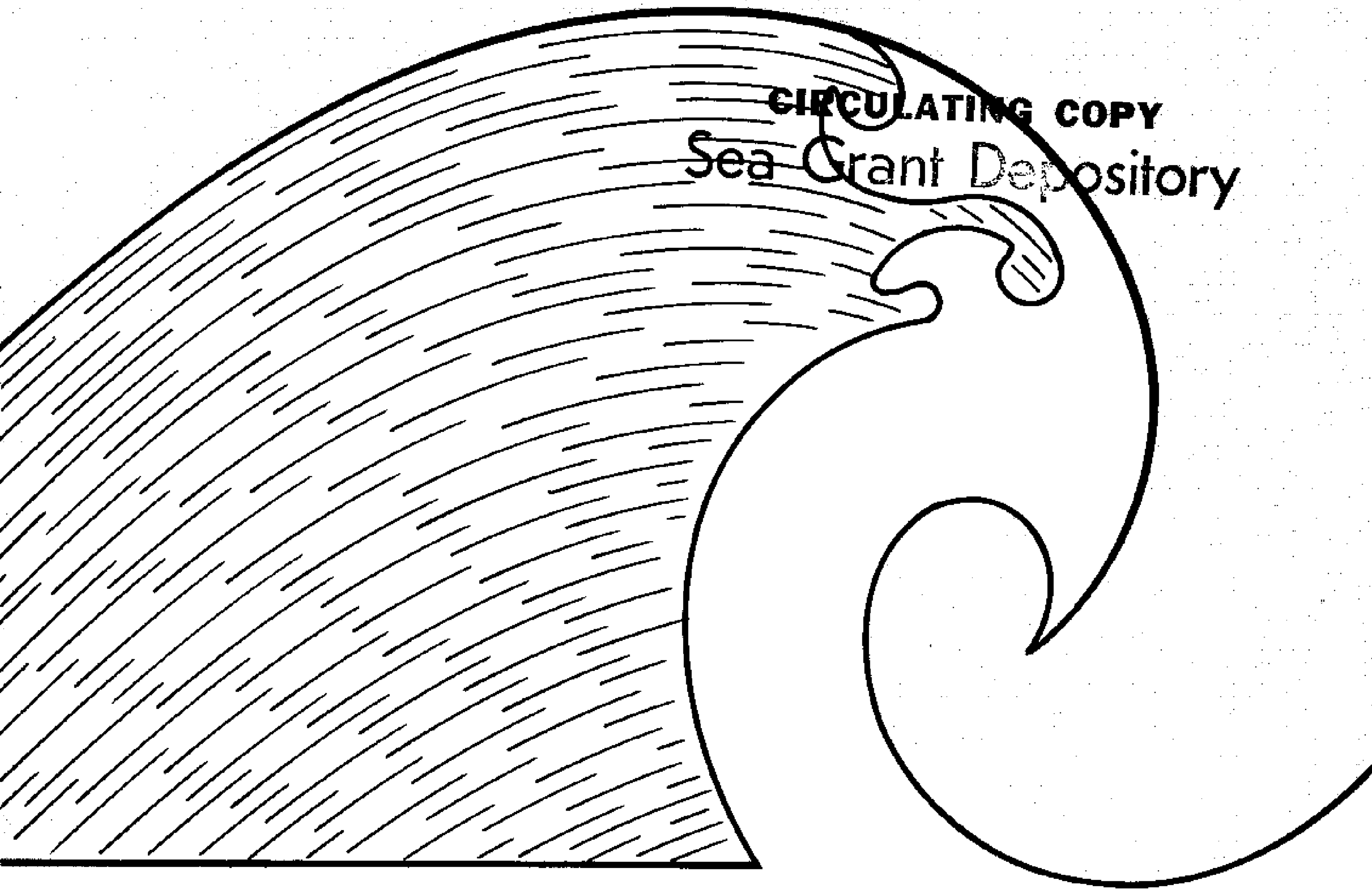


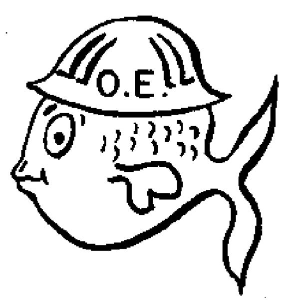
DEPARTMENT OF OCEAN ENGINEERING

SEA GRANT PUBLICATIONS

COLLEGE OF ENGINEERING UNIVERSITY OF RHODE ISLAND

Memorandum Number 3M

AN OCEANOGRAPHIC MONITORING SYSTEM FOR NARRAGANSETT BAY



BY
KURT W. HESS

5 MAY 1970

MEMORANDUM NUMBER 3M

AN OCEANOGRAPHIC MONITORING SYSTEM FOR NARRAGANSETT BAY: A PRELIMINARY STUDY

by

Kurt W. Hess

Prepared for

National Science Foundation

Under

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by

Department of Ocean Engineering

University of Rhode Island

5 May 1970

ACKNOWLEDGMENT

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INTRODUCTION

This study was undertaken to outline a procedure for designing a monitoring system for Narragansett Bay, in conjunction with the Bay Watch program. The basic procedure closely follows that set forth by Mountain and Hill (1). However, certain aspects have been investigated in depth, while others have been covered only briefly, or omitted entirely.

Many of the decisions made in the course of design are based on a superficial review of the relevant factors, or with reference to areas of knowledge with which the author is not extensively familiar. This is, however, a preliminary investigation of the problem, and only the broad aspects of the design are meant to be covered. Individuals with specialized knowledge will be called upon in the future to apply their skills to specific problem areas of the total system.

Several alternate approaches to the final design have been included, to maintain a certain flexibility in the discussion. It will be seen that accuracy and spacial sampling are the critical requirements placed upon the system. The effect of relaxation of these and other requirements is therefore explored to enhance the discussion.

DESIGN ASPECTS-AN OUTLINE

1 PURPOSE OF THE MONITORING SYSTEM

1.1 SPECIFIC APPLICATIONS

1.1.1 Weather Prediction

1.1.2 Pollution Studies

1.1.3 Fishery Hydrology

1.1.4 U/W Sound Studies

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1.2 DATA USAGE

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2 STATE OF THE ART

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3.1 GEOPHYSICAL SYSTEM DESCRIPTION

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3.2 PARAMETER RELATIONS

4 SPECIFICATIONS FOR PARAMETER MEASUREMENT

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4.2 PARAMETER PROCESS DESCRIPTION

4.3 DATA OUTPUT

1.0 PURPOSE OF THE MONITORING SYSTEM

1.1 SPECIFIC APPLICATIONS

This study was undertaken as an aspect of the Bay Watch program at the University of Rhode Island. It is a preliminary report on the feasibility of an oceanographic monitoring system for Narragansett Bay, with consideration of available manpower and the prospects of governmental funding.

Local needs and long-term priorities have focused the program upon a single aspect of the bay, pollution (see Fig. 1, page A-1). This investigation will proceed accordingly, although a certain flexibility will be maintained to facilitate applications to other aspects, such as fishery and sedimentation studies.

1.2 DATA USAGE

Information coming directly from such a monitoring system will probably have little immediate use for governmental agencies. However, an important beneficiary would be the concurrent mathematical model study. The data can provide valuble inputs and cross-checks for the model. The model, in turn, can be used to predict trends by varying its inputs; recommendations will probably be made from such predictive studies.

1.3 GOALS OF THE PROJECT

Specifically, then, the monitoring system will be designed to gather data for the mathematical model. The short-range goal of the model study is to predict tidal heights and velocities. The intermediate-range goal is to study pollution characteristics.

2.0 STATE OF THE ART

2.1 ENVIRONMENTAL SCIENCES

Some knowledge of estuaries in general, and Narragansett Bay in particular, is imperative. Excellent compendiums on the subject of estuaries by Lauff (2) and Ippen (3) are available. A comprehensive survey of the bay was given by Hicks (4). The bay is basically a two-layer-system with some vertical mixings. The sea connects to the south, through three channels; "fresh" water enters through numerous rivers near the northern end, the two major ones being the Backstone/Sekonk River and the Taunton River. River flow is well-recorded by the Geological Survey (5), but tidal flow has scarcely been studied (4). General distributions of characteristics have been given: current data (Fig. 2, page A-2) by Haight (5), and temperature, salinity, and phosphate (Fig. 3 & 4, pages A-3 and A-4) by the famous Hurricane Barrier studies (7).

Pollution sciences are rather empirical at this time, but a large body of literature is available on the subject. Basically, most municipal and industrial pollutants enter the bay through rivers or directly at the coastline. Some of the biological effects of pollutants have been examined by Waite and Gregory (8). The spreading and related dynamics have been studied by the U.S. Army Corps of Engineers (9) and by Le Gros, et. al. (10).

2.2 INSTRUMENTATION

The availability, reliability, and cost of specific monitoring system instruments will be paramount to the design. For example, temperature, pressure, and current magnitude and direction are relatively easy to measure electronically. Salinity and ion concentrations are somewhat more difficult, and will probably be critical parameters as far as continuous operation is concerned. Biological parameters, such as dissolved oxygen (D.O.) and E-coliform counts are very difficult or impossible to measure electronically in situ.

Typical problems encountered are basically marine fouling and corrosion. Transducer devices (temperature, pressure) may be subject to fouling by surface slime deposits. Mechanical systems (current meters) will meet seaweed fouling. Electrode devices (salinity, pH) will be subject to corrosion.

A good treatment on parameters and their measurement is given by Le Gros, et.al. (10).

2.3 DATA PROCESSING

Recent advances in this field have contributed greatly to our capability to manipulate data and estimate its reliability. Sampling theory is also well advanced. An excellent reference is Blackmen and Tukey (11).

2.4 HISTORICAL DATA

Much information is available from several national and regional sources. Atmospheric data is available from E.S.S.A. and N.O.D.C. Other federal sources include the U.S. Coast and Geodetic Survey, the Dept. of the Interior, the Corps of Engineers, and the Dept. of Public

Health. State agencies include the Water Resources Board and the Dept. of Public Health.

3.0 DESCRIP"ION OF THE OCEANOGRAPHIC DATA

3.1 GEOPHYSICAL SYSTEM DESCRIPTION

A partial list of relevant parameters is given in Table 1 (page A-5), with their approximate ranges in the bay. In terms of the limitations of this project, only a few parameters can be monitored.

For the initial phases of the Bay Watch project, only a few parameters can be monitored.

For the initial phases of the Bay Watch project, the currents and tidal heights are of prime importance. For the pollution study, several of the bio-chemical parameters are useful. Direct indices of municipal pollution are E-coli counts, the oxygen-demand factors (chemical oxygen demand--C.O.D.; and biochemical oxygen demand--B.O.D.), and ammonia, phosphate, ritrate and nitrate concentrations. Certain metal ions, like copper,nickel,and iron, may be indicators of industrial sewage. Thermal pollution will rely upon temperature surveys.

The previous discussion hinted at the sensor limitations. Most of the direct pollution indicators are not directly measurable. The biological involve lab tests, and the ionic usually require delicate spectrographic or conductivity tests.

Hence, a minimum number of parameters will be selected, in view of the practical limitations mentioned. It is decided that no pollution index be electronically monitored. The difficulties are presently too great to allow an economical method. Instead, a different approach will be taken. Information on pollution will be obtained from the Rhode Island Dept. of Public Health, which routinely makes such surveys. However, parameters relating to the dynamic of pollution transport will be monitored. In the Narragansett Bay, the important transport characteristic include tides, river run-off, wind stresses, density flows, diffusion and surface waves.

The temporal variations of river input (Fig. 5, page A-6) and surface currents (Fig 6, pg. A-7) lead to generalization of the frequency spectra (Fig 7, page A-8). The temperature, salinity and current spectra have energy divided into two ranges. The lower end is termed the "nominal-anominal" zone, and the upper the "turbulent" zone. The spectrum for surface wave, however, shows that most of the energy is in the high-frequency "turbulent" zone.

Thus the expected sampling interval would be an hour for nominal-anominal range, and greater for the turbulent range.

Spacial gradients are given in Table 3 (page A-9). They will be instrumental in the determination of horizontal grid spacing.

3.2 PARAMETER RELATIONS

Not all of the previously-mentioned transport phenomena will be monitored directly. The river run-off and wind effects can be obtained from other sources. Density flows and diffusion can be determined indirectly. The density can be calculated from the temperature and salinity. Diffusion coefficients can be estimated from current velocities and salinity gradients.

Thus the transport can be calculated from relatively few parameters: temperature, salinity, tidal height, current velocity, and surface wave heights. These particular parameters also provide a certain flexibility, since they are basic and are used to calculate many other properties.

4.0 SPECIFICATIONS FOR PARAMETER MEASUREMENT

4.1 APPLICATIONS OF THE DATA

The tidal dynamics provide the primary input for the short-range model study. Tidal amplitudes can be measured to about three inches with a pressure transducer. Current magnitudes to one-tenth knot will be considered sufficient.

Temperature and salinity are important from an oceanographic standpoint. Several other parameters, including density, can be calculated from them. Ideal accuracy would be to 0.1^{o}C and 0.01%. Instrument limitations force the adoption of tolerances of 0.5^{o}C and 0.5%. Model applications do not demand exact quantities, and even the diffusion calculations, which need the most precise data, will be rather reliable. Fishery studies demand even less accurate information. Breeding and other life functions are carried out in waters with a temperature range of several degrees. A table with frequency ranges appears on page A-10.

4.2 PARAMETER PROCESS DESCRIPTION

Tidal cycles are will-known, and temperature,salinity, and currents will vary with them. The semidiurnal period has a mean of 12.42 hours for the bay (see Fig. 6, pg. A-7). Even shorter periods, of 6 and 4 hours are also apparent. The chosen sampling times must account for this variation.

In addition, temperature and salinity show a strong annual cycle. Higher-frequency variations are also present. These are monthly and weekly changes due primarily to weather patterns.

The geophysical area as a whole can be divided into several types of regions, depending on their importance in the system and their parameter gradients.

Certain areas are of greater interest simply because events relating to the goals of the monitoring system occur frequently there. These shall be termed "critical regions". In this study, the Providence River and the Mt. Hope Bay-Taunton River complex are such regions. Most of the pollution occurs there, andthey will be targets of major "clean-up" projects.

Other model applications may designate other critical regions. For example, fish and shell-fish studies may place great importance on the upper bay or the smaller inlets around the bay. Thermal pollution studies may center aroundthe West Passage.

Several areas are necessary for the model study, because they represent potential points of data input (boundary conditions), and are usually water-mass junctions. These will be called "interface regions", and include the lower East and West Passages, the entrance to Mt. Hope Bay at Bristol Neck, the Sakonnet River at Tiverton, and the Warwick Neck - Patience Island channel. A chart of both critical and interface regions appears on page A-11.

4.3 DATA OUTPUT

The sampling intervals are chosen to be consistent with the parameter variability. Temperature, salinity, and current velocity require one representative value per hour. This will be accomplished by discrete or continuous sampling around the hourly time. Mean and variance values will be computed.

Surface wave measurements necedditate a more sophisticated sampling procedure. The wave height frequence spectrum is of a turbulent nature, so a power spectral analysis is in order. Either continuous or discrete sampling over several minutes will be prescribed. Representative values need be taker only a few times per day.

5.0 SAMPLING CRITERIA

5.1 TIME-SAMPLING THEORY

The theory is adequately discussed in Blackman and Tukey (11), and will not be reproduced here. See Fig 9, pg.A-12 for nomenclature.

5.2 SAMPLING TIMES

To obtain a reliable high-frequency Fourier estimate, the highest frequency of the parameter variation must be reproduced. This means that the parameter must be sampled at twice the maximum frequency. Considering the surface wave spectrum, a sampling frequency of 2 Hz. (corresponding to a sampling interval, Ts, of 0.5 sec.) is chosen, which assures that all frequencies below 1 Hz. will be included.

Auto-correlation technique allows for certain lag time. Since the wave heights will be sampled for only a finite time, Tp, the lag time is therefore limited. Blackman and Tukey (11) present a theoretical relation between the sampling time, Tp, and the maximum lag time, Tm.

From statistical theory, the resolution of the power spectrum, or, equivalently, the minimum frequency for which a spectral estimate is obtained, is given by

$$f_{min.} = f_{resolution} = 1/(2T_m)$$

Thus Tm is chosen to be 50 sec. (corresponding to $f_{min.} = 10^{-2}$ Hz.) by inspection of the spectrum.

Following the development of Blackman & Tukey, the number of samples (degrees of freedom) determines the reliability for the chi-squared distribution. The choice of 50 samples ensures that the value χ^2_{50} (taken to be the ratio of the sample variance to the population variance, s^2/σ^2) will fall within 25% of unity 80% of the time a group of 50 samples is taken.

Also, it has been shown that

$$2T_p / T_m \cong k$$

where k is the number of samples taken. Thus for k=50, the resultant Tp is 1250 sec, or 21 minutes. The wave heights may be sampled only a few times a day, compared to 24 for the other parameters.

The low-frequency parameters present another problem. A filter (electrical or mechanical) is required to reduce aliasing in the power spectrum, if it is computed. Suppose a filter with the function

$$H(f) = \left[\frac{\sin(T_p \pi f)}{T_p \pi f}\right]^2$$

is used. Then all frequencies higher than $f = \frac{1}{T_p}$ are eliminated. These characteristics prompt a choice of Tp = 100 sec. The accuracy can be computed from the central limit theorem. The results are shown in Table 4, pg. A-13.

5.3 SPACIAL SAMPLING

The theory for spacial sampling is less rigerous than for temporal sampling. The important factors to consider are gradient, requisite accuracy, and smoothness of variation. In general, the spacing will be equal to the accuracy divided by the gradient.

For example, in the Providence River, the maximum horizontal temperature gradient is (from Table 2) 1.25^{o}C/ n.m. For an accuracy of 0.5^{o}C, therefore, the spacing must be 0.4 n.m., or approximately 14 in the river. Clearly, this is too many for the initial proposed. Some of the requirements must be relaxed to permit a feasible proposal.

The vertical spacing presents a similar problem. In the Providence River, the temperature variations would necessitate a sensor every foot in the top few feet.

The problem of spacial sampling, restricts the feasibility of the monitoring system at this time. Compensating factors or theoretical development must eventually prevail.

7.0 DESCRIPTION OF A TYPICAL MONITORING SYSTEM

This is fairly standard information, and will not be covered in depth in this study. A typical system and monitoring station are shown in Fig 10 and 11, respectively.

8.0 SUMMARY AND CONCLUSIONS

8.1 OVERVIEW

The previous sections have presented a broad view of one approach to the problem of setting up a monitoring system for Narragansett Bay. Several requirements, including accuracy and spacial grid size have been found to be crucial to the system design. At this point, several alternative details will be considered, and their impact on the efficiency and cost of the total system examined. The alternatives are

1. Relaxation of the accuracy requirements
2. Reduction of number of monitored parameters
3. Limitations on the monitored areas
4. Use of land-based monitoring stations
5. Use of auxiliary techniques

8.2 ALTERNATIVES

8.2.1 Relaxation of Accuracy:

Some distinct possibilities exist here. It the accuracy in the

Providence River, for example, is reduced, a large reduction in total number of stations is achieved. In this particular area, temperature and salinity vary quite smoothly, so that fairly accurate data could probably be obtained with a larger spacing. However, such uniform gradients do notoccur in Mt. Hope Bay.

8.2.2. Reduction in Number of Monitored Parameters:

The parameters considered are very basic, except possibly surface spectrum, which has a relatively small influence on the transport phenomena. However, surface wave sampling has no net effect on the number of stations.

8.2.3 Limitations on Monitored Areas:

The short-range goal of the monitoring system is to provide tidal data for the mathematical model input. For this end, only three interface areas are important; they are:

1) Lower West Passage

2) Lower East Passage

3) Channel between Narragansett Bay proper and Mt. Hope Bay.

Provision of tidal heights, currents, temperature, and salinity in these areas gives tremendous information at low cost. The Mt. Hope Bay complex could be effectively eliminated in favor of a boundary condition, consistent with the modular approach. River inflow data is available from the U.S. Geological Survey.

The next most important area is the critical Providence River region. As mentioned before, station spacing may be stretched, owing to the rather uniform gradients. The area in the vicinity of the Conimicut light is a valuble interface area. Another location in the river would also be valuble; for example, a station near Fields Point.

Proceed in a similar manner for the other areas of the Bay.

8.2.4 Use of land-based Stations:

By this is meant the use of piers, bridge abutments and lighthouses for monitoring stations. The total number is again not effected, but the cost per station may decrease.

8.2.5 Use of Auxiliary Techniques:

In the open ocean, the periodic passage of storms and large eddies cause generally large changesin the current patterns, etc. However, in the Narragansett Bay, storms have a minimal effect, and variations due to large eddies are probably non-existent. The general pattern of circulation is fairly fixed. In this case, a single point can be used to infer the conditions in the immediate neighborhood.

As a practical application, an intensive survey of some area, perhaps the interface area in the lower West Passage, would be conducted. Several ships would be used, and data would be gathered from many stations in the vicinity. This data would then be correlated to the variation of the parameter at some fixed point . Then continuous information from this point would infer the other properties for the entire region.

This approach is especially effective in narrow channels. which are numerous in the bay.

8.3 ALTERNATIVE DESIGNS

Several alternes will be presented, inorder of increasing cost and refinement of the monitoring system. These should in no way be considered absolute plans, but a general list showing relative priorities.

The best plan of system expansion is to monitor the most "important" areas first, and to subsequently increase the number of stations in a definite way until the entire bay is covered.

Two specific approaches are outlined below. The first is based on the modular approach, in which a small segment of the bay is successfully modeled. Then another section is added, until the whole bay is monitored.

The second is the broad-outline approach. The macroscopic character of the circulation is studied, with more detail added as the number of stations is increased.

The modular approach provides an orderly plan in which the details and refinements of the model are worked out immediately, but the character of pollution dynamics for the whole bay does not appear for some time.

With the macroscopic viewpoint, the most general features of circulation are immediately resultant, but the detail follows much later.

STEP	ADDED STATIONS (TOTAL STATIONS)			
	MODULAR (Based on initial modeling of the West Passage)		MACROSCOPIC (Based on the initial neglect of the Mt.Hope Bay-Sakonnet River complex)	
I	1, 2, 3	(3)	1, 8, 11	(3)
II	4, 5, 6, 7	(7)	4,6, 12, 14	(7)
III	12, 13, 14	(10)	16, 19, 20, 21	(11)
IV	15, 16, 17	(13)	3, 7, 10, 22	(15)
V	8, 9, 10, 11	(17)	15, 17	(17)
VI	18, 19, 20, 21	(21)	5, 13, 18	(20)
VII	22, 23	(23)	2, 9, 23	(23)

Station locations appear in Fig. 12, page A-16. Data on the stations in Table 5, page A-17.

APPENDIX A

Supportative charts, tables and data.

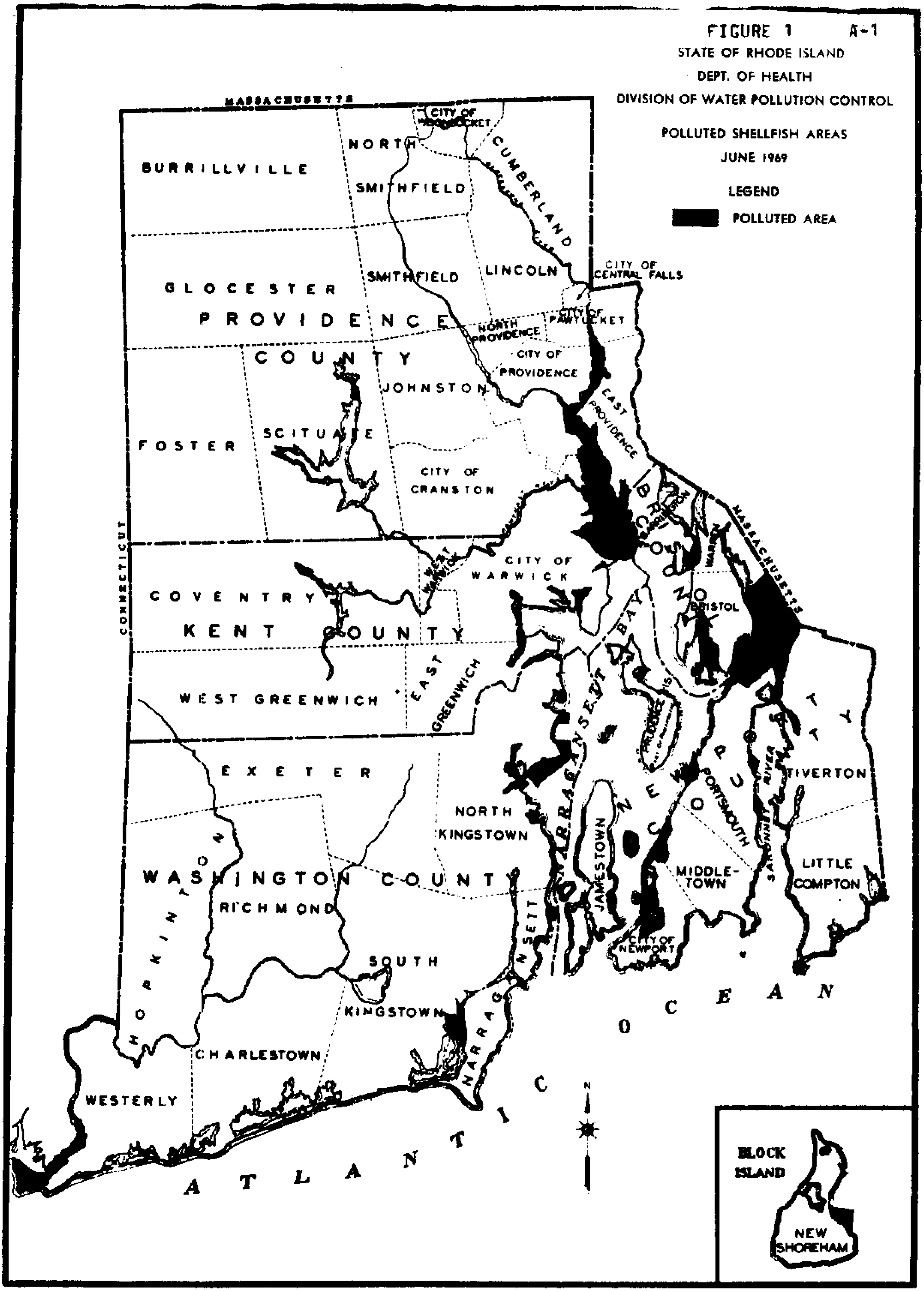
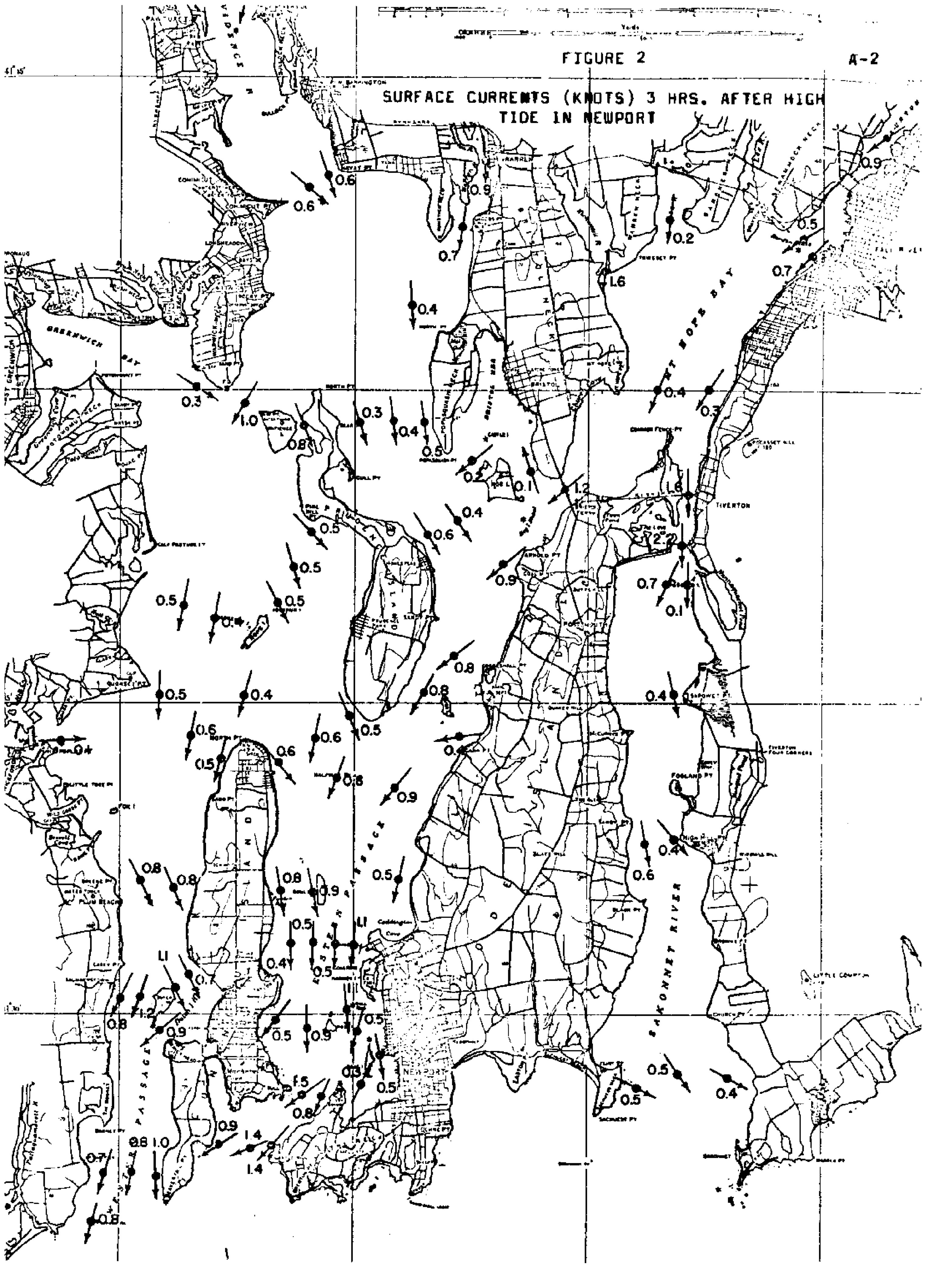


FIGURE 1 A-1
STATE OF RHODE ISLAND
DEPT. OF HEALTH
DIVISION OF WATER POLLUTION CONTROL
POLLUTED SHELLFISH AREAS
JUNE 1969
LEGEND
POLLUTED AREA
MASSACHUSETTS
CITY OF WOONSOCKET
NORTH SMITHFIELD
CUMBERLAND
BURRILLVILLE
SMITHFIELD
LINCOLN
CITY OF CENTRAL FALLS
GLOCESTER
PROVIDENCE COUNTY
CITY OF PAWTUCKET
NORTH PROVIDENCE
CITY OF PROVIDENCE
JOHNSTON
EAST PROVIDENCE
FOSTER
SCITUATE
CITY OF CRANSTON
CONNECTICUT
BRISTOL
BARRINGTON
WARREN
MASSACHUSETTS
WEST WARWICK
CITY OF WARWICK
COVENTRY
KENT COUNTY
EAST GREENWICH
WEST GREENWICH
NARRAGANSETT BAY
PRUDENCE IS.
NEWPORT COUNTY
TIVERTON
EXETER
NORTH KINGSTOWN
PORTSMOUTH
SAKONNET RIVER
JAMESTOWN
MIDDLETOWN
LITTLE COMPTON
WASHINGTON COUNTY
HOPKINTON
RICHMOND
CITY OF NEWPORT
SOUTH KINGSTOWN
NARRAGANSETT
CHARLESTOWN
WESTERLY
ATLANTIC OCEAN
N
BLOCK ISLAND
NEW SHOREHAM

FIGURE 2

SURFACE CURRENTS (KNOTS) 3 HRS. AFTER HIGH TIDE IN NEWPORT



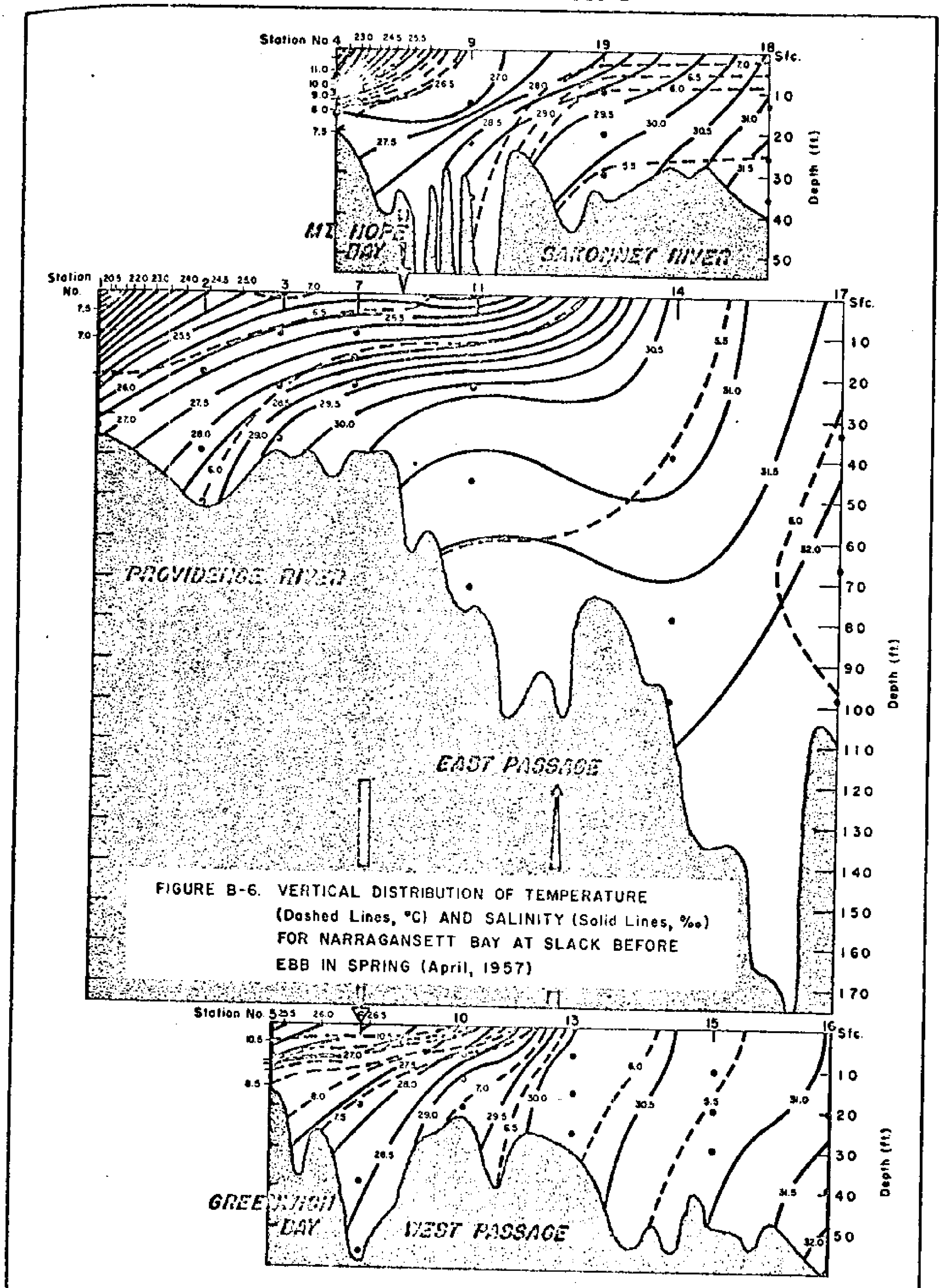


FIGURE B-6. VERTICAL DISTRIBUTION OF TEMPERATURE (Dashed Lines, °C) AND SALINITY (Solid Lines, ‰) FOR NARRAGANSETT BAY AT SLACK BEFORE EBB IN SPRING (April, 1957)

U.S. Dept. of Interior (1969)
Hurricane Damage Control
Narragansett Bay

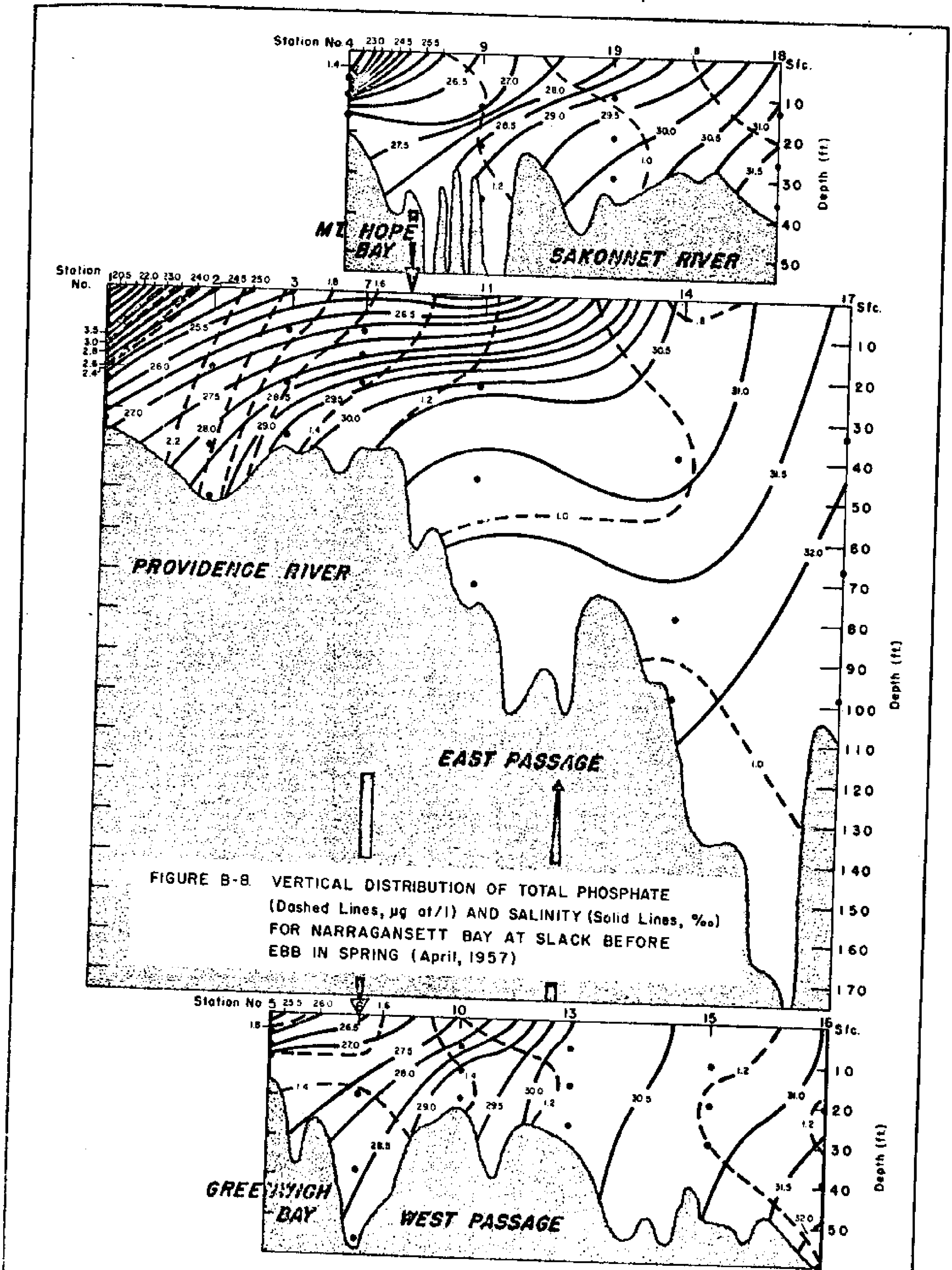


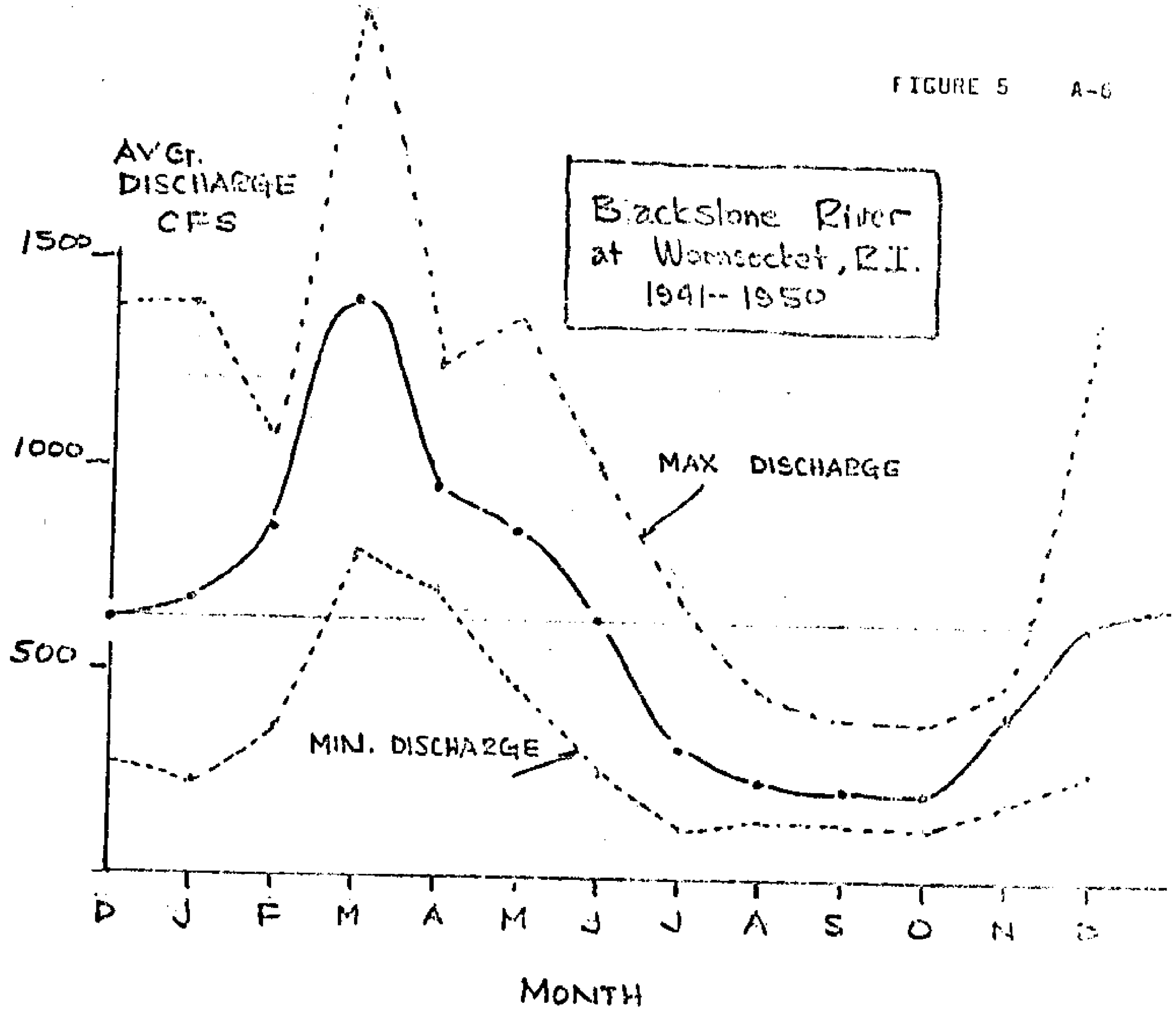
FIGURE B-8. VERTICAL DISTRIBUTION OF TOTAL PHOSPHATE (Dashed Lines, μg at/l) AND SALINITY (Solid Lines, ‰) FOR NARRAGANSETT BAY AT SLACK BEFORE EBB IN SPRING (April, 1957)

U.S. Dept. of Interior (1964)
Hurricane Damage Control
Narragansett Bay

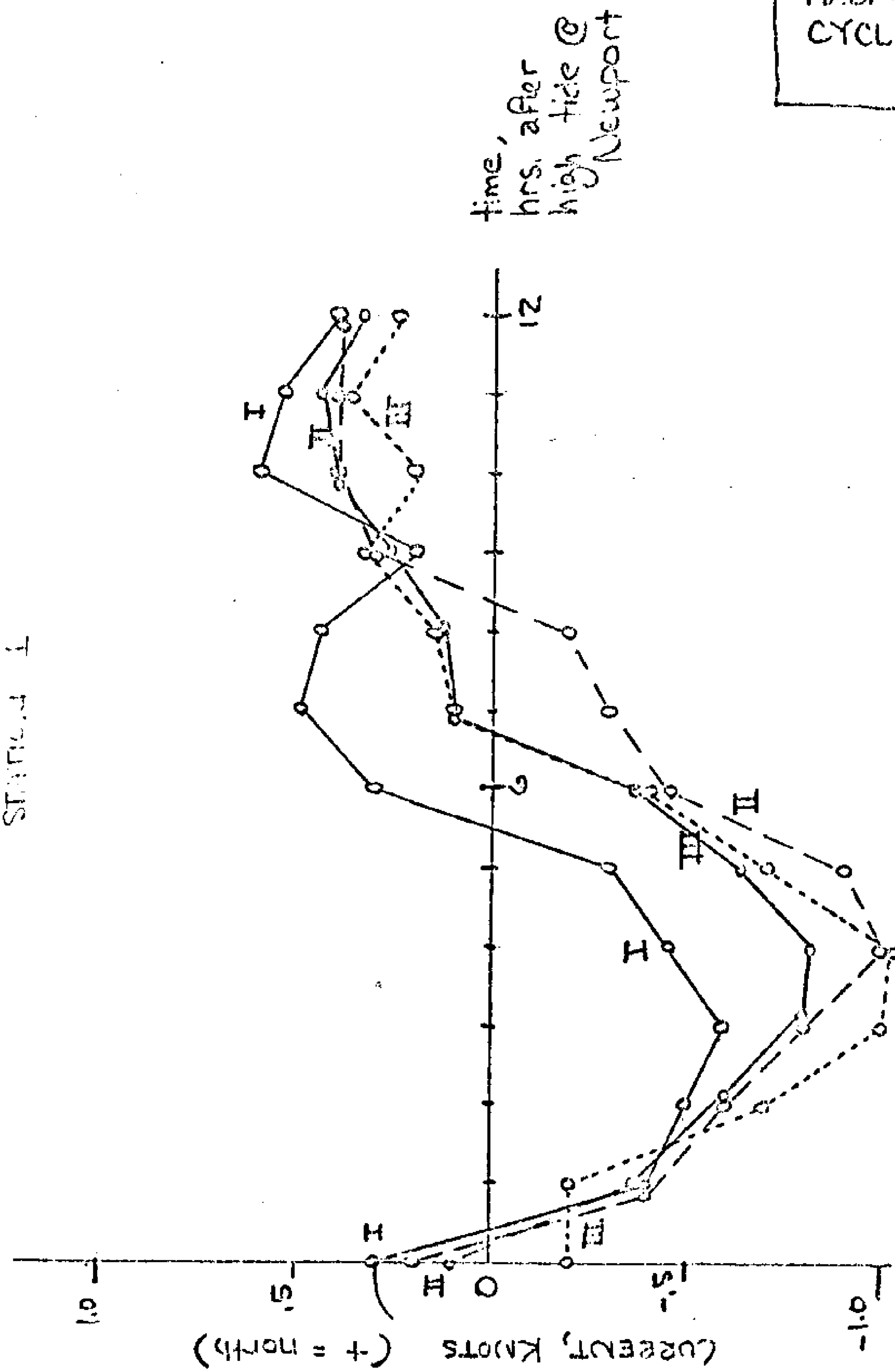
TABLE 1

OCEANOGRAPHIC PARAMETERS

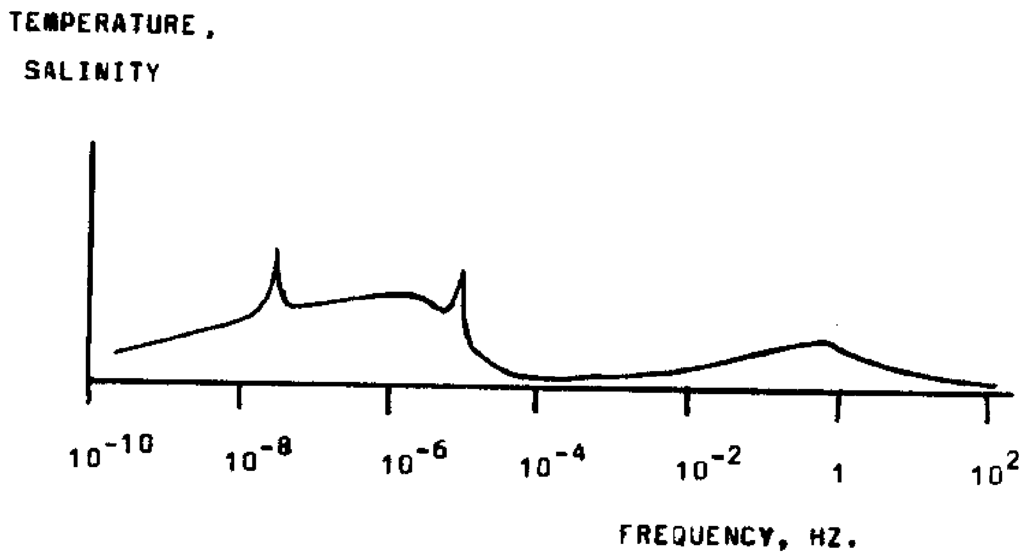
PHYSICAL PARAMETERS		BIO-CHEMICAL PARAMETERS	
TEMPERATURE	0-21 ^{o}C	D. O.	2.5-8.5ml/1
CURRENT MAGNITUDE	0-2.75 knots	E-COLI	0-2500 MPN/100ml
DEPTH	0-188 Ft.	CHLORINITY	5-17 $^{o}/oo$
TIDAL HEIGHT	0-4.6 Ft.	SALINITY	10-33 $^{o}/oo$
DENSITY (SP.)	1.010-1.02	ALKALINITY	1.4-2.0 me/kg
WAVE HEIGHT	0-7.0 Ft.	PHOSPHATE	1.2-6.5 $\mu g/1$
WAVE PERIOD	1.0-20.0 Sec.	CO_2	
DIFFUSION COEF.	($1.3\ 10^{-5}\ m^2/sec.$)	AMMONIA	
TURBIDITY	.01-.25 % Attn.	NITRATE/NITRITE	
COLOR		COPPER	
CONDUCTIVITY		IRON	
		NICKEL	

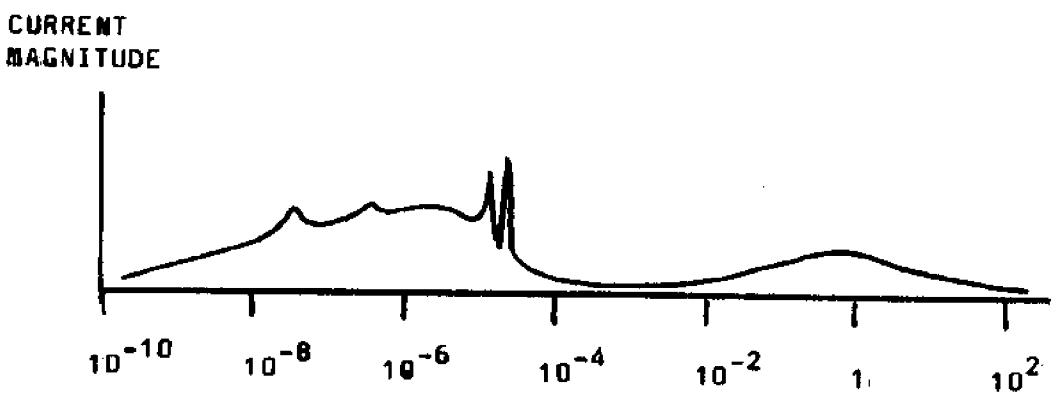

AVG. DISCHARGE CFS
1500
1000
500
Blackstone River at Woonsocket, R.I. 1941--1950
MAX DISCHARGE
MIN. DISCHARGE
D J F M A M J J A S O N D
MONTH

HALF-DAY CURRENT CYCLE - LOWER WEST PASSAGE



PARAMETER SPECTRA





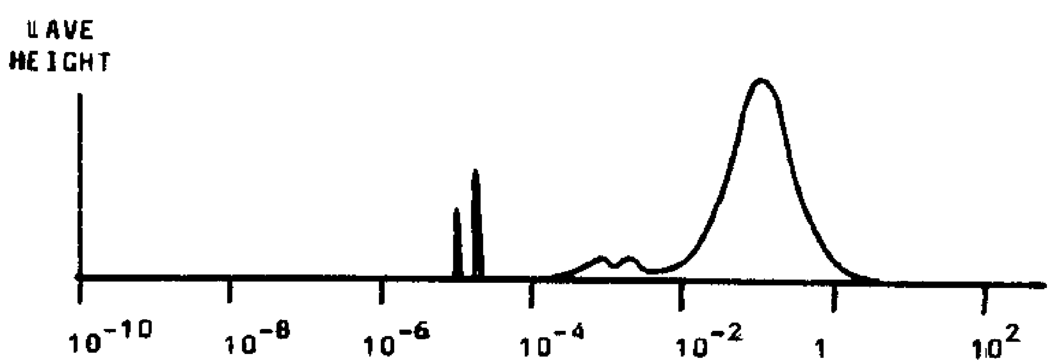


TABLE 2

PARAMETER GRADIENTS

HORIZONTAL GRADIENTS

PARAMETER	GRADIENT (CHANGE PER NAUTICAL MILE)			
	PROVIDENCE RIVER	MT. HOPE BAY	EAST PASSAGE	NON-CRITICAL AREAS
TEMPERATURE	1.25^{o}C	1.50^{o}C	0.30^{o}C	0.5-1.25^{o}C
SALINITY	2.5$^{o}/_{oo}$	2.00$^{o}/_{oo}$	1.00$^{o}/_{oo}$	1.0-2.0$^{o}/_{oo}$
CURRENT	0.1 knot	0.4 knot	0.1 knot	0.1-0.2 knot

VERTICAL GRADIENTS

PARAMETER	GRADIENT (CHANGE PER FOOT)			
TEMPERATURE	0.10^{o}C	0.15^{o}C	0.015^{o}C	0.05-0.15^{o}C
SALINITY	0.25$^{o}/_{oo}$	0.25$^{o}/_{oo}$	0.033$^{o}/_{oo}$	0.05-0.25$^{o}/_{oo}$
CURRENT	0.02 knot	0.04 knot	0.04 knot	0.01-0.04 knot

TABLE 3

PARAMETER SPECIFICATIONS

PARAMETER	AMPLITUDE	ACCURACY	FREQUENCY RANGE
TEMPERATURE	0-21.0^{o}C $\pm$0.5^{o}C	one part in fourty (1:40)	10^{-8}-10^{-3}hz
SALINITY	10-33^{o}/oo$\pm$0.5^{o}/oo	(1:350)	10^{-8}-10^{-3}hz
CURRENT MAGNITUDE	0-2.76 knot$\pm$0.1 knot	(1:70)	10^{-8}-10^{-3}hz
CURRENT DIRECTION	0-360^{o}$\pm$10^{o}	(1:36)	10^{-8}-10^{-3}hz
SURFACE WAVE HEIGHT	0-10.0 ft$\pm$0.25 ft	(1:40)	10^{-2}-1.0 hz
TIDAL HEIGHT	0-4.6 ft$\pm$0.25 ft	(1:20)	1.2*10^{-5}-5*10^{-4} hz

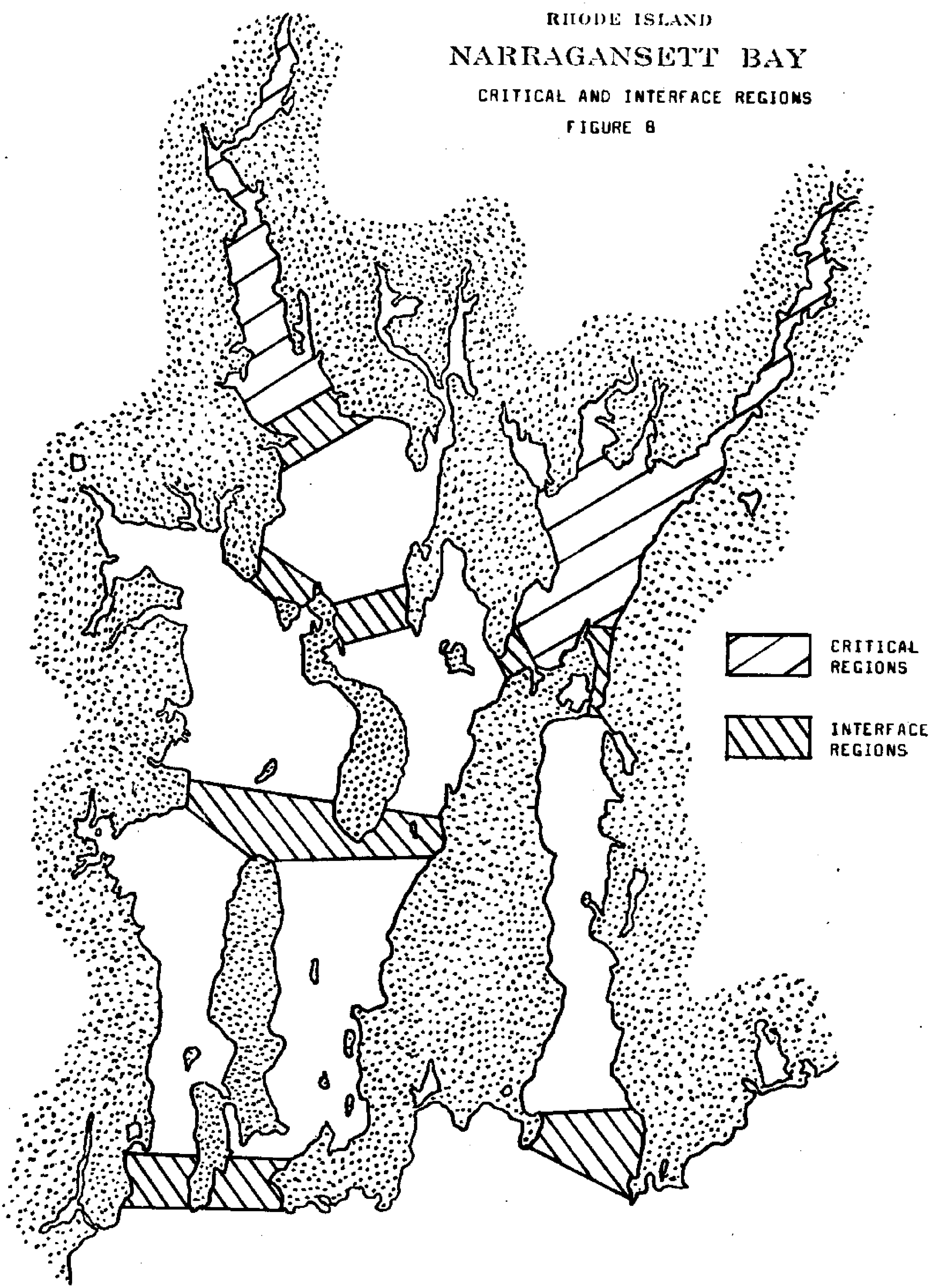
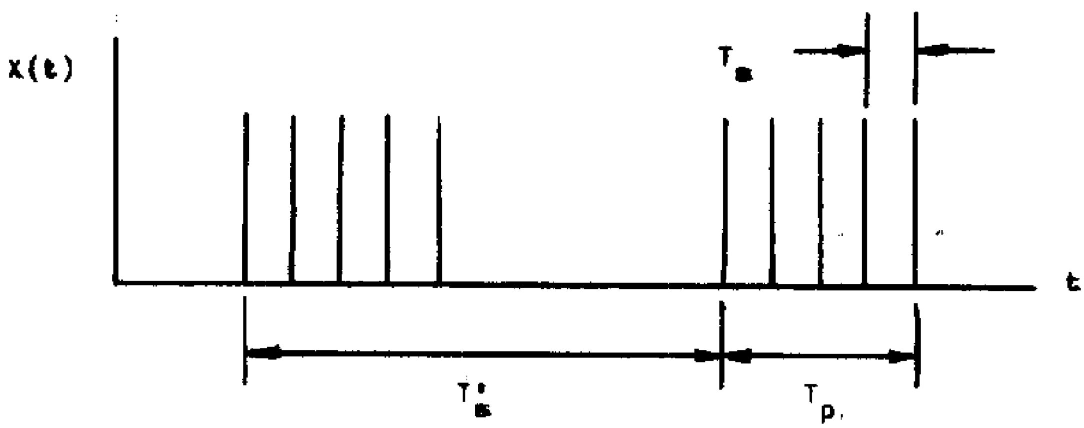

RHODE ISLAND
NARRAGANSETT BAY
CRITICAL AND INTERFACE REGIONS
FIGURE 8
CRITICAL REGIONS
INTERFACE REGIONS

FIGURE 9

SAMPLING
FUNCTION



POWER
SPECTRUM

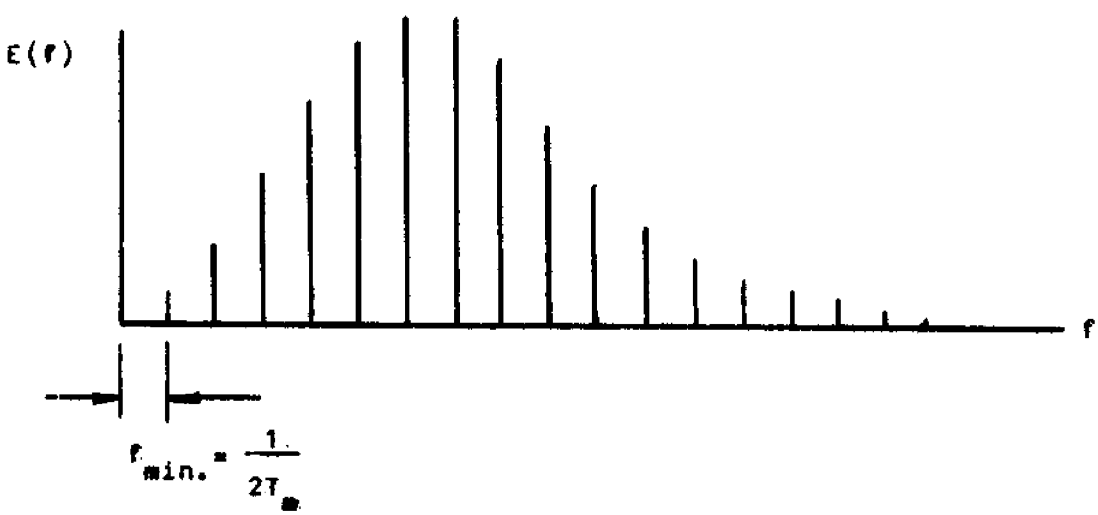
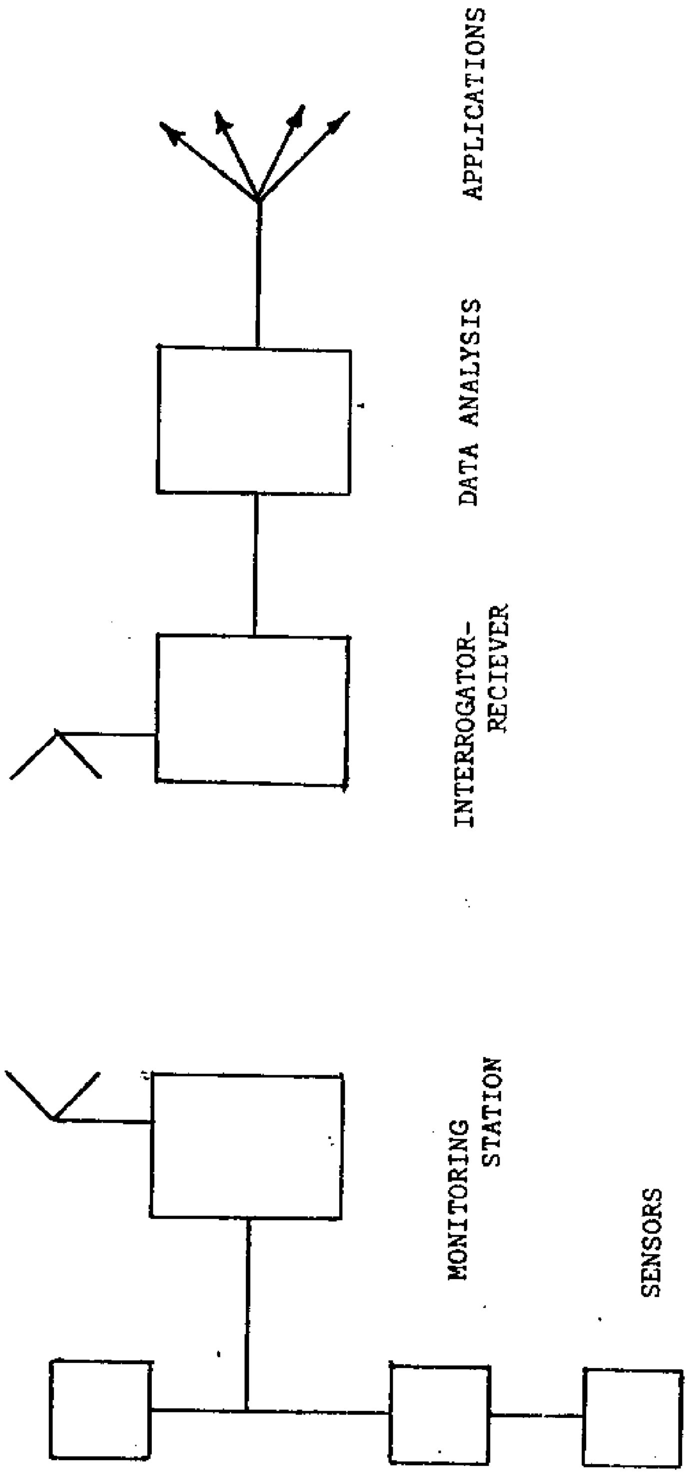


TABLE 4

PARAMETER TIME-SAMPLING

PARAMETER	REPRESENTATIVE VALUE INTERVAL T_s'	SAMPLING PERIOD T_p	SAMPLING INTERVAL T_s
TEMPERATURE	1 hr.	100 sec.	0.5 sec.
SALINITY	1 hr.	100 sec.	0.5 sec.
CURRENT MAGNITUDE	1 hr.	100 sec.	0.5 sec.
CURRENT DIRECTION	1 hr.	100 sec.	0.5 sec.
SURFACE WAVE HEIGHT	4-6 hr.	21 min.	0.5 sec. or continuous
TIDAL HEIGHT	1 hr.	100 sec.	0.5 sec.

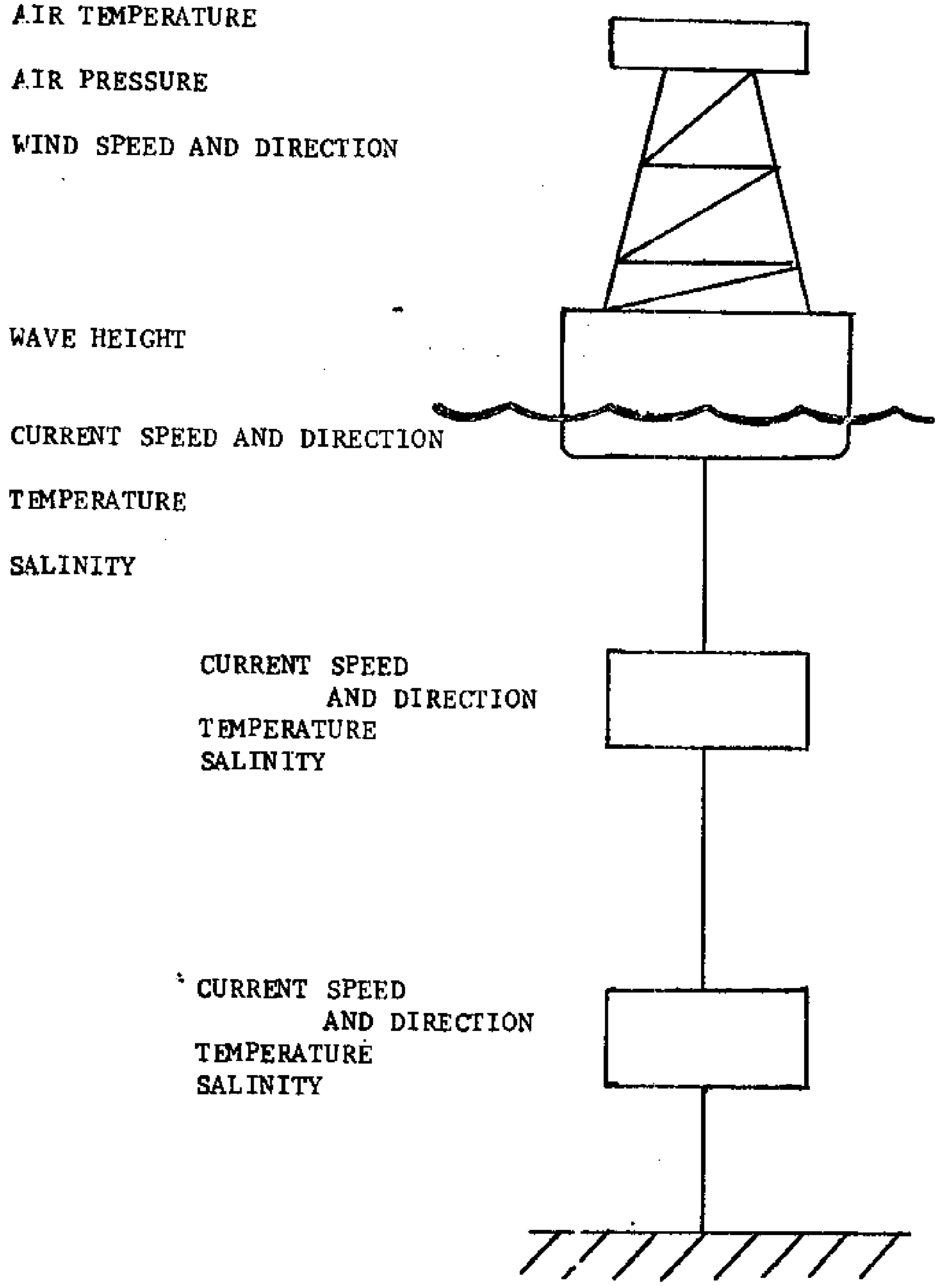
FIG. 10



SYNOPTIC DATA SYSTEM

FIGURE 9.1

FIG 11



SENSORS AND MONITORING STATION

[redacted]

RHODE ISLAND

NARRAGANSETT BAY

MONITORING STATION LOCATIONS

FIGURE 12

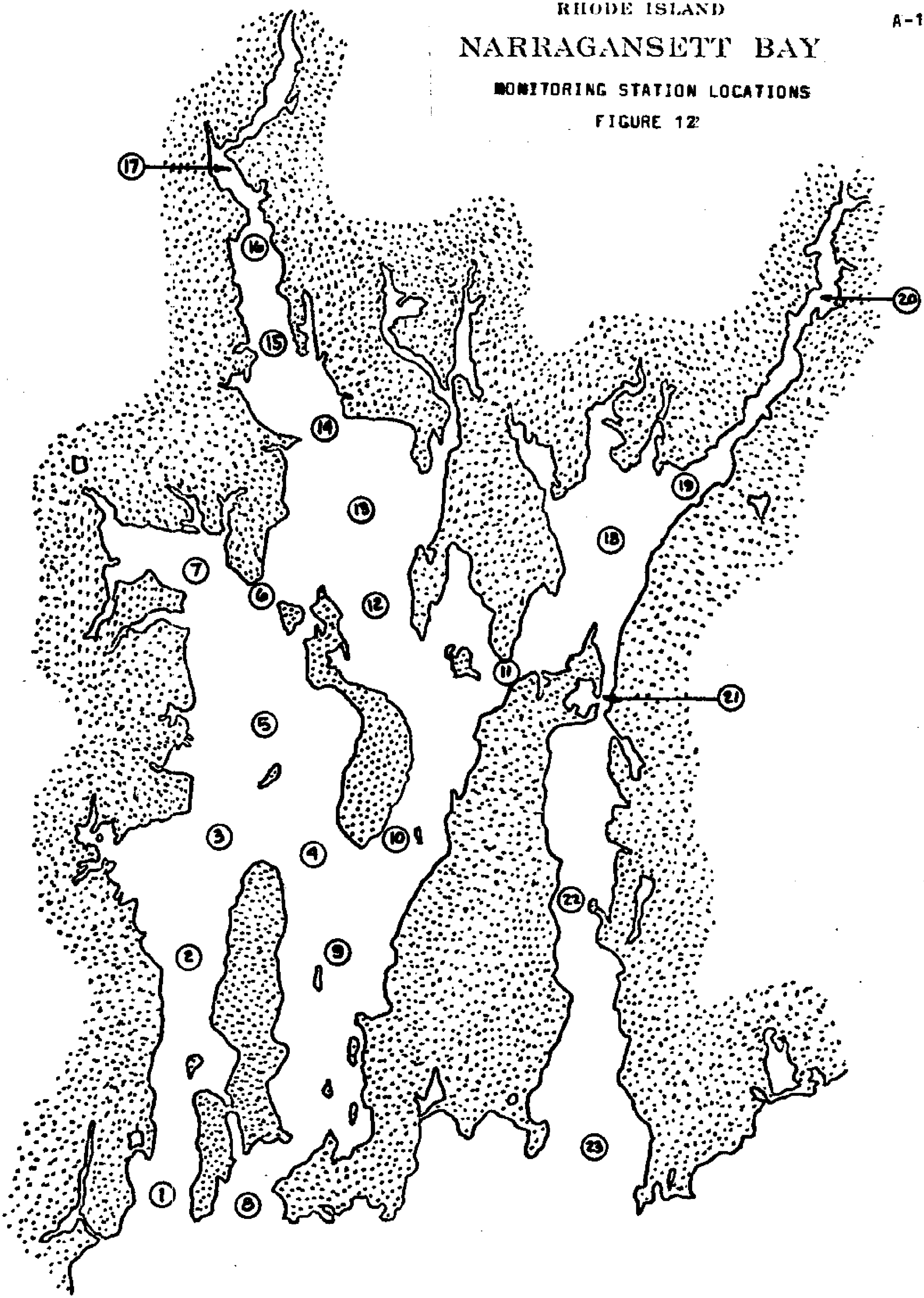


TABLE 5

STATION DATA

STATION	DEPTH(FEET)	SENSOR POSITIONS (FEET)
1	60	1-20-40
2	55	1-20-40
3	25	1-20
4	110	1-20-40-100
5	23	1-10-20
6	60	1-20-60
7	40	1-10-20-30
8	80	1-20-40-80
9	105	1-10-20-30-100
10	80	1-10-20-30-80
11	60	1-10-20-60
12	40	1-10-20-30-40
13	40	1-10-20-40
14	55	1-10-20-30-40-50
15	35	1-10-20-30
16	35	1-10-20-30
17	35	1-10-20-30
18	20	1-10-20
19	30	1-10-20-30
20	35	1-10-20
21	60	1-10-20-30-50
22	40	1-10-20
23	40	1-10-20-40

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