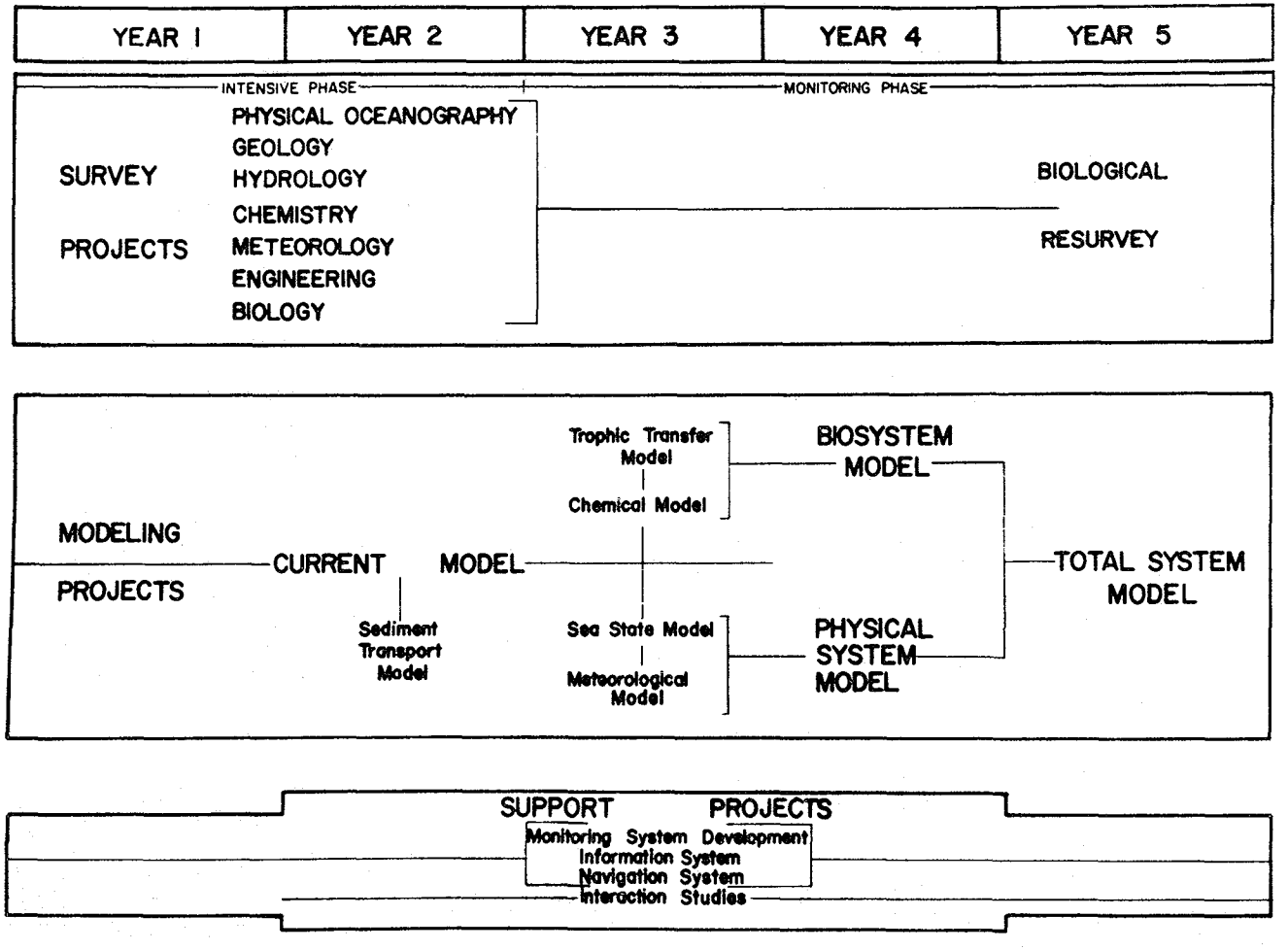
YEAR 1
YEAR 2
YEAR 3
YEAR 4
YEAR 5
INTENSIVE PHASE
MONITORING PHASE
SURVEY
PROJECTS
PHYSICAL OCEANOGRAPHY
GEOLOGY
HYDROLOGY
CHEMISTRY
METEOROLOGY
ENGINEERING
BIOLOGY
BIOLOGICAL
RESURVEY
MODELING
PROJECTS
CURRENT
MODEL
Trophic Transfer Model
Chemical Model
Sediment Transport Model
Sea State Model
Meteorological Model
BIOSYSTEM MODEL
PHYSICAL SYSTEM MODEL
TOTAL SYSTEM MODEL
SUPPORT
PROJECTS
Monitoring System Development
Information System
Navigation System
Interaction Studies

Figure 1

dissemination of data. Included are the implacement of an accurate navigation system for the bay, the design and installation of a real-time monitoring system, the adoption and continual updating of an information system, and an extensive series of interaction studies. These last will investigate the interactions between various organisms, and of organisms with environmental factors. In particular, the effects of various pollutants on individuals and communities will be discovered.

BIOLOGY

Introduction

The organisms of the estuarine system may be divided into various communities or local associations: the tidal marsh community, the benthic (or bottom) community, and the pelagic (or water-borne) community. Each of these plays a vital role in the total economy of the bay. The marshes and tidal creeks are the nurseries for many important species, and are also vital as a source of nutrients. The benthic community includes such shellfisheries as blue crab, oysters, and clams. It is also of importance as an indicator of pollution, as many of its organisms are immobile. The pelagic community encompasses the major finfisheries and the various species of plankton that form the foundation of the bay's food webs.

The biota of the bay can also be described by their functional character in the food chain. This allows us to follow the biological energy flow in a scheme that begins with the photosynthesizing plants as primary producers, runs through the primary consumers, on up to the top carnivores, and finally back down through the decomposing organisms that recycle the nutrients.

These two ways of describing the biology of the ecosystem may be displayed against one another in a matrix:

Functional / Communal	Primary Producers	Primary Consumers	Intermediate Consumers	Top Carnivores	Decomposers
Pelagic	Phyto-plankton	Zooplankton & Nektonic Organisms	Nektonic Organisms (Vertebrates&Invertebrates)		Bacteria & Fungi
Benthic	Benthic Algae	Benthic Invertebrates	Fish	Fish	
Marsh, Tidal Creek & Shore Zone	Algae & Higher Plants	Insects, Protozoa, etc.	Fish & In-vertebrates	Birds & Fish	

Here we have displayed the various trophic levels in the horizontal direction, while arranging the communities vertically. In each square we have placed the name of the group or groups of organisms functioning on a given trophic level in the appropriate community.

Having provided this overview of the estuarine biosystem, we are in a position to outline our approach to achieving the BLS objectives in this discipline.

The main features of the biological program of the BLS may be seen in Figure 2. The basic steps are:

A. Analysis of energy flow through the ecosystem (B-I)

B. Concurrent description of the distribution of organisms in space and time (B-II)

C. Characterization of the physical environment (C-I, M-I, PO-II-III)

D. Supplementation and integration of information derived from above (A-C) with intensive studies on "important"

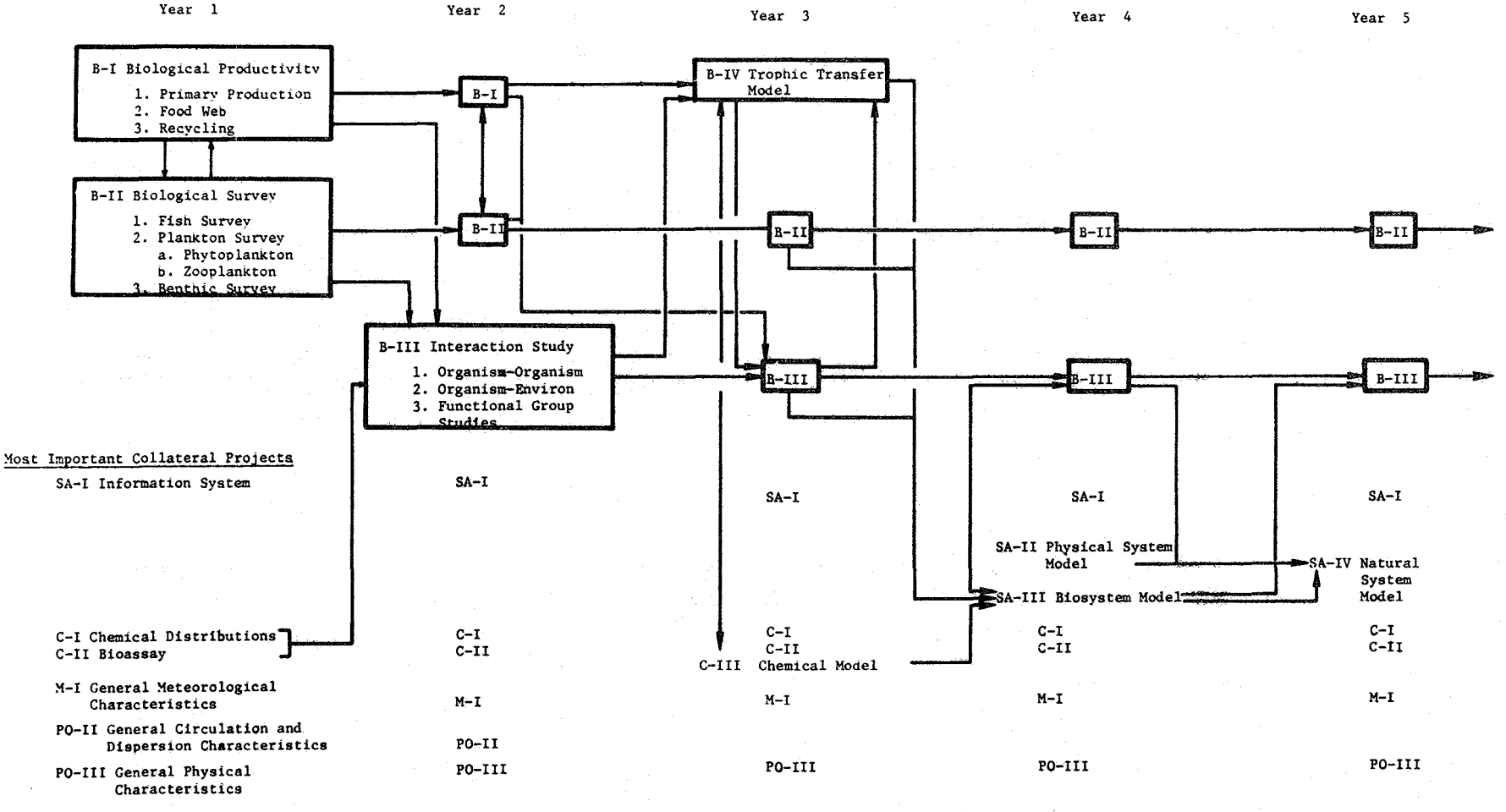
Year 1
Year 2
Year 3
Year 4
Year 5
B-I Biological Productivity
1. Primary Production
2. Food Web
3. Recycling
B-II Biological Survey
1. Fish Survey
2. Plankton Survey
a. Phytoplankton
b. Zooplankton
3. Benthic Survey
B-III Interaction Study
1. Organism-Organism
2. Organism-Environ
3. Functional Group Studies
B-I
B-II
B-III
B-IV Trophic Transfer Model
Most Important Collateral Projects
SA-I Information System
SA-I
SA-I
SA-I
SA-I
SA-II Physical System Model
SA-IV Natural System Model
SA-III Biosystem Model
C-I Chemical Distributions
C-II Bioassay
C-I
C-II
C-III Chemical Model
C-I
C-II
C-I
C-II
C-I
C-II
M-I General Meteorological Characteristics
M-I
M-I
M-I
M-I
PO-II General Circulation and Dispersion Characteristics
PO-II
PO-III General Physical Characteristics
PO-III
PO-III
PO-III
PO-III

Figure 2

species (B-IIK)

E. Development of computer models of the bay ecosystem or subsystems to assess effects of proposed environmental changes (B-IV, C-III, SA-II, SA-IV)

F. Generation of additional data at all levels to improve models (B-II in years 3-5, etc.)

The transfer of information between the various studies will be facilitated by the existence of a computerized information system (SA-I).

In the context of the BLS it is expected that most of the information under item "C" would be gathered by the other disciplines, with only the standard station data being taken by the biological investigators.

Background for Special Areas

A. Finfisheries*

June and Reintjes (1957) describe the Delaware Bay area as one of the most productive coastal regions in North America. As far as fish are concerned, this area is an important spawning and nursery ground for many species. Also the fish fauna present is distinct from adjacent estuarine systems in that it is a geographical overlap area for boreal and subtropical species. Since the demand for fish and sport fishing is constantly increasing, and since approximately 70% of marine fish depend directly on the estuary in some way, it is imperative that we understand how fish utilize

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*Prepared by Dr. Kent Price

this area. Without adequate knowledge of these natural demands we cannot properly dictate the guidelines man must follow in developing and utilizing this Delaware estuarine area. The fact that the Delaware estuary has been misused can be seen from the following figures. In 1954 the overall value of commercial fisheries landings in the State of Delaware was 7.8 million dollars. At present the overall value is probably less than 300,000 dollars, and this is a drop of 96%. De Sylva, Kalber, and Shuster (1962) stated that we lack comprehensive data on biological, physical, chemical, and geological characteristics of this estuarine area as they were years ago. The lack of a suitable yeardstick by which to measure changes will be more apparent as the trend of man-induced ecological changes increases in the estuary. Unless comprehensive surveys are begun at once, future generations will similarly decry our lack of foresight for not making inventories of our present resources, as small as they now may be, and doing something constructive about their conservation. Almost ten years ago this was being said, and still this baseline information is lacking.

The objectives of this study are to acquire adequate information about the abundance, distribution, and ecology of fish found in the Delaware estuary and nearby coastal waters. These data are necessary to understand how various fish utilize this area; and these data will be used in conjunction with data collected by other researchers, so that all major parameters of the Delaware estuary ecosystem can be integrated to get some idea of energy flow and to construct useful

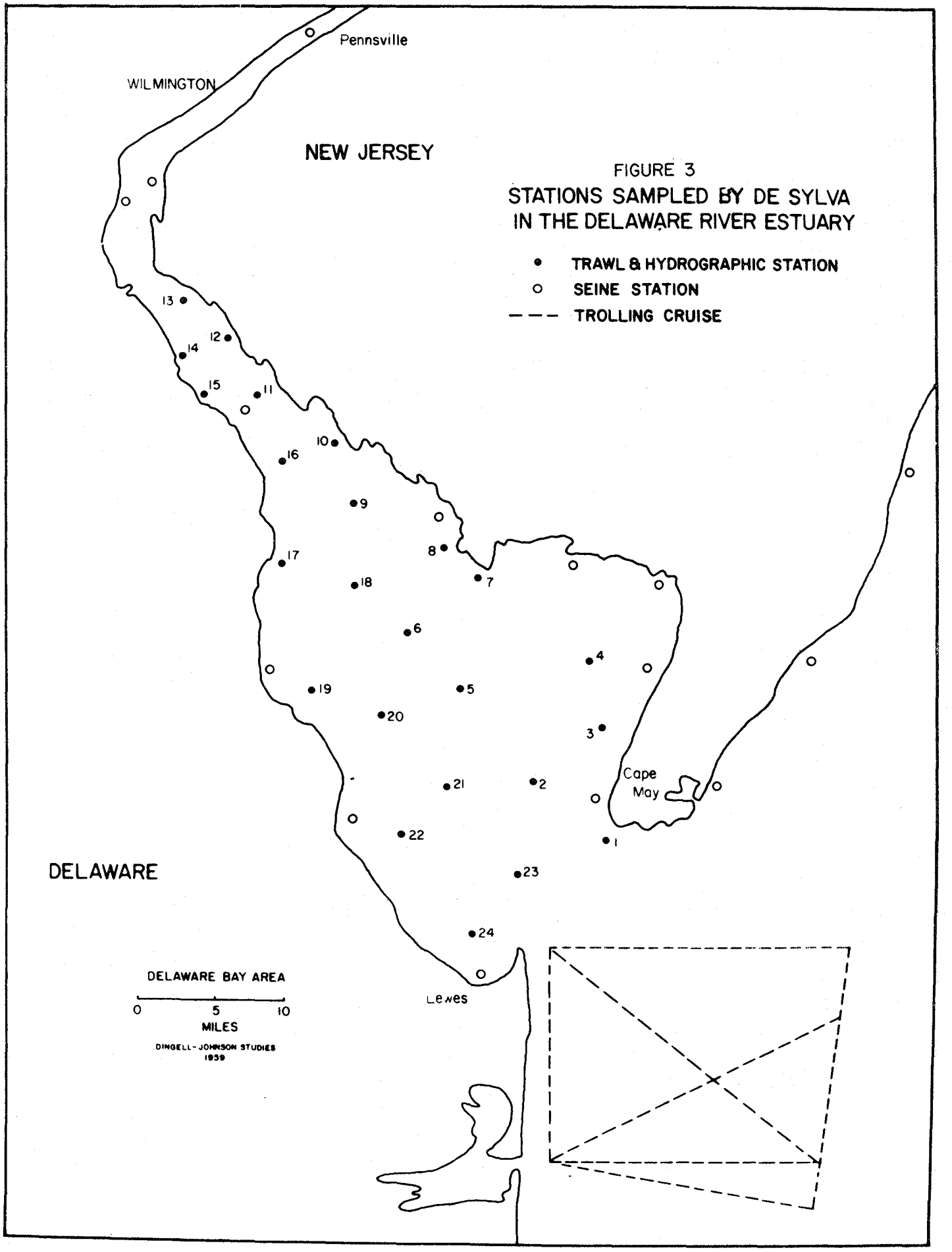
predictive models. With this information, we should be able to make knowledgeable decisions on how man can best develop and utilize the estuary within the guidelines of sound ecological principles.

Past History of Fisheries Research in the Delaware River Estuary

According to Stevenson (1952) the University of Delaware began an inventory of the marine natural resources of the state in January 1952. Before this time he states the only consistent records kept were annual estimates compiled by the Fish and Wildlife Service. Stevenson gives data on types of commercial fishing gear operating from Delaware ports in 1952, and also data on the marine sport fishery for the state south of Slaughter Beach in 1952. Daiber (1954a) lists catch statistics for commercial fishing in Delaware in 1952, pounds of fish landed by species for boats out of Lewes from 1947-1954, and data on the marine sports fishery in Delaware for 1953. Data on the relative abundance of fish as sampled in the commercial catch from 1951-54, and by a research vessel 1953-54 are given by Daiber (1954b). He also gives a brief description of a beach zone investigation for fish. Fish were collected with a 25-foot hand seine at five locations; Lewes Beach, Slaughter Beach, Kitts Hummock, Woodland Beach, and Augustine Beach. These stations were all sampled on the same day at biweekly intervals from September 1952 to October 1953. Data from this shore zone fish survey are given in Shuster (1959). Shuster (1959) also has a chart showing the commercial fishing areas in Delaware Bay, and from this we can relate the commercial catch to these areas of the bay.

June and Reintjes (1957) surveyed the fisheries in the coastal ocean area between Barnegat Lightship and Winter Quarter Lightship seaward to the 100-fathom contour line. Reintjes and Roithmayr (1960) did a supplemental survey in the above area. Another study on changes of fish populations in the middle Atlantic area was done by Perlmutter (1959). These reports will be valuable in comparing data to be collected in this study with that collected in the coastal area 15 years ago.

A fish survey program was organized and started for the Delaware River estuary and coastal area in 1958 by de Sylva (1959). This survey included 24 trawl stations and 20 shore seine stations; and four trolling cruises were made in the ocean off Rehoboth. The locations of these stations are given in Figure 3. Trawl sampling was done with a 30-foot otter trawl being towed 30 minutes at each station. Lengths, scales, and stomachs were taken from some fish caught. Other samples or observations taken at the trawl stations included a half-hour tow with a Clarke-Bumpus sampler or a 1-meter plankton net at the surface; 1-liter water samples at the surface, mid-depth, and bottom along with temperatures at these depths; secchi disk reading; and meteorological conditions, air temperature, and relative humidity. Water samples were analyzed for salinity, dissolved oxygen and oxygen saturation, and inorganic phosphate. The 24 stations were only sampled twice, once in September and once in October-November, because of lack of funds. The shore zone stations were sampled with a 50-foot 1/2 inch stretch mesh seine.


Pennsville
WILMINGTON
NEW JERSEY
FIGURE 3
STATIONS SAMPLED BY DE SYLVA
IN THE DELAWARE RIVER ESTUARY
TRAWL & HYDROGRAPHIC STATION
SEINE STATION
TROLLING CRUISE
13
12
14
15
11
10
16
9
8
17
7
18
6
4
19
5
20
3
21
2
Cape
May
22
1
DELAWARE
23
24
DELAWARE BAY AREA
0 5 10
MILES
DINGELL-JOHNSON STUDIES
1959
Lewes

Other data taken and observations made included air and water temperature; water samples; bottom type; and meteorological and general ecological conditions. Fifteen of these stations were sampled approximately every two months, while others were sampled more frequently. A total of 74 collections was made.

This shore zone survey was continued until February, 1960, with sampling of 16 of the 20 original stations being done approximately every two months (de Sylva, Kalber, and Shuster, 1962). Sampling under this program was done using a 60 x 4-foot seine with 1/2 inch stretch mesh and a 6-foot bag of 1/4 inch stretch mesh sewn in the middle. Normally, three hauls of about 50 yards in length were made at each station; the hauls being made with the tide whenever possible. Stomachs of fish were usually examined whenever sufficient fish were available. A description of the sampling stations is given in the report along with data collected. An excellent bibliography concerning fish found in Delaware waters and on fish populations in general is also given in this report. A limited Delaware shore zone survey was conducted in July and August 1966 (Smith, personal communication). Sampling stations were located at Lewes, Primehook, Bennetts Pier, and Woodland Beach. Sampling consisted of making several hauls with a 48-foot 1/2 inch stretch mesh seine. Various physical parameters were noted at the time of collections. Derickson (1970) and Scotton (1970) have done a shorezone fish survey and larval fish survey in Indian River and Rehoboth Bays, and this information will be very useful for comparison with that

collected in this study.

Franklin C. Daiber has done extensive survey work on fish populations of the Delaware River estuary. This work is reported in Annual Dingell-Johnson Reports to the Delaware Board of Game and Fish Commission from 1955 onward. De Sylva and Kalber (1960) also have a report on fishes captured by trawl in the Delaware Bay area. In August, 1966, a survey of fish populations in Delaware Bay was started and is continuing at present: Daiber and Abbe (1967), Daiber and Wockley (1968), and Daiber and Smith (1969 and 1970).

For this survey Delaware Bay was divided into 31 sectors, each sector being five nautical miles long by about four nautical miles wide (Figure 4). Sectors sampled so far include 2, 5, 8, 13, 14, 16, 19, 20, 21, 23, 24, 25, and 28. At least three of these sectors were sampled monthly, weather permitting. A total of 280 samples has been taken through January, 1971. Sampling each sector consisted of getting a bottom water sample for salinity (later in study dissolved oxygen also) and a water temperature, and then the trawl was put over and towed for 30 minutes. The trawl was a 30-foot otter trawl with 3-inch stretch mesh in wings and body, and 2-inch stretch mesh in the codend. Starting and ending positions were determined and tow length noted. A recording fathometer plotted water depth during the tow. Other information recorded was date and time, weather, tide stage, boat direction, and engine speed. Fish caught were identified and measured and/or counted. Stomachs of some fish caught were examined.

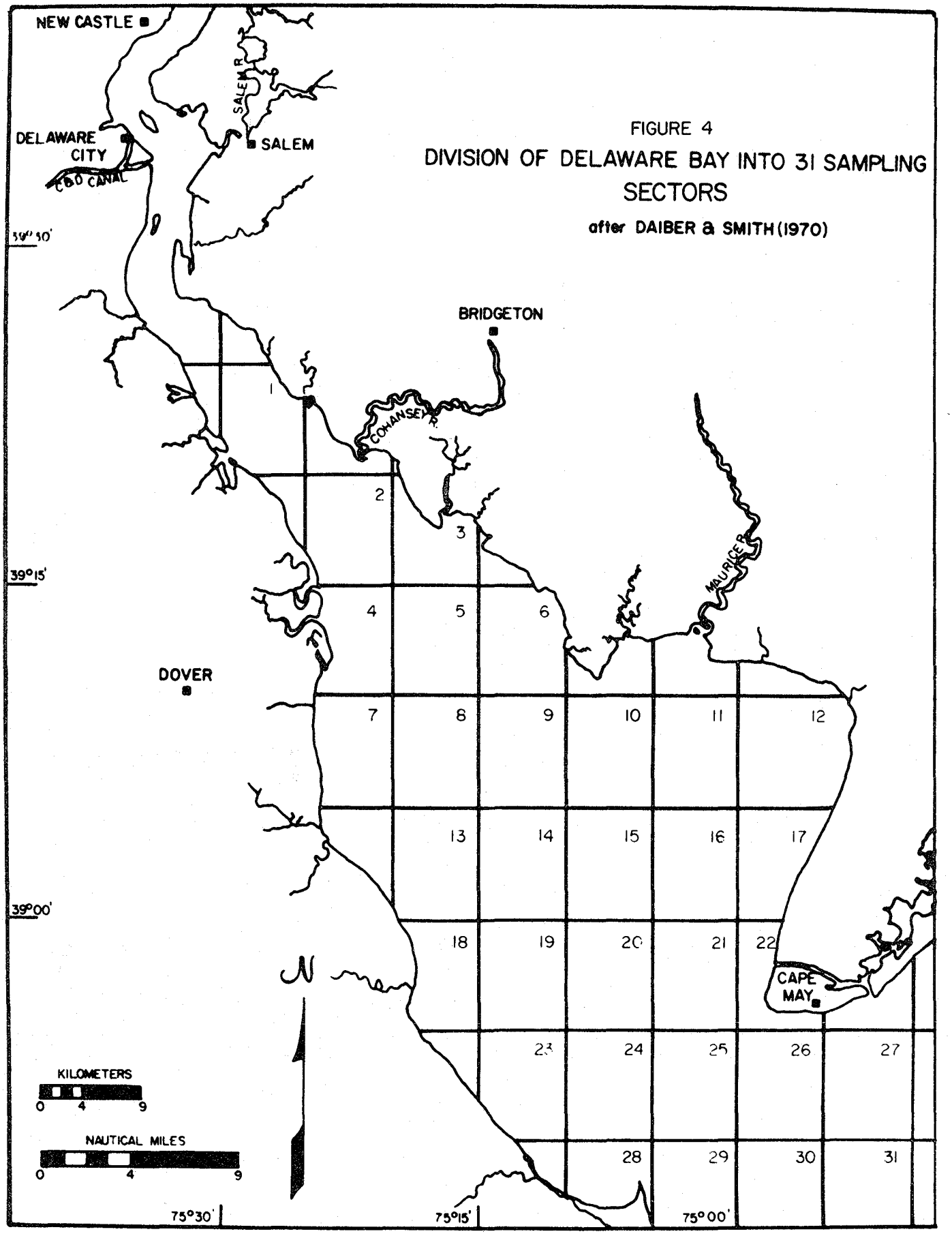


FIGURE 4

DIVISION OF DELAWARE BAY INTO 31 SAMPLING SECTORS

after DAIBER & SMITH (1970)

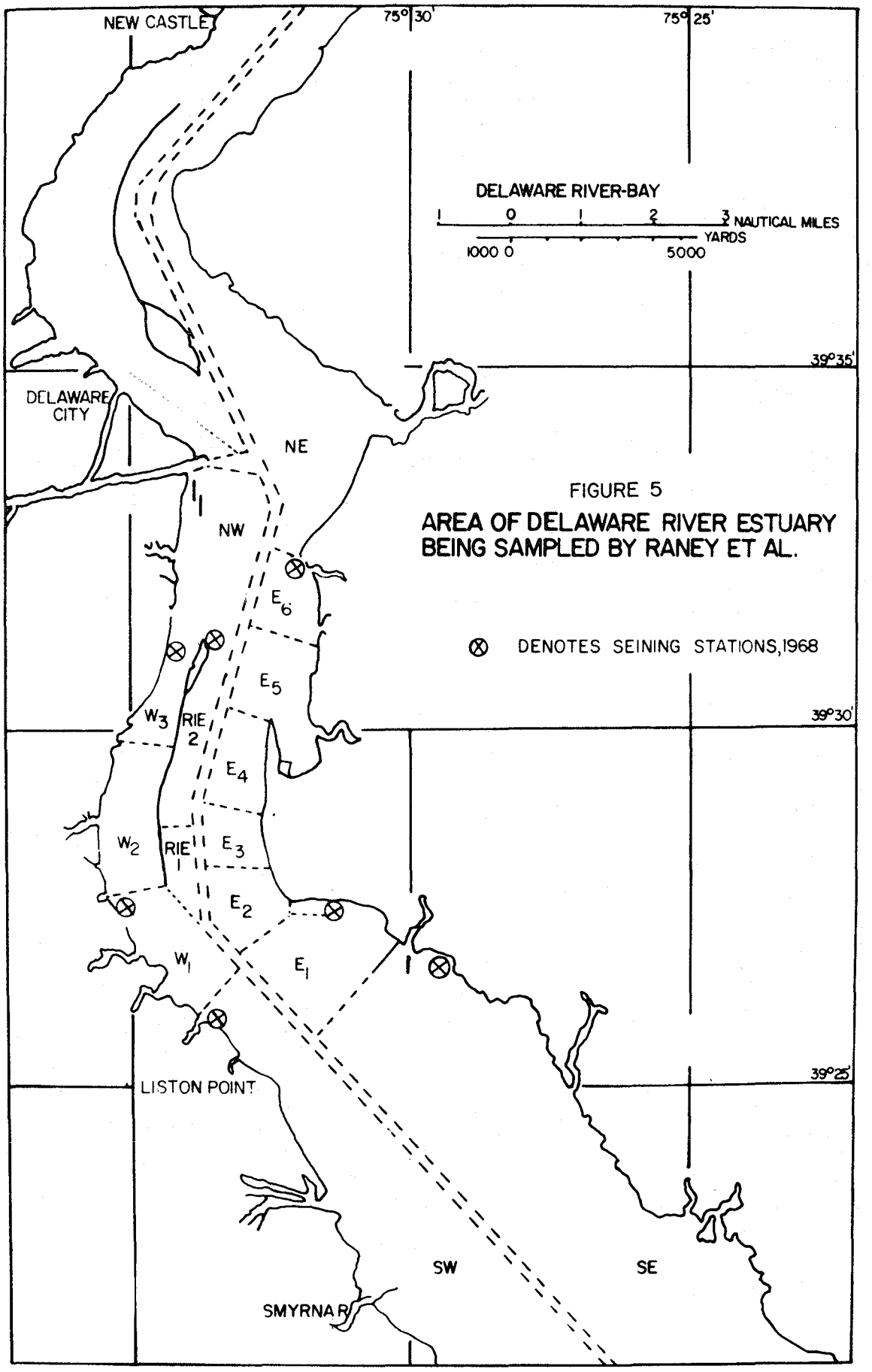


FIGURE 5

AREA OF DELAWARE RIVER ESTUARY BEING SAMPLED BY RANEY ET AL.

⊗ DENOTES SEINING STATIONS, 1968

An ecological study of the Delaware River around Artificial Island, New Jersey, was started in June, 1968, by Ichthyological Associates and is continuing at present (Raney, Schuler, and Denoncourt, 1969). The study area includes the river 10 miles above and below Artificial Island and the eastern end of the Chesapeake and Delaware Canal, as well as adjacent marshes and tidal creeks. This area is located just above where the river becomes the bay, and Figure 5 shows the area along with seining sites for 1968. Daily, seasonal, and yearly variations in numbers and distributions of organisms are being studied. Intensive sampling of fish populations is being done by trawl, haul seine, and gill net. The trawl used is a 16-foot semi-balloon trawl with 1 1/2-inch stretch mesh in wings and body, 1 1/4-inch stretch mesh in codend, and an innerliner of 1/2-inch stretch mesh in the codend. The trawl was towed for 10 minutes. For seining, 25- and 75-foot bag seines with 1/2-inch stretch mesh webbing, 5 feet deep, were used. From one to four hauls were made at each station, depending on the size of the seine, so that approximately 100 years was covered. Detailed studies are being made in the life histories of important fish.

An ecological survey including fish populations is currently under way in the Chesapeake and Delaware Canal, with stations also located around the mouth at either end (Daiber, personal communication). This study will include trawl samples and possibly seine samples, and will run until September, 1973. The methods used will be similar to those given by Daiber and Smith (1970).

Murawski (1968) has studied various aspects of fish abundance and distribution in the New Jersey area over the past five years or so. The reference noted is just one example of his research efforts, which should be very helpful in understanding data collected in this study.

All of the aforementioned work in the Delaware Bay area is valid research, the primary limitations being the restricted area covered and/or the short sampling time. This past work will be used to develop sampling schemes and to pick sampling areas so that the Baseline data collected can be compared to data collected in the past. Otherwise, there will be no adequate way to measure the change in fish populations over the last 10 to 20 years.

B. Benthic Organisms*

In order to fulfill the requirements of a Baseline Study of the Delaware Bay area, the biota in this environment must be known and their potential use evaluated as completely as possible. Invertebrate species will constitute about 85% of the biota. All these species are ecologically significant, some are commercially important, and a few fit both categories. For example, noncommercial species of polychaete worms and amphipod crustaceans are the major source of food for many fish. Hard clams, surf clams, blue crabs and lobsters constitute commerical shellfisheries. Predators and pests like drills, whelks, mud crabs and sea nettles; fouling organisms like barnacles, hydroids and sea grapes; marine boring organisms like

*Prepared by Dr. Donald Maurer

shipworms exert adverse commercial effects. On the positive side, oysters are particularly important as a commercial fishery on one hand, and they offer a substrate for an abundant and diversified community of invertebrates on the other hand.

Acknowledging that pollution has been occurring for some time, it is incumbent upon scientists to enter the spectrum and establish a baseline for future evaluations. At present there is no published account of the condition of invertebrate populations in Delaware Bay. In the wake of a catastrophe, there would be no objective way to evaluate the effect of such an event. Unlike fish, many invertebrates are sedentary and are unable to move from sources of pollution. As a result, benthic invertebrates are excellent indicators of pollution as they assay the environment. Thus a knowledge of invertebrate populations is a valid measure of the health and wealth of this environment.

The purpose of this research is to determine the composition, distribution, abundance and biomass of macroscopic invertebrates in the bay area. The recognition of commercial species, principal food species, and pollution indicator species will receive special attention. The principal theme involves the activity of these organisms as vehicles for the flow of energy through the ecosystem. What does a species eat (herbivore, carnivore, omnivore)? Who are its predators (finfish, other invertebrates, man)? How fecund is it (low production, high production)? What is its mode of reproduction (viviparous, ovoviviparous, planktonic)? What is the

survival rate of larvae (10% or 90%)? How does the species affect the environment (oyster bars, mussel beds, Sabellaria reefs)? How does the environment affect the species (response to salinity, temperature, oxygen, substrate)?

This list is not exhaustive, but if these kinds of questions can be answered in time and space for selected species, then the baseline will be on its way to understanding the living resources in the bay. Initially these data will provide a description of the ecosystem which will ultimately lead to recommending management criteria for the bay in the future.

Past Work

The literature on marine invertebrates is huge and even the subcategory of bottom-dwelling marine invertebrate communities is extremely large. A few of the major reviews on benthic communities includes Thorson (1957), Raymont (1963), Carriker (1967), Muus (1961), Pearce (1967), Lie (1968), and Jones (1969). These publications together with the extensive surveys off southern California by the Allan Hancock Foundation, University of Southern California, the biotic census of the Cape Cod area by the systematics Ecology Program, Woods Hole, Massachusetts, and the near shore and oceanic benthic investigations by the Duke Marine Laboratory, Beaufort, North Carolina represent the majority of work done in this field in the United States.

In terms of publications on benthic communities in Delaware Bay, the situation is considerably different. To date the only work has

been concerned with a single species, a specific taxonomic group or a special problem (Stauber 1950, Bousfield 1969, Watling and Maurer 1972 a, b). Although there is no published information on benthic communities in the bay area, this does not mean there has been no activity. The Rutgers University Oyster Laboratory has been collecting data on associated oyster fauna for many years. In the early fifties, Mr. William Amos, Resident Biologist, University of Delaware Marine Laboratories, conducted benthic research from the mouth of the bay almost to Trenton. At present a research group, Ichthyological Associates, is conducting an extensive survey in the area of Artificial Island. Research on benthic communities in Rehoboth and Indian River Bays was recently completed by our Laboratories. This research has resulted in a manuscript on "Shallow Water Amphipods of Delaware Bay" and a manuscript on "Shallow Water Hydroids of Delaware Bay," which have been accepted for publication. Experience gained in this work provided a springboard for the next segment of work in Delaware Bay proper involving the associated oyster fauna. The latter work is completed and a manuscript is in progress. These projects have prepared us for a comprehensive study of the bay.

Inadequacies

Most of the local benthic research conducted in the past had a variety of limitations. In some cases the work was seasonal, with greater emphasis on summer collections. In other cases surveys were restricted by geographic boundaries, hydrographic conditions, and ecologic units. Still others did not involve systematic

quantitative collecting methods. Finally, these studies did not have the advantage of being a part of a comprehensive integrated theme such as has been proposed for the entire Baseline Study.

Incorporation of Past Work

Recent contact with Icthyological Associates and Mr. William Amos has alerted us to the extent and scope of their work. With this information we will be able to avoid repetition and include those areas not adequately covered by their work. For example, Icthyological Associates has mounted a comprehensive fish and plankton survey of the area from the Chesapeake Bay-Delaware Canal to the Symrna River. However, they informed us that a benthic survey has not yet been initiated. Discussion with Mr. Amos revealed that some deeper water areas (Bay Mouth, off Big Stone Beach) should be sampled with heavier collecting gear than he had available. Our faunal work on Delaware's oyster beds permits us to deemphasize work here and concentrate benthic collecting in other areas.

B-I Biological Productivity

Objective: To arrive at a quantitative description of the biological productivity and energy flow in the Delaware Bay by communal zone in support of the development of a trophic transfer model (B-IV).

General Comments: This project is closely linked operationally with project B-II, the biological survey, and is distinguished from it only for the sake of conceptual clarity. It is expected, therefore, that

the principal investigators of this project will work in extremely close cooperation with those of project (B-II) if they are not identically the same individuals.

B-I-i Primary Productivity*

Specifications: The primary productivity of the Delaware estuary shall be investigated in order to develop a quantitative description of the space-time magnitude and distribution of primary production (P/P) in the estuary with respect to the various community types involved. A description of variables associated with the pattern observed above will be provided by other BLS studies. The latter variables shall include a taxonomic census of organisms or groups of organisms which are involved and their space-time distribution. Supporting data for these studies will be supplied by the biological survey project (B-II) as well as by the studies of general physical (PO-III) and meteorological (M-I) characteristics; of chemical distributions in the bay (C-I); of input water characteristics (H-I); and of the sediment content of the bay's water (G-II).

There are three major habitat types within the Delaware Bay ecosystem, viz., an extensive intertidal zone on the borders of the bay, a substantial bay bottom, and the open water of the bay. Since a strong salinity gradient exists along the NW-SE axis of the bay, the open bay should also be partitioned into sections that are characterized by specific salinity regimes. Since each of these habitat types, or environments, is occupied by a characteristic set

*Based on material submitted by Dr. Jonathan Taylor.

of primary producers, the determination of the primary production rates in these varied groups of organisms shall be accomplished by use of techniques appropriate to each.

In the Intertidal Zone a large foundation of information is available from studies carried out by earlier investigators of angiosperm production in the New Jersey marshes and in a marsh near Lewes, Delaware. Furthermore, much data is available in the College of Marine Studies on nutrient and hydrographic conditions in these marshes. Therefore, the present study shall be directed to the determination of the primary production of angiosperms in Delaware marshes other than at Lewes, and to a survey of vegetation types and quantities of salt marshes throughout the Delaware Bay system, possibly via remote sensing.* In such studies, harvest methods shall be employed. Small plots are to be clipped, rhizomes dug up, etc., on at least a quarterly basis. Sites shall be selected in marshes along both the Delaware and New Jersey sides of the estuary from the C & D Canal to the Capes. Specific parameters that are to be measured include plant densities, standing crop, wet and dry biomoss, ash-free weight, caloric content and chlorophyll. Other physical and chemical environmental parameters are to be developed as appropriate. These data shall be made available to the rest of the BLS by being fed into the information system (SA-I)

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*Since this was written an analysis of the dominant vegetative types in the Delaware marshes has been conducted using remote sensing. This was accomplished by Dr. V. Klemas under funding from NSF/RANN.

as they become available.

The results of studies now under way by graduate students in the College of Marine Studies on salt marsh algae and of a study proposed to UDRF of the hard substrate intertidal aspects of the system should be correlated with the BLS in an investigation of the intertidal zone.

The study of the Subtidal Benthic Photo Zone (0-2m) shall consist of at least quarterly field studies made at selected stations on the Delaware and New Jersey shores of the bay to estimate the following parameters:

Biological: Floristic composition; standing crop caloric content; wet, dry and ash-free weight; diversity; chlorophyll pigment; and perhaps L-D oxygen production.

Environmental: Standard station data, and nutrients (P, N in all forms). This data shall be fed into the information system (SA-I) for use by the appropriate collateral studies. They, in turn, will be supplemented by the more frequent data acquisition efforts of the PO-III and C-I studies.

The Open Bay-Coastal Waters habitat is the dominant habitat type in the Delaware Bay system; therefore, major emphasis shall be placed on it in this BLS project. Permanent stations shall be established in the bay as shown in Figure 6 and in adjacent coastal waters so as to encompass the salinity gradient within the bay, the immediate coastal water masses that interact with the bay, and the bathymetric characteristics of the bay. These stations

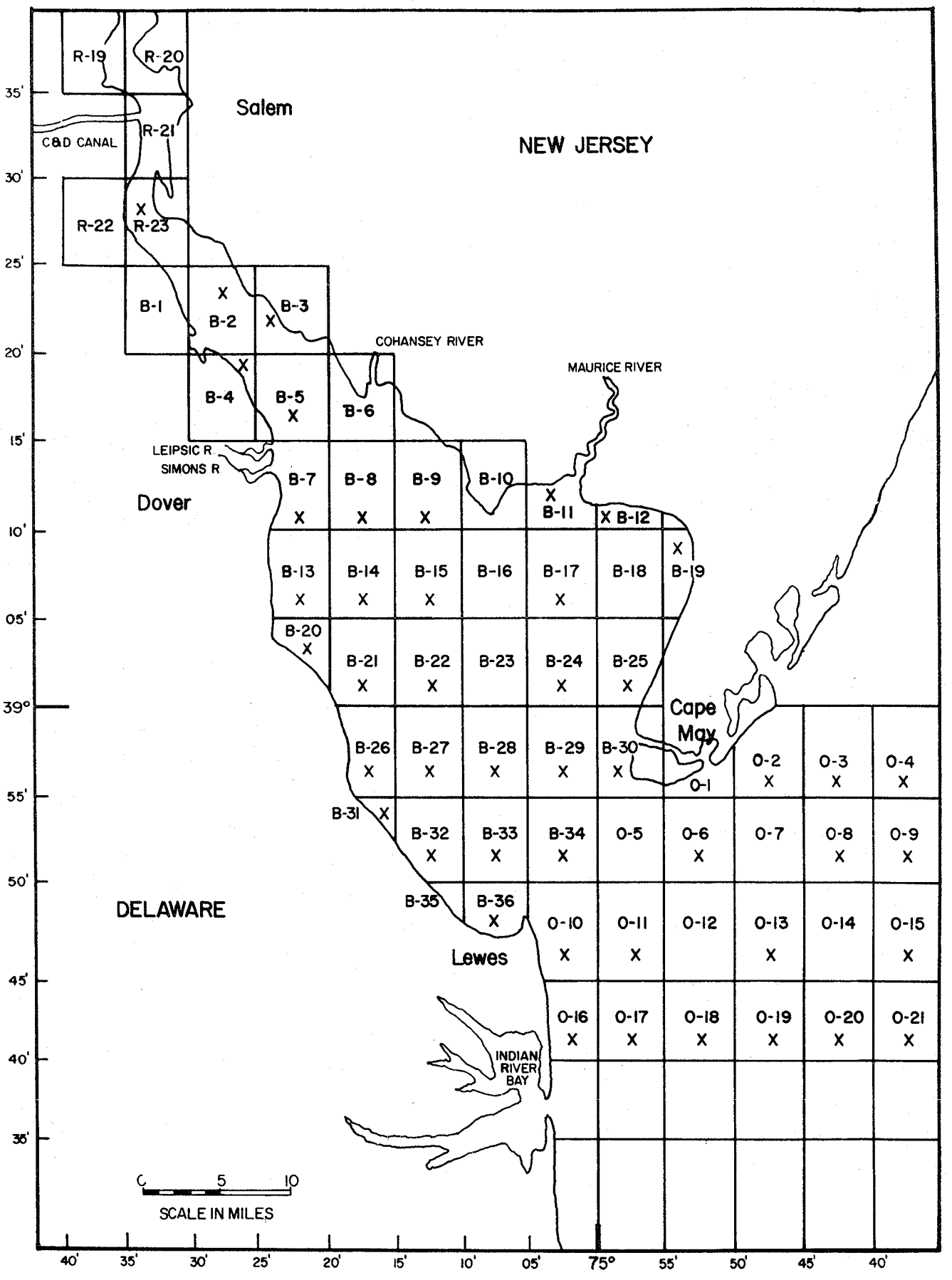

Figure 6. Delaware River-Bay and Atlantic Ocean, showing division of area into sampling sectors. Those with an X are sectors to be sampled.

shall be sampled on a monthly schedule. The parameters to be estimated as a function of depth, time and location are:

Biological: C^{14} fixation, O_2 production, chlorophyll concentration, other pigments. (Data on species composition and cell numbers will be provided by the B-II project which will be operating in conjunction with this project.)

Chemical: Samples will be provided to the C-I project for analysis as to phosphorus (all forms), nitrogen (all forms), alkalinity, micronutrients (Si, Fe, Mn) and dissolved organics (total). Similarly, the sediment project (G-II) will analyze for particulate organics (total). The measurement of pH shall be done in the field.

Physical: Standard station data shall be taken at each station and fed into SA-I.

Comments: Interpretation of these data is to depend heavily on the results of investigations of physical (PO-II, -III) and chemical oceanography (C-I, -II) and the biological survey (B-II), especially the zooplankton portion.

The estimated cost of the first year's work as outlined above is $141,910 and of the second is $93,990. These costs include salaries and wages, travel, supplies and expenses, equipment, other expenses, and overhead.

Schedule: This work is to be completed in the first two years of the BLS.

B-I-ii Food Web Analysis

Comments: This portion of the biological productivity study is charged with the description and quantitative analysis of the food web of Delaware Bay from the primary consumers through the top carnivores of the estuarine community. Both the "classical" and detrital food chains are to be followed. Techniques will range from literature search through the analysis of stomach contents; however, detailed laboratory studies are excluded from the project as they are included in the interaction studies project (B-III).

Schedule: This work will be accomplished during the first two years of the BLS.

B-I-iii Recycling Processes

Comments: This portion of the biological productivity study is charged with the discovery and quantitative analysis of the nutrient recycling processes of Delaware Bay. This includes the distribution of recycling processes in space and time and a description (in so far as is possible from field data) of their dependence on physical and chemical factors.

It is to be understood that detailed laboratory studies of interactions will be carried out by the interaction studies project, B-III.

Schedule: This work will be carried out during the first two years of the BLS.

B-II Biological Survey

Objectives: To describe quantitatively the space-time distribution of the biota in the Delaware Bay system in support of the development of a trophic transfer model (B-IV), and to establish a biological baseline for the system.

B-II-i Ichthyofauna Survey*

Specifications: The abundance, distribution and ecology of fish, both larval and larger size, in the Delaware estuary and nearby coastal waters shall be determined.

The geographical area to be studied shall be the Delaware estuary from the upper reaches of tidal currents in the Delaware River at Trenton, New Jersey, southerly through Delaware, to and including the coastal area of Cape Henlopen. The entire area shall be divided into sampling sectors of 5 degrees latitude by 5 degrees longitude (i.e., sectors 5 miles long and approximately 4 miles wide). The sampling sectors are shown in Figures 6 and 7, with river sectors designated by "R" with a number from 1 to 23, bay sectors designated by "B" with a number from 1 to 36, and ocean sectors designated by "O" and a number from 1 to 21.

Both larval and larger fish shall be sampled at designated stations. In addition to the fish collected, the following information or samples shall be taken at each station: standard station

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*Based on material supplied by Dr. Kent Price.

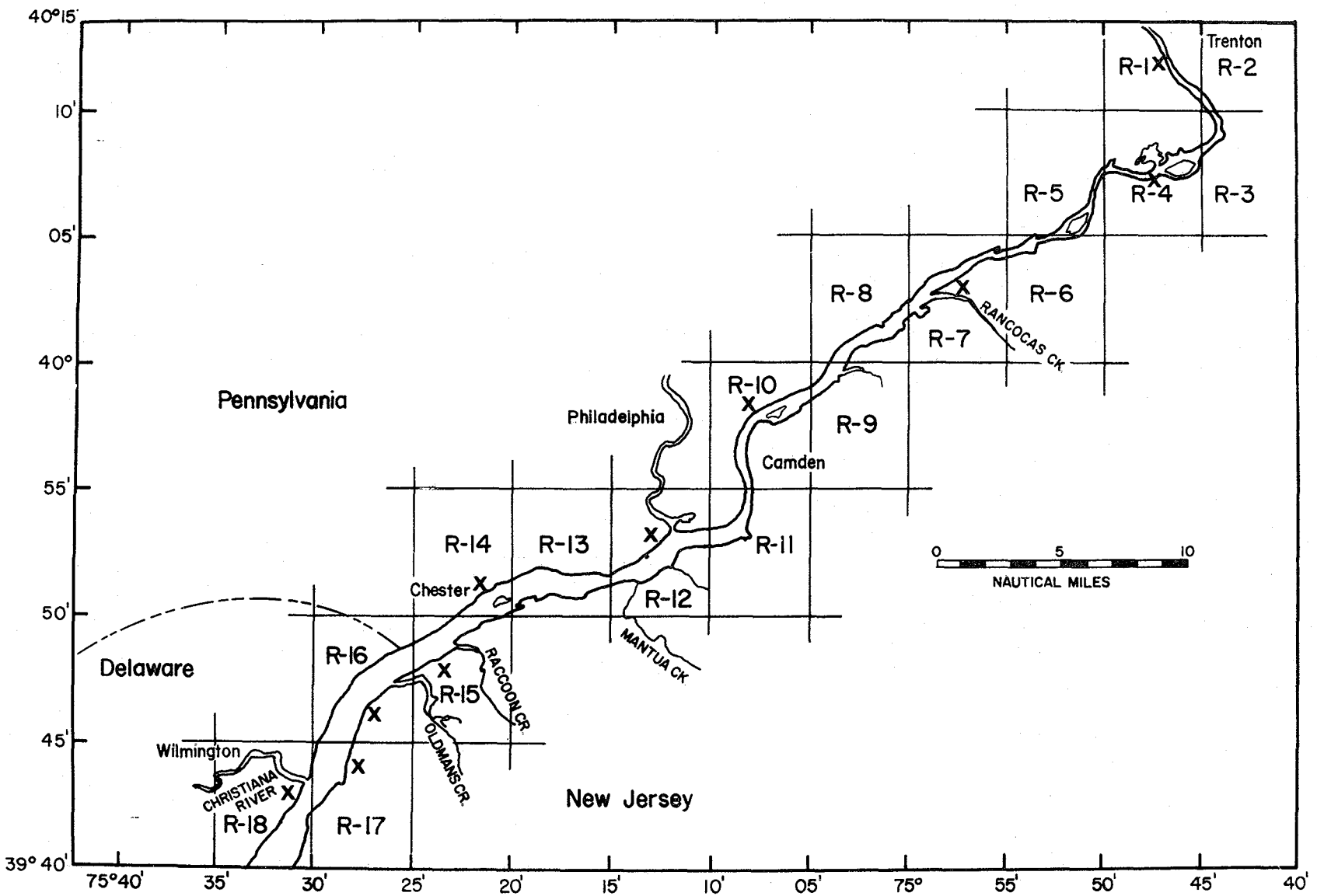

Figure 7. Delaware River from Trenton, N.J., to just below Wilmington, Delaware, showing division of river into sampling sectors. Those with an X are sectors to be sampled.

data; water samples to be analyzed by the chemical distribution study (C-I) for salinity, dissolved oxygen, heavy metals, pesticides, and dissolved organics (pH shall be measured in the field); particulate organics and turbidity will be determined from water samples by the sediment study (G-II); in addition at shore stations, type of shoreline and bottom. Those data which are of general interest to the BLS shall feed into the information system (SA-I).

In the fish survey operations, sectors to be sampled by seine and/or trawl are designated by an "X" in Figures 3 and 4. A total of 56 sectors will be sampled; 12 in the river, 29 in the bay and 15 in the nearby ocean. Those sectors to be sampled by seine only are R-17 and B-3, -4, -11, -12, -19, and -31; those by seine and trawl are R-1, -4, -7, -10, -12, -14, -15, -16, -18, -21, -23 and B-2, -7, -9, -13, -20, -25, -26, -30, -32 and -36; those by trawl only are B-5, -8, -14, -15, -17, -21, -22, -24, -27, -28, -29, -33, and -34 and O-2, -3, -4, -6, -8, -9, -10, -11, -13, -15, -16, -17, -18, -20 and -21. Sampling sites within each sector shall be determined by (1) accessibility by boat for trawling and by vehicle for seining; (2) location of sampling sites used in previous investigations; and (3) the need for coordination with other BLS projects. Sampling shall be conducted bi-monthly.

Sampling fish with a seine shall be done using a 60 x 4-foot seine, with 1/2-inch stretch mesh, having a 6 x 4-foot bag of 1/4-inch stretch mesh sewn in the middle. Two hauls shall be made at each station, each covering approximately 50 yards. Sampling by trawl shall be done using a 30-foot otter trawl having 3-inch stretch

mesh in the wings and body, and 2-inch stretch mesh in the codend. The trawl shall be towed for 30 minutes at each station. Fish captured by seine and trawl will be identified and measured; however, when more than 50 individuals of any one species are caught, a random subsample of 50 shall be weighed to establish length-weight relationships, in order to get biomass estimates for energy conversions, and so forth.

Samples of each species collected shall be provided to the food web analysis sub-project (B-I-ii) for analysis of stomach contents, and to the bioassay project (C-II) for chemical analysis.

Fish eggs and larvae shall be sampled by one-meter plankton nets of number 0 mesh size. At trawl stations, three plankton nets shall be fished simultaneously (surface, mid-depth and bottom) and are to be towed for 10 minutes. At seine stations, one plankton net shall be towed by hand for a period of 5 minutes. In both operations, the volume of water fished per net shall be measured. Samples collected shall be preserved with 5% formalin and saved for future sorting and identification at the laboratory.

A reference collection of rare or unusual fish and larval stages of all fish shall be made a part of this study. These specimens shall be preserved in buffered formalin for at least 2 weeks and then transferred to ethyl alcohol. In addition, a subsample from each station of each species taken in any month shall be preserved in the same manner for future analysis should that become necessary.

The estimated cost for the first year of this two-year study is $99,000 and for the second year $72,030. These costs include salaries and wages, major equipment, expendable equipment, travel, data handling and processing, publication costs and indirect costs.

B-II-ii-a Benthic Survey*

Specifications: The composition, distribution, abundance, and biomass of benthic invertebrates in the Delaware Bay area shall be determined.

The benthic survey shall be conducted in the Delaware River estuary from Trenton, New Jersey, to approximately 25 miles off the Delaware Bay mouth. Samples shall be taken at approximately 16 stations in the river, 62 in the bay and 30 in the ocean. Specific locations of the bay stations are indicated in the attached figure. Sampling shall be taken on transects perpendicular to the axis of the bay as shown in Figure 8. Sampling shall be stratified depending on bottom topography. Quantitative samples shall be taken with $1/10m^2$ Smith-McIntire grab, and qualitative samples with an epi-benthic dredge. Samples shall be sieved through screens of 2.00, 1.0 and 0.5mm mesh. A portion of each sample is to be saved intact for later work on the meiofauna. The Foraminifera and Ostracods of the meiofauna are to be studied in detail by the subproject (B-II-ii-b). The sampling schedule shall include runs each summer covering all 108 stations (216 samples in two years) and a quarterly

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* Based on material supplied by Dr. Donald Maurer.

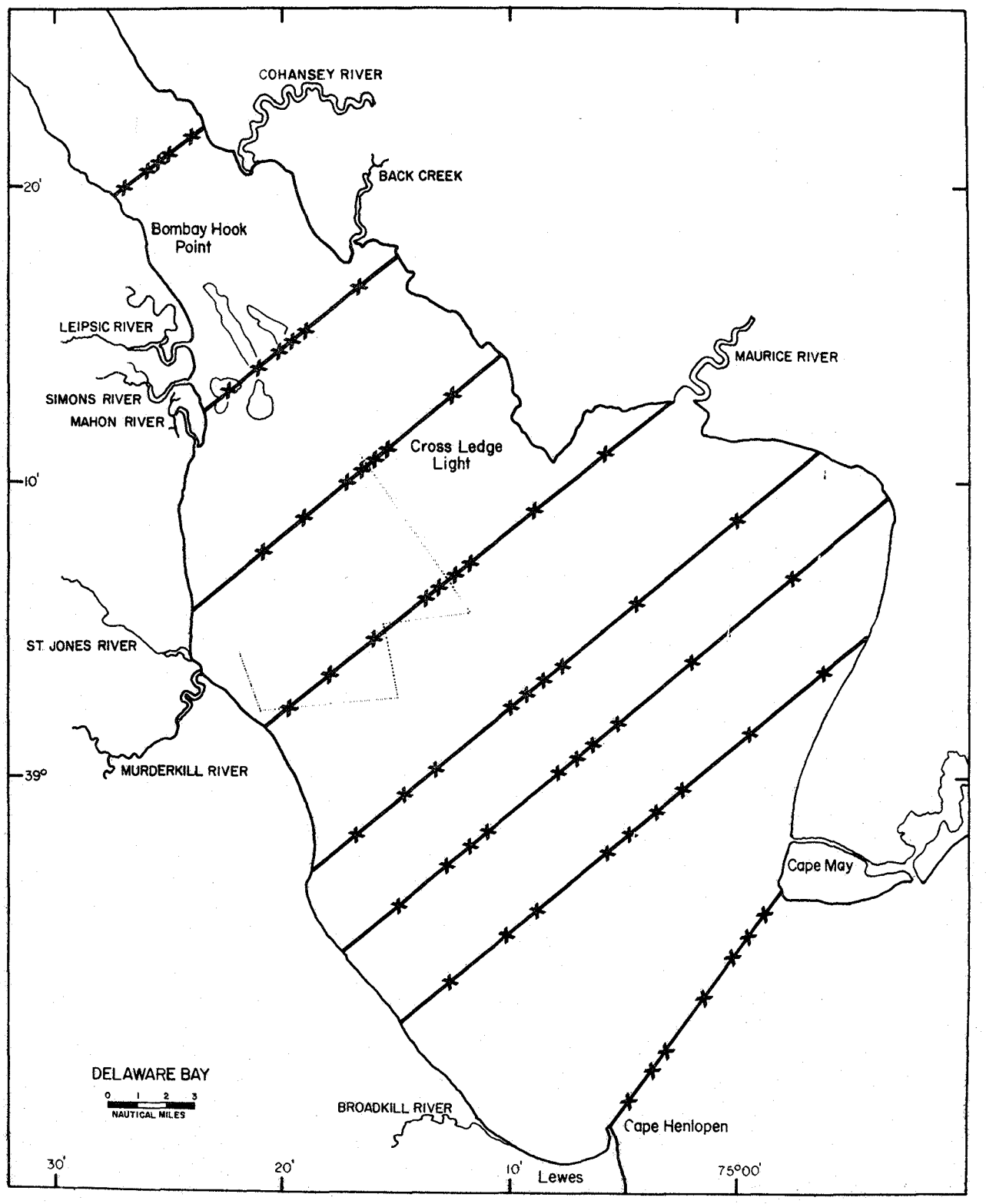
COHANSEY RIVER
BACK CREEK
20'
Bombay Hook Point
LEIPSIC RIVER
SIMONS RIVER
MAHON RIVER
MAURICE RIVER
Cross Ledge Light
10'
ST. JONES RIVER
39°
MURDERKILL RIVER
Cape May
DELAWARE BAY
0 1 2 3
NAUTICAL MILES
BROADKILL RIVER
Cape Henlopen
30'
20'
10'
Lewes
75°00'

Figure 8

monitoring of 25% of the stations (162 samples in two years). In addition to the biological collections taken at these stations, standard station data shall be taken and made available to the other BLS projects by means of the information system (SA-I). Furthermore, as a cooperative effort with the geochemical and bottom sediment surveys (G-III and G-IV), sediment samples shall be collected for examination by those projects. Finally, plankton hauls shall be taken between stations to provide samples to the phytoplankton (B-II-iii-a) and zooplankton (B-II-iii-b) portions of the biological survey.

The benthic samples obtained in this survey shall be combined with a reference collection from earlier surveys to form the nucleus of a local reference collection of invertebrates from Delaware Bay. The samples shall be fixed in 10% buffered formalin and then switched to 70% isopropyl alcohol. Some samples shall be maintained in formalin pending biomass studies. For these biomass studies the samples shall be sorted, picked, identified, counted, measured and weighed. Flotation techniques to reduce hand picking are to be applied where feasible.

The results of this study will be qualitatively extended to the entire bay by making use of the results of the bottom photo survey (G-I).

The estimated cost of the first year of the project (including salaries, wages, ship and land travel, equipment, and miscellaneous supplies) is $104,294. The second year's cost is estimated at $110,000.

B-II-ii-b Distribution of Foraminifera and Ostracoda of Delaware Bay and Shelf*

Specifications: The distribution and identity of the species of Foraminifera and Ostracoda in the meiofauna of Delaware Bay and the nearby Atlantic Ocean shall be determined.

Portions of the samples collected at the 108 stations specified in the benthic survey of the Delaware Bay region (B-II-ii-a) are to be studied. These will be supplemented by dredge and core samples obtained at selected stations. The distribution of the species of Foraminifera and Ostracoda in the samples shall be measured and their toxonomy verified at storage centers for type material. Physical and chemical parameters at the several stations will be available to this study through the information system (SA-I).

The supplementary dredge and core sampling may be conducted by an assistant using suitable boat and sampling equipment, and shall be coordinated with the sampling for the benthic survey (B-II-ii-a). Laboratory facilities are available in the Department of Geology.

The estimated cost of the first year of the project is $23,700. Total cost for the 2nd year is approximately $12,500.

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*Based on material supplied by Dr. Frederick M. Swain.

B-II-iii-a Phytoplankton Survey*

Specifications: The microscopic and submicroscopic components of the Delaware River Estuary shall be determined from phytoplankton samples collected at representative stations in Delaware Bay and in streams and rivers entering the bay.

Samples shall be taken at the 23 stations in the Delaware River and the 34 stations in the bay specified in Survey section B-II-ii-a, and at land stations on streams entering the bay. Sampling shall be carried out ten times a year. Samples shall be taken in conjunction with the benthic survey project (B-II-ii) four times a year and in conjunction with the fish survey (B-II-i) six times a year. These samples will be used to determine species composition and cell numbers.

A portion of the phytoplankton samples obtained will be used to study the dynamics of blue-green and related algae in the bay. This part of the project shall determine the identity and distribution of the algal species in the bay; obtain an assay of algal viruses in the bay and in the streams entering the bay; and isolate pertinent blue-green algae and their associates. These assays will provide the basis for judging the quality of the pollution of the bay and the potential of the bay for primary productivity.

Use shall be made in this and in the zooplankton subproject (B-II-iii-b) of the results of the PO-II study's description of tidal currents in order to translate the results of sampling to a common referent, e.g., the low water slack tide position of the water

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*Based on material supplied by Dr. Jonathan Taylor

mass. Later the information system (SA-I) will be able to provide this correction.

Reference collections of samples obtained shall be maintained.

B-II-iii-b Zooplankton Survey

Specifications: A survey of the zooplankton of the Delaware Bay shall be conducted, using portions of the samples collected above in the phytoplankton survey. The same station system and sampling schedule specified there shall be used here.

B-II-iv Bacteriological Survey

Specifications: A bacteriological survey of Delaware Bay shall be conducted in order to provide information of use to public health officials and to the investigation of the bay's recycling mechanisms (B-I-iii). This survey shall make use of the same sampling station pattern and schedule as the plankton surveys above. It shall include an analysis of the concentrations of coliform and fecal coliform bacteria as well as an assay of the bacterio-chemical activity of the water samples gathered. A count shall be taken of the concentration of gram-negative bacteria.

Schedule: The work described in the specifications part of this project shall be accomplished during the first two years of the BLS. Thereafter, the work shall consist of monitoring at a selected subset of the stations until the fifth year. During the fifth year

the work described in the specifications section shall be repeated for the period of one year.

B-III Interaction Studies

Objective: To investigate the interactions of the biota of the bay system with each other and with their physical and chemical environment in support of the trophic transfer model (B-IV) and the biosystem model (SA-III).

Comments: This study will be concerned with the following types of laboratory studies: (1) functional group interactions; (2) functional group physical responses; (3) organism life cycles; (4) organism-organism interactions; (5) organism-environment interactions. In addition, experimental field studies may be carried out as required. All of the studies will be primarily concerned mainly with functional groups rather than individual species. Exceptions to this rule will be made only for important species. Importance will be judged on the basis of the following criteria:

(a) Species of direct economic import
    (1) Commerical fish, shellfish, etc.
    (2) Sport fish
    (3) Game waterfowl
(b) Principal food species for above
(c) Indicator species i.e., those particularly sensitive to various pollutants (Identification is a major task.)

(d) Any other single species identified as being of pivotal import in the various biological cycles

(e) Organisms harmful to human health (e.g., disease organisms, sea nettles, biting flies, etc.)

(f) Organisms harmful to human works (i.e., marine-boring organisms)

Specifically, this project will include at least the following studies: (1) A study of the effects of viruses on the blue-green algae species of the bay based on work carried out in project B-II-iii-a's survey of the algae and their environment. (2) The laboratory study of selected species of invertebrates based on information gathered in B-II-ii-a. Several commercial species and key ecological species will be maintained and their survivorship, growth, feeding type, fecundity, and recruitment will be studied. Emphasis will be placed on predator-prey relationships, grazing, tolerance to various pollutants, including a study of sublethal toxicity effects. Aquaria experiments involving a few species (primary producer, primary consumer, herbivore, carnivore, scavenger) in a microecosystem are envisioned. (3) The joint analysis of data from the benthic survey (B-II-ii) and the bottom sediment survey (G-IV) to develop organism-sediment relationships. (4) Other interactions that may become apparent as a result of the bioassay (C-II), geochemistry (G-III), productivity (B-I) and/or biological survey (B-II) projects.

Schedule: This work will begin in the second year of the BLS and continue through the fourth year.

CHEMISTRY

C-I Chemical Distribution

Objective: To determine the distribution of ecologically and chemically important substances for the purpose of supporting the development of a chemical model (C-III).

Specifications: The waters of the Delaware River Estuary shall be analyzed for the purpose of determining the distribution of certain chemical elements, compounds and ions. The information generated shall be fed into the information system (SA-I) as soon as it becomes available.

The upper Delaware Estuary is currently being sampled weekly at 17 stations between Trenton, New Jersey and Reedy Island, Delaware by the Delaware Department of Natural Resources and Environmental Control in its Delaware Estuary survey; and the samples are currently being analyzed for the following chemical parameters: Dissolved oxygen (DO), biochemical oxygen demand (BOD), Kjeldhal nitrogen, NH_4^+, NO_2^-, NO_3^-, pH, acidity, alkalinity, hardness, chloride, oxidation-reduction potential, conductivity, total PO_4^{---}, chlorophyll, Cr, Cu, Fe, Ni, Zn and turbidity. The results of this survey shall be utilized in this section of the BLS. In addition, this study shall analyze portions of the above river samples on a monthly basis for the following parameters: dissolved and particulate organics, phenols, vitamin B_{12}, organic pesticides,

As, Ca, Cd, Co, halogens, Hg, Mg, Mn, Mo, Pb, S, Se, Si, V, and radioactivity (total α, β, and γ counts per minute).

Samples will be supplied to this study monthly from stations in the Delaware Bay by the general physical characteristics project (PO-III), and by the biological survey project (B-II). A judiciously selected subsample of 75 of these shall be analyzed for all of the chemical parameters specified above for the river survey, except that turbidity and pH will be measured in the field by the PO-III and B-II projects. The analyses of the bay samples for the parameters presently being carried out by the Department of Natural Resources and Environmental Control in the river samples should be carried out by that Department. The analyses of the bay samples for the other parameters shall be carried out by the same investigators that are determining the second group of parameters in the river samples.

Samples not analyzed shall be placed in the Reference collection stored in well-seasoned citrate bottles.

Finally, the data shall be presented in terms of maps displaying the monthly distribution of the various substances specified above. In plotting this data it should be referred to a common referent (e.g., low water slack tide position), using data from PO-II. Later SA-I will be able to provide this correction. This project will also have the responsibility of analyzing and presenting in an intelligible format the standard station data on visible pollution including surface films.

Comments: The estimated cost of obtaining the chemical analyses specified above, excluding those provided by the Department of Natural Resources and Environmental Control, and the collection of samples by the Physical Oceanography investigators, is about $86,000 for one year. This fugure is based on Brandt Associates, Incorporated price list for 15 specific analyses of 1,200 samples (100 samples per month) and reflects a 25% discount for more than 30 samples. (This estimate does not include costs of determining dissolved and particulate phosphorous, phenols, Vitamin B_{12}, Cd, Pb, Se, V, organic pesticides, or radioactivity in the year's total of 1,200 samples.)

Schedule: The work as specified above shall be carried on for the first two years of the BLS. Thereafter, the same analyses shall be carried out on a quarterly basis until the end of the BLS.

C-II Bioassay

Objective: To analyze organisms for contamination from pollutants.

Comments: This project will be responsible for analyzing samples of all of the organisms collected by the biological survey project (B-I). Among the substances to be looked for are heavy metals (arsenic, cadmium, chromium, copper, lead, manganese, mercury, selenium, vanadium, and zinc), chlorinated hydrocarbons, and phenols. Problems uncovered as a result of the project will be further studied by the interaction study (B-III).

A pilot project, supported by Sea Grant, was funded for FY 1971 and continued through FY 1972. This project is scanning oysters and hard clams for heavy metals.

Every attempt should be made to calibrate analyses made under this program with the same standards as are used by others working in the Atlantic area, e.g., IDOE projects. In particular, mercury analyses should be calibrated with the IAEA reference sample of "fish solubles" used by Scandinavian and other European workers on mercury pollution. Use should also be made of Bowen's "kale standard."*

Schedule: This project will include two years of intensive effort to establish the initial baseline, and three years of less intense monitoring effort.

C-III Chemical Model

Objective: To model the chemistry of the Delaware Bay so that the distribution of ecologically important substances in the bay can be determined on the basis of monitored stream and river quality.

Comments: This study shall utilize the data gathered in the chemical distribution study (C-I), geochemical study (G-III) and input water characteristics study (H-I) to develop a model yielding the distributions of the various quantities specified in the C-I study. The

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*Bowen, H. J. M., 1967. "Comparative element analyses of a standard plant material." Analyst, 92: 124-131.

model shall use as input data the output of the monitoring system (E-III) to be left in and around the bay. Accordingly, its needs will specify in part the characteristics of that monitoring system.

The model shall utilize the current model (PO-I) as a framework and means of calculating the transport and mixing of substances in the system, as well as for the calculation of water temperatures. The sediment transport model (G-IV), meteorological (M-I), and physical oceanographic (PO-III) data will be available for the calculation of light levels as needed for the modeling of photochemical interactions. Finally, the trophic transfer model (B-IV) will be undergoing simultaneous development and should be able to provide information on some of the more fundamental biochemical interactions.

This model will be used as one of the building blocks of the biosystem model (SA-III).

Schedule: The model is to be synthesized during the third year of the BLS.

ENGINEERING

Introduction

The projects in this area are either survey projects (E-I, -IV) or support projects (E-II, -III).

Engineering Survey Projects - Background

Present and potential engineering activities in the bay area generally fall into one of the following categories:

1. Marine Transportation
2. Waste disposal and water utilization
3. Recreational development
4. Shoreline protection and flood control

The engineering information required for these activities covers a broad spectrum from geological parameters to physical oceanographic parameters. Since the BLS is a multidisciplinary endeavor, many of these parameters will be studied by the relevant basic science disciplines. The engineering survey projects will concentrate this effort on those unique to engineering applications.

Scattered engineering information in the bay area can be obtained from various state and federal agencies, and sometimes from industries. For example, channel dredging and shoaling information can be obtained from the Army Corp of Engineers and dumping or sewage effluent information can be obtained partially from the data inventory at the Federal Water quality Control Agency, or from local county or

city engineering divisions. This information could be extremely valuable if it were collected, synthesized and correlated, and then stored in the information system (SA-I); however, it is presently inadequate to the foreseeable needs for one or both of the following reasons:

1. The information is not directly related to the bay proper but to the adjacent urban areas.
2. The information is in the form of records of case histories which are local in nature, specialized in purpose and near term in perspective.

Furthermore, much of the engineering information required for the future planning of regional resource developments is completely lacking. A case in point is provided by the controversial offshore terminal facilities; little or no factual guidance is available for decision making and for design purposes. Further field work, basically a systematic data collection and survey, is required.

Engineering Support Projects - Background

All of the field-oriented efforts of the BLS require accurate location of events in space. The reason for this is perspicuous, viz., that if the history of a changing phenomenon is to be accurately observed, the investigator must be able to locate himself in the same position time and again. The navigation system is planned to answer this need.

The need for up-to-date information on the bay, together with

the cost of manpower and ship time, points to the need for an automatic, cheap, and reliable data acquisition system. The number of technological alternatives, and their varying quality and cost, make the reasoned design of such a monitoring system essential. The monitoring system project is charged with this task.

E-I Bay Utilization Survey*

Objective: To describe quantitatively the utilization of the Delaware Bay during the baseline period.

Specifications: This project shall conduct a survey of the physical utilization of Delaware Bay during the first year of the Baseline Study and maintain a cognizance of the changes occurring thereafter. In particular it shall concern itself with the following:

1. Solid, liquid, and thermal waste disposal
2. Sand and gravel extraction
3. Port and anchorage facilities
4. Shipping and boating statistics
5. Harbor characteristics including resonance, seiche, and transport characteristics
6. Offshore dredging and filling
7. Offshore dumping

The prime area of interest is the Delaware River Channel, from

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*Based on material supplied by Dr. Hsiang Wang.

Cape Henlopen to the Philadelphia-Camden ports. This subtask shall be carried out by data searching, analysis and interpretation, and by field measurement.

In Item #1, a significant amount of data has been collected in the Delaware River from Trenton, New Jersey, to Liston Point, Delaware, by the authors of the Delaware Estuary Comprehensive Study. Little is known in the Delaware Bay itself. Therefore, data sampling will be conducted basically within the bay. The sampling area shall extend to include Rehoboth Bay, and the greater Wilmington and New Castle County areas which are heavily industrialized. Primary attention shall be given to major subestuaries, present and potential outfall locations, major beach areas, and totally or partially enclosed bay areas. Pilot sampling shall be conducted within the bay outside the primary areas.

Item #2 shall be accomplished by a survey of users and by consultation with the Delaware Geological Survey and the Department of Geology of the University of Delaware. Items #3, 6, and 7 shall be basically data searching, analyzing, and interpreting. Items #4 and 5 shall be accomplished partially through data survey and partially through on-site measurements. As an example, commercial shipping data will be obtained through port survey, whereas the boating statistics such as daily, monthly, and yearly traffic volumes will be obtained through data collection at strategic sites. Harbor characteristics will be measured at major ports and potential sites of large marinas. The cost estimate

for the first year is $139,500.

Schedule: As stated above, the main work will be conducted during the first year of the BLS with only updating thereafter.

E-II Precision Navigation System

Object: To select, install, and maintain in the Delaware Bay region a precision navigation system.

Specifications: A precision navigation system shall be selected and installed in the Delaware Bay region. It shall be an all-weather system capable of providing a position anywhere in the area from the Marcus Hook region of the Delaware Estuary, through the entire bay, to the edge of the Continental Shelf opposite the entrance to Delaware Bay. The maximum absolute error shall not exceed 30 meters.

Comments: All field studies will make use of this system.

Schedule: This system shall be installed as soon as possible after the funding of the BLS, and should be constantly maintained.

E-III Monitoring System

Objective: To design, install and operate an automatic monitoring system in the Delaware Estuarine System.

Comments: This is a multiphase project. Phase I consists in preliminary design and tying into the present monitoring equipment in and around

the Delaware Bay system. This consists in a few stream gaging and water quality monitoring stations. The preliminary design will take into account the type of input data required by the foreseeable models, and especially that required by the hydrodynamic numerical model (PO-I).

Phase II will consist in the purchase and deployment of required monitoring equipment that is commercially available, and the detailed design of such equipment as is not presently available. At this point many of the functions of the hydrological study (H-I) shall be assumed by this project.

Phase III consists in the manufacture and installation of the equipment designed during Phase II, and the operation of the entire system.

The data from the monitoring system shall be fed automatically into the information system (SA-I), where it will be available to all participants of the BLS (e.g., to the various modeling efforts such as the meteorological model (M-III), the chemical model (C-III), and so forth.

Schedule: The entire system should be operational by the end of the second year of the BLS.

E-IV Substrate Characteristics*

Objective: To provide information on the mechanical properties of

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*Based on material supplied by Dr. Hsiang Wang.

the substrate of Delaware Bay.

Specifications: This project shall determine the mechanical characteristics of the bay's substrate. The parameters to be determined include:

1. Type and depth
2. Bearing capacity
3. Compression strength
4. Shear strength
5. Tensile strength (breakout force)
6. Anchor-holding powers

The prime area of interest of this subtask is the subaqueous area from Cape Henlopen to Port of Wilmington. Within the boundary, sampling sectors will be delineated, each covering an area approximately five kilometers square. In each sector, core sampling, substrate echo sounding, an anchor holding power test and breakout test shall be performed, and the data analyzed. In addition to the mechnical properties, special note will be taken of the existence of minable deposits of sand, gravel, clay or oyster shell. The coordination shall be maintained with the bottom sediment survey (G-IV), and use shall be made of the bottom photo survey (G-I) to extend the results of this study. In addition, use can be made of samples collected by the National Ocean Survey (formerly the Coast and Geodetic Survey) in their remapping of the Delaware Bay. The cost estimate for the first part of this project is $74,000.

Schedule: This work will be performed during the second year of the BLS.

GEOLOGY

Introduction*

Sediments or sedimentary materials have characteristic classes of properties which reflect their mode of origin or their environment of deposition. These properties include biological, chemical, physical and engineering characteristics. Biological properties include, for example, the amounts of shell contained in the sediment, the intensity of microbal processes, and the degree to which materials are described or reworked by burrowing organisms. Chemical properties include the characterization of organic and inorganic elements and compounds, mineralogy, and the exchange of substances between the water and the sediments. Sediment particle size and related characteristics, water content, and to some extent mineralogy, comprise the physical properties of sediments. Bearing capacity, tension, compression and shear strength, and bank stability comprise some of the engineering properties of sedimentary materials (See project E-IV.) The classes of properties are not mutually exclusive, as, for instance, some engineering properties depend on the physical properties of particle size and water content; water content depends, in part, on the activity of burrowing organisms; burrowing organisms depend in part on the chemical environment of the sediments.

Sediments of the estuarine system also have well defined modes of occurrence. Sedimentary materials are found in three distinct

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*Prepared by Dr. Robert Biggs.

environments: they may be suspended in the water column, on or just beneath the bay bottom, or buried deeply beneath the bay.

If the two factors are displayed against each other, the matrix illustrated below is produced. Although the attempt to force-fit categories into the matrix is somewhat artificial, the illustration does provide a working guide for the major areas of research which must be studied to provide baseline information on the geology of the estuary.

<table>
<tr><th>PROPERTIES / OCCURRENCE</th><th>BIOLOGICAL</th><th>CHEMICAL</th><th>PHYSICAL</th><th>ENGINEERING</th></tr>
<tr><td>SUSPENDED</td><td>BIOLOGY</td><td colspan="2">SEDIMENTATION</td><td></td></tr>
<tr><td>SURFACE</td><td>BIOLOGY
PALEONTOLOGY</td><td rowspan="2">GEOCHEM</td><td colspan="2" rowspan="2">SEDIMENTATION

GEOPHYSICS
ENGINEERING</td></tr>
<tr><td>SUBSURFACE</td><td>PALEONTOLOGY</td></tr>
</table>

In the following section, each of the study areas from the matrix will be examined for past, on-going, and proposed work of relevance to the BLS.

Background

The Department of Geology and the U. S. Army Corps of Engineers have been conducting estuarine and marine geological research on Delaware Bay and the nearby Atlantic coast for many years.

Sedimentation

Studies of the distribution and concentration of suspended sediment have been conducted near the bay mouth by the Department of Geology and in the upper estuary by the Corps. Some results have been published (see bibliographic references by Jordan and Oostdam) while other data, particularly those of the Corps, are unpublished but accessible. The Corps have performed some analyses to determine the mineral composition of the suspended materials in the upper estuary, and size analyses have been performed by the Department of Geology on a small number of samples from the lower bay. Dr. Robert Jordan was principal investigator on a FY 1971 Sea Grant project to study "Sediments and Sedimentary Processes of the Delaware Bay." The objective of the project is to study the distribution of suspended sediments in order to better understand the processes of transport involved and to derive some measure of predictability applicable to siltation in the natural and artificial channels of the estuary. It is proposed to continue this project from Sea Grant funds through FY 1976. Assuming continued Sea Grant support, adequate baseline information on the concentration and distribution of suspended sediments should be developed.

Baseline information on the composition (mineral and chemical) and size of the suspended sediments of the estuary is lacking. The small amounts of data which have been developed by the Corps and Geology Department are insufficient to characterize the estuary. The Corps and the Department of Geology have performed extensive in-

vestigations on the surface and subbottom sediments of the estuary and coast. The Corps has studied the middle and upper estuary to obtain data on subbottom composition and structure for channel dredging purposes, and has surveyed the lower bay, particularly near Cape May, for sand supplies to nourish beaches. Most of these data will be available in open files or as mimeographed reports. Dr. John Kraft of the Department of Geology has been investigating the effect of the recent transgression of the sea on the Delaware Coast and the Continental Shelf. Dr. Kraft is participating in the Sea Grant Program, serving as principal investigator on the project "A Geologic History of Rate of Change of Shorelines and Bottom Morphology of Delaware Bay." The objective is to summarize the geology of the bay during the Pleistocene-Homocene epochs. Delineation of bottom sediment-structural relationships should form a basis for better understanding the rate of change in morphology of the shoreline and bottom sediment features. Dr. Kraft anticipates that such a study will provide the background to develop a comprehensive study on "The Geology of Coastal Change"; an analysis of the methods, processes, morphology, volumes of material involved, and rate of change of Delaware's coast. The basic objective will be prediction of short- and long-term coastal changes and their effect on environmental change, inhabitation of the coast by man, and coastal planning. In addition this research may have a bearing on the requirements and availability of sand and gravel resources for beach nourishment. Dr. Kraft has proposed that this project be funded during

FY 1973 and FY 1974 with funds from Sea Grant. Assuming Sea Grant support, actual inclusion in the BLS is not necessary to provide baseline data on sedimentation in the bay.

A study of the distribution and mineral composition of surface sediments in the estuary has been proposed, and support requested from Sea Grant. Dr. Billy Glass has proposed to determine the source of Delaware Bay sediments by size and heavy mineral analyses and to develop a technique, based on grain size distribution, for classifying and identifying the environment in which the sediment was deposited. Data obtained from this study should be of great value to the BLS. Sea Grant funding is anticipated for FY 1972 and FY 1973.

Paleontology

Little work has been done on the paleontology of the estuarine area. That which has relevance to the modern estuary is concerned with the position and structure of oyster shell deposits. The Department of Geology is currently involved in a study of the distribution, structure and ecologic setting of buried shell beds. This program is funded by Sea Grant and should provide baseline data on the distribution of the beds.

Geophysics

Both the Corps and the Department of Geology have researched the subbottom structure of the estuary and shelf. Some of the Corps work has been published (Moody and Van Reenan, 1967), the rest is available in open files. Dr. Robert Sheridan of the Department of

Geology has been developing subbottom seismic profiles in the lower estuary and along the coast for the last several years. Dr. Sheridan is presently working on the distribution of buried shell deposits in the bay and the subbottom structure of the coastal area with funds supplied by Sea Grant and the Office of Naval Research, respectively. Dr. Sheridan is developing a proposal on "Pleistocene and Holocene Geology of Delaware Bay and the Continental Shelf off Delaware" for submission to Sea Grant for FY 1973 and FY 1974. This proposed project has a bearing on the shape and distribution of sand and gravel resources.

Assuming continued support of geophysical programs in the bay area, there should be reasonable baseline information on the subbottom structure in the bay and on the nearby shelf by the close of FY 1973.

Geochemistry

Some information is being developed on both organic and inorganic geochemistry of sedimentary materials. Dr. Frederick Swain is working on a Sea Grant project, "The Analysis of Organic Matter in the Sediments of Delaware Bay," to study the geochemistry of sediments deposited during and before industrialization of the area around the bay. Dr. Swain plans to continue this study through FY 1973 and should be able to provide adequate baseline characterization of the organic matter at that time. Little effort has been expended on the inorganic geochemistry of the sediments of the estuary. A pilot project, supported by Sea Grant, was funded for FY 1971 and 1972, and is continuing through FY 1973. This project

was designed to scan oysters and hard clams and their associated sediments for heavy metals. Results of these studies are published in Sea Grant reports DEL-SG-3-72, DEL-SG-9-72 and DEL-SG-10-72.* (See project C-II.)

Summary - Background Information

Adequate baseline data are being developed or will be developed on the concentration and distribution of suspended sediments, the composition and texture of surface sediments, stratigraphy and geophysics of subbottom materials, and the paleontology and organic geochemistry of the estuary. Completion of these projects is dependent upon continued Sea Grant support.

It is felt that existing data and proposed programs are inadequate for baseline objectives in the area of the composition and size of suspended sediments (G-II) as well as the general inorganic geochemistry of the bottom sediments of the estuary (G-III). These studies should be supplemented by a photographic survey of the bay's bottom (G-I) which can be used qualitatively to extend the results of the other geological projects. Finally, the results of the sediment work should be incorporated in a sediment transport model (G-IV).

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*Some preliminary surveys have also been conducted under the auspices of the Delaware Department of Natural Resources and Environmental Control. The results have not been published.

G-I Bottom Photo Survey

Objective: To characterize the bottom of Delaware Bay by photographic means in order to aid in the determination of drag coefficients and to extend the results of surveys of the benthos (B-II-ii) and surface sediments (G-IV).

Specifications: This project shall provide bottom photographs of the Delaware Bay from the C & D Canal to the line between Capes May and Henlopen. These shall be color photographs with no visible grain in a 9" square enlargement. Each photograph shall show square area between 5 and 10 feet on an edge together with a means for determining the true scale and direction. The photos shall be taken on a grid 2.5 kilometers on an edge.

Comments: The estimation of drag coefficients is essential to the development of the current model (PO-I). In addition to this, the photo survey will provide qualitative information which can aid in the interpretation and extension of the benthic portion of the biological survey (B-II-ii) and of the geochemistry and bottom sediment projects (G-III, -IV) as well as geological data already in hand.

Schedule: This project is to be completed during the first year of the BLS.

G-II Sediment Content*

Objective: To determine the composition and size of suspended sediments of the Delaware Bay.

Specifications: The suspended materials in Delaware Bay shall be sampled for the purpose of determining their particle size and minerological and organic composition.

Six to ten samples will be provided from 50 stations throughout the bay six times during the year (i.e., a total of 1800-3000 samples). These will be collected by project PO-III. Sampling shall be coordinated with sampling for other aspects of the Baseline Study.

Laboratory analyses for particle size, and mineralogical and organic composition of the collected samples shall be conducted by the principal investigator with equipment provided by the Department of Geology.

The estimated cost of the project including salaries and wages, equipment, supplies, travel, publication costs, and indirect costs is $25,000 for the first year.**

Comments: This study will be supported by the input water characteristics study (H-I). It will provide the data base for the sediment transport model (G-V) and in support of the productivity study (B-I).

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*Based on material supplied by Dr. Robert Biggs.
**Add $2,000 for ship time if cooperation with PO-III is not possible.

Schedule: The bulk of the work will be completed during the first year of the BLS, with monitoring continuing through the last four years.

G-III Geochemical Survey*

Objective: To provide basic data on the geochemistry of the sediments of Delaware Bay.

Specifications: (For the first two years) - The bottom sediments of Delaware Bay shall be sampled for the purpose of determining the presence and distribution of certain trace metals, viz., arsenic, cadmium, copper, lead, chromium, manganese, mercury, selenium, vanadium and zinc, in these bottom materials.

Samples shall be supplied to this effort from the 62 stations indicated on the attached figure throughout the bay on research cruises conducted six times during the year (i.e., a total of 372 samples). Sampling shall be coordinated with sampling for the benthic portion of the biological survey (B-II-ii) and will be provided by that project from the locations shown in Figure 8.

Laboratory analyses of the collected samples for the above-specified elements shall be conducted by the Principal Investigator with equipment provided by the Department of Geology.

Portions of all samples shall be retained to provide a reference

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*Based on material supplied by Dr. Robert Biggs.

collection for possible future analyses for elements not included in the present study.

Use shall be made of the results of the bottom photo survey (G-I) to qualitatively extend the results of this study to the entire bay.

The estimated cost of the project including salaries and wages, equipment, supplies, travel, publication costs, and indirect costs is $22,100 for the first year.

Comments: This study will provide a portion of the data base for the chemical model (C-III) as well as basic information which will aid in the identification of specific problems to be investigated by the biological interaction studies (B-III).

Schedule: The intensive effort on this project will take place in years one and two with monitoring continuing through the course of the BLS.

G-IV Bottom Sediment Survey

Objective: To describe the distribution and movement of surface sediments of Delaware Bay.

Comments: This project will be charged with the development of information on the bottom (as opposed to suspended) transport of sediments and shall perform size and density analyses on sediment samples provided to it by the benthic portion of the biological

survey (B-II-ii). These analyses will be used to provide ground truth for the photo survey project (G-I), which will in turn extend (in a qualitative sense) the results of this project. They will also aid in the development of the sediment transport model (G-V). Coordination shall be maintained with the substrate characteristics project (E-IV). Information developed in this project will be analyzed by the interaction studies project to develop sediment organism interactions.

Estimated cost is $4,500 per year.

Schedule: This project will be carried out during the first two years of the BLS.

G-V Sediment Transport Model

Objective: To model mathematically the sedimentation processes occurring in Delaware Bay.

Comments: This project will develop a computer model capable of predicting the rate and type of sedimentation occurring in the bay, given either the present or a modified hydrography. Among its outputs should be the rate and composition of benthic sedimentation, the turbidity throughout the estuary, and the rate of shoreline erosion or accretion.

It will be based on the numerical hydrodynamical model (PO-I) and will make use of data gathered in the G-I, -II, and -IV projects.

Schedule: This model will be developed during the third year of the BLS.

HYDROLOGY

H-I Input Water Characteristics

Objectives: To describe qualitatively and quantitatively the characteristics of the surface water inputs to the Delaware Estuary.

Comments: This project is responsible for a description of the volume and chemical composition of surface water run-off and effluent discharges to the Delaware Estuary during the period of the BLS. Included in this are: (1) the gaging of the weekly discharges of all tributaries contributing 1% or more of the annual discharge at the mouth of the bay which are not otherwise gaged; (2) a chemical analysis on a monthly basis of these waters for all of the substances listed in the specifications for the chemical distribution project (C-I) (the C-I project will provide analytical support as required here and in task #3); (3) a monthly chemical analysis of all identifiable effluent sources discharging directly into the estuary; (4) acquisition of weekly data on temperatures of gaged tributaries and thermal pollution sources; and (5) acquisition of weekly data on the turbidity of gaged tributaries.

These requirements are based on the following criteria: the provision of stream flow, temperature and turbidity data to PO-I and PO-II; data on sediment transport to G-II; data on nutrient inputs to B-I; and data on chemical inputs to C-I.

Schedule: This project will proceed as described above during the

first two years of the BLS. From the third to the fifth year those parameters which have exhibited a predictable regularity will be subject to less frequent observation. Also, portions of this work will be carried out by the monitoring system developed by project E-III.

H-II Aquifer Survey

Objective: To define the aquifer systems in the vicinity of the Delaware Bay.

Comments: This project is charged with locating and defining the coastal and subaqueous aquifers of Delaware Bay in order that: (1) accidental interference with them can be avoided; and (2) their contributions to the water balance of the estuary can be determined, if possible. This last objective will support the PO-I model. In regard to the latter point, this study shall identify and evaluate the recharge areas along the coastal margin of the bay, and in addition determine the rate and location of subaqueous discharges to the bay.

Schedule: This work shall be accomplished during the first two years of the BLS.

METEOROLOGY

M-I General Meteorological Characteristics

Objective: To describe the meteorological characteristics prevailing over the study area during the BLS and to correlate them with conditions observed at standard National Weather Service Stations.

Comments: This study is designed to function in the dual role of a service project and as the basis for a meteorological model of Delaware Bay (M-III). In addition to its own data-gathering activities, it is charged with the analysis of the Standard Station Data pertaining to meteorology which will be available through the information system. (SA-I).

As a service project it will provide: wind data to PO-IV and PO-V; wind and barometric data to PO-I; air temperature, solar radiation and precipitation data to PO-III; and solar radiation data to B-I. In its own right it will be concerned additionally with evaporation from the surface of the estuary.

The station net is shown in Figure 9.

Schedule: This project will have an initial two-year intensive phase, followed by three years of monitoring.

M-II Meteorological Hazards

Objective: To develop the ability to forecast the probability of

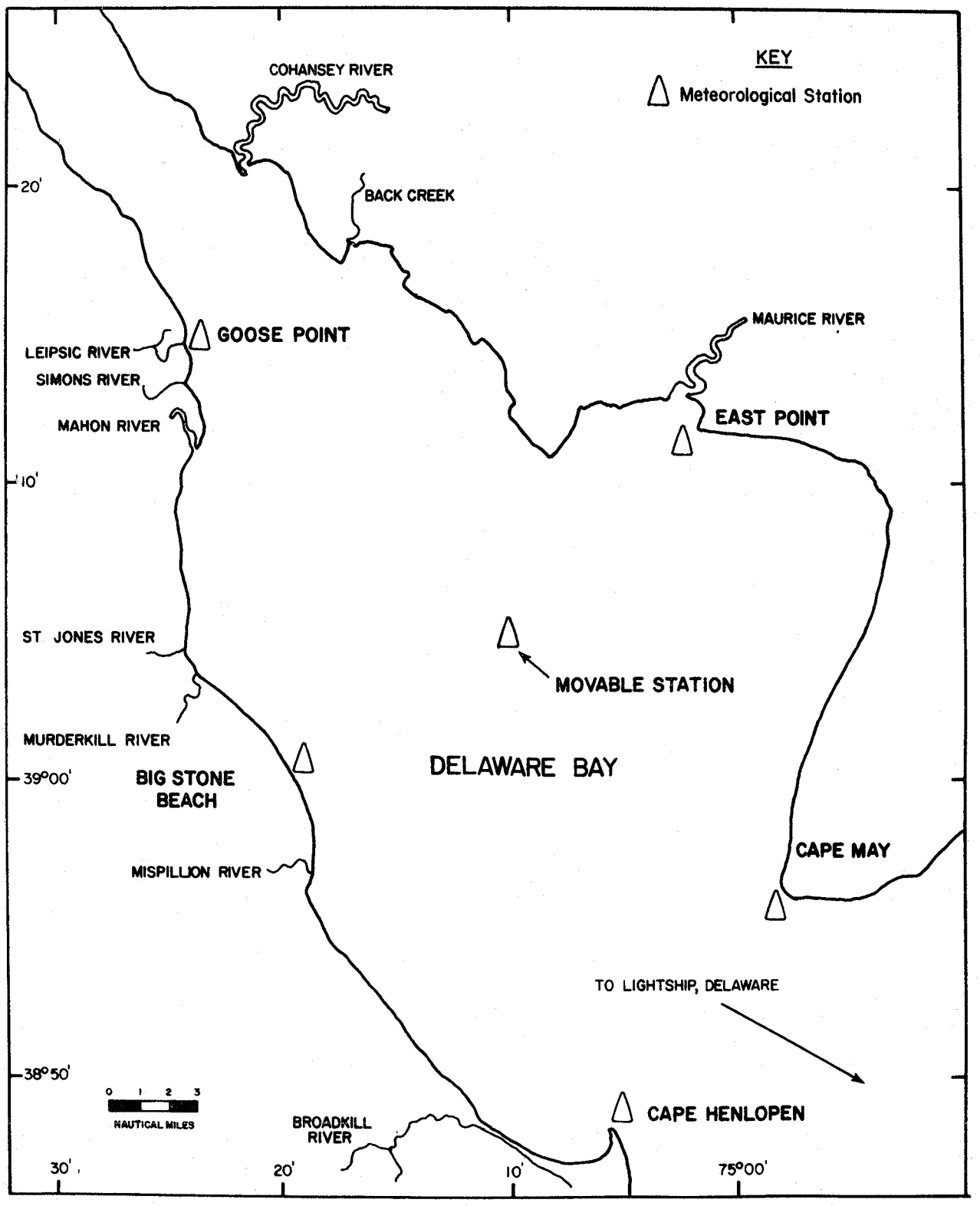

Figure 9. Locations of Meteorological Stations

occurrance of various meteorological hazards and catastrophes under given circumstances.

Comments: This study shall update the existing work of the Department of Geography on the historical occurrence of adverse meteorological conditions in the vicinity of Delaware Bay. Included shall be fog, ice, and storms in the bay. An attempt shall be made to develop crude long-range predictive criteria for these phenomena (e.g., from a Gumbel-type analysis of recurrence rates) as well as more accurate short-range capabilities.

These predictive capabilities will be refined by the M-III modeling study.

Schedule: The bulk of this project will take place in the first year of the BLS, with only updating occurring thereafter.

M-III Meteorological Model

Objective: To develop a model which will use the observed conditions at selected land stations to determine the meteorological conditions over the bay.

Comments: This model will have available the results of the meteorological observations taken in M-I project together with the modeling of water surface temperature in the bay by the hydrodynamic numerical model PO-I. It will use as input the data gathered by the monitoring system (E-III). It is one of the elements

that will be combined in the physical system model (SA-II).

Schedule: This model will be developed during the third year of the BLS.

PHYSICAL OCEANOGRAPHY

PO-I Numerical Hydrodynamic Model

Objective: To develop a multilayer model of the general circulation, tidal currents, salinity, temperature and dispersion characteristics of the estuary from Trenton, New Jersey to the line between Capes Henlopen and May. This model will form a framework on which many of the other models will be built.

Comments: At present a single-layer hydrodynamic numerical model (HNM) developed by Dr. Laevestu at the Naval Environmental Research Prediction Facility in Monterey, California has been adapted to Delaware Bay by Kupferman and Polis. Shortly a multilayer HNM will be available from the same source. This can provide the basic model to be adapted to our system. The information system (SA-I) will be available for support after the first year.

Specifications: The first year's work will proceed on the basis of the present navigation charts, the tidal current data available from the National Ocean Survey, the current data collected by the U. S. Army Corps of Engineers in the 1940's for the verification of the Vicksburg model, and the stream flow data of the Geological Survey.

At the end of the first year, the model shall have its grid system and outputs defined so that it may be incorporated in the sediment transport model (G-IV). Additionally, it shall be sufficiently operational so that the results of the first year's modeling can

be used in the planning of the second year's effort for subprojects PO-II and PO-III. The model will also be used at this time by the tidal characteristics project (PO-V) and the monitoring system project (E-III). The most important use to be made of the model after the first year, however, is its use in the information system to refer data taken at different tidal stages to a common referent.

In the second year, use shall be made of the data gathered by the general circulation and dispersion characteristics field study (PO-II); in addition, we shall have information on the characterization of the bottom by the photo survey (G-I); the salinity and temperature data from the general physical characteristics study (PO-III); wind velocity and barometric data from the meteorological effort (M-1); and the stream flow temperature, and turbidity data from the field study of the input water characteristics (H-I). It is hoped that some data may be available on the subaqueous water input out of aquifers from the aquifer survey (H-II).

At the end of the second year, the model shall be available for incorporation in other models -- the sea state model (PO-IV) (C-III), the chemical model and possibly the meteorological model (M-III).

In the third year, fine tuning of the model shall be accomplished using the further results of projects PO-II, PO-III, M-I, and H-I. In addition, use shall be made of detailed data on the tidal height in the estuary from PO-V; and late in the year, on the form of the surface between the Capes from PO-VII. At the end of the third

year, the model will be ready for incorporation into the physical system model SA-II.

Schedule: This modeling work shall be accomplished during the first three years of the study according to the timetable outlined above.

PO-II General Circulation and Dispersion Characteristics

Objective: To describe quantitatively the general circulation, tidal currents, and dispersion characteristics of the Delaware Estuary from Trenton, New Jersey to the line between the Capes, for the purpose of supporting the development of a computer model (PO-I) of these characteristics.

Comments: This study will also lend early support to the study of chemical distributions in the bay (C-I) and to the survey of the plankton populations in B-II. Data collected by this effort will also be used in support of the general physical characteristic study PO-III. Data on stream flows temperature and turbidity will be available from H-I.

It is anticipated that the bulk of the work will concentrate on the area of the estuary below the C & D Canal. A lesser amount of survey work will also be done in the off-shore area of the Atlantic. Advantage will be taken of the Corps of Engineers physical model at Vicksburg, Mississippi as well as the single-layer model of Kupferman and Polis in the detailed planning of this effort.

Among other things, this study should provide information on

the tidal prism of the bay and on its flushing time.

Schedule: The first year's work will begin with preliminary work with the models, followed by extensive field work. The second year's work will be based on the preliminary results of the PO-I modeling project and its need for further specific data.

PO-III General Physical Characteristics

Objective: To develop information on the distribution of temperature, salinity, and transparency as a function of tidal stage, season, and river flow.

Specifications: At least 50 stations throughout the bay shall be occupied on a monthly basis during years one and two. At each station, the standard station data shall be taken, including light transmission profiles in the red, blue, and green portions of the spectrum. This data shall be provided to the information system (SA-I) in a timely fashion and the samples shall be distributed as required by other BLS projects (see below).

The analysis of all water temperature, salinity, and transparency data available in SA-I shall be the prime responsibility of this project. It shall also be the responsibility of this project to obtain the historical information in this area and place it in SA-I. Graphical presentation of data on a monthly basis shall be provided.

The field work for this study shall also provide samples for

the sediment content study (G-II) and the chemical distribution study (C-I).

Comments: Data from this effort will be used in support of the hydrodynamic numerical modeling effort (PO-I) and the investigation and modeling of biological production (B-I and B-IV, respectively.)

Schedule: This project will be the subject of intensive effort (on a monthly regimen) for years one and two; thereafter, a seasonal schedule will be followed, although field data will be incorporated into it as it becomes available from other field work and the monitoring system (E-III).

After the first year, this project will have available the guidance of the model PO-I for the selection of critical areas of study.

PO-IV Wave Spectra

Objective: To relate sea state in the bay to sea conditions in the Atlantic, tidal currents and local meteorological conditions.

Comments: This study will combine wave spectra obtained by the Stillwell method and sea level observations of wave height as a function of time with observations of surface wind conditions from the meteorological characteristics study (M-I). The study shall also make use of the standard station data on sea state.

This will be used to support the sea state model (PO-VI). The location of surface stations will be as shown in Figure 9 accompanying

project M-I.

Schedule: This study will be largely confined to year two, with contingency funding to allow for the taking of wave spectra under unusual conditions during year three.

PO-V Tidal Characteristics

Objective: To obtain detailed information on the tidal heights at various points in the Delaware Bay for the purpose of tuning the hydrodynamic numerical model (PO-I).

Comments: This project will be designed on the basis of the preliminary results of the PO-I modeling effort. In addition to tuning PO-I, this study will also provide a foundation for the study to determine the form of water between the Capes (PO-VII). Meteorological support for this project will be provided by M-I. The project will include a detailed review of the historical tidal data available from the Corps of Engineers and the National Ocean Survey.

Schedule: The intensive portion of this study will take place during year two, with monitoring of selected locations extending into the third year.

PO-VI Sea State Model

Objective: To develop a model of the sea state in Delaware Bay,

given the wind conditions over the bay, tidal stage and swell received from the Atlantic.

Comments: The modeling will be based on the wave data gathered by PO-IV, on the meteorological data gathered by M-I, and on the hydrodynamic numerical model (PO-I).

It, in turn, will form one of the components of the physical system model (SA-II).

Schedule: This work is to be undertaken and completed in the third year of the BLS.

PO-VII Form of Water Between the Capes

Objective: To determine the form of the surface of Delaware Bay at its seaward boundary throughout the tidal cycle.

Comments: This work is to be used in the final tuning of the hydrodynamic numerical model (PO-I).

Schedule: This work is to be undertaken and completed during the first 9 months of the third year of the BLS in order to feed into PO-I in sufficient time to allow its completion by the end of the third year.

SYSTEMS ANALYSIS

SA-I Information System

Objective: To develop a system whereby access may be had to all BLS and historical data by type, time, and location.

Comments: The central function of the system will be to receive input from all data-collecting efforts, and provide output to all modeling efforts. Beyond this, the system will make data more generally useful; for example, the data would be available to CMS, NREC, NJDEP, and others.

The system should be compatible with the NODC, FWQA, and EDS systems, and should include quality control information. Graphical presentation should be available.

The Chesapeake Bay work funded by IRRPOS can form the basis of this system.

The information system should have the ability to refer data collected at different tidal stages to a common frame of reference -- say, low water slack. In order to do this, it should incorporate the latest version of the hydrodynamical numerical model (PO-I) to translate data to the common referent.

Schedule: To be developed the first two years of the BLS, thereafter to be maintained as data becomes available.

SA-II Physical System Model

Objective: To model the physical processes of the Delaware estuarine system.

Comments: This model combines the hydrodynamic numerical (PO-I), sea state (PO-IV), sediment transport (G-V) and meteorological (M-III) models together with the National Weather Services Hydrometeorological model into a single model capable of predicting tides, currents, temperature, salinity, sea state, dispersion and sediment transport characteristics in real-time given meteorological (M-I) and physical oceanographic (PO-III) monitoring data.

It requires a large computer facility. This is one of the two components of the Natural System Model (SA-IV).

Schedule: This model is to be developed in the fourth year.

SA-III Biosystem Model

Objective: To combine the chemical (C-III) and trophic transfer (B-IV) models together with information developed in the interaction studies (B-III) into a model capable of predicting the ecological effects of chemical and physical changes in the environment, as well as the normal ecological patterns in the absence of such changes.

Comments: This model will take into account nutrient flows resulting from the normal dispersion characteristics of the estuary, as well as thermal effects, as both of these will be available from the chemical model (C-III) which is built around the hydrodynamic

numerical model (PO-I). Further, it will incorporate information developed by the interaction studies relating species distributions to elements of the physical environment, such as sediment sizes. It will not be able to make predictions on the basis of real-time information, as it will not take account of sea state or meteorological data other than incident radiation. This model will be combined with SA-II in the Natural System Model (SA-IV).

Schedule: To be accomplished during the fourth year of the BLS.

SA-IV Natural System Model

Objective: To combine the Physical System model (SA-II) and the Biosystem model (SA-III) into a single model capable of predicting the state of the ecosystem on the basis of real-time data.

Comments: This model should also be useful for Monte-Carlo studies to predict the possible consequences of proposed actions. Data will be available late in the year from the biological re-survey (B-II-5) for checking the biological predictions of the model.

Schedule: This modeling is to be accomplished during the fifth year.

SSD Standard Station Data

Objective: To insure uniformity in the acquisition of standard station data.

Comments: The accompanying two sheets are to be used in the collection and recording of station data. Field crews should be trained to use these forms on all BLS cruises. Copies of the completed forms should be provided to SA-I within two days after the completion of a cruise. The BT need not be taken if time does not allow.

Standard Station Data

Short Form

Boat_____ Chief of Party_____

Station # _____ Date:_____ Time_____hrs.

Location_____ Depth_____m. Tide Stage_____

Long form compl. Yes_____ No_____

Weather Conditions

Weather Code_____ Cloud Cover Code_____

Wind speed_____kts. Direction_____

Air Temperature_____ C (dry bulb) _____C (wet bulb)

Incident Solar Radiation_____ $cal/cm^2/min.$

Sea Conditions

Sea $H_{1/3}$_____m. Domin Period_____sec. Dom Dir._____°mag.

Swell:_____m. Domin Period_____sec. Dom Dir._____°mag.

Estimate of Current Speed_____kts. Direction_____°mag.

Visible Surface Pollution ( ) yes
( ) no Nature_____ Extent_____

Bucket Thermometer_____C pH_____

Secchi Depth_____m

Take and label

BT ( ) 2 liter surface sample ( )

Standard Station Data

Long Form

Boat_____ Chief of Party_____

Station #_____ Date_____ Time_____hrs.

Location_____ Depth_____m. Tide Stage_____

Longer Stations Only

Current measurement Surface speed _____k Dir_____° mag.

(if anchored - profile if time)

Take and label 2 liter samples at 3 or 6 m intervals ( )

Depth (m) '						
Temperature (°C)						
Salinity (°/$_{oo}$)						
Dissolved Oxygen mg/l						
Current m/s						
Direction ° mag.						
Turbidity						

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APPENDIX

PARAMETERS COVERED BY BASELINE STUDY

Parameter or Task	Responsible Project(s)
BIOLOGICAL	
Algal Virus Concentration	B-II
Chlorophyll Distribution	C-I
Ecological Modeling	B-IV, SA-III, -IV
Ecological Systems Studies	
Experimental Studies	B-III
Functional Group Interaction	B-III
Functional Group Physical Response	B-III
Intensive Special Studies	
Organism-Environment Interaction	B-III
Organism Life Cycles	B-III
Organism-Organism Interaction	B-III
Population Survey	
Distribution (Time & Space)	B-II
Function (Ecological Role)	B-I, -III
Taxonomic (Identification)	B-II
Productivity	B-I
Sublethal Toxicity Effects	B-III
Tagging of Select Fish Species	B-II
CHEMICAL	
Distribution of:	
Acidity	C-I
Alkalinity	C-I
Biochemical Oxygen Demand	C-I

Parameter or Task	Responsible Project(s)
Organic Pesticides	C-I
pH	C-I
Cloride	C-I
Chlorophyll	C-I
Elements	C-I
arsenic	C-I
cadmium	C-I
calcium	C-I
chromium	C-I
cobalt	C-I
copper	C-I
halogens	C-I
iron	C-I
lead	C-I
magnesium	C-I
manganese	C-I
mercury	C-I
molybdenum	C-I
nickel	C-I
nitrogen (all forms)	C-I
phosphorous (all forms)	C-I
selenium	C-I
silicon	C-I
sulfur	C-I
vanadium	C-I
zinc	C-I
Micro Nutrients	C-I
O_2 Levels	SSD, C-I
Phenols	C-I
Plant Nutrients	C-I
Radioactivity	C-I
Redox Potential	C-I
Salinity	C-I
Surface Film	SSD, C-I
Vitamin B-12	C-I
Chemical Compos. of Effluents	H-I
Ecological Modeling (Chemical Emphasis)	C-III
Analysis of organisms for:	
Chlorinated Hydrocarbons	C-II
Trace Metals:	
arsenic	C-II
cadmium	C-II

Parameter or Task	Responsible Project(s)
chromium	C-II
copper	C-I
lead	C-II
manganese	C-II
mercury	C-II
selenium	C-II
vanadium	C-II
zinc	C-II
Phenols	C-II
Radioactivity (total α, β, γ counts/min.)	C-II
GEOLOGICAL	
Detailed Geological Processes	(Studies in progress by Geol.
	(Dept. & Del. Geol. Survey
Geochemistry of Pollutants	(G-III
Geological History	(Studies in progress
	(by Geology Department
Geological Structure	(& Del. Geol. Survey
Locale and Extent of Minable Deposits:	E-IV
Clay	(Studies in progress
Sand and Gravel	(by the Del. Geol. Survey
Oyster Shell	(and the Dept. of Geology
Seismology	(Studies in progress by
	(Geol. Dept. & Del. Geol.
Sedimentology	(Survey
Substrate Character:	
Anchor-Holding Power	E-IV
Bearing Capacity	E-IV
Compression Strength	E-IV
Shear Strength	E-IV
Tension Strength	E-IV
Type and Depth	E-IV
Transport Phenomena:	
Long-term Nature of Change	Study in progress by Geology Department
Sand Transport at Major Beaches	Study in progress by Geology Department

Parameter or Task	Responsible Project(s)
Sediment Discharges (suspended and bottom)	G-II
Shoaling and Erosion at Major Beaches	Studies in progress by the Corps of Engineers, State Highway Department, Department of Geology and Water Resources Center.
Turbidity in Major Tributary Channels	H-I
HYDROLOGICAL	
Chemistry of Input Waters	H-I
Coastal Aquifers (fresh water)	H-II
Location of Subaqueous Aquifers	H-II
Salt Water Incursion	H-II
Subterranean Drainage	H-II
Hydrometeorological Model	Operating under National Weather Service aspices
River Discharge	H-I
Surface Runoff	H-I
METEOROLOGICAL	
Barometric Pressure	SSD, M-I
Cloud Cover	SSD, M-I
Evaporation	M-I
Fog	SSD, M-I, -II
Ice in Bay	SSD, M-II
Meteorological Modeling	M-III
Precipitation (distribution & volume)	SSD, M-I
Storm Duration	M-II

Parameter or Task	Responsible Project(s)
Winds (direction & speed)	SSD, M-I
PHYSICAL OCEANOGRAPHY	
Currents:	PO-II
Velocity Field	PO-II
Velocity Flows at Sea Boundary	PO-II
Volume Rate of Flow Field	PO-II
Dispersion Characteristics	PO-II
Form of Water Surface at Capes	PO-VII
Flushing Time	PO-II
Harbor Characteristics:	
Residence Time	E-I
Resonance	E-I
Seiche	E-I
Transport Velocity	E-I
Wave Conditions	E-I
Hydrographic Survey	Being Conducted by National Ocean Survey
Modeling	PO-I
Radiation - Incident and Penetrating	SSD, PO-III
Sea Temperature Fields	SSD, PO-III
Seasonal Sea State	SSD, PO-IV
Stratification Phenomena	PO-III
Tidal Prism	PO-II
Tides:	
Currents	PO-II, -V
Heights	PO-V
Meteorological (inc. surge)	M-II

Parameter or Task	Responsible Project(s)
UTILIZATION	
Dredging, Filling, etc.	E-I
Effluents and Withdrawals (temperature & volume)	E-I, H-I
Off-Shore Dumping	E-I
Port and Anchorage Facilities	E-I
Shipping and Boating Statistics	E-I
Boating Days	E-I
Recreation, etc.	E-I
Ship Sizes	E-I
Total Tonnage	E-I