PROCEEDINGS OF

UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

(SELECTED PAPERS ON SPECIAL PROBLEMS IN OCEAN ENGINEERING)

COLUMBIA UNIVERSITY

Volume VII: 1972 - 1973

PROCEEDINGS OF

UNIVERSITY SEMINAR ON POLLUTION AND WATER RESOURCES

(SELECTED PAPERS ON SPECIAL PROBLEMS IN OCEAN ENGINEERING)

Volume VII: 1972 - 1973

Edited by

GEORGE J. HALASI-KUN

and

KEMBLE WIDMER

COLUMBIA UNIVERSITY

in cooperation with

THE NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

COMMISSIONER David J. Bardin

Bureau of Geology & Topography

BULLETIN 75-A

ACKNOWLEDGMENTS

The preparation of this volume was sponsored by the United States Bureau of Land Management. Further generous support from the New Jersey Bureau of Geology and Topography and Rutgers University Marine Sciences Center made this publication possible.

CONTENTS

INTRODUCTION

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

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

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

George J. Halasi-Kun
Chairman
University Seminar on Special
Problems in Ocean Engineering
Columbia University

DISPERSION AND DEPTH OF DISTURBANCE STUDIES ON FORESHORE BEACH SEDIMENT, SANDY HOOK, NEW JERSEY

by

WARREN E. YASSO, Ph.D.

Associate Professor of Natural Sciences,
Teachers College, Columbia University

INTRODUCTION

Fluorescent tracer coatings applied to natural beach sediment have proved valuable in previous studies of beach sand movement at Sandy Hook, New Jersey (Yasso, 1966). Extensive testing of fluorescent tracers began in the Soviet Union in 1959 (Zenkovich, 1967, pg. 329-334). Development of fluorescent tracer materials in the United States and their early use in tracing the movement of sand on beaches and in submarine canyons has been summarized by Ingle (1966). This report on the use of fluorescent tracers in dispersion and depth of disturbance studies is based on data only some of which have been published as a Department of Defense report having limited distribution (Yasso, 1962, pg. 23-25, 31-34).

FIELD TESTING

Foreshore sand dispersion under a dominant tidal regime

In a previous experiment, designated Test Y-1-F, (Yasso, 1966, pg.296-300) fluorescent tracer particles were placed on the surface of a foreshore spit-bar at Horseshoe Cove, Sandy Hook, New Jersey (Figure 1). Emplacement was along a North-South trending profile line, designated S_5, normal to the elevation contours. One of the batches of tracers contained 21,500 particles of each of five different sieved sand sizes. Sampling after a complete tidal cycle revealed that the tracer material of all sizes had moved downdrift[1] along an initial trajectory that was of approximately the same orientation as the deep water direction of wave approach. It was also noted that the dispersion zone (area over which tracer particles were found in the samples) was different for different sizes of tracer sand. In order to investigate this phenomenon, additional experiments of the same nature were planned using larger volume of tracer particles and improved sampling technique. The test described below was conducted to achieve this objective.

Test Y-2-F

During evening low tide on 29 August 1961 a mixed batch of three differently colored fluorescent tracer sizes[2] ($1.168 > d > 0.991$ mm, $0.840 > d > 0.701$ mm, $0.589 > d > 0.495$ mm) was placed in a 0.92 foot diameter circle on the surface of the lower foreshore spit-bar at Horseshoe Cove. Each tracer size was represented by 407,000 particles. Center of the emplaced batch was on the S_5 profile line 26.60 feet seaward of the spit-bar crest and at a point where beach elevation was 1.72 feet above mean sea level. Wave conditions during rising tide were:

Wave period, $T = 2.1$ seconds
Maximum breaker height, H_b max. = 0.5 feet
Deep water wave direction relative to profile line = 45 degrees

---

1. Upbeach and downbeach transport directions refer respectively to onshore and offshore movement at right angles to elevation contours; alongshore movement is parallel to contours in a downdrift direction. Downdrift direction is the resultant of both components of movement.

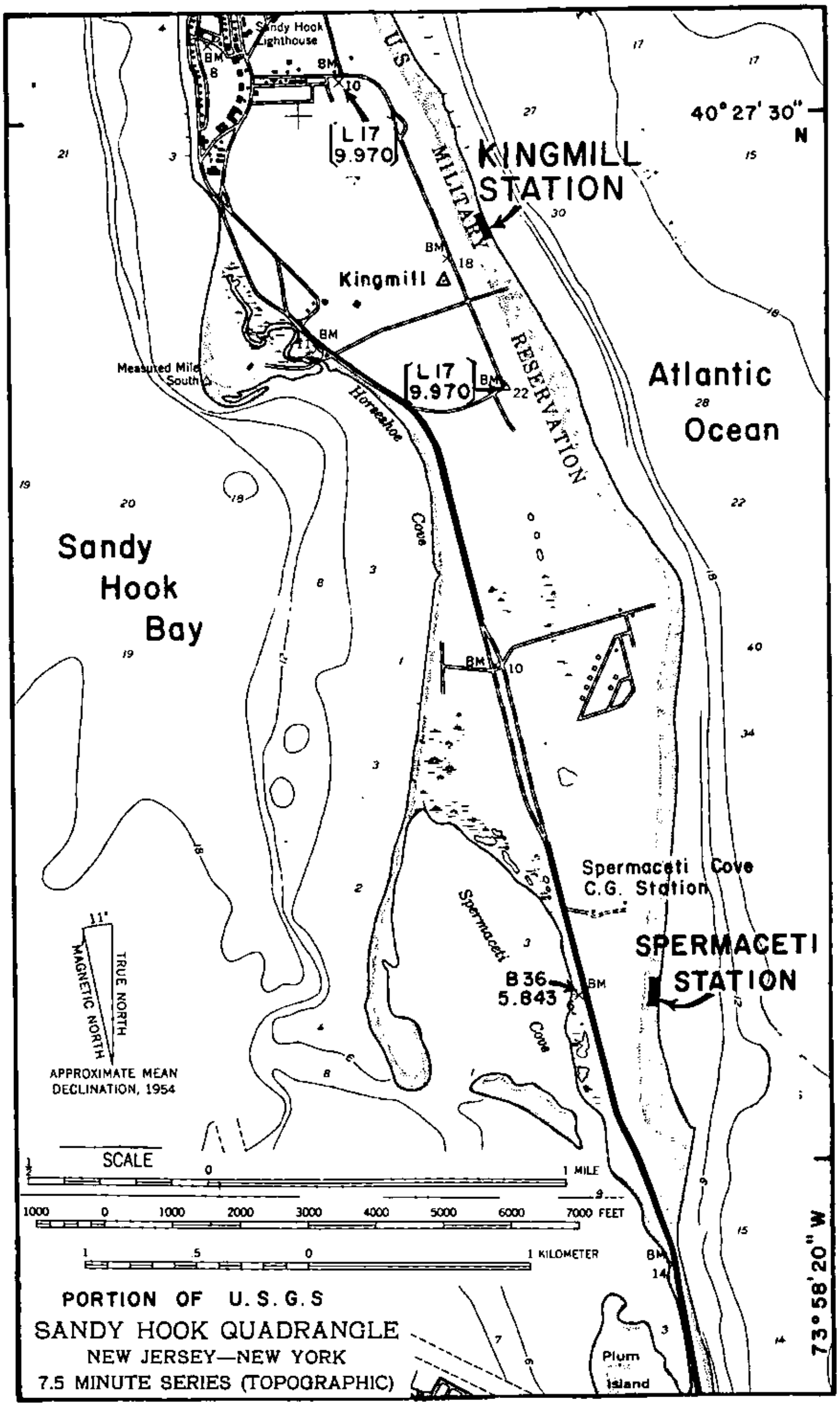


Figure 1. Location map, Sandy Hook, New Jersey

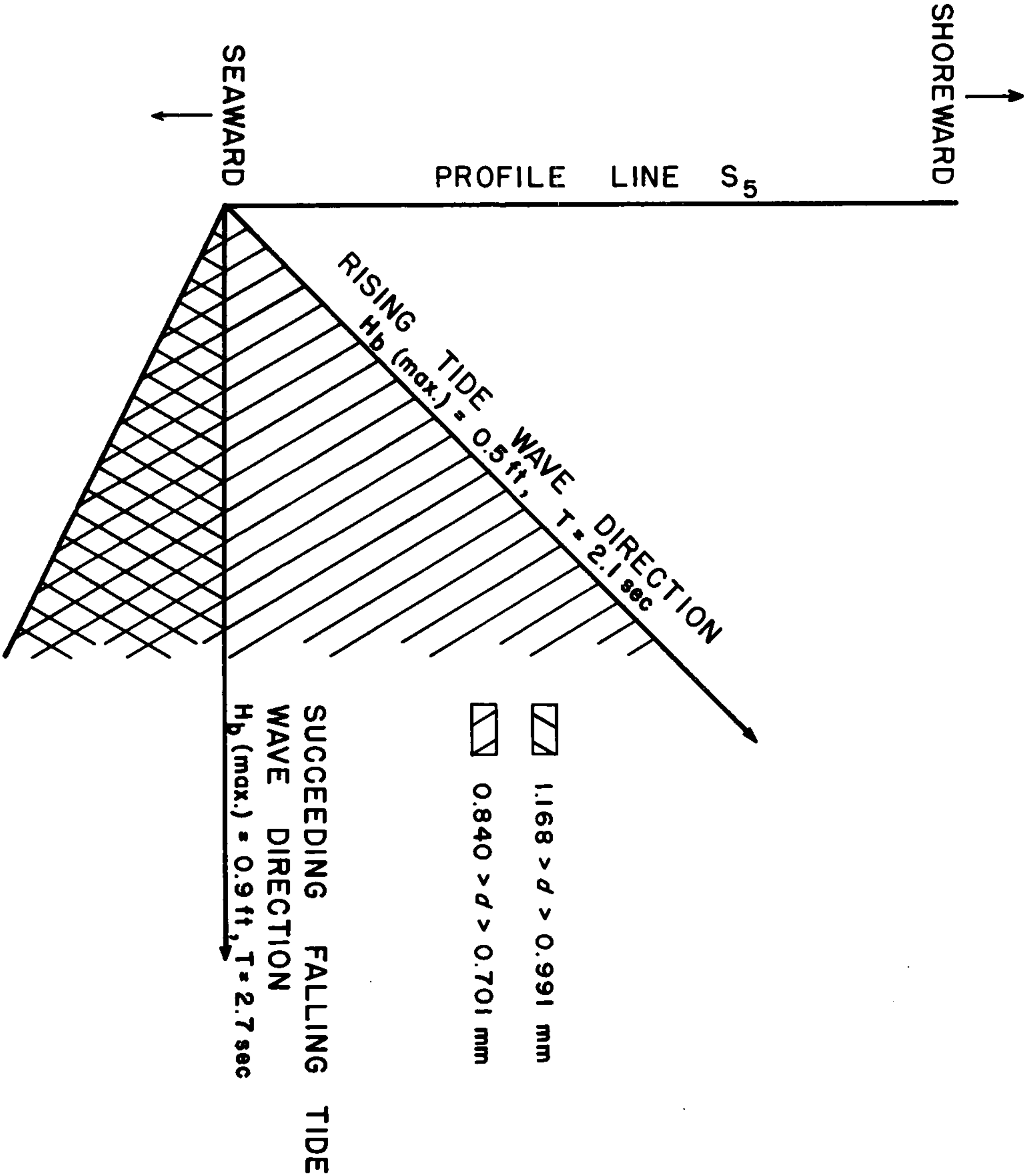


Figure 2. Plan view of foreshore at Horseshoe Cove, Sandy Hook, showing wave directions and dispersion zones for fluorescent tracer particles used in Test Y-2-F.

After tide level had risen above the tracer emplacement point, the waves in Sandy Hook (Raritan) Bay died down. From about time of high tide to the succeeding low tide waves from a new direction were generated by a strong Northwest wind. Wave conditions during falling tide were:

Wave period, $T = 2.7$ seconds
Maximum breaker height, H max. = 0.9 feet
Deep water wave direction relative to profile line = 90 degrees

At low tide, a string-constructed sampling grid 30 feet long and 10 feet wide, having 2 foot sample point spacing, was laid down on the foreshore surface with one long side coincident to the profile line. One short side was nearly coincident to the landward edge of the spit-bar in a downdrift direction. The lowermost sampling line was 2 feet seaward of the tracer emplacement point. Ninety-six samples were taken at grid intersections to a depth of 0.3 feet, using a thin-walled plastic coring tube with piston insert (Yasso, 1967). The grid was then shifted alongshore to obtain an additional group of samples but as these did not contain any tracer particles used in this test no further mention will be made of them.

In a room darkened except for long-wave ultraviolet illumination, samples spread out on canvas were examined for presence of tracer particles. In spite of the twenty-fold increase in number of tracer particles used for this second dispersion test, marked particle recovering totaling 0.014% was, as in the previous test, inadequate to allow contouring of particle recovery in the dispersion zone. However, recovery was sufficient to identify the boundaries of the dispersion zone for each size of tracer particles. As the dispersion pattern for the smallest tracer size ($0.589 > d > 0.495$ mm) is practically identical with that for the intermediate tracer size ($0.840 > d > 0.701$ mm), the discussion will be simplified by referring to results for only the largest and intermediate tracer sizes.

From sample analysis it is concluded that low waves impinging on the foreshore during rising tide were capable of transporting only particles smaller than the largest tracer size (Figure 2). However, larger waves impinging on the foreshore during the succeeding falling tide were capable of transporting particles of all sizes up to and including the largest tracer size. As is also shown in Figure 2, the initial trajectory for dispersion of the two smaller tracer sizes corresponds exactly to the deep-water wave direction during rising tide. In turn, initial trajectory for the largest tracer size corresponds exactly to the deep-water wave direction during the succeeding falling tide. These observations confirm and extend the knowledge about interaction between wave, sand, and topographic parameters gained from the results of Test Y-1-F.

Depth of disturbance studies

Detailed knowledge of the volume of sediment being transported as bed load in any current field requires measurement of sediment velocity and

2. Particle size range is given in the form $1.168 > d > 0.991$ mm, meaning that the particles pass through the 1.168 mm screen and are retained on the 0.991 mm screen.

thickness of the mobile portion of the bed layer. Early tests to determine the depth of wave-induced sand disturbance on beaches were performed by King (1951; 1959, pg. 172-176) around the shoreline of England and Wales. Vertical strips of dyed sand emplaced at low tide across the foreshore were excavated at the succeeding low tide to measure, in effect, the remaining depth of dyed sand as an indication of depth of disturbance. Most measurements were made where changes in beach elevation over a tidal cycle were small. It was felt that net erosion or accretion, occurring at an unknown time relative to wave disturbance of foreshore sand, would confuse interpretation of test results.

Ingle (1966, pg. 159-161) used empirical knowledge of average annual sediment transport conditions shoreward of the breaker zone to derive the average annual depth of the mobile bed layer. However, additional data are needed because the possibly significant relationship between sediment movement through the breaker zone and net accretion behind breakwaters could not be evaluated for the three Southern California beaches used in Ingle's calculations.

Narrower and steeper foreshores, larger average grain size of foreshore sediment, and relatively greater importance of tidal regime over wave climate on Sandy Hook beaches, compared with those described by both King and Ingle, suggest the continued usefulness of depth of disturbance studies on local beaches. In addition, a new dimension has recently been added to this type of investigation as a result of the study of foreshore elevation changes over a tidal cycle reported by Strahler (1966). It was discovered that above approximately mean sea level on equilibrium beaches at Sandy Hook, New Jersey, a tidal rise is generally accompanied by an initial deposition of a 0.02 foot layer of sand followed by a scour phase that lowers the beach by 0.02 feet. The scour phase is followed by a step deposition phase that raises the beach by about 0.5 feet. The initial deposition and scour phases are present at all levels on the foreshore, but step deposition decreases in magnitude at progressively higher levels and is absent near the upper limit of the swash zone. Obviously, foreshore sand is also disturbed to some depth by wave action throughout the erosion and accretion phases just described. Because of surveying difficulties in the breaker zone, Strahler was not able to determine whether upbeach migration of the step caused erosion of the foreshore deeper than that caused by the scour phase. It was thought that fluorescent tracer sand might also be employed in studies of foreshore disturbance over the tidal cycle.

During low tide on 20 July 1961, two 0.5 foot-thick cores of fluorescent sand were emplaced in the Sandy Hook foreshore at Spermaceti Station (Figure 1). Beach elevation at core locations is given in the third column of the first two rows of Table 1. Beach slope and sand size characteristics of the foreshore at each location are given in columns 4 through 7 of the table. Wave conditions during succeeding high tides were:

Wave period, $T = 6.8$ seconds
Maximum breaker height, $H_b$max. = 2 feet
Deep water wave direction relative to the shoreline = 30 degrees

TABLE 1. DEPTH OF DISTURBANCE DATA

Date and location	Core designation	Original beach elevation (ft.)	Beach slope	Sieve analysis of sand removed for core emplacement		
				Median dia. (mm)	Geometric mean dia. (mm)	Trask sorting index
20 July 1961, Spermaceti Station	Core 1	0.84	5°40'	0.463	0.548	1.48
"	Core 2	2.62	5°50'	0.356	0.403	1.42
26 May 1962, Kingmill Station	Core 1	0.90	7°10'	0.589	0.539	1.30
"	Core 2	2.12	7°45'	0.564	0.474	1.34

Date and location	Core designation	Final beach elevation (ft.)	Total depth of disturbance	Sieve analysis of sand deposited above core		
				Median dia. (mm)	Geometric mean dia. (mm)	Trask sorting index
20 July 1961, Spermaceti Station	Core 1	0.94	0.40	0.533	0.557	1.35
"	Core 2	2.87	0.20	0.372 (upper layer, 0.22 feet thick) 0.899 (lower layer, 0.23 feet thick)	0.379 0.869	1.24 1.28
26 May 1962, Kingmill Station	Core 1	0.91	0.15			
"	Core 2	2.19	0.05			

Plunge zone of the waves had migrated shoreward of Core 1 location prior to time of high tide. From a partial series of half-hourly topographic profiles taken during the tidal cycle, it is known that the scour phase at Core 2 location resulted in erosion of at least 0.137 feet below the original foreshore level. This was follwed by an anomalous increase in foreshore elevation at Core 2 location, which proved indicative of a net accretion for the entire profile over the tidal cycle. This is shown by the final elevation data in column 8 of Table 1.

Core locations were sampled during succeeding low tide by the plastic tube coring technique described earlier in this report. Measured loss of the upper portion of each core is listed in column 9 of Table 1. Because it is known from the topographic survey that accretion followed the scour phase, the magnitude of combined scour and wave disturbance of foreshore sand is also as given in column 9. Interestingly, the known scour depth of at least 0.137 feet at Core 2 location suggests that swash-backwash disturbance of foreshore sand at about mean-high-water level under the prevailing wave conditions is less than 0.06 feet.

During low tide on 26 May 1962 two cores of fluorescent sand were emplaced in the foreshore at Kingmill Station (Figure 1). Beach elevations at core locations are given in the third column of the third and fourth rows of Table 1. Beach slope and sand size characteristics are given as before. Wave conditions during succeeding high tide were:

Wave period, T = 3.4 seconds
Maximum breaker height, $H_b$max. = 2 feet
Deep water wave direction relative to shoreline = 5 degrees

Final elevation of the foreshore measured at succeeding low tide (Col. 8, Table 1) suggests that equilibrium beach conditions were present during the tidal cycle.

Assuming that the slight net accretion on the profile occurred after the scour phase during tidal rise, then the amount of core removal given in column 9 of Table 1 represents the combined effect of scour and wave disturbance of foreshore sand. Comparison of the data from both experiments suggests that magnitude of beach disturbance decreases progressively between plunge point of the waves and upper limit of the swash. Also, under shorter period waves of the same maximum breaker height, coarser beaches are subject to less total disturbance than are beaches with lesser average sand size.

On the basis of the limited data available it would seem desirable that similar studies should be conducted over longer periods on both equilibrium and non-equilibrium beaches. Such studies should lead to a quantification of the relative contribution of tidal scour phase, step phase, and superimposed wave disturbance to foreshore sand mobility and stability. In similar manner, it should be possible to sort out the relationship between sand size, tide range, wave parameters, and depth of disturbance.

SUMMARY

Studies of foreshore sediment dispersion and depth of foreshore disturbance over the tidal cycle were performed at Sandy Hook, New Jersey, during the summers of 1961 and 1962. A test of sand dispersion on a spit-bar at Horseshoe Cove confirmed results of an earlier test that suggested the coincidence of deep water angle of wave approach and initial trajectory of fluorescent tracer particles moved by swash from the waves. The occurrence of two different sets of waves during the dispersion test herein reported revealed that the swash from waves of 2.1 second period and 0.5 foot maximum breaker height was not able to transport particles in the largest fluorescent tracer size used for the experiment ($1.168 > d > 0.991$ mm). Larger waves of approximately the same period were able to transport all particle sizes up to and including the largest tracer size.

Depth of disturbance tests, on the Atlantic Ocean shore of Sandy Hook, using cores of fluorescent sand emplaced in the foreshore confirmed the presence of the scour phase that accompanies the high tide cycle. Foreshore disturbance shows a progressive decrease in intensity between plunge point of the waves and upper limit of swash. Under conditions of equal maximum breaker height, depth of disturbance seems to be a function of both sand size and wave period.

ACKNOWLEDGMENTS

The field studies described in this report were supported by the Geography Brancy of the Office of Naval Research (Project NR 388-057) under Contract Nonr 266(68) with Columbia University. The project director was Professor Arthur N. Strahler, who kindly supplied the precise topographic survey data for Spermaceti Station. Field and laboratory assistance was generously provided by G. Walcott and C. Ware. The writer is indebted to Professor Strahler for use of Figure 1 and to G. Antonini for preparing Figure 2.

REFERENCES CITED

Ingle, J. C., Jr., 1966, The movement of beach sand: New York, Elsevier Publishing Co., 221 p.

King, C. A. M., 1951, Depth of disturbance of sand on sea beaches: J. Sed. Petrology, v. 21, p. 131-140.

_____1959, Beaches and coasts: London, Edward Arnold Ltd., 403 p.

Strahler, A. N., 1966, Tidal cycle of changes in an equilibrium beach, Sandy Hook, New Jersey: J. Geology, v. 74, p. 247-268.

Yasso, W. E., 1962, Fluorescent coatings on coarse sediments: an integrated system: U. S. Navy, Office of Naval Research, Geography Branch, Project NR 388-057, Tech. Rept. 1, 55 p.

_____1966, Formulation and use of fluorescent tracer coatings in sediment transport studies: Sedimentology, v. 6, p. 287-301.

_____1967, Plastic-tube technique for coring unconsolidated wet sand, a discussion: J. Sed. Petrology, v. 37, p. 714.

Zenkovich, V. P., 1967, Processes of coastal development: Edinburgh, Oliver and Boyd, 738 p.

DATA ON THE HYDROLOGY OF GREAT SOUTH BAY, LONG ISLAND, NEW YORK

by

George Claus, Ph.D.

The American Academy of Ocean
Sciences, Inc., New York City

The increasing levels of pollution in coastal waters, estuaries, and tributaries has had a dramatic effect on the natural animal and plant communities of these bodies of water. The rapidly expanding population, coupled with the growing amounts of wastes generated by our civilization, has escalated the demand for the utilization of these waters, both as recreational facilities and discharge basins. There is a basic conflict of interest between the demands of home owners, industry, and communities, which would like to dispose of their wastes into the sea as cheaply as possible, and that of the recreation-seeking public who want to use clean water for bathing, boating and sport fishing. This conflict has created a climate of nitpicking, rhetorics and political jockeying, rather than focusing attention on solving the problems of the rapidly deteriorating marine environment. A prime example of the marine environment facing such fast impairment is supplied by the waters around Long Island. On the North the relatively deep Long Island Sound and on the South a series of bays surround the Island, which harbors an ever increasing population of over 4,000,000. The present study is focused on the bays, and for the past three years an attempt has been made by the Members of our Institute to conduct a comprehensive hydrological survey of these waters, especially those of Great South Bay.

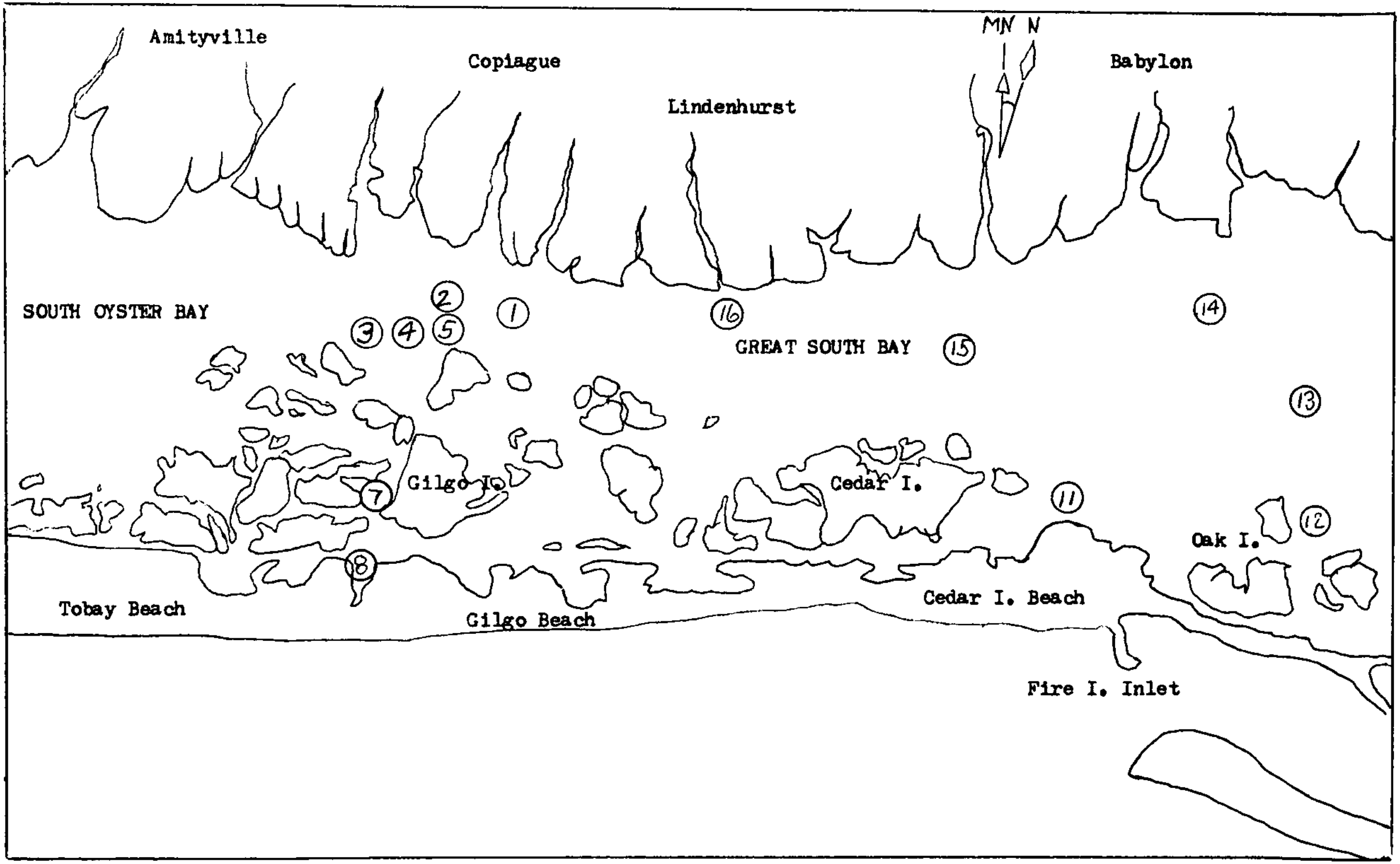
From the geomorphological point of view, the bays on the South of Long Island are shallow lagoons which are protected from the open ocean by a barrier island, Fire Island, permitting only limited access through two inlets into these lagoons. The shallowness of these waters account for many of the interesting and unusual features of their biotic population.

Starting with the first reports written on the bays, it became evident that there is a continuous increase in the area of wetlands and also that large portions of waters navigable 50 years ago turned first into pastures and later into grounds used for developments. The sediment characteristics of the bay are mostly unknown and only a few core samples exist, taken by the U. S. Geological Survey at sites of bridge constructions. In order to obtain data on the sediments of these waters, a comprehensive sampling was instituted by Penn (1968). The sample locations are given in Fig. 1. Grain size analysis showed, without exception, a tri-modal distribution of sand particles which might be the result of different shore layers originating from the last glacial and interglacial periods having been eroded and carried into the bay.

Mineralogical examinations of the highly reducing and alkaline sediments resulted in several interesting discoveries. Three different categories of opaque-anisometric particles were found. These were: angular granules identified as limonite, rhombohedral ilmenite and microspheres thought to be ferromanganese concretions. All of these minerals are stable under reducing conditions and the putrefying bottom ooze, with its abundant anaerobic flora, provides suitable environment for their formation.

The main quantity of the sediment is composed of typical non-eroded quartz crystals and some other layer lattice silicates or clay minerals. Their preliminary identification resulted in the definition of glauconite. The very low potassium content found in the spectrographic analytical results, however, contradicted this and the conclusion was reached that glauconite, through alkaline, anoxic diagenesis, will turn into montmorillonite, which was then accepted as the predominating clay mineral.

FIGURE 1



MAP OF AREA INVESTIGATED WESTERN GREAT SOUTH BAY, SUFFOLK COUNTY, LONG ISLAND, NEW YORK

Some data were obtained about the rate of the sedimentation which served as the basis of projective calculations. According to this, the present rate of sediment formation and its movement into the bay, the latter will be filled up, turning it into a salt marsh, in approximately 80-100 years. The richness of the top layer of sediments in organic constituents (80% weight loss on ignition) provided the basis for investigations into the amounts of marine humus.

Core samples were taken at the sites used earlier for the investigation of sediment characteristics, and the humic acid content of each sample was determined. Contrary to earlier opinions about the insignificance of marine humification, it was found that each sample contained between 3-5% of humates, which was invariably higher than that of the terrestrial control samples (Table 1). The more anoxic the environment the higher levels of humates were found. Whalen (1969) carried out infrared spectral analyses of the isolated humates and the spectra showed excellent correlation to similar works conducted on terrestrial sources. A surprising finding of the spectral analysis led to the conclusion that in all probability differently oxidized states of humic acids exist in marine sediments; namely, those samples which originated from highly reducing environments (eH-90 and below) contained more reduced functional groups (aldehyde vs. acids) than those which came from slightly reducing or mildly oxidizing environments (eH-10 and above) (Fig. 2).

The investigations on both the inorganic and organic constituents of the sediments do not in themselves present the complete picture of the sedimentation processes in the bay. Currents greatly influence sedimentation characteristics and current velocity measurements and the determinations of tidal exchange rates are essential for predicting the possible fate of the bay. Such studies care carried out by Jamieson (1962) and Fig. 3 shows the stations where the current velocity measurements were conducted for several tidal cycles in order to establish the main trends in current patterns and to be able to calculate the value of tidal exchange and flushing time.

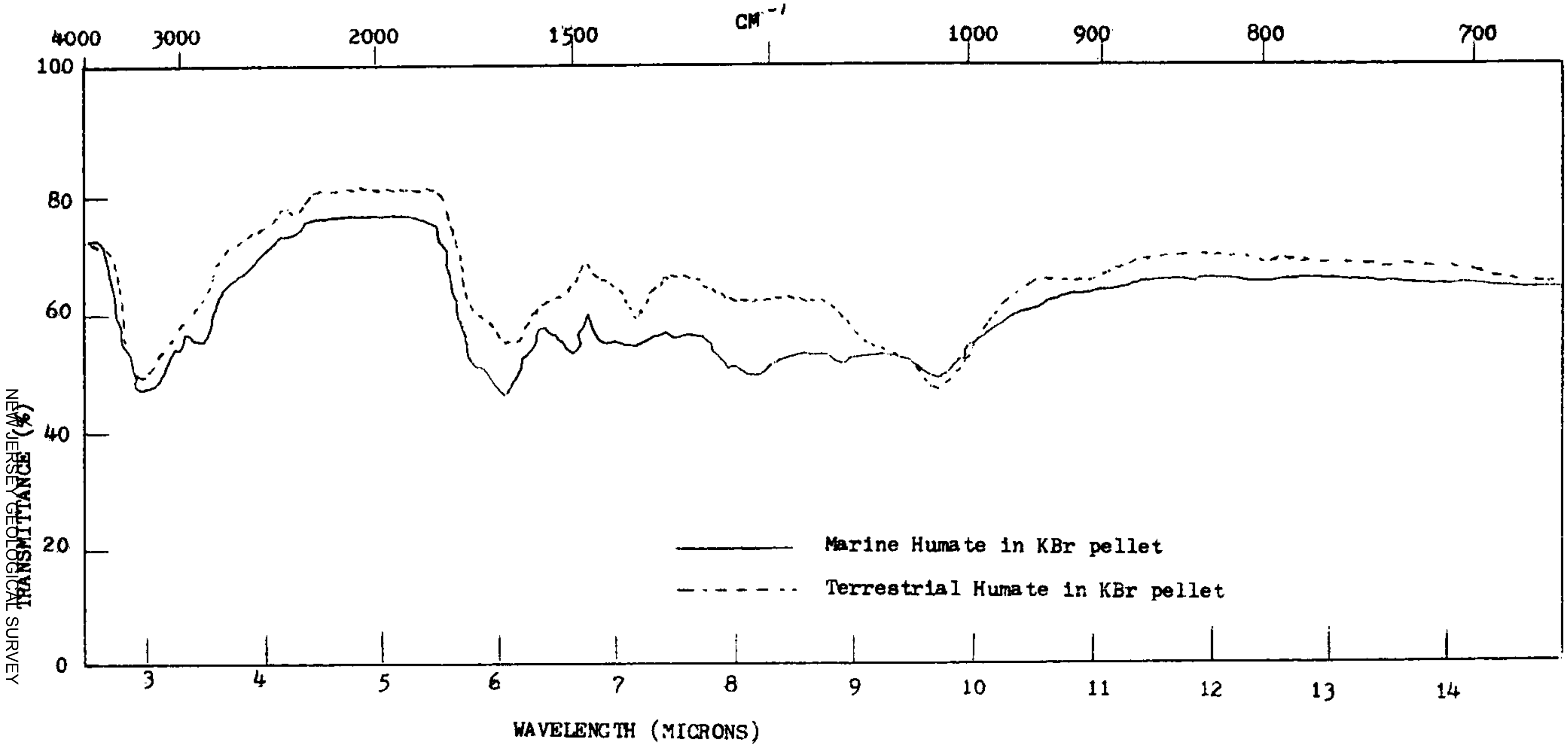
The velocity direction and excursion of currents flowing between South Oyster bay and Great South Bay resulted in the determination of a tidal flow towards the East of 224 million cubic feet during flood tide, and a westward flow of 217 million cubic feet during ebbtide, producing a 7 million cubic feet net eastward flow during each cycle. The maximum velocity recorded was 1.9 knot and the excursion during the incoming tide was approximately 3 miles. The typical counterclockwise flow pattern in the bay causes a faster flow in the East-West New York State boat channel and also gushing out of water at Fire Island inlet. The earlier estimate of Redfield (1951) about a 48-day flushing time in the bay had to be revised in light of the data obtained by employing the calculations of Gibson (1959) (Fig. 4). It resulted in 2.5 days whereas the approaches proposed by Ichiya (1966, 1967) that is the "simple tidal prism" method gave a result of 3 days and the "modified tidal prism" technique resulted in 11.5 days. Obviously, the flushing time of the bay is somewhere between 3-12 days, which is much faster than it had been presumed.

Measurements of different wave lengths of light absorption at different depths of the water could serve as an excellent method for studying sedimentation characteristics. A special underwater spectrophotometer has been constructed and supplied with specially made narrow band-width color absorption filters. For several months Rabin (1968) carried out measurements at the stations identified in Fig. 2. He found that, dependent upon the quantity and

TABLE 1

Sample Characteristics and Humic Acid Contents as Percent of Total Sample Weight

Sample No.	Location	Character of Sample	pH	Eh	% Humic acid/wt.
2-1	40°39.1'N,73°24.7'W	Gray Silt & Black Mud	6.7	-35	4.4%
2-2	40°39.0'N,73°25.1'W	Black Mud	7.2	-180	4.2%
2-3	40°38.8'N,73°25.1'W	Gray Silt	6.9	+90	3.8%
2-4	40°38.8'N,73°25.1'W	Gray Silt	6.7	-20	4.0%
2-5	40°38.8'N,73°25.0'W	Black Mud	7.1	-240	4.4%
2-6	40°38.2'N,73°25.0'W	Black Mud	7.2	-390	5.0%
2-7	40°37.5'N,73°25.0'W	Black Mud	7.1	-130	4.5%
2-8	40°37.0'N,73°24.9'W	Silt & Sand	7.4	-300	4.8%
2-11	40°38.8'N,73°19.6'W	Coarse Sand	7.3	-120	4.0%
2-12	40°39.2'N,73°17.7'W	Brown Sand	7.2	-120	4.2%
2-13	40°39.8'N,73°17.7'W	Black Mud & Gray Sand	7.2	-120	4.1%
2-14	40°40.0'N,73°19.0'W	Black Mud & Silt	7.3	-85	3.9%
2-15	40°39.6'N,73°20.8'W	Black Mud	7.1	-375	4.9%
2-16	40°39.5'N,73°22.6'W	Black Mud	7.6	-160	4.3%
Control No. 1	Massapequa St. Park	Soil, lawn grass	7.0	+40	3.4%
Control No. 2	Massapequa St. Park	Soil, Forest	6.8	+110	3.1%



Ratio of Humate/KBr = 50mg/1000mg

Figure 2

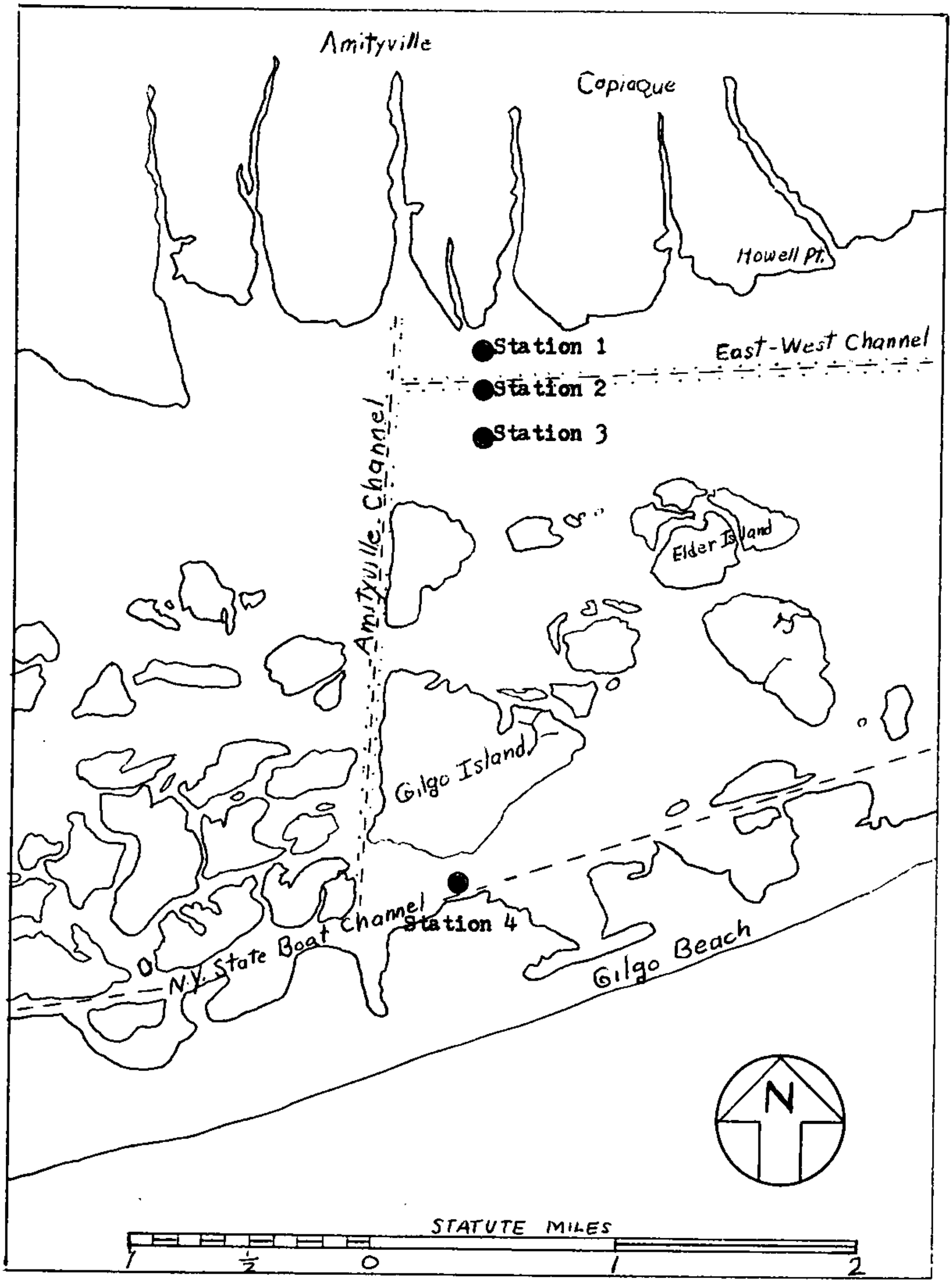


Figure 3 LOCATIONS OF STATIONS FROM WHICH OBSERVATIONS WERE MADE

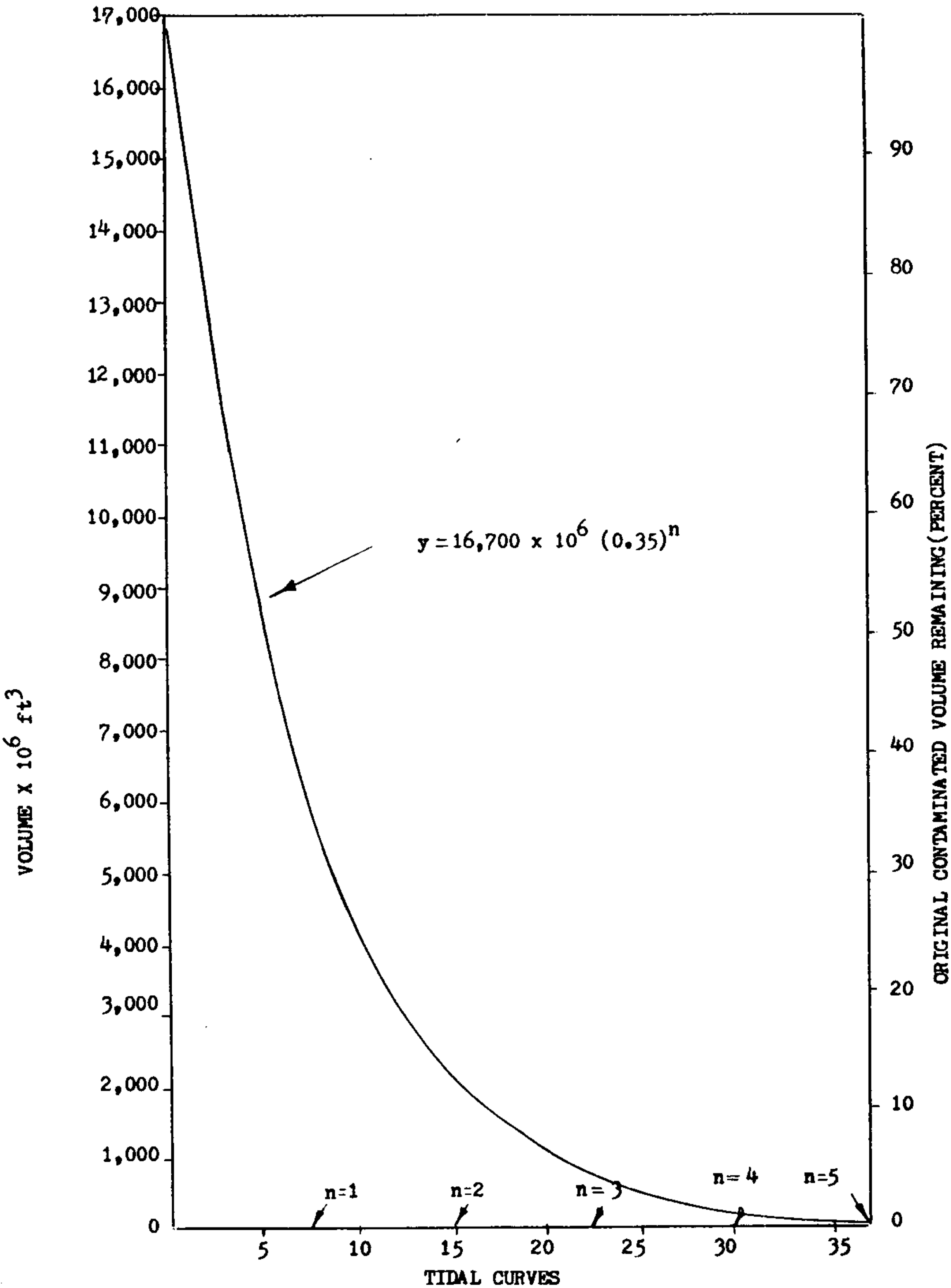


FIGURE 4 -FLUSHING CURVES

quality of floating material, different absorptions resulted in any particular transect of the waters. Close to the bottom, where the highest absorption values were expected to occur, an invariable upwelling of light in the blue region was found. This could be attributed to diffuse reflectance from sedimenting silt (Fig.5,7). Absorbancies of the top layers frequently showed maxima, at 540 and 680 millimicra, peaks of chlorophyll absorption. These observations coincided with the occurrence of heavy algal blooms. Turbulences in the water caused by extensive boating activities, dredging, or rainfalls could be followed through absorption measurements both in time and space. Lowest values were obtained when no human activity was present, and in the waters of relatively rapid movement around Fire Island Inlet. Here probably the currents already dropped their sediment load and waters gushing off to the ocean were less turbid than those circulating in the bay.

The possibility of using light absorption measurements for the rapid identification of degree of pollution through the development of massive plant growth or through the identification of turbidities as a result of surface runoffs has been pointed out.

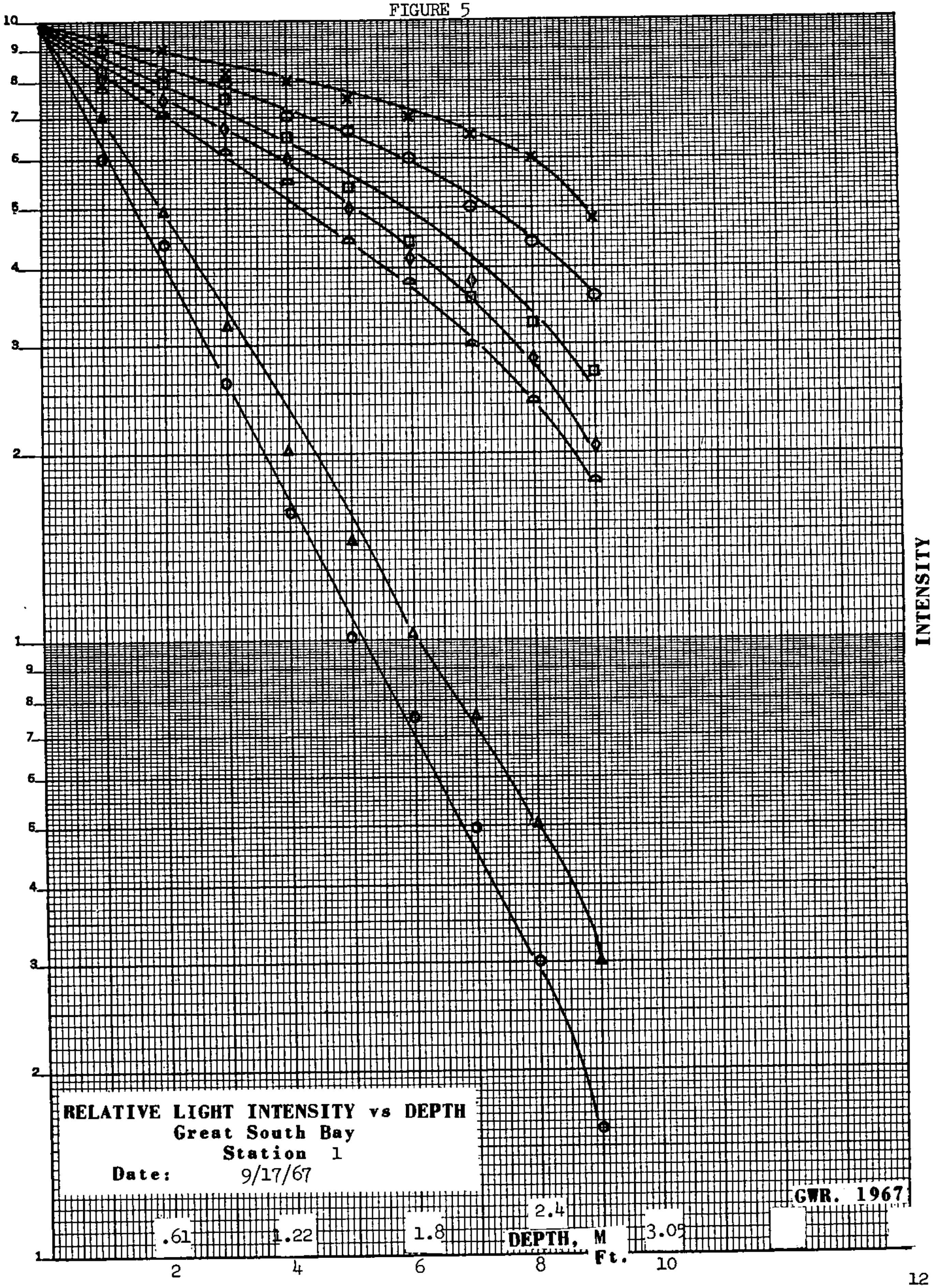
Another rapid technique for possible characterization of pollutional loads presents itself in the determination of values of light reflectance measured as upwelling absorption. Fig. 6 shows the sites where such measurements were taken from overflying airplanes. The stations were selected by Castiglione (1969) in such a way that one was close to the mouth of a polluted small stream and the others were located close to the shore but in the bay, where the original pollutional load has already been dispersed. Simultanteously with the absorption measurements, water samples at the stations were collected and analyzed for the abundance and quality of different algal species. The qualitative analyses were carried out in situ on wet mounts while for the quantitative samples 0.45 micron millipore filter preparations were used. Dependent upon the presence of major plant pigments in the water, a good correlation was found between the dominating algal phylum and the absorption peaks observed (cf. Fig. 7 and Table 2). Thus, in all cases a sharp peak for chlorophyl "a" was present accompanied by the broad carotene peak. However, in case of diatomaceous dominants the carotene peak was more pronounced and the secondary chlorophyl "e" peak also showed up.

In the polluted small river, a peak occurred which was eventually identified as a reflectance maximum of bile pigments. The river carried a pollutional load originating from duck farms and the peak observed was most probably the result of leaching of duck manure into the water.

The good correlation found between the dominant algal forms in the water, or even some colored pollutant such as bile pigments and reflectance peaks, could serve as an efficient and rapid method for remotely sensing types and probable quantities of pollutants.

For measuring dissolved organic matters, a new and fast spectrophotometric method has been worked out by Truglio (1968). Dissolved organic material always contains a usually proportional amount of proteins or their derivatives, including aminoacids. The high and characteristic absorption peak of tyrosine at 280 millimicron is not masked by any other dissolved material in sea water. By measuring the tyrosine peak of the water, one can

FIGURE 5


INTENSITY
10
9
8
7
6
5
4
3
2
1
9
8
7
6
5
4
3
2
1
RELATIVE LIGHT INTENSITY vs DEPTH
Great South Bay
Station 1
Date: 9/17/67
GWR. 1967
.61
1.22
1.8
2.4
3.05
DEPTH, M
Ft.
2
4
6
8
10
12

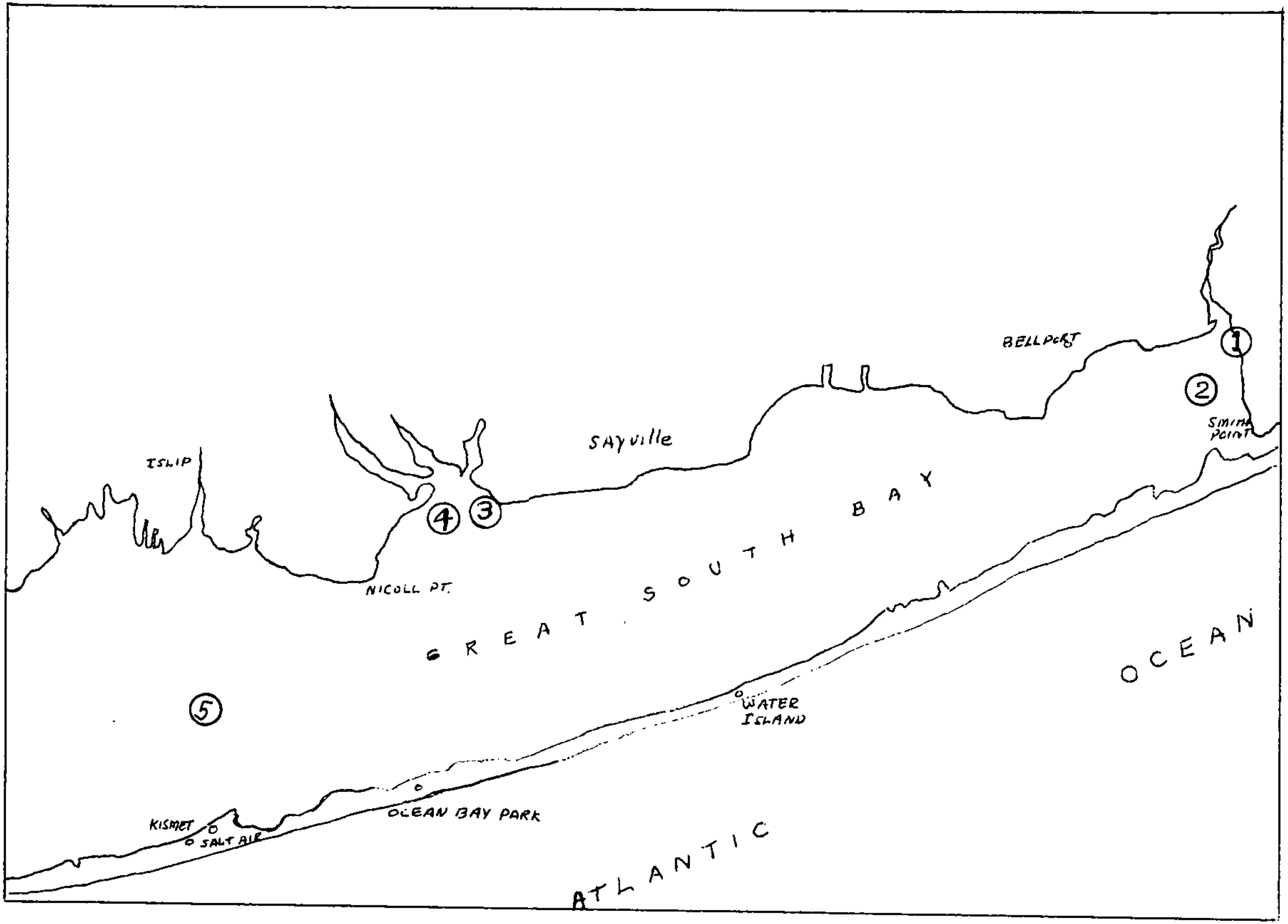


Fig. 6 LOCATIONS OF TEST STATIONS IN GREAT SOUTH BAY

AVERAGE ABSORPTION OF STATION 2

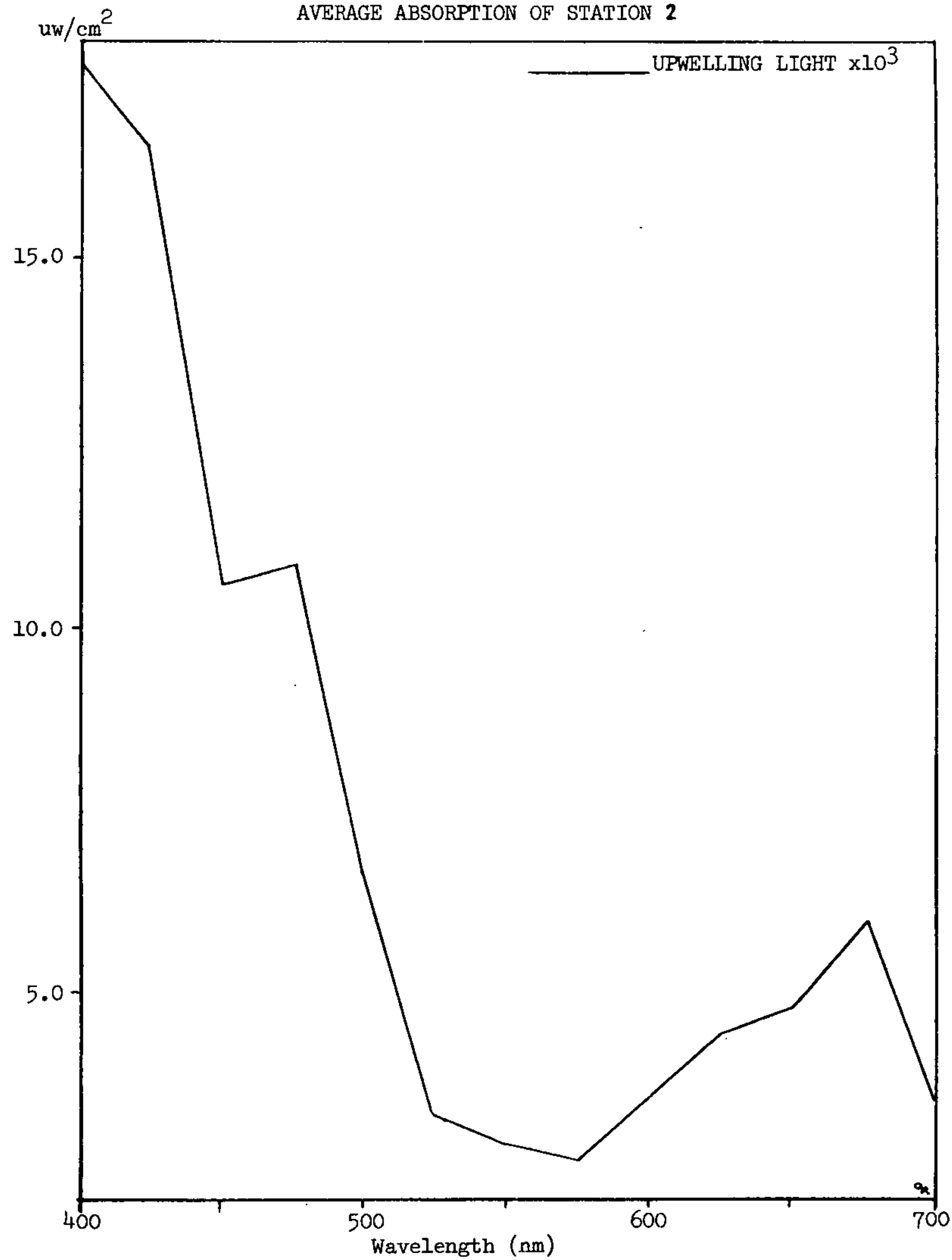


FIG. 7

TABLE 2

Millipore Analysis July 23, 1968

Sample Point: Mouth of Carmen's River   Station: II Surface   Slide: 4S

Classification of Algae Viewed

Class	Average #/100 cc	Percent
Chlorophyta	420	50.5
Chrysophyta	273	32.8
Bacillariophyta	138.60	16.7

Organisms	# Viewed	Average #/100 cc
Coscinodiscus	16	36.3
Lagenula	120	273
Navicula	30	68.3
Chlorella	185	420
Pinnularia	15	34

Sample Point: Mouth of Carmen's River   Station: II Middepth   Slide: 4M1

Classification of Algae Viewed

Class	Average #/100 cc	Percent
Chlorophyta	156	80.5
Bacillariophyta	36.5	18.8
Chrysophyta	2.41	1.24

Organisms	# Viewed	Average #/100 cc
Chlorella	65	156
Navicula	15	36.5
Lagenula	1	2.41

Sample Point: Mouth of Carmen's River   Station: II Middepth   Slide: 4B1

Classification of Algae Viewed

Class	Average #/100 cc	Percent
Bacillariophyta	138.30	100.0

Organisms	# Viewed	Average #/100 cc
Navicula	36	86.8
Pinnularia	11	27.5
Coscinodiscus	6	14.4
Melosira	4	9.6

express the dissolved organic materials in tyrosine equivalents. Simple conversion factors based on a general 3% tyrosine in proteins and a 30% protein content of organisms yields the total of dissolved organic materials in the water. Extensive organic carbon determinations on the samples confirmed the general applicability and usefulness of the tyrosine equivalent data.

Parallel to the measurements of the tyrosine equivalents, a study of primary productivity, coliform densities, and abundance estimates of eel grass has been conducted. It was found that the highest levels of productivity occurred during the summer and early fall and these quantities showed a good correlation with the coliform numbers (Fig. 8). Coliform bacteria are known to survive for various periods of time in sea water in an actively multiplying state, thus their high numbers in the bay is not surprising. The unexpectedly-found distribution of the bacteria, however, was noteworthy. In highly polluted regions, in the small boat canals or marinas, relatively low numbers of coliforms were found during the whole year of investigation; whereas at the mouths of the canals and at the completely uninhabitated area of Fire Island Inlet large quantities of coli bacteria occurred. The only explanation for this lies in the fact that in the canals and marinas large quantities of detergents from household usage and hypochlorites from the macerators of marine toilets entered the water, which then either become degraded or diluted adequately by the time they reached the mouth of the canals, thus their bacteriocidal effect was eliminated, permitting the development of an E.coli flora. The known counter-clockwise circulatory pattern of the bay waters swept away the coliforms from the canals and deposited them around Fire Island Inlet where, in this way, a natural enrichment of bacteria occurred. Indeed, the waters around the Inlet, both within the bay and as they entered the open ocean, contained three to four times more coliforms per cc. than the rest of the bay.

By graphing (cf. Fig. 8) temperature, primary productivity, coliform counts and dissolved organic materials, the following correlations could be drawn. Primary conductivity followed closely the temperature curve, which was also similar to the results of observations on coliform numbers. The amounts of dissolved organic material, however, always preceded the peaks of productivity or coliform abundance. It seemed that when higher quantities of dissolved proteinaceous materials were available, both bacteria and micro algae showed an upsurge in multiplication - probably by utilizing the available organic material. By the time their numbers reached a peak, most of the organics had become depleted.

The abundance of eel grass in the bay did not show any correlation either with the amount of available proteinaceous matter or with the values of productivity. For the abundance of the grass some other factors, not determined in this study, must have been responsible.

A prime example of the economic loss suffered by a once-flourishing industry as a result of increased and unchecked pollution is that of the catastrophic decline in the shellfish production on Long Island. In 1910, oysters and clams grown in Long Island Sound and in the bays yielded a revenue close to 50 million dollars. In 1960, however, the total production was worth only 1.5 million dollars. The famous Blue point oyster lives only in its name. It no longer is found in Great South Bay. The gradual decline started to

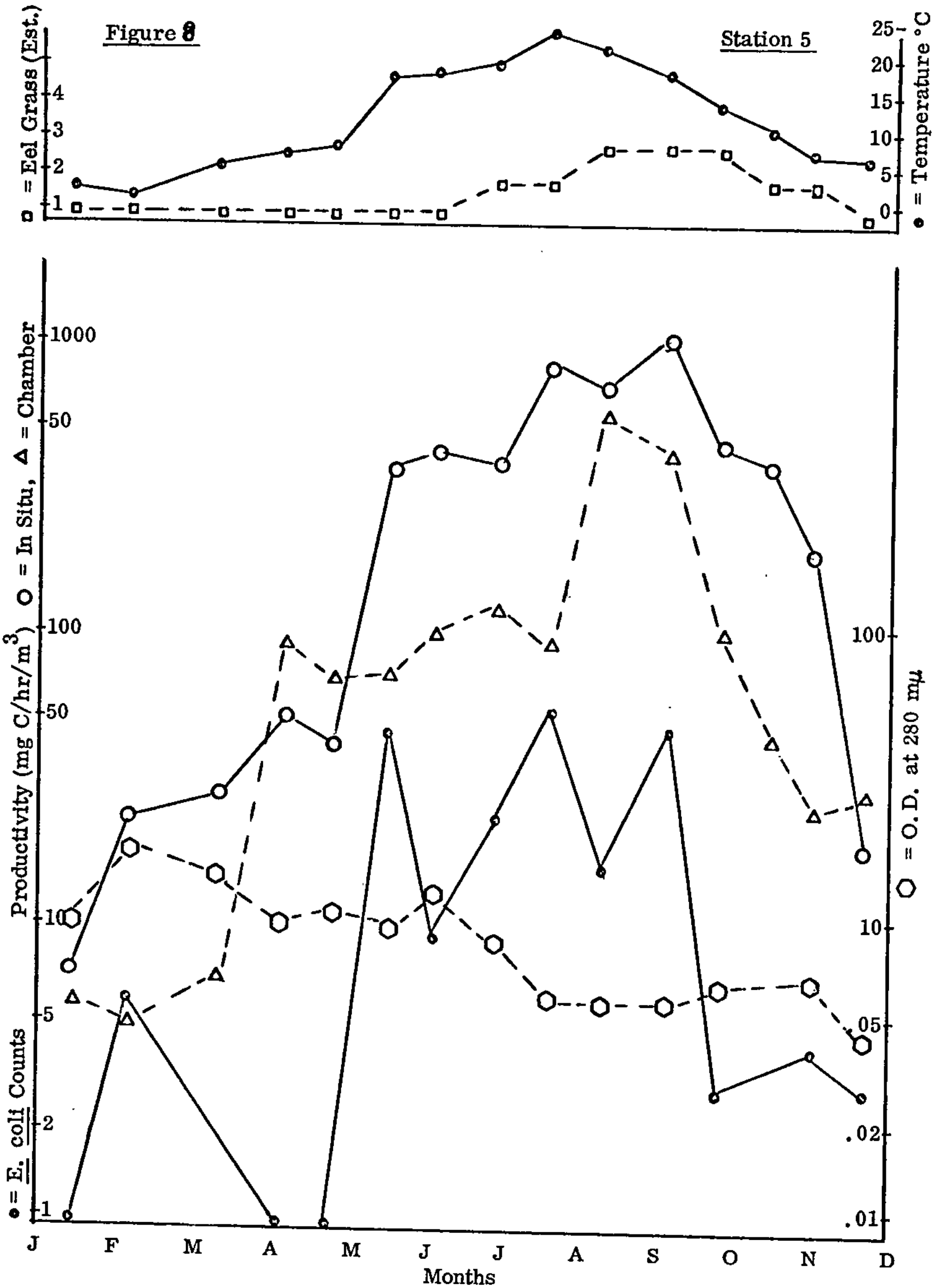


Figure 8
Station 5
= Eel Grass (Est.)
1
2
3
4
25
20
15
10
5
0
= Temperature °C
Productivity (mg C/hr/m3) = In Situ, = Chamber
1000
50
100
50
10
5
2
1
= E. coli Counts
100
10
.05
.02
.01
= O.D. at 280 mμ
J
F
M
A
M
J
J
A
S
O
N
D
Months

reach alarming proportions during the early forties. Concerned municipalities commissioned the Woods Hole Oceanographic Institution to conduct surveys of the waters of Great South Bay and, if possible, to pinpoint the cause or causes which led to the decrease in shellfish-catch. Each summer, for 10 years, scientists from Woods Hole analyzed the chemical and physical properties of the waters and determined the types and quantities of microscopic organisms: bacteria, algae and protozoa. It was observed that during the warm summer months the water turns a murky green as a result of a sudden and tremendous growth of a unicellular green alga called "small form" by the local oyster growers. Mass mortality of shellfish ensued when such blooms appeared. Scientists studying the problem found several interesting correlations: they identified the "small forms" as Nannochloris atomus, a species of green algae, the numbers of which, during blooms, frequently exceed 1 million per 1 cc of water. The organism induces shellfish mortality through three different mechanisms: 1) by their massive occurrence, Nannochloris suppresses the growth of useful food organisms, while it itself, not being consumed by the mollusks, deprives them of food; this leads, in certain cases, to starvation; 2) because of their small size the algae seem to clog the fine ciliary tracts of the bivalves, thereby preventing them from taking up food normally; 3) some experimental evidence has been gathered which indicates that Nannochloris when ingested by shellfish is outrightly toxic, killing the animals in a few days.

What caused the sudden outbursts of algal blooms? The answer was supplied by water-chemistry studies. The assays showed that there is an unusually high level of phosphates dissolved in the bay. Phosphates are an essential nutrient and growth-promoting factor for algae. Coupled with high summer temperatures, the overabundance of phosphates created ideal conditions for the multiplication of Nannochloris. The source of the phosphates was then easily established. Duck farms abound in the eastern section of Long Island. Several million ducklings are hatched, grown and slaughtered every year. The waste products of these farms (mostly duck manure) were dumped untreated into the channels and small tributaries of the area entering Moriches Bay. This latter body of water is connected to Great South Bay and, in lack of direct outflow to the Atlantic Ocean, its contents flushes into it. (In 1934, a hurricane permanently filled up and closed Moriches Inlet, hitherto the gate of Moriches Bay to the open ocean.)

Using quantitative chemical determinations, it was shown that a phosphate gradient exists between Great South Bay and Moriches Bay, and that it was at maximum at the mouths of the small tributaries carrying the duck wastes to the bay. Also, the flushing rate of the whole bay system was calculated and found to be 48 days, which gave ample opportunity for the development of water blooms.

In recent studies, however, no higher coliform counts were obtained in the East-West channel of the bay where waters from the supposedly highly polluted Moriches Bay are mixed with those of Great South Bay. Most of the duck farms located on Long Island still drain their sewage into Moriches Bay, and the enrichment of these waters with coliforms originating from duck manure was supposed to result in the contamination of shellfish beds located in this area. Since higher coliform counts were not found in the channel, the aerating lagoon treatment instituted by the duck farmers to purify their wastes seems to be quite efficient.

Long Island occupies a peculiar position among shore communities. The population density of the western part of the Island equals that of any large city. The small plots of the developments are almost exclusively covered with lawn, while the eastern, less densely populated region, is characterized by large potato farms. Both lawn owners and potato farmers use large amounts of fertilizers "to keep up with the competition." As a consequence, the per-acre fertilizer usage on the Island is 50 times higher than the national average. The phosphates in the fertilizers are only partially bound in the soil, and their greatest proportions are carried into the bay, either by ground water seepage or by storm-fall overlows. Besides supplying nutrients to plant growth, most homeowners and farmers also use unwarrantedly high amounts of weed killers and other pesticides. These highly toxic materials are eventually carried into the bay, too, and accumulate on its shore, exerting their detrimental influence on the native biotic population. None of the pollution abatement measures take into consideration the removal of phosphates and pesticides from the water. Although ambitious plans are being developed for installing more efficient sewage treatment facilities, either through upgrading existing plants or installing new ones affording secondary treatment, there are no provisions for the establishment of plants providing tertiary treatment, which would be required for phosphate removal. The complete canalization of each community on the Island, to do away with the commonly used cesspools for preventing the pollution of the ground water, and the development of a combined domestic and rainwater sewer system would cost over $1 billion, an investment which is way beyond the reach of the community fathers.

During the past 20 years, several solutions have been offered to solve the problems posed by pollution in Great South Bay. Legislation has been enacted to force the duck farmers to treat their waste through chlorination and open lagoon aeration. Supposedly, by 1970, all duck farm effluents will conform to the standards prescribed by the State Health Department. A plan has been drawn up to dredge a major east-west channel in the bay, thereby facilitating water movements and decrease flushing time. Since great numbers of pleasure boats on the bay are not outfitted with appropriate marine waste disposal systems, laws are being drawn to compel the owners to install certified marine toilets. It is, however, still questionable whether any or all of these measures will be adequate to maintain even the current deteriorated state of the bay.

At present, the toxic effect of household and industrial sewage entering the bays is not yet at the level where it would endanger the biota. In fact, the amounts of inorganic nutrients (nitrates and phosphates) create favorable conditions for algal growths, upon the dead bodies of which a luxuriant microfauna thrives. Both the algae and some of the small protozoans serve as excellent food for shellfish. It was indeed recently ascertained that the bottom of Moriches Bay and the small tributaries carrying the duck farm wastes into it are covered with great numbers of hard clams (Vojvoda, 1966). The Town of Riverhead undertook an ambitious program to dredge these animals and, for purposes of depuration, transfer them into waters declared to be clean and safe by the Health Department. Eighteen hundred bushels of clams were transported last year, but the project proved to be too successful. The town never was able to reclaim and economically utilize the depurated clams because before the employees of the town had had an opportunity to lift the animals, they had already been dug up by local clam diggers! The economic loss suffered by Riverhead in its efforts to make use of the polluted organisms of Moriches Bay put an end to this venture.

That the waters on the South Shore of Long Island are highly fertile has been known for the past 30 years. In fact, this great fertility manifests itself each year in abundant algal blooms or in the occurrence of large quantities of eel grass (to the chagrin of the home owners or pleasure boaters). In early June, at the peak of the eel grass season, petitioners storm the local authorities demanding the cleaning from the bay of these nuisance organisms. Eel grass, a higher aquatic plant, has well-developed root systems and its long, slender leaves reach clear to the top of the water, entangling the propellers of local crafts. During storms they may be ripped off and then deposited in quantities on the shore, where they undergo a rapid decomposition, discoloring paint and producing odors which are detectable for miles. Eel grass does, however, play a very important role in the eco-system of the bay. That the waters in the bay have not yet turned into a bog is mainly due to the abundance of the grass and to the periodic algal blooms.

The bay is silting at a rather rapid rate. In certain areas an increase in bottom sediment of over an inch per year was noted. Because of the high productivity of its waters, these sediments contain large quantities of organic materials. During the cool nights of the summer, oxygen deficiency can frequently develop in the waters, permitting anaerobic microbes to proliferate in the sediment. One consequence of anaerobiosis is the liberation of hydrogen sulphide, methane and other noxious gases from the accumulated organic matter. These highly toxic substances, if produced in large enough quantities, may kill the oxygen-producing algae and the other higher aquatic plants, turning the bay into a bog. At this moment a delicately balanced system exists in the water and due to the abundance of algal blooms and eel grass enough oxygen is liberated through assimilation to upset the deadly consequences of the anaerobic processes in the sediment. Elimination of eel grass or a further increase in the introduction of toxic waste materials into the bay may easily cancel out the beneficial effects of algae and other plants and there will no longer even be the possibility of postponing the salvaging of the bay.

One could summarize the major problems besetting Great South Bay and also the adjacent bays on the South Shore of Long Island as follows: the ecological difficulty stems from the presence of exceedingly high concentrations of phosphates in the water, which originate mostly from surface runoffs and inadequate sewage treatment facilities. A second major contributing factor is provided by the continuous seepage of organically highly enriched domestic wastes from the thousands of cesspools on the Island.

Thus, gradual eutrophication of the waters brings about conditions favorable to continuous algal blooms which, on the other hand, through the accumulation of organic matter, increase the rate of sedimentation, hastening the filling up of the bay.

To find an optimal solution and thus to save the bay from becoming obliterated would require several, and almost heroic, measures. First of all, a combined sewer system would have to be established throughout the whole island which would eliminate the entering of storm drainage into the bay without treatment. Such plants would have to be equipped with a capacity for tertiary treatment to remove phosphates. Furthermore, the existing cesspools would have to be eliminated and substituted with municipal sewage collecting and treating facilities. In addition, the thousands of small boats and yachts sailing the bay will have to be supplied with their own waste treatment equipment in order to prevent the pollution of the waters by these crafts. Finally, in certain areas of the bay, the accumulated layers of the sediment would have to be dredged, transferred and dumped in the open ocean to decrease the vicious circle of supplementing the availability of nutrients in the water through the recirculation of decaying organic matter. Since at the present time no such plans exist, it is highly questionable whether or not the bay will be saved.

This pessimistic forecast raises the question as to the fate of the shellfish industry of Long Island. Since there are few solid plans and certainly the finances are not now available which would be required to stop further deterioration of the bay, oyster men utilizing conventional techniques are not likely to enjoy a prosperous future. In view of this, one hope for the shellfish industry lies in establishing controlled environmental conditions for their mariculture projects. Bivalves will then be raised from eggs to maturity in large tanks or basins in which the quality of the water and the food supply is continuously and closely monitored.

It may be necessary to give up hope for the conservation of the bay itself. It will eventually turn into an anaerobic bog which will be transformed into pastures or sites for developments in the next 100 years at the present rate of sedimentation. Man's activity only hastens a natural phenomenon which would have taken place anyway even without the existing pollution problems. The time necessary for this would probably have been only double the present rate. One should remember that at the end of the past century Coney Island was still an island and that where Kennedy Airport lies now, a flourishing fishing village stood with boats sailing the waters. These areas filled up by natural processes and became part of the land mass, not because of man's adverse activity but because of erosion and sedimentation.

REFERENCES

Castiglione, L.I., 1969. In situ study of the natural population absorption spectra in the Great South Bay, L.I., N.Y. Accepted for publication in Ann. Am. Acad. Ocean Sci. 1 (2) pp. 46.

Gibson, W., 1959. A method for estimating the flushing time of estuaries and embayments. U.S. Navy Hydrographic Office, Washington, D.C. pp. 1-18.

Ichiye, T., 1966. Tidal flushing of South Oyster Bay and Great South Bay. Unpubl. Rep. Lamont Geol. Obs., Columbia Univ., New York, N.Y. 1:1-10, 2:1-41.

__________, 1967. Tides and tidal currents of South Oyster Bay and Great South Bay. Unpubl. Rep. Lamont Geol. Obs., Columbia Univ., New York, N.Y. 1:1-11, 2:1-18, 3:1-13, 4:1-8, 5:1-6.

Jamieson, W., 1968. Data to the hydrography of Great South Bay, Long Island, N.Y. Accepted for publication in Ann. Am. Acad. Ocean Sci. 1 (1) pp.48.

Penn, S., 1968. Preliminary analysis of the sediments of Great South Bay, Long Island, N.Y. Accepted for publication in Ann. Am. Acad. Sci. 1 (1) pp. 48.

Redfield, A.C., 1951. Report on a survey of the hydrography of Great South Bay made during the summer of 1950 for the town of Islip, New York. Unpublished manuscript. Ref. 50-48. Woods Hole Oceanographic Institution, Woods Hole, Mass. pp. 1-30.

Robin, G.W., 1968. Water transparency studies, observations and their analysis in Long Island's Great South Bay. Accepted for publication in Ann. Am. Acad. Sci. 1 (2) pp. 59.

Truglio, D., 1968. Studies on primary productivity, bacterial pollution and dissolved proteinaceous matter in the Great South Bay, Long Island, N.Y. Accepted for publication in Ann. Am. Acad. Ocean Sci. 1 (2) pp. 1-19.

Vojvoda, R., 1966. Statement. Proc. Conf. water pollution. Patchogue, N.Y. Sept. 20-22, 1966. U.S. Dept. F.W.P.C.A. pp. 471-476.

Whalen, C., 1969. Determination of humic acids in estuarine sediments. Accepted for publication in Ann. Am. Acad. Ocean. Sci. 1 (1) pp. 16.

SHELLFISH AND PUBLIC HEALTH

by

William Jamieson, Ph.D.

Columbia University Seminars on
Pollution and Water Resurces

1970

INTRODUCTION

Shellfish can be broadly defined as any aquatic animal having a shell. This definition would include crustacea such as lobsters, shrimps, and crabs as well as bivalves such as clams, oysters, mussels and scallops. In the context of public health matters, it is this latter group which is the source of concern because it is this group that may be eaten raw and, being filter feeders, have the ability to concentrate impurities in their bodies.

Since the days of early man, shellfish have been a valuable source of high-grade protein. In Charles Dickens' time the plentiful oysters were so inexpensive they were considered to be a poor man's food. When the European colonists landed in the new world they found the estuaries to be rich in shellfish. Recognizing the value of this resource, the Dutch council of New Amsterdam passed an ordinance regulating the taking of oysters in the East River in 1658 -- over three hundred years ago (Houser (9)).

As populations along the river banks and estuarine shores increased, the sewage and waste products entering the waters likewise increased; and the sanitary quality of shellfish decreased -- sometimes to the point where illness could be traced to the consumption of these shellfish. As more has been learned of the nature of the transmission of disease by shellfish, appropriate sanitary controls have been adopted and, despite the ever worsening quality of the estuarine water, few, if any, epidemics which could be traced to the consumption of shellfish have occurred in the United States for the last forty-four years.

HISTORY

The public health problems associated with shellfish are not new. In Europe, shellfish from polluted water were suspected of causing illness in 1603. In the United States, serious outbreaks of typhoid occurred in the 1890's.

In a 1905 report the New York Bay Pollution Commission noted that oysters taken in the New York Bay area were not shipped directly to market but were immersed in fresh or brackish water in order to bleach and swell the oysters. Many of these "drinking" places were found to be heavily polluted. The Kill Van Kull, for example, had an excess of 7,000,000 gallons of raw sewage discharged into it daily within a distance of three miles; yet approximately 10,000 bushels of oysters were treated there each day. The report stated that outbreaks of typhoid fever had been traced to oysters treated in this manner and urged that the practice be outlawed (Anonymous 24)).

In the winter of 1924-1925 New York, Chicago and other large cities were hit with severe epidemics of typhoid. The cause was attributed to oysters harvested from waters polluted with human sewage.

Government control of shellfish growing and processing was obviously required. On September 25, 1925 the first recommendations for the sanitary control of the shellfish industry were submitted to the Surgeon General of the U. S. Public Health Service. Thus, a cooperative program involving the States, the shellfish industry and the Public Health Service was initiated. This program, the National Shellfish Sanitation Program, is still in existence and is revised as new information and conditions dictate.

The National Shellfish Sanitation Program has done much to control the spread of disease through contaminated shellfish, but it has not entirely eliminated that threat. In 1961 an outbreak of hepatitis attributable to the eating of polluted oysters occurred in Pascagoula, Mississippi. That same year several cases of hepatitis were reported that resulted from the consumption of clams gathered from the waters of New York, New Jersey and Connecticut (Ridge, et. al. (18)). In 1966 several cases of typhoid traced to the consumption of polluted oysters were reported in Florida.

NATURE OF THE PROBLEM

At the very heart of the problem is the manner in which the shellfish receives its nourishment. The clam, oyster, scallop and mussel are all bivalves -- better known as "filter feeders." The feeding mechanism, however, is not a simple filter, as the name suggests. The original respiratory gills, through evolution, have become a complex organ for removing fine particles carried in suspension in the water. The gills have the ability to adjust the distance between adjacent gill elements, thereby controlling the size of particles accepted. The lamellae of the palps sort out the particles and permit only particles of the proper size (up to 45 microns) to reach the orifice of the mouth (Montemurro (16)). The accepted particles may be composed of dinoflagellates, unicellular algae, protozoa, particles of industrial waste, chemicals, bacteria and, quite often, sand grains. The food then passes into the digestive gland where intracellular digestion occurs. The shellfish cleanse themselves by means of ciliary action thereby removing the unwanted particles from the mantle in the form of pseudofeces.

The pumping rate of the eastern oyster, Crassostrea virginica is believed to be between 4 and 15 liters/hr. That of the hard clam, Mercenaria mercenaria is from 6 to 7 liters/hr (Montemurro (16)). Pumping rates are exceedingly temperature and salinity dependent. During winter the shellfish feed less actively and often lie dormant (Hamwi (8)).

The microscopic particles of pollutants such as bacteria, virus, radionuclides and organisms containing paralytic poisons are thus removed from the water, accumulated in the shellfish and eaten along with the shellfish. This is the nature of the problem.

It follows that the water environment in which the shellfish grows is of paramount importance. In clean, pollution-free water there are few harmful particles; therefore, large concentrations of any pollutant are not likely to occur in the body of the shellfish. However, shellfish are usually found in shallow coastal waters such as sounds, bays, estuaries and, quite often, rivers. Unfortunately, it is these very waters that receive the major portion of the pollutants civilization discharges into the marine environment. Since most shellfish are non-motile after they have passed the larval stage, they are not capable of changing their location to escape an unfavorable environment. Thus, they will remain in the polluted waters and, if they live, will accumulate in their bodies concentrations of some of the pollutants in the water. For example, concentrations of trace metals may be thousands of times greater than the concentrations of the same metals in the water in which they live (Pringle (17)). Shellfish have been found to thrive downstream from some sewage discharges. The plentiful sewage bacteria become prey of ciliates which, in turn, are food for the shellfish (Ingram (10)).

THE CONTAMINANTS

Chief among the contaminants found in shellfish taken from polluted waters are bacteria and viruses. Although shellfish are not directly affected by the pathogens, they do serve as concentrators and carriers. The organisms tend to collect on the gills, and, in some cases, in the shell liquor. Though they do not seem to multiply in shellfish, they are capable of surviving for several days.

Salmonella is one of the disease-producing bacteria associated with shellfish either grown in polluted water or subject to unsanitary handling during processing. It is a genus of the order Eubacteriales and the family Enterobacteriaceae. They are gram negative and ferment glucose and other carbohydrates.

Two diseases can be caused by the ingestion of live Salmonella bacteria. The more common one is salmonellosis caused by S. choleraesuis and S. paratyphi A, B and C. The symptoms of the disease are diarrhea, abdominal pain, chills and fever, and vomiting. The incubation time can range from 6 to 72 hours depending on the number of live organisms ingested (Salvato (19)).

The other disease is typhoid fever and it is caused by the species S. typhi. It is an extremely dangerous disease and is often fatal. The victim experiences abdominal pain, a headache and fever. The infection originates in the small intestine but the organisms often enter the blood stream and affect various organs of the body. The incubation period is from one to three weeks.

Another contaminant sometimes found in shellfish produced or handled under unsanitary conditions is hepatitis virus. One type of this virus (sometimes called type A) is transmitted through the fecal-oral route and can cause the disease known as infectious hepatitis. This disease is not to be confused with serum hepatitis which is transmitted through blood or venipuncture. Although somewhat similar to infectious hepatitis in symptoms, it is not a gastrointestinal disease and cannot be transmitted by food.

Infectious hepatitis produces — in addition to the typical jaundice symptoms -- abdominal pain, fever, and loss of appetite. Incubation period is from 10 to 56 days (Ridge (18)). In recent years outbreaks of infectious hepatitis, attributed to polluted shellfish, have been reported in Sweden, Mississippi, New Jersey, New York, and Connecticut.

Irradiation has been tried as a means of removing virus from shellfish but to date this method does not show much progress (DiGirolamo (4)).

Of public significance is paralytic shellfish poisoning (P.S.P.) which is caused by a toxin contained in various dinoflagellates, with Gonyaulax tamarensis, Gonyaulax catenella, and Gymnodinium breve being the principal offenders in the United States. The toxin is not toxic to the flagellate nor to the shellfish which ingest the flagellate and greatly concentrate the toxin, but it can cause a paralytic effect and even death in vertebrates (Wass (23)). A single serving of shellfish containing a few milligrams of the toxin can cause extreme illness in humans. There is no known antidote although it is believed a resistance can be built up. People living in Nova Scotia coastal regions have been known to eat large quantities of toxic mussels with no ill effects. Dr. Sparks of the University of Washington reported an experience with a clam digger who plies his trade near the entrance to Sequim Bay, Washington. Toxicity levels for these waters average 1,500 to 2,000 mouse units. The clam digger explained that he ate clams all year round and could tell when the "red tide" was in because his fingertips, toes and ends of his ears tingled. Also, it was during that period of time that most of his cats would die (Jensen (11)).

Toxicity of the toxic substance is expressed in mouse units (m.u.). A mouse unit is the amount of toxin which will cause death with paralytic symptoms in a standard 20 gram mouse in 15 minutes (McKee, et. al., (13)). One mouse unit is equal to about 0.2 micrograms of purified toxin.

Although all shellfish can concentrate this toxin, the scallop is known to accumulate large quantities of it in the visceral mass. However, since only the abductor muscle, which is free from toxin, is eaten, there is no health problem. A recent investigation shows the mussel to rank highest in the degree of toxicity followed by the butter clam, the soft shell clam, and finally the oyster (Sparks, et. al. (21)).

Twelve cases of paralytic poisoning were reported in Quebec due to the consumption of rough whelks (Buccinum undatum). It is believed the whelks must have fed on bivalves containing the toxin.

The public health importance of P.S.P. has prompted much research into the nature of the problem. Probably one of the most complete monographs on the subject of paralytic shellfish poison was published by McFarren, et. al., in 1960 (McFarren et. al. (12)). Recent studies have attempted to better define the relationship between intoxification and detoxification after the exposure of the shellfish to waters with a known concentration of dinoflagellates (Cummins (3)).

One of the new contaminants to pollute the shellfish growing areas is radionuclides. These radioactive isotopes enter the flesh of shellfish through the ingestion of nanoplankton which have absorbed the radioelements in the water. Mollusks are adept at concentrating radionuclides at levels high above that of the surrounding water. For example, the concentration factor for $Zinc^{65}$ in oyster meat is said to be about 1,400. Shellfish can stand these higher concentrations better than humans. A dose of 5,000 to 20,000 roentgens is required to cause a 50 percent mortality in mollusks, whereas only 450 roentgens would be required for humans (McKee et. al. (14)).

Most radionuclides in the oceans come from nuclear detonation although some come from natural sources (such as K^{40}), waste discharges from power plants, nuclear vessels, sea disposal of radioactive wastes, and sewage and effluents from hospitals and industry. Although shellfish may contain fairly high levels of $Zinc^{65}$ and $Iron^{59}$, it is not believed that they present a serious health hazard at this time (Campbell (2)).

Agricultural chemicals are entering the near-shore waters in increasing amounts. The ability of shellfish to accumulate these compounds has not yet been established; nor has their ability to concentrate the chlorinated hydrocarbons being experimentally used to control oyster predators or herbicides used to control aquatic plants been determined. Some experimental work has been done to determine if the ability of shellfish to concentrate pesticides could be used to advantage by using them as biological monitors of pesticide levels. Oysters were evaluated as monitors in the marine environment (Anonymous 25)) and freshwater mussels in the freshwater environment (Bedford (1)). Both experiments indicated that the shellfish might be used advantageously as indicators. Other investigations have shown that freshwater mussels concentrated not only the chlorinated hydrocarbon insecticides but also organophosphate insecticides such as diazinon and parathion (Miller (15)).

Estuarine waters adjacent to industrialized areas are especially prone to contamination by trace metals -- mainly copper, cadmium, chromium, zinc, iron, manganese, lead, nickel, and cobalt. The ability of shellfish to concentrate trace metals has posed a serious health problem and increasing attention is being paid to it, although the health significance of trace metals in the water has been investigated for the past decade (Schroeder, et.al.(20)). Recently, it has been found that for each doubling of the environmental level of a trace metal, the tissue level in the shellfish approximately doubled, while the initial tissue level of any given metal appears to be directly related to the rate of removal of the metal after the shellfish is exposed to a non-contaminated environment (Pringle et. al (17)).

THE NATIONAL SHELLFISH SANITATION PROGRAM

Since its inception in 1925, the National Shellfish Sanitation Program has acted to insure that shellfish shipped in interstate commerce will be safe to eat. Under this program the States, the Federal government through its Public Health Service, and the shellfishing industry have each been given specific responsibilities. These responsibilities as delineated in the three-part National Shellfish Sanitation Program Manual of Operations (Public Health Publication No. 33) are:

1. Procedures to be followed by the State - Each shellfish-shipping State adopts adequate laws and regulations for sanitary control of the shellfish industry, makes sanitary and bacteriological surveys of growing areas, delineates and patrols restricted areas, inspects shellfish plants, and conducts such additional inspections, laboratory investigations, and control measures as may be necessary to insure that the shellfish reaches the consumer in a sanitary manner. The State annually issues numbered certificates to shellfish dealers who comply with the agreed upon sanitary standards, and forwards copies of the interstate certificates to the Public Health Service.

2. Procedures to be followed by the Public Health Service - The Public Health Service makes an annual review of each State's control program including the inspection of a representative number of shellfish processing plants. On the basis of the information thus obtained, the Public Health Service either endorses or withholds en-

dorsement of the respective State control programs. For the information of health authorities and others concerned, the Public Health Service publishes a semimonthly list of all valid interstate shellfish-shipper certificates issued by the State shellfish-control authorities.

3. Procedures to be followed by the Industry - The shellfish industry cooperates by obtaining shellfish from safe sources, by providing plants which meet the agreed upon sanitary standards, by maintaining sanitary plant conditions, by placing the proper certificate number on each package of shellfish, and by keeping and making available to the authorities records which show the origin and disposition of all shellfish.

It is customary for the Public Health Service to arrange a Shellfish Sanitation Workshop every two or three years. The purpose of the Workshop is to discuss current technical and administrative problems, review related research findings, and review proposals for changes to the manual.

The manual of operations is divided into three parts:

Part I - Sanitation of Shellfish Growing Areas

Part II - Sanitation of the Harvesting and Processing of Shellfish

Part III - Public Health Service Appraisal of State Shellfish Sanitation Programs

Part I covers the administrative and laboratory procedures to be followed in the operation of the program, the sanitary survey of the growing areas and area classification, the closure of areas, the control of harvesting from closed areas, and the preparation of shellfish for marketing.

Prior to receiving the State approval as a growing area for shellfish, a comprehensive sanitary survey is required. The thoroughness of the survey is determined by existing conditions. Included in the survey is an evaluation of all sources of actual and potential pollution of the area, the distance of the pollution source from the growing area, effectiveness and reliability of nearby sewage treatment facilities, effect of tidal flow, wind, etc., on the distribution of the pollutants, and the presence of pesticides, industrial wastes and radionuclides in the growing area. When the sanitary survey indicates a need for laboratory tests they are conducted.

Growing areas are classified as:

1) Approved - Shellfish may be harvested for direct marketing.

2) Conditionally Approved - Shellfish may be ordinarily taken for direct marketing. However, a potential for contamination exists which requires close monitoring of water quality. A failure to meet the set quality standards is immediately reported to the State shellfish authority, which closes the conditionally approved area to shellfish

harvesting. Potential sources of such pollution are malfunctioning sewage plants, sewage from recreational use of water, high levels of runoff from rivers and streams and the presence of commercial or military vessels in the area.

3) Restricted - Shellfish may be harvested by may not be marketed until after controlled purification or relaying. This classification indicates a limited degree of pollution. The coliform median of the water may not exceed a MPN of 700 per 100 ml. and not more than 10 percent of the samples may exceed an MPN of 2,300 per ml. under the most unfavorable conditions.

4) Prohibited - Shellfish may only be harvested by special permit and must be carefully purified or relayed before marketing. The classification of an area as prohibited indicates that it is either contaminated with industrial wastes or with radionuclides, or that the MPN of the water exceeds 700 per ml., or that more than 10 percent of the samples have a coliform MPN in excess of 2,300 per ml. Coastal areas which have not been surveyed are automatically classified as prohibited.

In addition to the above classifications, the State shellfish control agency periodically collects and assays samples of shellfish from areas where shellfish toxins are likely to be found. Whenever an unsafe level of toxicity is reached, the area is closed to harvesting of that particular species of shellfish in which the poison was found.

Shellfish from prohibited or restricted areas must be prepared for marketing by one of two means -- both of which must be closely supervised by the State shellfish control agency. Relaying is the most commonly employed method. In this process the shellfish harvested from restricted or prohibited areas are transplanted into approved areas where they cleanse themselves of polluting materials. Experiments have shown that shellfish respond rapidly to changes in the bacteriological quality of the water (Vasconcelos (22)). Oysters have been known to eliminate virus in 48 hours when exposed to adequately and continuously flowing sea water monitored with regard to environmental factors (Hamblet (7)). Factors influencing the time needed to accomplish this cleansing process are (1) original level of contamination, (2) water temperature, (3) pH, (4) salinity, and (5) the presence of matter inhibiting or increasing the physiological activity of the shellfish. The American oyster, C. virginica, for example, will not feed, and hence most pumping ceases, at temperature below 7°C (Anonymous (26)).

Controlled purification is the alternate method of preparing shellfish from restricted or prohibited areas for market. Purification of shellfish from prohibited waters is only allowed when relaying is not practicable for biological reasons and no public health hazard will result. Purification is carried out in a purification (or depuration) plant.

The typical depuration plant is composed of:

1) Dry storage for untreated shellfish.

2) Washing and culling facilities prior to depuration.

3) Depuration tanks - Sea water equal to or better in quality than that found in approved areas is circulated through the tanks. The water must be carefully controlled as to flow rate, temperature, turbidity, bacterial quality and chemical quality.

4) Washing and culling facilities following depuration.

5) Controlled storage following depuration.

The length of time required for depuration is a function of the initial level of pollution, the final level of pollution desired, and the environmental conditions in the purification system (Furfari (6)).

The whole process of depuration is carefully monitored by the State shellfish control agency. The industry is assisted by the informational and technical guidelines presented in the Public Health Service report Depuration Plant Design.

Shellfish harvesters are informed by warning signs or by direct notification of areas closed to shellfish harvesting. To prevent illegal harvesting, closed areas are patrolled by a State agency or by local organizations to which the state has delegated the authority. The State shellfish control agency has the power to apprehend and prosecute offenders. Under certain conditions, complete removal of market-sized shellfish from polluted waters is considered to be the best assurance that the polluted shellfish will not reach the market. In such cases the "depletion" is performed under the direction of the State shellfish control agency.

Part II of the Manual of Operations deals with the handling and harvesting of shell-stock, the shucking and packaging of shellfish, the packing and shipping of shell-stock, the repacking of shellfish and the reshipping of shellfish.

All boats used in tonging, dredging or transporting shellfish and all trucks used in the transportation of shell-stock must be constructed and maintained in such a way as to prevent contamination of the shellfish. Bilge water must be prevented from reaching the shellfish. Shellfish containers must be kept clean and the shell-stock itself must be washed free of bottom sediments as soon after harvesting as practicable. Body wastes must not be washed overboard into harvesting areas but, instead, holding tanks must be employed. The contents of the holding tanks are emptied into approved shoreside disposal facilities.

The shucking and packing of shellfish is carefully controlled from a sanitation standpoint under the National Shellfish Sanitation Program. Attention is given to such matters as:

- wet storage for shellfish prior to shucking
- processing plant layout
- dry storage for shell-stock
- floors, ceiling and walls
- heating and ventilation
- sewage disposal

- construction of shucking benches and tables
- utensils and equipment
- cleanliness
- storage of equipment
- plumbing
- refrigeration of shell-stock
- shucking of shellfish
- shell disposal
- handling of single-service containers
- packing of shucked shellfish
- refrigeration of shucked shellfish
- record keeping
- health of employees
- supervision of employees
- cleanliness of employees

The packing and shipping of shell-stock is monitored under this program. The washing of shell-stock is required and the shipping procedure is closely supervised. Likewise, the repacking of shucked shellfish and shell-stock is closely regulated.

Part III of the Manual of Operations covers the Public Health Service appraisal of the State shellfish sanitation programs. The complete procedure to be followed in that appraisal is discussed, including the preparation of the rating officer's report.

SANITARY CONTROL OF SHELLFISH IMPORTS

When the National Shellfish Sanitation Program was adopted, the United States was exporting oysters to Canada. At the request of Canada, a bilateral agreement was reached between Canada and the United States, providing for the use of equivalent sanitary standards and occasional joint inspections. Thus, today's imports of Canadian produced shellfish into the United States present no problem.

The advances in freezing and air transport technology now make possible shipments from shellfish producing countries throughout the world. In addition to Canada, the foreign nations exporting fresh and frozen shellfish into the United States are Japan, Mexico, Portugal, Italy, Hong Kong, Spain, France, and India.

The problem of providing adequate sanitary controls over such imports has not yet been resolved. The Public Health Service believes that sanitary control can best be obtained through "control-at-source," the principle used in the National Shellfsih Sanitation Program. Laboratory examination at port of arrival would not necessarily give an indication of the condition under which the shellfish were grown. Such laboratory tests have yet to be devised for domestically produced shellfish. Attempts have been made to give the Public Health Service authority to monitor production in foreign countries, but, to date, all have failed. Currently, the Pure Food and Drug Administration can clear shellfish to enter the country. Each state must make the decision as to whether the imported shellfish is safe to eat (Faulkner (5)).

EFFECTS OF WATER POLLUTION CONTROL LEGISLATION ON SHELLFISH SANITATION

In recent years federal legislation has been enacted for the purpose of upgrading the quality of the natural waters in the United States. Each state has been required to set quality standards for all of its interstate waters with the authority for approving such standards resting with the Secretary of the Interior. Along with such standards, a timetable for meeting the standards is required.

As more and better waste and wastewater treatment plants go into operation, it is conceivable that some of the shellfish growing areas now graded as restricted or prohibited will be reclassified as approved areas. Some of the waters which today will not even grow shellfish may, through time, become the great shellfish producing regions they once were.

CONCLUSIONS

Generally speaking, the American people are well protected from the dangers of polluted or toxic shellfish. Where outbreaks of shellfish-caused sickness have been reported, they are usually due to the harvesting of shellfish from prohibited areas. Sometimes this is done through ignorance of the law. Sometimes the harvester knows the regulation but believes it to be unreasonable. And, fortunately quite rarely, the harvester has no regard for the law.

Imported shellfish continue to present a problem. The need for a clear national policy is required if the general public is to continue to receive the high level of protection it has enjoyed since the start of the National Shellfish Sanitation Program in 1925.

REFERENCES

1. Bedford, J.W., Roelofs, E.W., and Zabick, M.J., 1968. The Freshwater Mussel as a Biological Monitor of Pesticide Concentrations in a Lotic Environment, Limnology and Oceanography, Vol. 13, No. 1, pages 118-126.

2. Campbell, J.E., 1961. Radionuclides in the Marine Environment, Proceedings of the Shellfish Sanitation Workshop, U.S. Department of Health, Education and Welfare, pages 187-188.

3. Cummins, J.M. and Jones, A.C., 1968. Uptake and Elimination of Gymnodinium Breve Toxin(s) by the Oyster, Crassostrea Virginica, Proceedings of the National Shellfisheries Assoc., 59:1.

4. DiGirolamo, R., 1968. Preliminary Observations on the Uptake, Depuration and Effect of Irradiation on Viruses in Pacific and Olympia Oysters, Proceedings of the National Shellfisheries Association, 59:2.

5. Faulkner, J.D. and Jensen, E.T., 1961. Public Health Service Position with Respect to the Sanitary Control of Shellfish Imports, Proceedings of the Shellfish Sanitation Workshop, U.S. Department of Health, Education and Welfare, pages 59-61.

6. Furfari, S.A., 1966, Depuration Plant Design, U.S. Public Health Service, pages 1-34.

7. Hamblet, F.E., Hill, W.F. Jr., Akin, E.W., and Benton, W.H., 1968. Oysters and Human Viruses: Effect of Seawater Turbidity on Poliovirus Uptake and Elimination, American Journal of Epidemiology, 89:562-571.

8. Hamwi, A., 1967. Pumping Rate of Mercenaria mercenaria as a Function of Salinity and Temperature, Proceedings of the National Shellfisheries Association, 58:4.

9. Houser, L.R. (Editor) 1965. National Shellfish Sanitation Program of Manual of Operations (PHS, Pub. No. 33), Part I, page vii.

10. Ingram, W.M., MacKethun, K.M., and Bartsch, A.F., 1966. Biological Field Investigative Data for Water Pollution Surveys, Federal Water Pollution Control Administration, page 75.

11. Jensen, E.T. (Editor), 1961. Discussions - Paralytic Shellfish Poison Situation in the United States and Canada, Proceedings of the Shellfish Sanitation Workshop, U.S. Department of Health, Education and Welfare, page 39.

12. McFarren, E.F., Schafer, M.L., Campbell, J.E., Lewis, K.H., Jensen, E.T. and Schantz, E.J., 1960. Public Significance of Paralytic Shellfish Poison, Advances in Food Research, Vol. 10, Academic Press, Inc., New York, pages 135-179.

13. McKee, J.E. and Wolf, H.W. (Editors), 1963. Water Quality Criteria, Resources Agency of California, State Water Control Board, pages 116, 117.

14. McKee, J.E. and Wolf, H.W. (Editors), 1963. Water Quality Criteria, Resources Agency of California, State Water Control Board, page 117, 354.

15. Miller, C.W., Zuckerman, B.M. and Charig, A.J., 1966. Water Translocation of diazinon-C^{14} and Parathion-S^{35} off a Model Cranberry Bog and Subsequent Occurrences in Fish and Mussels, Trans. Amer. Fisheries Soc., 95:345-349.

16. Montemmuro, A.J., 1968. A Comparative Study of Depuration Rates of Salmonella Newport in Crassostrea Virginica (American Oyster) and Mercenaria Mercenaria (Hard Clam), Master's Thesis, Long Island University, Page 1.

17. Pringle, B.H., Hissong, D.E., Katz, E.L., and Mulawka, S.T., 1968. Trace Metal Accumulation by Estuarine Mollusks, Journal of the Sanitary Engineering Division, Proceedings of the ASCE, 94:455-475.

18. Ridge, M.E., Clem, J.D., Linkner, R.E. and Sherman, L.K., 1961. A Case Study on Transmission of Infectious Hepatitis by Raw Clams - Report from Greenwich, Conn., U.S. Public Health Service, 36 pages.

19. Salvato, J.A. Jr., 1958. Environmental Sanitation, John Wiley & Sons, page 27.

20. Schroedor, H.A., Nason, A.P., Tipton, I.H. and Balassa, J.J., 1967. Essential Trace Elements in Man: Zinc. Relation to Environmental Cadmium. J. Chron. Dis. 20:179-210.

21. Sparks, A.K. and Sribhibhadh, A., 1961. Status of Paralytic Shellfish Toxicity Studies in Washington, Proceedings of Shellfish Sanitation Workshop, U.S. Department of Health, Education and Welfare, pages 266-274.

22. Vasconcelos, G.L., Jakubowski, W. and Erickson, T.H., 1968. Bacteriological Changes in Shellfish Maintained in an Estuarine Environment, Proc. of Nat. Shellfisheries Assoc., 59:67-83.

23. Wass, M.L., 1967. Biological and Physiological Basis of Indicator Organisms and Communities. Pollution and Marine Ecology, Interscience, 1967, page 278.

24. ________, 1905. Report of the New York Bay Pollution Commission, pages 77 and 78.

25. ________, 1965. The Effects of Pesticides on Fish and Wildlife. U.S. Department of the Interior, Fish and Wildlife Service Cir. No. 226, 77 pages.

26. ________, 1968. Industrial Waste Guide on Thermal Pollution, Pacific Northwest Water Laboratory, FWPCS, Corvallis, Oregon, pages 43, 44.

NOISE IS POLLUTION

by

Gerald W. Robin, M.S. in Marine Biology

Columbia University Seminars
on Pollution and Water Resources

ABSTRACT

The problem of detecting sounds emanating from ships and submarines is confounded by a background of manifold noises within the water layer of the ocean. Mainly, three sources of noise are discussed: water motion, marine life, ship and man-made sources. Some of the major difficulties in the analysis of underwater noises are discussed, as are the damaging or polluting effects noises have on the operation of acoustical signal processing.

The progress of civilization has brought with it the crashing and clashing of steel and the thundering of machinery. The city dweller is, unfortunately, all too familiar with his daily plunge into a sea of disagreeable sounds. He is surrounded by noisy vehicles, roaring subway trains and jet planes, shrill whistles, loud horns, and many other undesirable noises. The problem was recognized in Great Britain as early as 1872 and according to English Common Law freedom from noise was essential to the full enjoyment of all in a dwelling house and acts which affected that enjoyment were considered actionable as nuisances[1]. So important was this problem that in October, 1929, Dr. Shirley W. Wynne, Commissioner of Health for the City of New York, as a result of growing complaints from residents of the city, appointed a committee to study the situation and make recommendations for its improvement.

Noise is similar to air and water pollution; even though you can not see it, smell it, or taste it, it is pollution nonetheless. It is apparently one of the unavoidable by-products of an industrialized society. Pollution of the sound spectrum is as troublesome as air and water pollution, and may soon become as dangerous as these two more common types of environmental problems. Unlike the other two, however, noise cannot be completely eliminated because noise is sound and the difference between its levels is subjective and depends upon who is hearing it. Noise is mostly a nuisance now but at its present rate of increase may become a hazard to the health of our society. The problem has been recognized for years, but as with air and water pollution, it will probably get worse before any improvement is noticed.

We all realize that noises are objectionable and we are all ready to welcome any developments which will lead to their reduction. In order to conduct intelligent research in noise reduction, it is desirable to have means for quantitative measurements and to understand the phenomena called noise.

Noise can be broadly defined as being "any loud, confused, indistinct, disagreeable, and random sound or persistent disturbances that obscures or reduces the clarity or quality of a signal," and of course, it may also occur as unwanted signals, such as static that interferes with radio transmission. The very nature of the universe gives rise to noise. All objects in the universe radiate energy over a very broad spectrum. Much of the energy generated by the sun in the form of radio interference is of prime interest in radio transmission. In communications, interfering disturbances are called "noise" even though the interference may be magnetic storms or electrical, rather than auditory in nature. There is still another source of noise that could be eliminated within the limits of present technology, but which for a number of reasons remains. In this category is the man-made noise generated by the machinery of our advanced society[2]. In a very real sense, man-made noise may be more detrimental than noise created by natural phenomena. It can disrupt the biological functions of many life forms, including man, by creating changes in our chromosome make-up which may eventually bring about changes in future generations[3].

For countless centuries, a source of noise has been and is the action of ocean waves beating on the shores of our land masses. In this case, unimaginable quantities of energy released in the form of loud and thunderous sounds, together with the waves, have for the most part reduced many steep-faced and rocky shores into coarse and heavy grained beaches. The continued weathering action of the sea and the grinding of coarse materials eventually produced the smooth beaches we know today, of pebbles and small particles of sand.

The term underwater noise is used to describe the unwanted underwater sounds which impair the performance of acoustically operated underwater devices, man-in-the sea activities, and communications. These noises are caused by marine life, by shipping, by the breaking of waves on beaches, and by other natural phenomena such as storms or rain falling on the surface of the sea, as well as by wind and water motion. Thus, at any point in the ocean there are always present sounds from these and other causes, not all of which are identifiable. Such sounds form a continuous spectrum of frequencies, being greater in intensity at low frequencies than at high frequencies[4]. When this background noise has no clearly identifiable source, such as nearby marine life or ships, it is referred to as ambient noise. It is the sound normally prevailing in water, usually from a multiplicity of sources such as water motion, marine life, and unwanted ship sounds. Usually it is not possible to specify quantitatively the contribution of sound from each of the sources present, but frequently a particular type of source is known to be predominant. That is, noise increases with increasing sea state, indicating that such physical phenomena at the sea's surface is a prime source of noise. In such a case, it is convenient to refer to the ambient noise more specifically as water noise, noise from marine life, ship noise, etc. This ambient noise is the ultimate limiting factor in the detection of far distant sounds.

Sounds from marine life often interfere with the operation of underwater sound detectors[5]. A wide variety of fish produce noises; for example, the sea robin drums on the side of an air bladder with special muscles, whereas the trigger fish accomplishes this drumming with fins. Although a single fish does not produce much noise, many of them in concert may produce a loud throbbing roar, far in excess of ambient sea noise. Snapping shrimp is another variety of sea creature producing noise of interfering proportions.

Sound is used occasionally by marine animals[6] themselves for navigation (by echo sounding) and communication purposes as, for example, in the emission of a characteristic distress sound. The porpoise, in particular, emits many types of meaningful sounds over a very wide frequency range.

Ship and submarine noise are characteristic of the acoustical energy radiated into the water. This type of noise varies widely, depending upon the size of the ship, its propulsion machinery, propeller arrangement, and the speed at which it is operating[7]. Ship sounds are so characteristic of the type of ship that a trained sonar operator uses them for identification. A ship's spectrum of noise is made up of both a continuous band of frequencies from cavitation, and discrete frequencies from the rotation of the propeller and other machinery. Cavitation is caused by vortices at the propeller blade tips and by the water flowing by the ship's hull. Cavitation noise also is modulated by the propeller's rotation. Thus there is considerable sound radiated at frequencies corresponding to the propeller blade and shaft frequencies. An immobile ship can act as an underwater sound source too because of the operation of on-board machinery and the hull oscillations. Auxiliary machinery can serve as a sound source aboard a submarine lying on the bottom. Thus ships virtually always generate a primary acoustic field.

Machine noise can be divided into airborne and structureborne. Mostly, airborne noise is produced and propogated inside a compartment which houses the operating machines and mainly affects the inhabitants of that compartment.

Only a portion of it passes through the hull and contributes to the acoustic field of the ship. Structureborne noise, on the other hand, is propogated into the water, with minor losses. Structureborne noise is transmitted through the machine mountings, fittings, gears, piping, and other physical structures that provide a rigid path to the hull and then through the hull into the surrounding seawater. Therefore, reduction of structureborne machine noise is of paramount importance, not only to help in silencing the acoustical field around the ship, but also to help reduce those sounds and vibrations that are associated with structural fatigue.

The causes of structural noise are varied. Low frequency noises are characteristic of piston engines and are generated by detonations of explosive mixtures in the cylinders and by the noises of the valves. Gas turbines generate noise as the blades pass the nozzles. This type of noise usually lies in the ultrasonic band of frequencies. The frequency of the noises generated by the reduction gears is usually considerably lower than the noise frequencies generated by the turbines themselves. In atomic-powered ships, the coolant circulating system is a noise source together with the turbines and reduction gearing. Any kind of mechanism can act as a sound source if the bearings are improperly installed, if rotating parts are poorly balanced, or if there is inadequate rigidity of the hull or of the machine mountings[8], Figure 1.

When electrical motors are operating, the effects of magnetic and mechanical forces are the prime sources of structural noise. For example, the pulsation of the magnetic field in the air gaps of an operating rotor and the change in current generate a vibration in the motor's constituent parts. The motor ventilating system generates strong airborne noises[9], the highest noise level being that of fast-rotating, enclosed motors of the air-cooled type. In this type of electric motor, the fan is located close to the casing which causes air turbulence to cool the motor. Even though moving air can cause noise, the motor's electrical characteristics, such as the brushes in d-c motors, also cause noise. Splash-proof motors and water-cooled converters have a low noise level[10].

One of the chief problems in developing mathematical models of the ocean results from the many parameters in underwater acoustics. This is because all good models must reflect the physical facts to the extent of permitting meaningful conclusions and realistic experiments. Some of these difficulties can be appreciated through a brief description of the general properties of seawater and the ocean.

Oceans cover about 71 percent of the earth's surface. Of this area, 46 percent is the Pacific, 23 percent is the Atlantic, and 20 percent is the Indian Ocean. Away from the continental shelf the average depth is 4 kilometers, and the distances over the oceans' surface extend from 5000 kilometers in some places to as much as 15,000 kilometers in others. In general, the salinity of the ocean is about 35 grams of dissolved material per kilogram of water. Sodium accounts for about 10 grams, magnesium about 1.2 grams, and chlorine about 19 grams. These dissolved salts are responsible for the ocean's electrical conductivity and its corresponding poor performance as a medium for electromagnetic waves. The magnesium ion accounts for a large portion of the absorption of acoustical energy at higher frequencies.[11] For this reason electromagnetic radiation is severely attenuated. Acoustic energy, which is in the form of mechanical energy, also suffers some losses, but they are less severe.

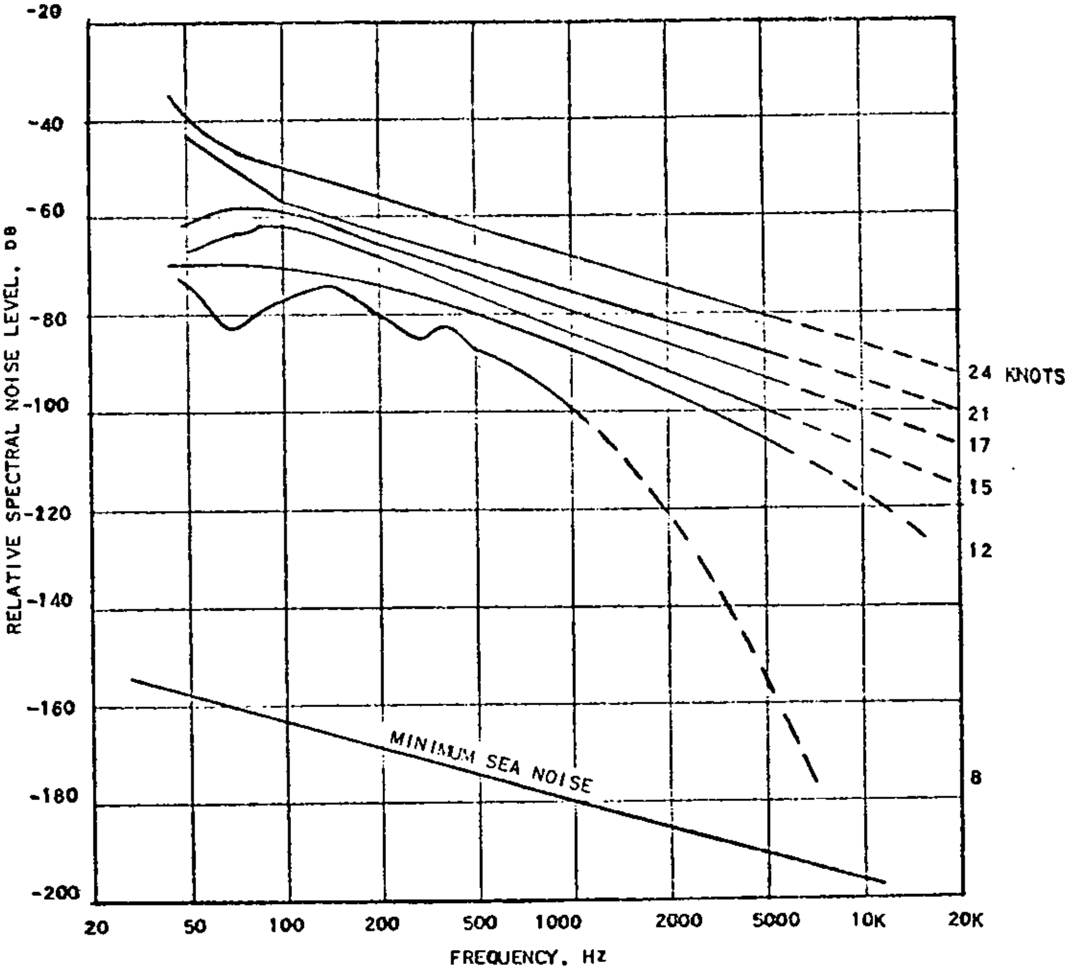


Figure 1. The noises of ships of various classes and types have a very individual characteristic signature. These curves are spectral level characteristics of a cruiser at various speeds. (Ref. 21)

In the ocean, acoustic loss mechanisms almost preclude the use of acoustic devices of frequencies of 100 kHz and above. This has to be considered a rather restrictive upper limit to the acoustic frequency spectrum in that in the atmosphere or in space the electromagnetic spectrum is usable up to about 10^7 kHz. Because of this relatively low upper limit on usable frequencies, the maximum possible information rate over an acoustic channel in seawater is much smaller than the maximum obtainable over an electromagnetic channel in the atmosphere. Even within this relatively narrow frequency range, acoustic channels in oceans are plagued by noise from the three sources mentioned before, namely: Water Motion, Marine Life, Ship and Man-Made Sources (Figure 2).

Because background noise makes it difficult to determine the presence or absence of desired signals or their characteristics, an understanding of the nature of the noise is vital in determining its sources and characteristics.

The sound velocity in seawater is influenced by several factors: the ion concentration in seawater or its salinity; static water pressure; and its temperature. Because of the earth's gravity, static water pressure increases linearly with depth. Temperature is typically constant with depth in the upper 100 meters, in the so-called mixed layer. This layer has a temperature of approximately 20°C in the mid-latitudes, although the temperature varies with season and geographical location. Below the mixed layer the temperature decreases rapidly until, at a depth of about 1000 meters, it reaches about five degrees C. It stays approximately at this value below that depth.

The combined changes of static pressure and temperature give rise to a profile of acoustic speed of propagation which is best described by a graph, (Figure 3). In general, the speed of sound increases with depth as the water gets colder and the pressure builds up.[12] But, there is a minimum in the sound speed profile. Speed decreases to a certain depth, and then begins a steady increase as the water gets deeper. Under some conditions, this minimum allows the ocean to act as a gigantic wave-guide or transmission line. At great depths the speed profile is fairly stable. Near the surface, wind and solar radiation perturb the profile. In the lateral directions, changes in acoustic velocity with distance can, for practical purposes, be ignored.

Three major causes of noise transmission losses can be distinguished: 1) conversion of acoustic energy to heat; 2) spreading of energy as it propagates outward from the source; and 3) the loss when acoustic energy is redirected or scattered from its intended direction. For example, by marine life or from inhomogeneities in the ocean caused by small temperature fluctuations.[13]

There are four mechanisms for losses of the heat conversion type: 1) classical heat flow; 2) viscous loss; 3) loss due to magnesium sulfate dissociation; and 4) loss due to change in energy level of different energy states of water. For all four, loss varies with the square of the frequency and, for this reason, heat conversion loss is significant only above 1000 Hz. At lower frequencies, scattering by marine life and temperature inhomogeneities predominate.[14]

There are several interesting features which introduce constraints on the transmission of noise in the ocean. The main effect is the phenomenon called refraction;[15] that is, a sharp noise generated in the ocean may be heard several times, even without reflection from the boundaries. Because the speed

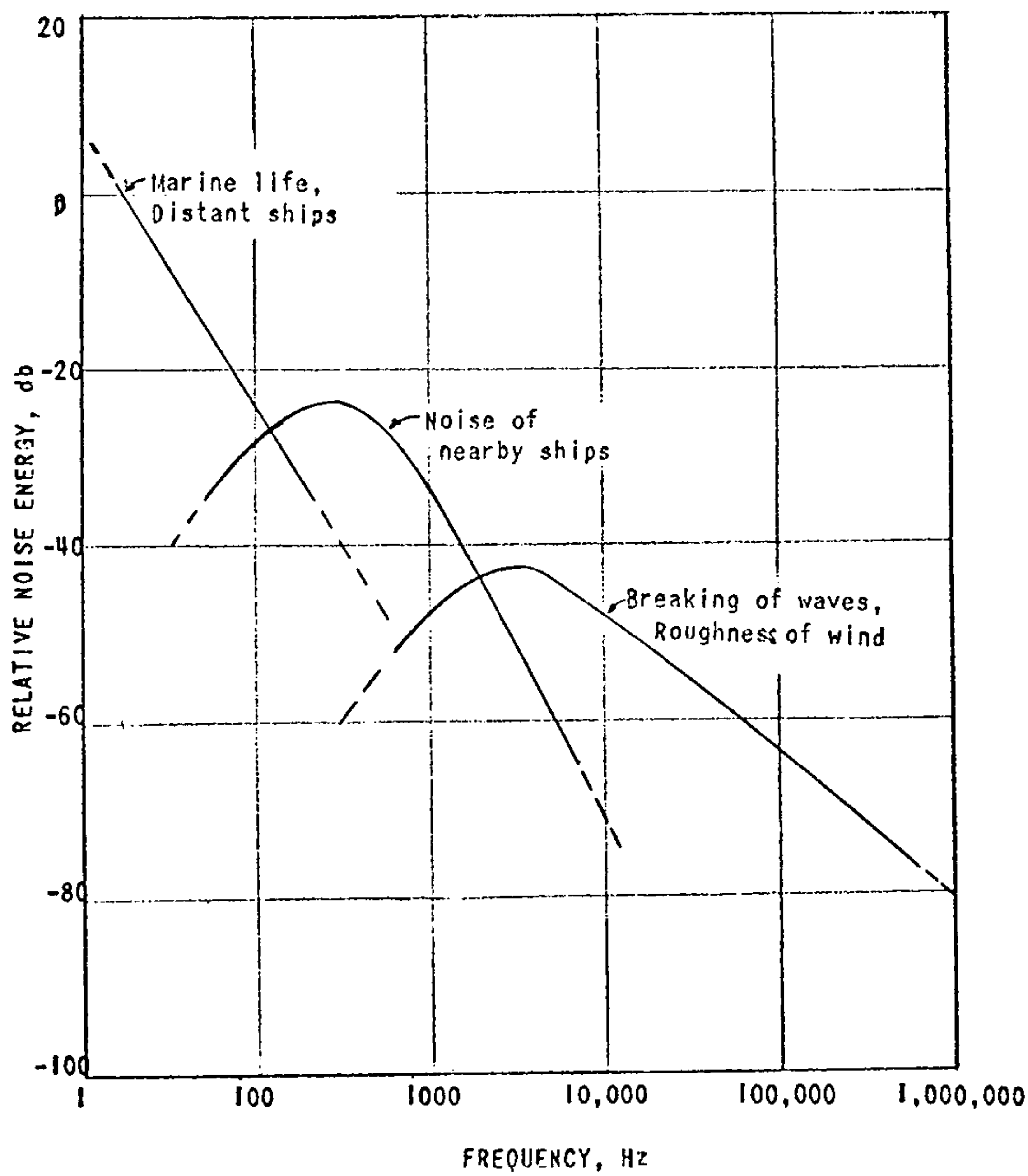


Figure 2. The main sources of noise in undersea communications channels may be grouped into three classes according to their frequency ranges. Ships passing at a distance and marine life are the two significant factors below 10 Hz. Nearby shipping greatly affects the range from 10 to about 300 Hz. Above this value, waves are the major noise sources, which, of course, depend on the wind. (Ref. 22, composite of Figures 12, 13, 14 and Ref. 23, Figure 4.)

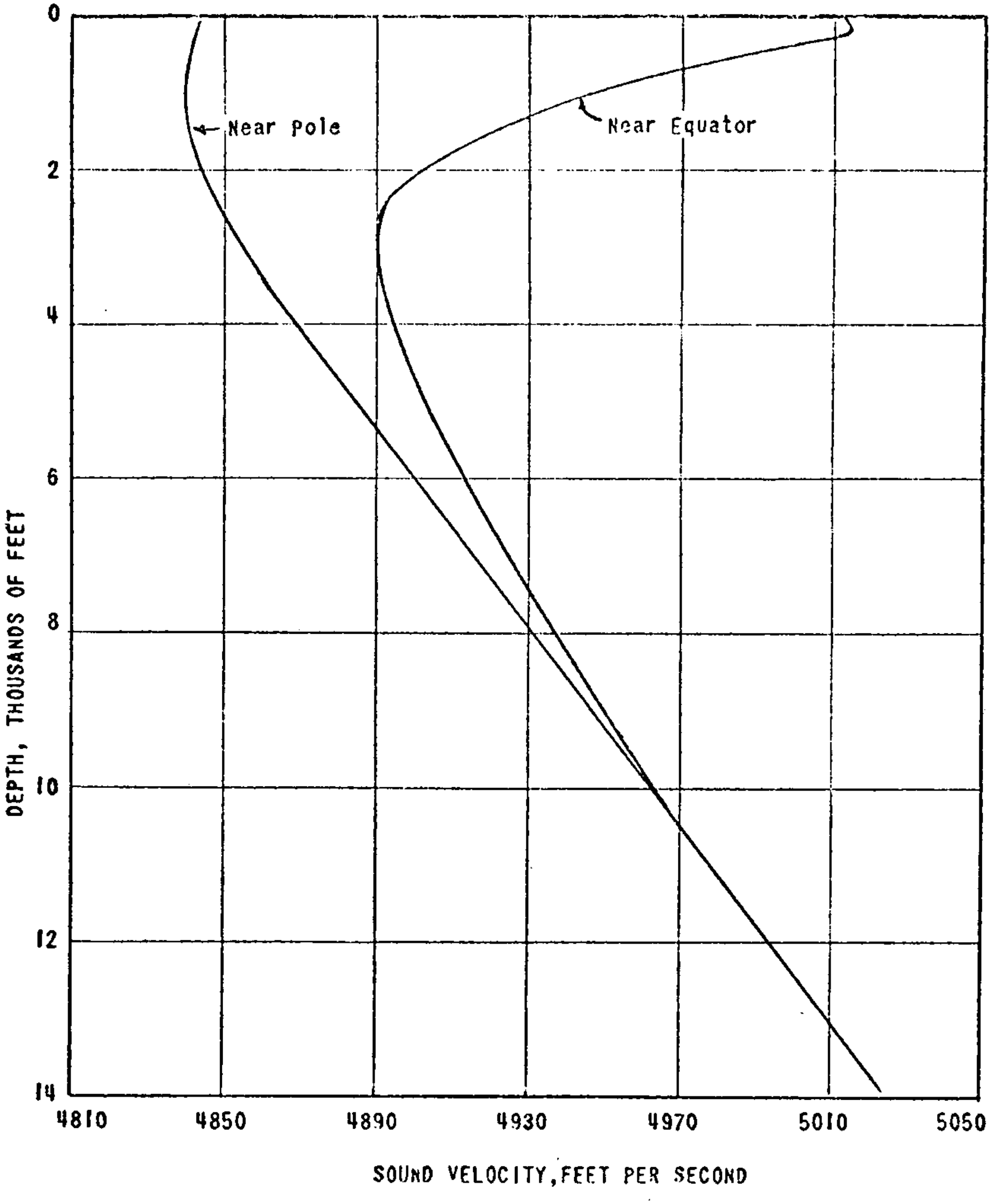


Figure 3. In the oceans, the speed of sound near the surface critically depends on the water temperature. Near the equator (near 19°N latitude) the minimum speed is attained at a much greater depth than the near polar regions (near 61°N latitude). From the minimum value, however, both curves show that the speed increases almost linearly with depth, regardless of the geographical location. (Ref. 24, profiles 41 and 143).

of sound in water is not constant, there is more than one path along which energy can propagate between two points. In other words, the energy does not travel in straight lines, but always bends towards the region of lower sound speed.

For sources and receivers near the surface, the sun and wind can introduce additional changes in the sound speed profile. Because of the warming effect of the sun the sound speed profile changes near the surface. In the morning the surface is cool, and the velocity gradient near the surface is not steep. But as the sun warms the surface, the sound velocity near the surface increases and the sound rays are bent more sharply. As the rays are bent more sharply and refracted into deeper water, a shadow zone[16] is created through which acoustic energy is severely attenuated (Figure 4). The boundary of such a region depends on the location of the source and on the sound speed profile. This boundary is called a caustic. A submarine or ship inside it could not be detected with sonar. This is not a trivial effect. Just a slight change of one or two degrees C in the near-surface temperature can reduce the range of sonar from 1000 to 300 yards.

The interaction of sound energy with the ocean's surface and bottom has no effect in some situations. However, it is significant in other circumstances, and in such cases the interaction between the sound wave and the surface and the bottom is complicated. First, neither the surface nor the bottom is smooth. When a sound wave impinges on either of them, the direction in which it is reflected depends on the local orientation of the surface. Thus, the direction of reflection of a sound wave (noise impulse) from the air-water interface changes with time and location. This can result in serious fading problems or degeneration of the signal. For the most part, however, all of the incident sound energy is reflected at the surface, but not at the ocean bottom. Energy impinging on the bottom usually penetrates it and is lost or absorbed. Thus, the bottom[17] is another loss factor. In addition, little is known about the structure of the bottom in deep water. In fact, geological exploration of the ocean bottom at great depths is one of the more important applications of noise signal processing.[18] In fact, there are some advantages to noise detection in the sea besides detecting and locating ships and submarines. They are valuable for searching out and localizing schools of fish,[5] for detecting icebergs, and for surveying the ocean floor. Surveying is useful both for geological purposes and for locating sunken objects. For most of these types of applications, the frequency range is between 1 kHz and 50 kHz. The geological explorations include determination of the depth of the bottom and the characteristics of the sub-bottom, and exploration for oil[19]. Such studies are conducted by examining the characteristics of the reflected sound wave which is influenced as it passes through the ocean bottom and then reflected by various impervious layers.

Underwater communication and telemetry systems are another important class of underwater acoustics easily affected by the influence of ambient or background noise. Among the communications methods used by divers and surface ships to avoid the influence of noise are frequency modulation of a carrier and coded pulses. Typical applications of underwater telemetry are to give the depth of a fishing net, or a measurement of temperature, or for finding fish[20].

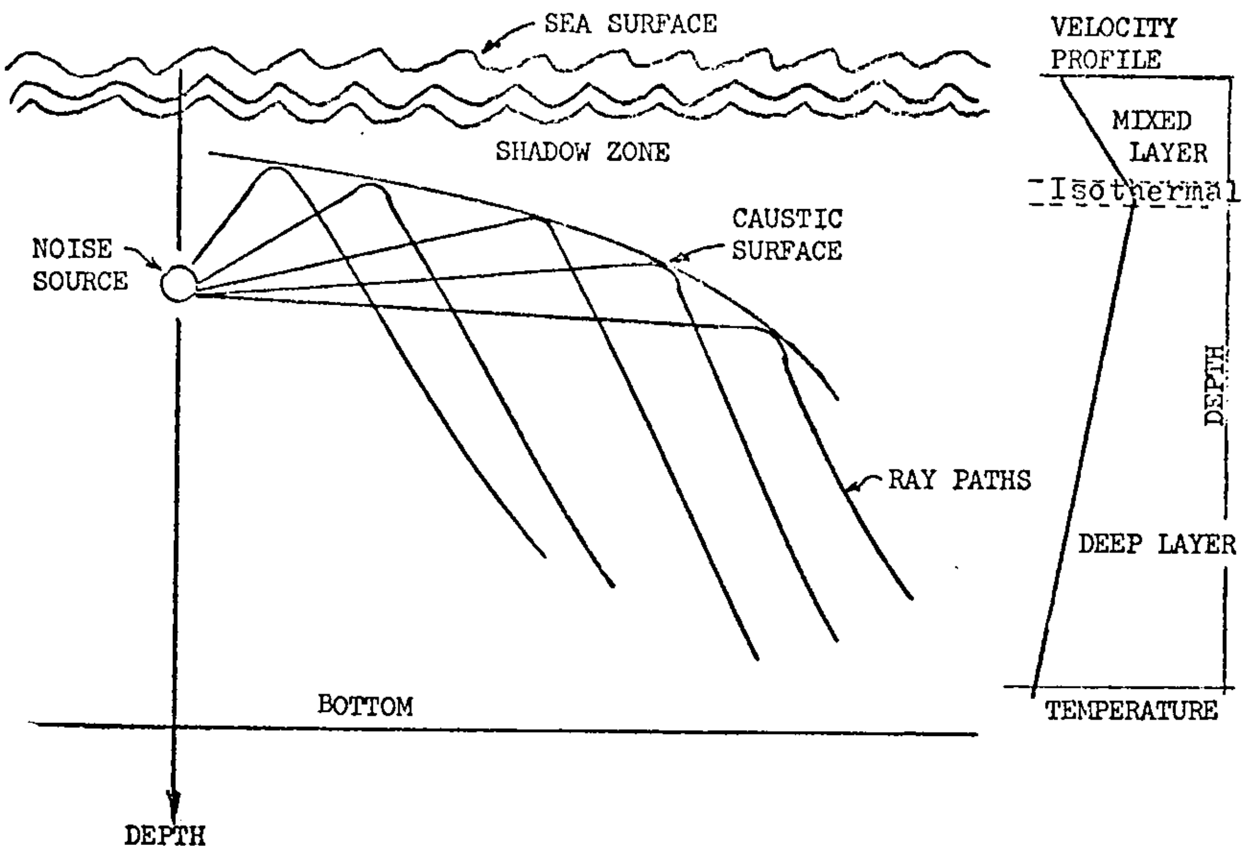


Figure 4. In a "shadow Zone" phenomena, a positive temperature gradient exists in an upper layer and a negative gradient exists in a layer below it and sound from a noise source will be concave downward in the lower layer and concave upward in the upper layer. The water layer in which the positive thermal gradient turns into a negative thermal gradient is called the isothermal layer. The layer above is called the mixed layer and the layer below is called the deep water layer.

In conclusion, a summary of the principal sources of ambient noise, their particular frequencies, and their energy levels will be given, showing some relationship between identifiable noise sources and their frequency spectra.

SHIPPING NOISE - is sea surface traffic noise resulting from the combined effect of all ship traffic, excepting the immediate effects of ship noise. Ship noise is the noise from one or more ships at close range and may be identified by short-term variations in the ambient noise characteristics, such as the temporary appearance of a narrow band of components at frequencies below 1 kHz, a comparatively rapid rise and fall in noise level, and a broad band cavitation noise extending into the 1 kHz region and above, often with low frequency modulation patterns. Ship noise is usually obvious to even the uninitiated in noise identification and, therefore, generally can be and is deleted from the category called ambient noise. The factors which influence the level of ambient noise caused by surface traffic are: a) transmission loss; b) number of ships; c) distribution of ships; and d) kinds of ships.

Wenz has derived some curves[5] (Figure 5) that show the probable shape of traffic noise spectra deduced from ship-noise source characteristics and attenuation effects. For example, he defines the expected spectrum shape at 100 nautical miles (185 km) from a source whose noise spectrum is flat up to 100 Hz and decreases -6 db per octave above Hz, the effective source depth being 20 feet (6m). A 105 db value of the average transmission loss at 100 Hz for 500 nautical miles is reasonable; accordingly:

No. of Ships	Range, Nautical Miles	Loss
1	500	20-40 db
10	500	30-50 db*
100	500	40-60 db*

*on the assumption that power is added.

Also, at 1000 nautical miles, all values will be only 3-6 db lower.

SURFACE WAVES - are the principal source of deep water ambient noise in the 50 to 500 kHz frequency band. Due to the difficulty of making accurate wave height measurements, and the lack of correlation between ambient noise and sea state under transient conditions, the usefulness of wave height is of questionable practical value in determining noise levels. However, the correlation of noise levels to surface waves would be meaningful under the steady state condtion of a fully arisen sea. An alternative, and more reliable method of determining noise level, is local wind speed. Under steady state conditions both wind speed and wave height are interchangeable measures of noise levels. Local wind speed has the advantage, however, of being easily measured and validated as an indicator of noise levels under transient seas.

BIOLOGICAL - noise sources have been studied between the frequency range of 10 Hz to 100 kHz. The level of these marine noises varies with frequency, time, and location. For some sources, habits, habitats, diurnal, seasonal, and geographic patterns may be predicted for indications of the conglomerate noise pressure levels[5].

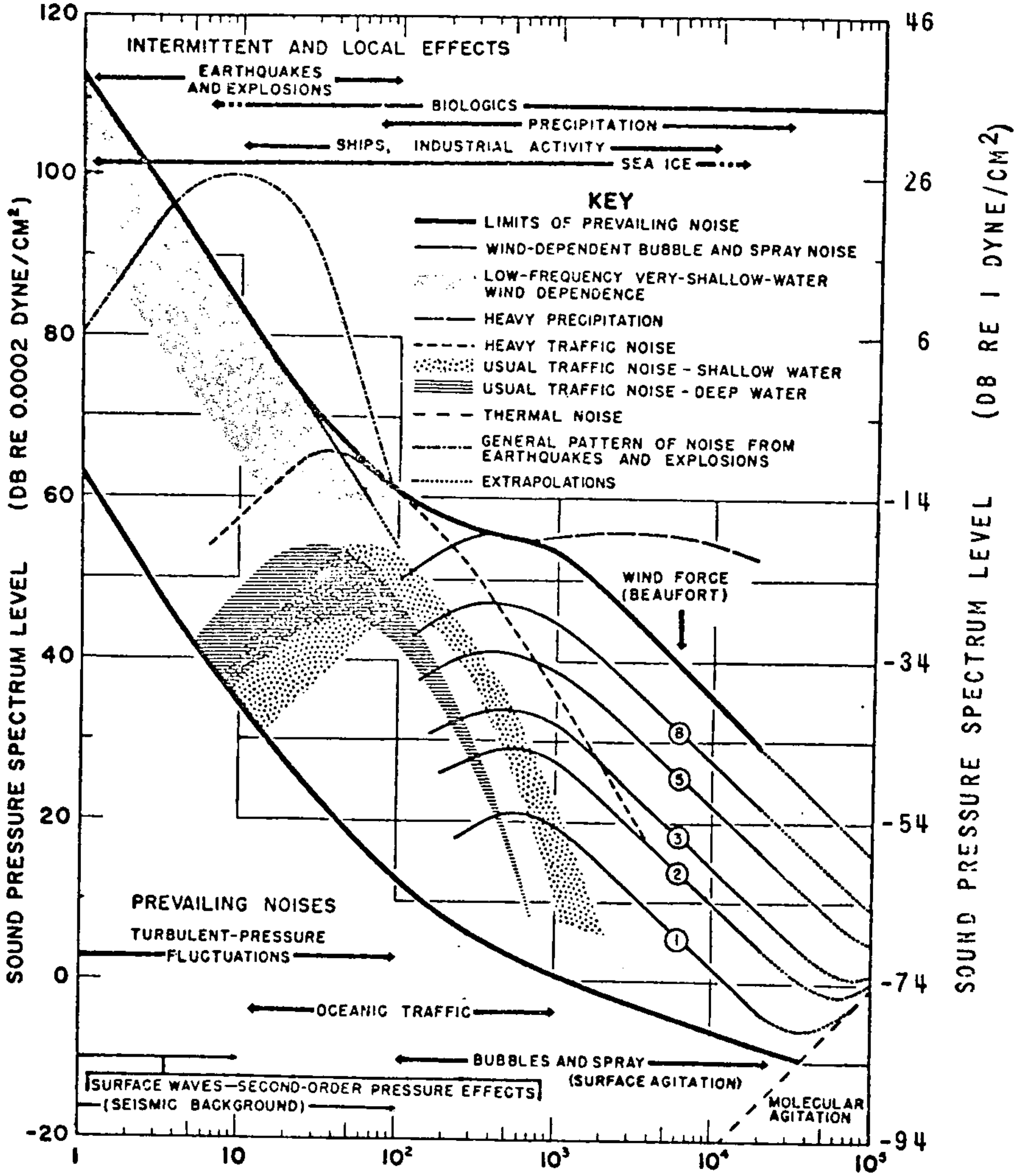


FIG. 5 A composite of ambient-noise spectra, summarizing results and conclusions concerning spectrum shape and level, and probable sources and mechanisms of the ambient noise in various parts of the spectrum between 1 cps and 100 kcps. The key identifies component spectra. Horizontal arrows show the approximate frequency band of influence of the various sources (after Wenz, 1962).

ICE - surfaces in northerly regions are the main source of noise in the 10 to 10 kHz frequency range. These noise sources produce noise by either of two distinct mechanisms. One mechanism, which produces impulse noise, results from a shrinkage of the surface ice, which is caused by decreasing air temperatures. The second mechanism, which produces gaussian noise, results from the interaction of the granular ice surface with the wind. When the air temperature above the ice decreases, there is a large increase in the underwater impulse noise, with most of the energy being generated at frequencies below 2 kHz. The impulse noise power can be related to the rate of decrease of the air temperature with time, rather than with the extent of decrease of temperature alone. This is almost a certainty, and is a result of the ice cracking caused by thermal stresses in the ice. There is a gaussian noise component that is proportional to the average wind speed. The spectrum of this wind-generated noise is approximately "white" and this appears to be the major noise source at frequencies in the region of 10 kHz.

RAIN - when falling on the sea's surface is an intermittent source of deep water noise in the 100 Hz to 50 kHz frequency band. However, in effect, it is the prime source of noise. Not much data are available to determine the effect of rain storms on ambient noise levels. A reference[11] to storms indicates it is a noise source somewhat equivalent to distant ship traffic; that is, distant storms have the same effect as distant ship traffic in the 50 Hz to 500 kHz frequency range.

SEISMIC - noises are produced in the oceanic environment as a result of volcanic and tectonic action within the earth. The earth's crust is in "motion" and as a result it is an important cause of low frequency noise in the ocean. The spectrum characteristics of this noise source depend upon: a) the magnitude of the seismic activity; b) the range and extent of the activity; and c) the path of propagation. The general spectrum frequency range may extend from 1 to 100 Hz. The noise is usually a single transient pulse or a series of transient pulses which are of relatively short duration and which are infrequent in occurrence. The associated pressure changes from these sources range between 60 to 100 db (relative 1 dyne per square centimeter).

OCEANIC TURBULENCE - has been considered[4] a source of ambient noise. Turbulence manifests itself in the form of irregular random movement of water masses near or at the measuring hydrophone. The noises which are created may be a composite of two mechanisms: a) shaking or rattling of the hydrophone; and b) pressure changes at the hydrophone. The second is the most important acoustic effect of turbulence. Whereas the first mechanism is of secondary importance and may be classified as self-noise, Wenz has summarized[4] the turbulent pressure level spectra as they are derived from theoretical and experimental relationships, as related in the following listing:

Type of Turbulence	Frequency Range	Pressure Level
Ambient, 2cm per sec.	0.1 to 10 Hz	60-90 db
Swift Ocean Currents 10cm per sec.	0.5 to 50 Hz	100-110 db
Extreme Tidal Currents 30cm per sec.	0.5 to 100 Hz	110-130 db

Pressure level referenced 0.0002 dyne per square centimeter.

THERMAL AGITATION - can be expressed as an equivalent thermal noise sound pressure level for ordinary temperatures between 0° and 30°C, where f is the frequency in kiloHertz; by utilizing the equation[11]:

$$N_t - -115 + 20 \log f \text{ (in db)}$$

This level will be the minimum noise level for the medium under the effects of thermal agitation. From this equation, it can be shown that the thermal noise spectrum has a slope of 6 db per octave[11]. Examples of computed levels would be -24 db at 35 kHz and -75 db at 100 kHz.

During the past twenty-five to thirty years, ambient noise measurements have been made over a frequency range of 1 Hz to over 100 kHz in the ocean under a large variety of oceanographic, meterological, and geographical conditions, from the sea surface to the deep sea floor. However, it is in the shallow areas of the oceans (near shore areas) where most of the work has been done. Much data are lacking for the larger and deeper portions of the oceans where greater and further understanding is needed.

New possibilities are appearing in oceanography in connection with the development of techniques which make it possible to record and analyze noises within the sea. Some of the major difficulties in the analysis of underwater noises have been discussed, along with the damaging or polluting effects they have on the operation of acoustical signal processing.

REFERENCES

1. Gaunt vs Finney, 1872, 8 ch., Ap. 8, Common Law, England.

2. Karpus, H.B. and G.L. Bonnvalet, 1953. A noise survey of manufacturing industries, Am. Ind. Hyg. Assoc. Quart. 14, 235-263.

3. Knudsen, V.O., 1968. Federal Council for Science and Technology, Special Report, Univ. of Calif.

4. Wenz, G.M., 1962. Acoustic ambient noise in the ocean, J. Acoust. Soc. Am., 34, 12, p. 1952.

5. Robin, G.W., 1969. Bioacoustic noise in the sea, Operations Analysis Report PDR-OP-T69-43, Grumman Aerospace Corp., Bethpage, New York.

6. Dudok Van Heel, W.H., 1962. Sound and cetacea, Netherland J. Sea Res., 1, 4, 407-507.

7. Albers, V.M., 1963. Underwater acoustics handbook, Univ. of Penn., Phila., Penn., p. 202-210.

8. ___________, 1965. Underwater acoustics handbook II, The Penn State Univ. Press, Univ. Park, Penn., 234-235.

9. Kenny, R.J., 1968. Noise in air-moving systems, Mach. Des., Sept. 26, 138-149.

10. Naval Engineering Jour. 1962, Vol 74, No 2; 1963, Vol 75, Nos 1-4; 1964, Vol 76, Nos 1, 4, 6; 1965, Vol 77, No 2.

11. Urick, R.J., 1967. Principles of underwater sound for engineers, McGraw-Hill, New York, p. 87.

12. Mackenzie, K.V., 1960. Formulas for the computation of sound speed in seawater, J. Acoust. Soc. Am., 33, 1113.

13. Principles of Underwater Sound, Natl. Defense Res. Comm. Sum. Tech. Rept. 7, sec. 3.4, National Res. Council, 1946.

14. Physics of Sound in the Sea, Natl. Defense Res. Comm. Sum. Tech. Rept. 8, sec. 5.2.2, National Res. Council, 1946.

15. Galkin, O.P., and V.S. Grigorev, 1960. Instruments for plotting refracted rays, Soviet Phys. Acoust., 6, 20.

16. Morse, R.W., 1950. Dependence of shadow zone sound on the surface sound velocity gradient, J. Acoust. Soc. Am., 22, 857.

17. Nafe, J.E., and C.L. Drake, 1961. Physical properties of marine sediments, Lamont Geol. Obs. Columbia Univ. Tech. Rept. 2.

18. Bennett, W.R., 1956. Methods of solving noise problems, Proc. IRE, 44, 609.

19. Albers, V.O., 1965. Underwater acoustics handbook II, The Penn State Univ. Press, Univ. Park, Penn., 272.

20. ____________, 1965. Underwater acoustics handbook II, The Penn State Univ. Press, Univ. Park, Penn., 271.

21. Prostakov, A.L., 1969. Underwater sound and the ship, Shipbuilding Publishing Office, Leningrad, USSR, 1967, Trans. Div. Naval Intell. Comm. Headqtrs., Wash., D.C., p.77.

22. Wenz, G.M., 1962. Acoustic ambient noise in the ocean, J. Acoust. Soc. Am., 34, 12, p.1948, 1952, 1955.

23. Furduev, A.V., 1964. Underwater noise of dynamical origin, Soviet Phys. Acoust., 9, 3, p.222.

24. An interim report on the sound velocity distribution in the North Atlantic Ocean, U.S. Naval Oceanog. Office Tech. Rept. 171, 1965.

EFFECT OF WATER SALINITY ON THE INCIDENCE OF SYMBIONTS OF THE BLUE CRAB, *CALLINECTES SAPIDUS* (RATHBUN)

by

Virginia M. Scrocco, M.S.

Department of Life Sciences,
New York Institute of Technology
New York City, N.Y. 10023

The purpose of this investigation was to identify organisms associated with the blue crab Callinectes sapidus (Rathbun) and to learn about their habitats, the frequency of their appearances on or in crabs of both sexes and of various sizes from different locations, and the type of their symbiotic relationship. A knowledge and understanding of such organisms and their life histories can lead to a more complete identification of crabs as to their stocks, physiological age and habitats. The nemertean worm Carcinonemertes carcinophila (Kölliker) (1,2); barnacles such as Balanus eburneus (Gould) (4,5), Chelonibia patula (4), and Octolasmis loewi (2,5); the bryozoan Acanthodesia tenuis (3); and the sea anemone Diadumene leucolena were found to associate with male and female crabs.

The barnacles, Balanus eburneus and Chelonibia patula, attach to the shell of the crab. The bryozoan Acanthodesia tenuis becomes encrusted on the shell of the crab and may perhaps form what is called a phoresis. Octolasmis loewi becomes commensal on the crabs' gills (2). The nemertean worms are found on the gills of certain blue crabs. They leave the gills and go to the crabs' eggs on the pleopods. Here they feed upon the eggs as parasites (6), becoming sexually mature on the eggs in regions of high salinity from August to November. The worms mate, lay their eggs in mucous tubes, and return to the crabs' gills. In about eleven days the worms' eggs hatch into free-swimming larvae. These larvae go to crabs' gills, undergo metamorphosis, and become encapsulated (Fig. 1) in mucous sheaths between the gill lamellae (7).

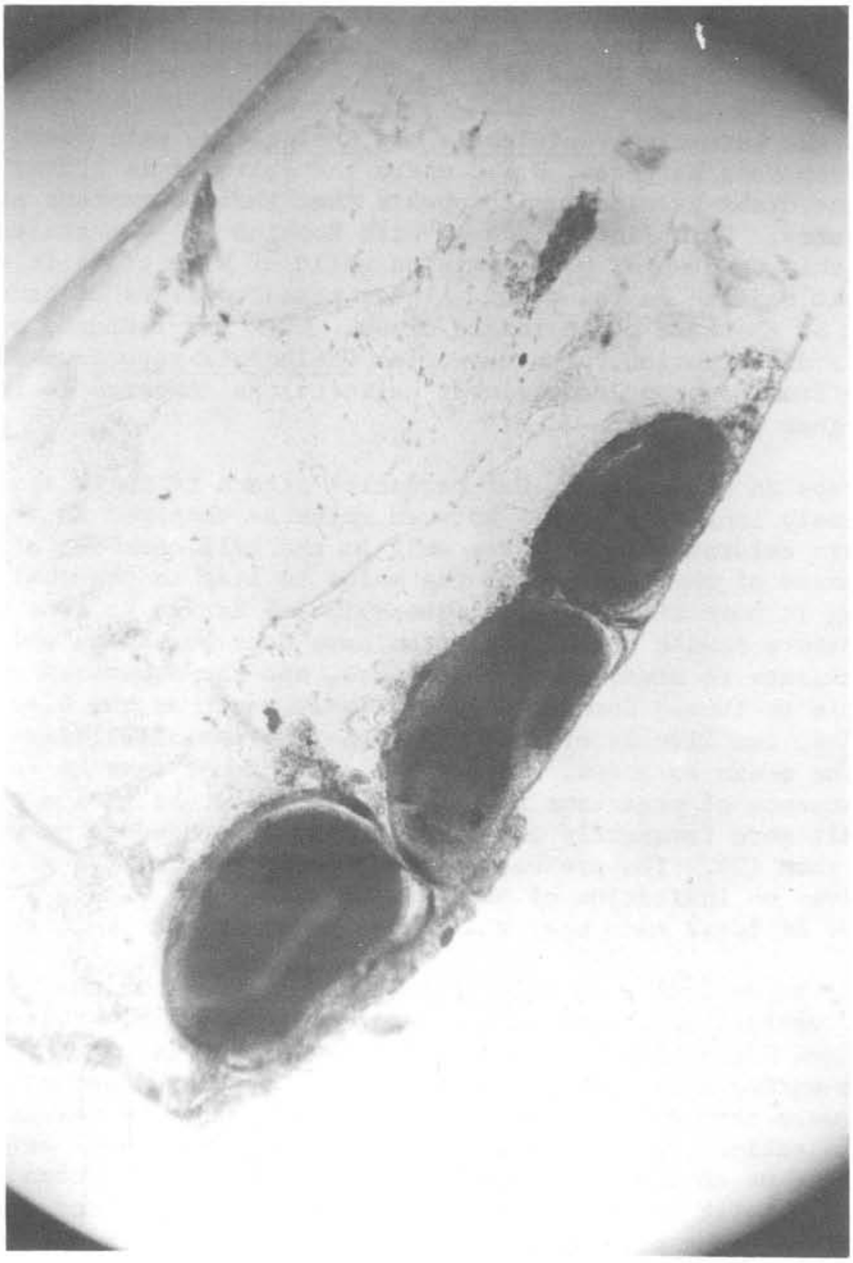
Salinity as a limiting factor. A great deal of work done as reported by Gunter (8) has shown that salinity is a limiting factor to the distribution of many marine organisms, especially as it varies downward. He informs us that the endemic fauna of estuaries is mostly sessile. The motile fauna consists mostly of the young of species which spawn offshore in high salinity water. Examples are menhaden, mullet, croakers, and blue crabs -- all important in major fisheries in the United States. Estuaries may be described as nursery grounds. Populations of sessile, or only slightly motile marine organisms, become stunted when the salinities vary away from the optima, either upward or downward. The smaller and younger motile organisms generally distribute themselves in lower salinity water and then move towards the sea as they grow larger. The organisms that cannot withstand lowered salinities decline in species numbers with the salinity gradient decline in estuaries.

The crabs used in this study were collected from the waters between the Virginia Institute of Marine Science pier and Sarah's Creek (York River) salinity 16.2 ppt (low salinity); Chesapeake Bay, salinity 28.2 ppt; mouth of the River, salinity 18.98 ppt; Hampton Roads, Va., salinity 18.25 ppt; and Cape Hatteras, N.C., higher salinity 35.3 ppt.

STUDY OF ASSOCIATED ORGANISMS

Collected juvenile and adult crabs of both sexes were measured in size and examined for the presence of various symbiotic organisms. The first study made was to determine the correlation of the presence of Carcinonemertes carcinophila with male and female crabs of different sizes and from waters of different salinities. The crabs' gills were examined through a dissecting microscope for the presence of the nemertean capsules and young worms on the gills.

FIGURE 1



The gills were also examined for the presence of Octolasmis loewi and the shells for Balanus eburneus and Chelonibia patula, and for sea anemones and bryozoans.

The incidence of associated organisms according to age of male and female crabs, provenance and water salinities is summarized in Tables I and II. The results show that the male crabs had no nemerteans, and in water of high salinity had some Chelonibia and Octolasmis (Table 1). The juvenile female crabs had no nemerteans and no associated organisms, while many of the adult female crabs had large red (adult) nemertean worms on their gills. Those female crabs from water of higher salinity (35.3 ppt) also had many more of the barnacles Chelonibia (on shell) and Octolasmis (on gills) (Table II). The results show no correlation between the incidence of the nemerteans and the low and high salinities of the water (Tables I and II).

Many of the barnacles, Octolasmis and Chelonibia, were found on adult female crabs from Cape Hatteras, N.C., where the salinity is higher than in localities of other crabs examined. It appears that these organisms prefer waters of high salinity. This finding agrees with Hopkins (9) who states that the presence of this species of Octolasmis on gills of blue crabs in the bay indicates a recent sojourn in the ocean. These same two kinds of barnacles were seen on many of the same adult female crabs. This may indicate an association between their distribution. The barnacles Chelonibia patula were quite small on the crabs from Hampton Roads (lower salinity) as compared to those from North Carolina (higher salinity).

Male crabs do not migrate, but barnacles attach to their shells because of their relatively longer intervals between molts as compared to females. The nemertean worm evidently cannot live well in the gill chambers of male crabs, probably because of the tendency of the males to stay in the shallow, fresher water, making it more difficult for free-swimming larvae to come in contact with them (2). Mature female crabs more often have many barnacles and nemerteans since they migrate to areas where larvae are, and the nemertean worm completes its life cycle on them. Some estuarine animals, such as the blue crab, Callinectes sapidus, can live in or near water that is essentially fresh, but must go back to the ocean to spawn, since their eggs cannot develop in fresh water (10). The absence of organisms on juvenile female crabs is due to the fact that they molt more frequently and have no eggs, which would prevent worms from thriving on them (2). The presence of Carcinonemertes on the gills of the female crab gives an indication of her physiological age. Crabs which have already spawned at least once nearly all have red worms on their gills (11).

In order to determine if Carcinonemertes is parasitic on the gills of Callinectes, various dyes such as methylene blue solution, green food coloring, neutral red and Evans blue were injected into the hearts of a number of mature female crabs during this study. The worms and capsules found on the gills of these crabs were then examined under dissecting microscope several hours or days after injection. No dyes were detected in the nemertean worms of these crabs, which seems to indicate no parasitic relationship between them and their hosts. The symbiotic relationship of the other associated organisms on shells of crabs appears to be of phoretic nature. Octolasmis association is probably also of the same nature.

TABLE I

Associated Organisms, Size of Male Crabs and Water Salinity

Specimens	Maximum Body Width (mm)	Total Number of: Nemerteans	Total Number of: Associated Organisms
a) Low salinity (16.2 - 28.2 ppt):			
4*	65-100	none	none
3*	107-145	none	none
b) High salinity (35.3 ppt):			
1**	105	1	1 Chelonibia
7**	122-165	none	8 Chelonibia
			2 Octolasmis
			1 Acanthodesia

* Sarah's Creek or mouth of York River, Va.

** Cape Hatteras, N.C.

TABLE II

Associated Organisms, Size of Female Crabs, and Water Salinity

Specimens	Maximum Body Width (mm)	Total Number of: Nemerteans	Associated Organisms
a) Low salinity (16 - 30 ppt)			
8	50-97	none	none
4	100-127	none	none
6	143-152 a	very many, some large (red)	12 Chelonibia 3 Acanthodesia 1 Octolasmis
5*	159-165	very many large (red), some in external egg mass	9 Chelonibia 2 Acanthodesia 1 Balanus
b) High salinity (35.3 ppt)			
7**	152-172	Present very many or absent b	51 Chelonibia Many Octolasmis 0 Acanthodesia

a - Adult crabs. Those smaller than 127 mm are juvenile crabs.

* - Hampton Rds., Va. The other crabs came mainly from Chesapeake Bay, Md.

b - One third of the crabs had no nemerteans.

** - Cape Hatteras, N.C.

DETERMINATION OF LENGTH OF LIFE OF NEMERTEANS IN VARIOUS SALINITIES

The investigation also included a study of the survival of nemertean worms isolated from crabs and experiments to determine length of life of nemerteans in waters of different salinities. Salinities were determined by silver nitrate titration. Some nemertean worms taken from crabs' gills were placed into watch glasses containing sea water of various salinities ranging from 26.20 ppt to 3.5 ppt. Some nemerteans were kept in a watch glass containing tap water. Crabs' eggs were added to some watch glasses to serve as food for the worms. The water in the containers was changed daily. Observations of the nemerteans in sea water and sea water with crabs' eggs showed that all the nemerteans in the sea water of the salinities ppt of 18.98, 14.83, 26.20, 9.95 were still living approximately three weeks later, when the experiment was discontinued. Nemerteans in sea water of salinity 3.5 ppt lived only two days. Nemerteans put into tap water were dead the next day.

FACTORS THAT AFFECT SALINITY AND ORGANISMS OF INLAND WATERS AND ESTUARIES

According to Reid (12) salinity is a very critical factor in the distribution and survival of many organisms in the estuary. In his book he gives us these facts about changes that occur in community composition in estuaries. The waters of the James River estuary of Chesapeake Bay grade from fresh to a salinity of about 17 ppt near the mouth, therefore the James River would be classified on the basis of salinity range as mixohaline. Throughout much of North America most streams have been changed, to different extents, from their original state. These changes are in many cases the results of pollution. The ways in which pollution and the subsequent change in community composition come about are: (1) by the introduction of erosional products, such as silt and clay, through improper control of soil in mining, agricultural practices, and timbering; (2) through the flowing in of materials from industrial operations, making the environment uninhabitable; and (3) by the dumping of domestic sewage or industrial substances which result in a lowering of the oxygen concentration below the limits tolerated by the original inhabitants. Chemical effluents from industrial plants can change the density or chemistry of the water and make the environment untenable. Streams become highly saline from brine from oil fields. It has been learned more recently that wastes from mining of uranium ore may greatly lower the pH of streams in the vicinity if it is unrecovered. Effects on stream communities of the dumping of domestic sewage and organic substances are chiefly through uptake of oxygen beyond the "normal balance" of natural photosynthesis and respiration processes in streams. It is known that the effects of pollution decrease with distance downstream, if no additional pollution occurs.

Copeland (13) explains that a survey of the literature shows that high salinity, resulting from low input of fresh water can cause far-reaching changes in the ecology and productivity of an estuary. Some of the results of high salinities, he claims, may be the multiplication of parasites and species competing with oysters, lessening of reproduction of the blue crab, lowering of primary productivity, and upset of the life cycles of fish. The author believes that there should be careful consideration given to the effects on the ecology of estuaries that result from regulating river flow by dams.

Some of the specimens used in this study were from Chesapeake Bay, but there is a concern for the factors that imperil the well-being of the bay's inhabitants. In a report (14), pressures bearing down on the bay area are described as: the daily discharge of 400-million gallons of untreated sewage toxic to fish life and causing oxygen depletion; the planned construction of additional nuclear power plants in Virginia and Maryland, creating thermal pollution; dredging operations by the Army Corps of Engineers to deepen Baltimore Harbor and the Chesapeake and Delaware Canal, causing water to be diverted from the Susquehanna River at the top of Chesapeake Bay into Delaware Bay, thus raising the salinity in the rest of the bay by the loss of fresh water and affecting the organisms here; and the constant runoff of pesticides and fertilizers from nearby farmland. It is stated here that although Maryland and Viriginia have anti-pollution laws, many scientists feel that these two states are so committed to industry that the long-run prognosis is bleak. Emphasized in this report is the need for a well-financed effort to understand life cycles and food chains and the way changes in water chemistry affect these ecological relationships.

Holden (15) reported more recently some of the same pressures affecting the Chesapeake Bay area and also ones such as chemical effluents from industry and oil from tankers. She describes this estuary of the Susquehanna River as having a heavy growth of flora and a rich benthic community of oysters, blue crabs, and soft-shell clams because of its accessibility to sunlight and the variations in its salinity (from almost no salt at the top to 30 ppt where it meets the sea) and as being the source of a $65-million-a-year fish and shellfish business for Maryland alone. It is related here that although the bay area has long been a laboratory for marine scientists, no comprehensive plan has yet been developed to protect its bounty and order its progress.

REFERENCES

1. Coe, W.R., Nemertean Parasites of Crabs, Ginn, Boston, Massachusetts (1902).

2. Humes, A.G., "The Morphology, Taxonomy, and Bionomics of the Nemertean Genus Carcinonemertes, Ill. Biol. Monogr. 18, No. 4 (1942).

3. Osburn, R.C., "A Survey of the Bryozoa of Chesapeake Bay," Chesapeake Biological Laboratory, Solomons Island, Md. (1944).

4. Pilsbry, H.A., The Sessile Barnacles (Cirrepedia) Contained in the Collections of the National Museum, Smithsonian Inst. Bull. No. 93 (1916).

5. Coker, R.E., "Notes on a Species of Barnacle (Dichelaspis) Parasitic on Gills of Edible Crabs, Bull. U.S. Fish Commission 21, Wash. Gov. Printing Office (1901),

6. Van Engel, W.A., "The Blue Crab and Its Fishery in Chesapeake Bay," Com. Fisheries Rev. 20, 6 (1958).

7. Cheng, T.C., The Biology of Animal Parasites, Saunders, Philadelphia, Pennsylvania (1968).

8. Gunter, G., "Some Relations of Estuarine Organisms to Salinity," Limnol. and Oceanogr. 6 (2):182-190 (1961).

9. Hopkins, S.H., "B. Parasitism," The Geol. Soc. Amer., Memoir 67, Vol. 1, ed. by J.W. Hedgpeth (1957).

10. Pearse, A.S. and Gordon Funter, "Salinity," Geol. Soc. Amer., Memoir 67, Vol. 1, ed. by J.W. Hedgpeth (1957).

11. Hopkins, S.H., "The Nemertean Carcinonemertes as an Indicator of the Spawning History of the Host, Callinectes Sapidus, J. Parasitol, 33. No. 2 (1947).

12. Reid, G.K., Ecology of Inland Waters and Estuaries, Reinhold Pub. Corp., New York (1961).

13. Copeland, B.J., "Effects of Decreased River Flow on Estuarine Ecology," Water Pollut. Contr. Fed. J. 38 (11) 1831-1839, Illus. (1966).

14. "Chesapeake Bay Fights for Its Life," Business Week, No. 2114 (March 7, 1970) p. 40-44.

15. Holden, Constance, "Chesapeake Bay, Queen of Bays, Is a Rich Commercial and Recreational Resource, but March of Progress Imperils Her Health," Science Vol. 172, No. 3985 (May 21, 1971).

COASTAL MORPHOLOGY OF BRIGANTINE INLET, NEW JERSEY:

HISTORY AND PREDICTION, 1877-1977

by

William F. Rittschof*

A study for the New Jersey Bureau of Geology and Topography in cooperation with Fairleigh Dickinson and Columbia Universities.

*Present address: Department of Geology
University of Rhode Island
Kingston, Rhode Island 02882

ABSTRACT

The everchanging coastline of the Atlantic is exemplified by the tidal inlet at Brigantine, New Jersey. Over the past 100 years, a cyclical pattern of sediment migration has been observed. Both east-west and north-south trends have been established for this migration. Dramatic shifts in the migration patterns are due mainly to local storms. It appears that the storms can cause great progradation and retrogradation along the shoreline.

Predictions can be made from the history of sediment migration. The inlet will remain open, but will go through a northeastern prograding phase when there are sufficient offshore shoal deposits. When there are few or no shoals, the inlet will go through a southwestward retrograding phase. These patterns are subject to change by such factors as gross alteration of current velocity within the inlet (due to the opening or closing of a nearby inlet).

INTRODUCTION

General Statement

Brigantine Inlet is a typical barrier island inlet of the Atlantic coast of New Jersey, but has the unique quality of not being controlled by groins, jetties, or other man-made obstructions. This study is concerned with sediment movement, as evidenced by change in coastline morphology, near the mouth of this inlet. The objective is to find general trends in sediment movement over a 100-year span and project these trends into the future to predict shoreline changes.

Location and Description of Study Area

Brigantine Inlet is located about 6 miles north of Atlantic City, New Jersey, and lies between 39° 25' and 39° 27' 30" N latitude and 74° 20' 30" and 74° 20' W longtitude (Fig. 1). The present topography and general features of the area are described by McMaster (1954). He described it as an area of the New Jersey coastline where the foreshore width is 100 feet with a normal slope of 3 degrees. The backshore, when fully developed, is 100 feet wide and has a slope of 1 degree. In 1887 there were dunes in the backshore (Fig. 4). These dunes have since been eroded and only a few remnants are observable today. Behind the barrier islands is a lagoonal area, mostly salt marsh, but cut by channels, streams, and open water.

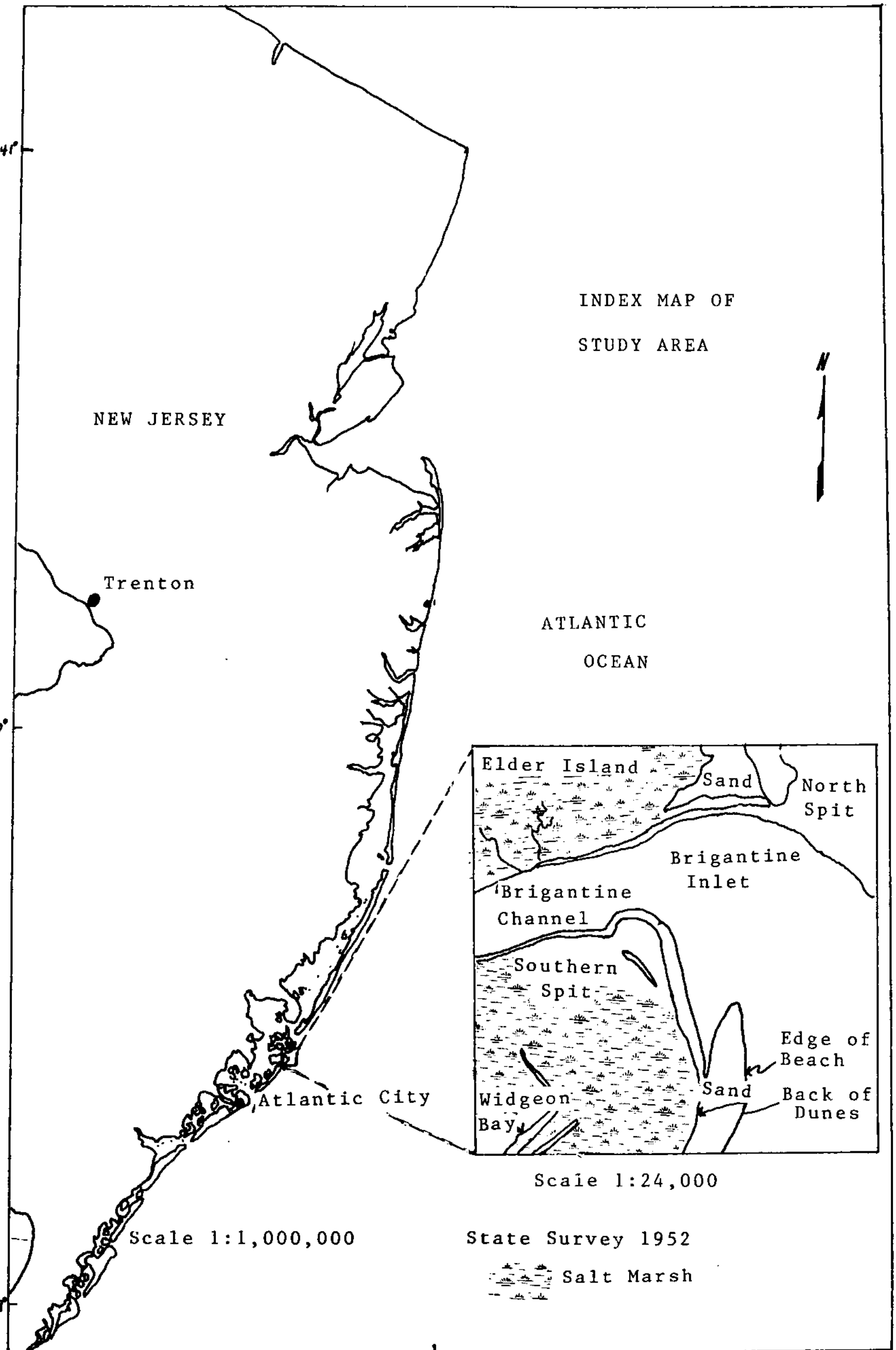
Previous Work

The Brigantine Inlet area has been studied before. Plusquellec (1966) touched upon the area in his study of coastal morphology between Brigantine and Beach Haven Heights. Charlesworth (1968) mentions the inlet in his study of the sedimentation between Beach Haven and Little Egg Inlet. Wicker (1965) also mentions Brigantine Inlet in his study of the New Jersey coastline. McMaster (1954) noted the area in his study of New Jersey beach sands.

These reports were useful in this study for general information only. The scope of the previous work has been much greater than that of this report and the information is necessarily of a more general nature.

Methods

Direct measurements, taken from scaled, sequential, aerial photographs and maps are the basis of the interpretations below. It was necessary to establish a reference point near the inlet due to the lack of landmarks which remained stable in position over the 100-year period of study. This point was established by projecting a line along Brigantine Avenue north for 2 miles from the intersection of 14th Street in the town of Brigantine (Fig. 2). This method was used on the aerial photographs. The same point was located on charts at 29° 25' 40" N latitude and 74° 19' 30" W longitude. Measurements were compass headings and distances from the point of reference to identifiable features (Fig. 3).



41°
40°
39°
74°
INDEX MAP OF
STUDY AREA
N
NEW JERSEY
Trenton
ATLANTIC
OCEAN
Atlantic City
Elder Island
Sand
North
Spit
Brigantine
Inlet
Brigantine
Channel
Southern
Spit
Edge of
Beach
Sand
Back of
Dunes
Widgeon
Bay
Scale 1:24,000
Scale 1:1,000,000
State Survey 1952
Salt Marsh

Figure 1

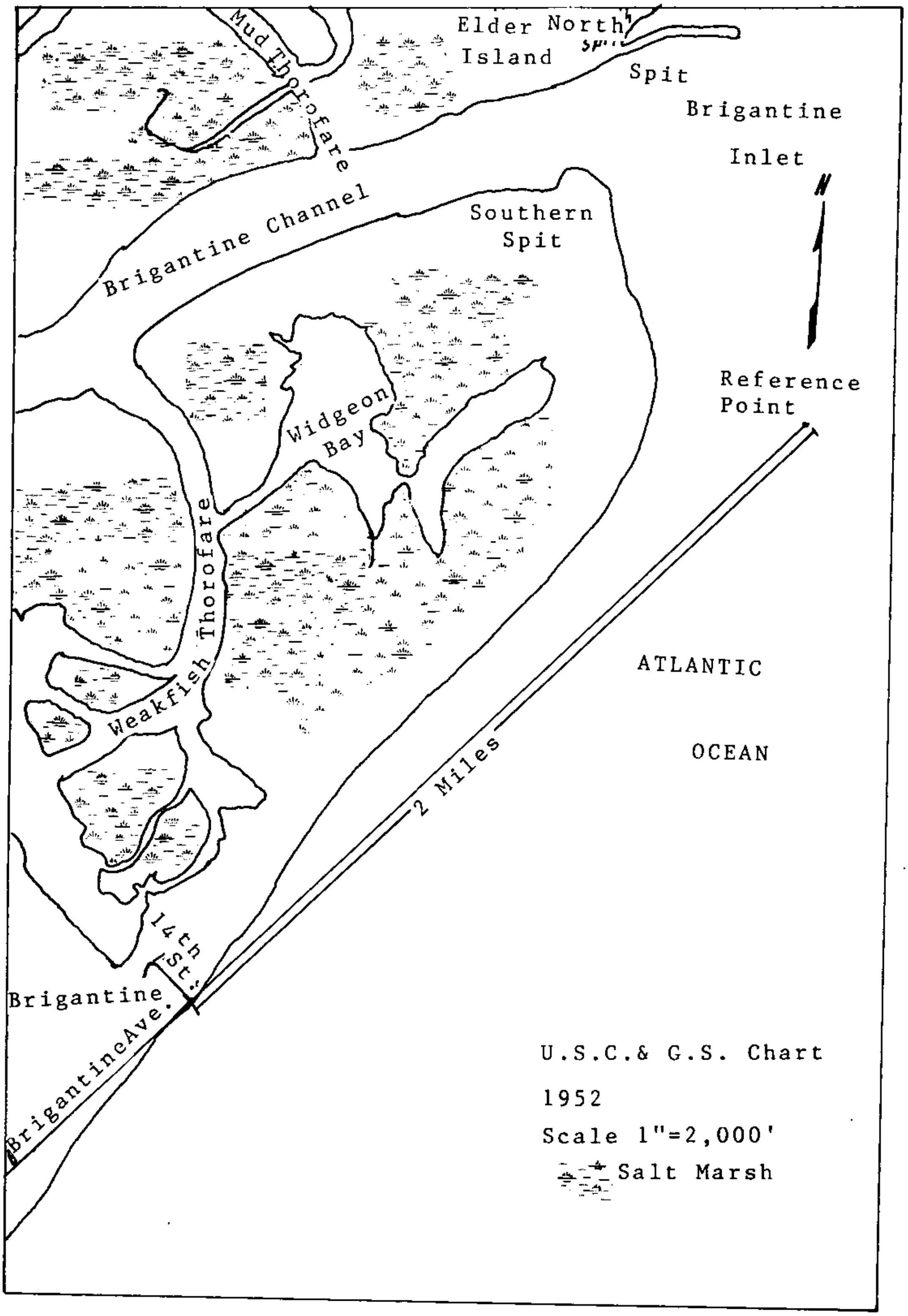

Mud Thorofare
Elder Island
North Spit
Spit
Brigantine
Inlet
N
Brigantine Channel
Southern Spit
Reference Point
Widgeon Bay
Weakfish Thorofare
ATLANTIC
OCEAN
2 Miles
14th St.
Brigantine
Brigantine Ave.
U.S.C.& G.S. Chart
1952
Scale 1"=2,000'
Salt Marsh

Figure 2

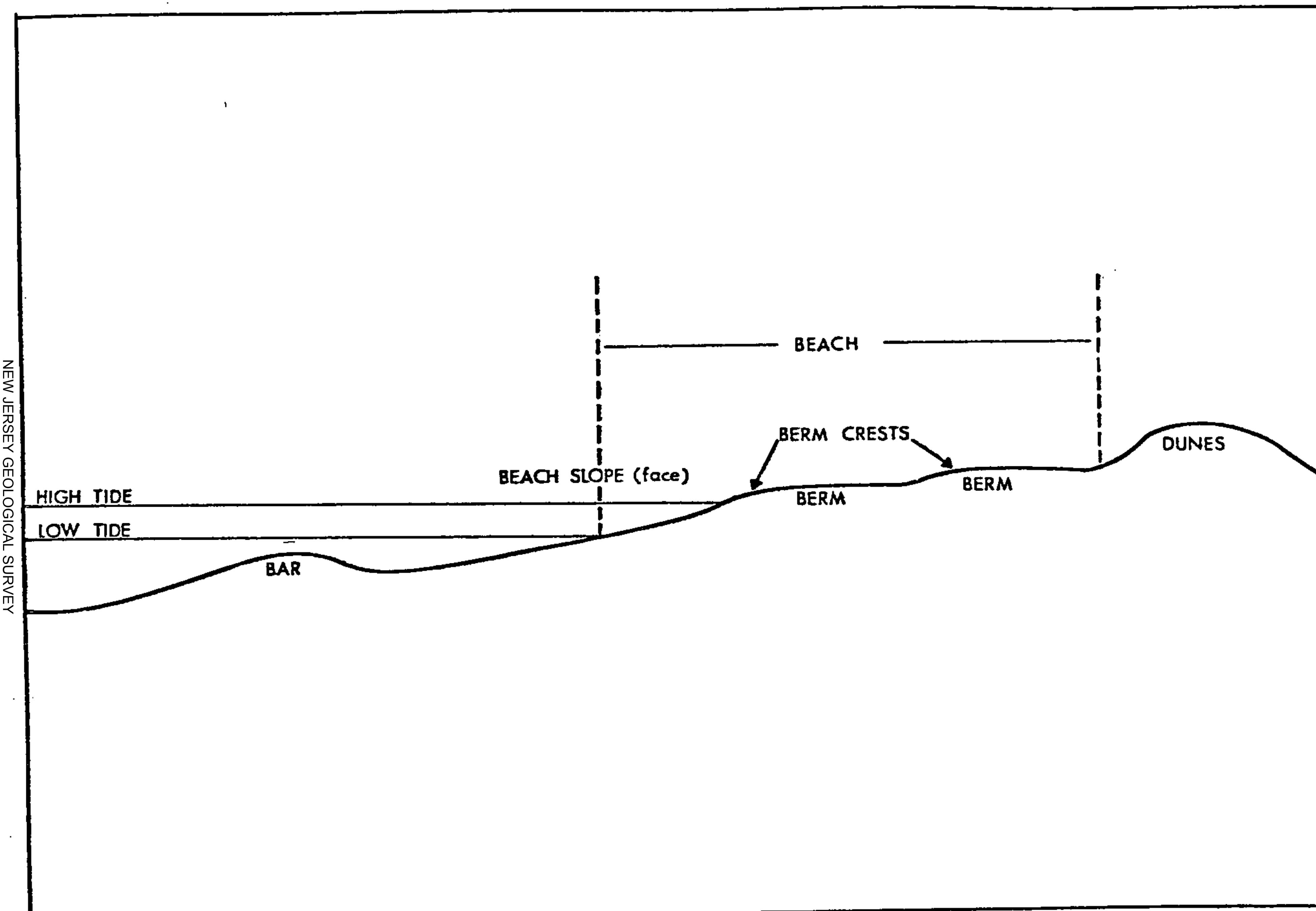


Fig 3 Diagram showing terminology of beach profile.

Overlay sketches were made from the maps and aerial photographs (Figs. 4 to 13). These sketches include all the features of interest in the interpretation of topographic data.

<u>Limiting Factors</u>

A few factors limited the scope of this study. Incomplete air coverage was the basic factor separating the data used for quantitative measurements and those used for visual intrepretation only (see Tables 1 and 2). Another was the lack of information on the exact time of photography and, consequently, tide level on the aerial photographs. This was taken into account by placing a fifty foot scientific error on all measurements. This was calculated by assuming a 3-degree foreshore slope (McMaster, 1954) and a 4-foot tidal range (Wicker, 1975), giving an 80-foot horizontal distance between average high and low tide lines. Taking seasonal tide changes into account and assuming the photographs were taken, on the average, at some time between high and low tide, a 50-foot tolerance is reasonable for calculation of areal extents of features.

PHYSICAL PROCESSES AFFECTING BRIGANTINE INLET

<u>Currents Within the Inlet</u>

The currents in a tidal inlet are produced by two different forces, tides and wind. These currents are in turn affected by the width of the inlet, the nearshore topography, and the opening and closing of inlets nearby. Current strength is one of the primary factors involved in keeping an inlet open. The volume of sediment transported by the current is dependent upon the current velocity. A high current velocity would remove sediment which would tend to fill or cut off an inlet. Quantitative study of currents is, however, beyond the scope of this report.

<u>Tides</u>

The tides in this area are semi-diurnal. Since 1911, the average height has been approximately 4.1 feet. Storms have been known to raise the ocean 5.4 feet above mean high water and to lower it 3.5 feet below mean high water (Wicker, 1965).

<u>Wind</u>

The U.S.N. Weather Command Report (1970) for Atlantic City reported that, over the last 90 years, during the stormy months of October through March, the dominant winds have been from the northwest. During the calmer months of April to September, the dominant winds have been from the southwest. Historically, the prevailing wind direction is from the southwest while the strongest commonly occurring winds are from the northwest. Most storms, however, approach from the northeast and have their strongest winds from the northeast.

This indicates that a longshore current should be established to the north in this area, at least for the calmer months when the predominant wind is from the southwest.

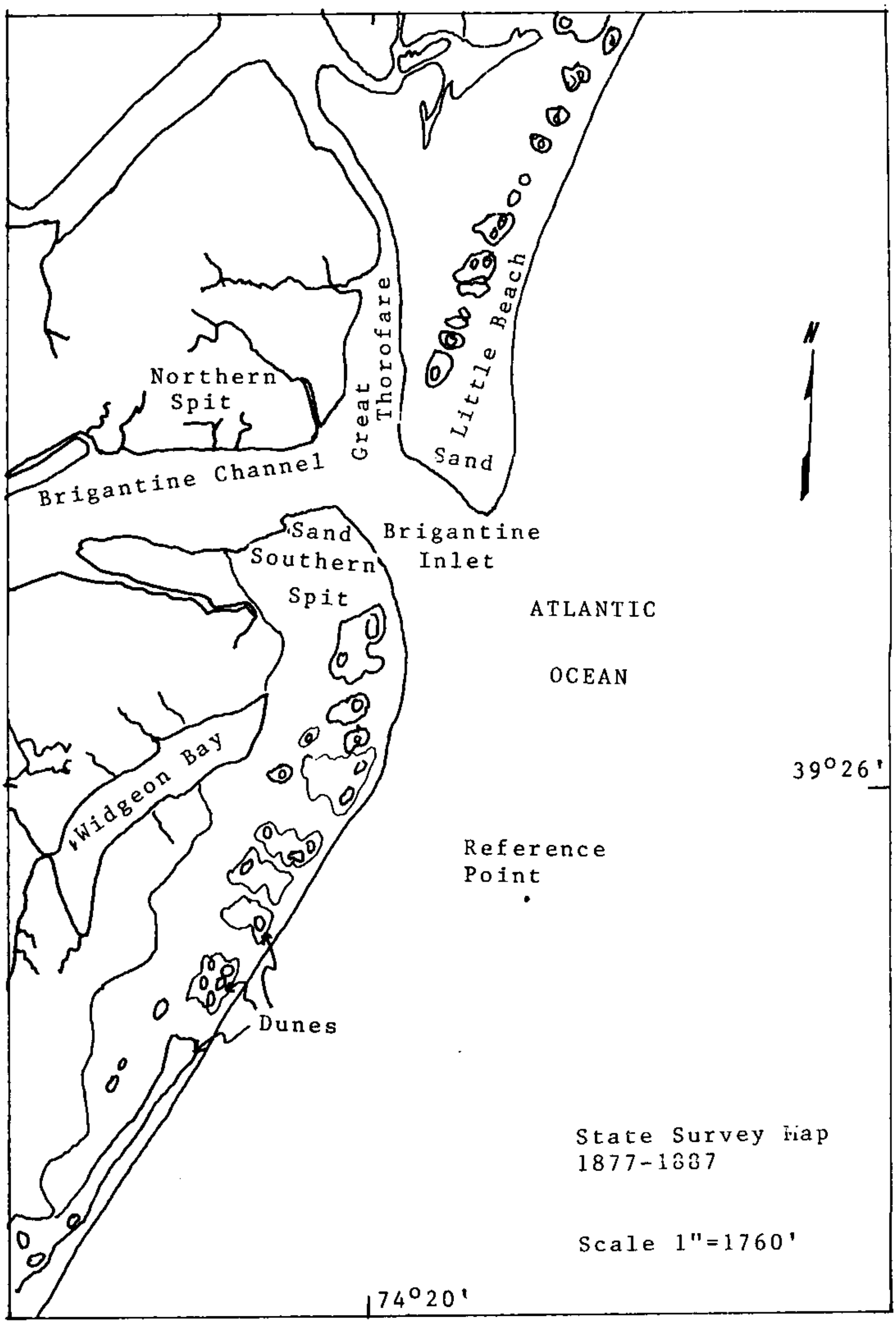

Northern Spit
Great Thorofare
Little Beach
Sand
Brigantine Channel
Sand
Brigantine Inlet
Southern Spit
ATLANTIC
OCEAN
Widgeon Bay
$39^{o}26'$
Reference Point
Dunes
State Survey Map 1877-1887
Scale 1"=1760'
$74^{o}20'$
N

Figure 4

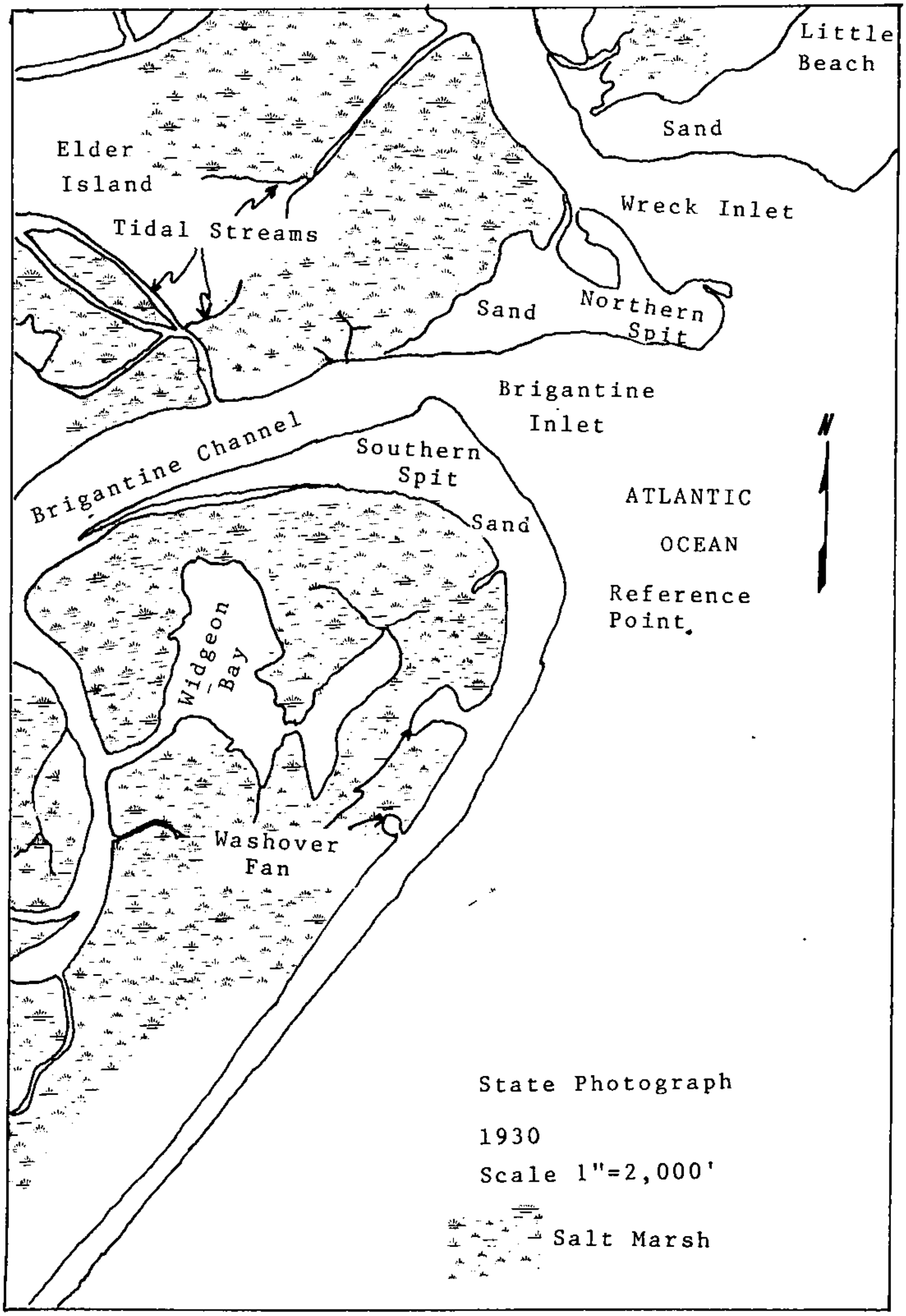
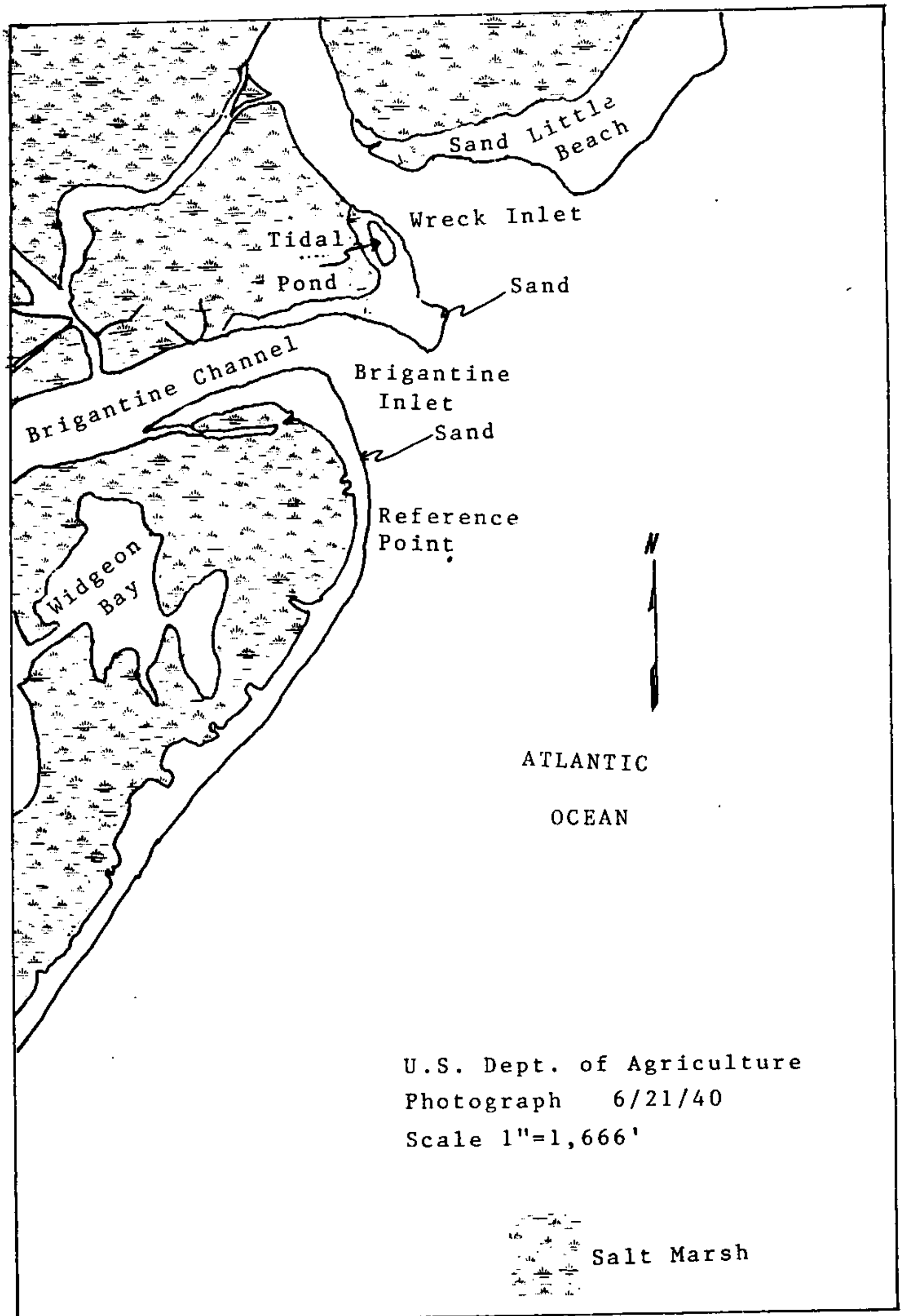
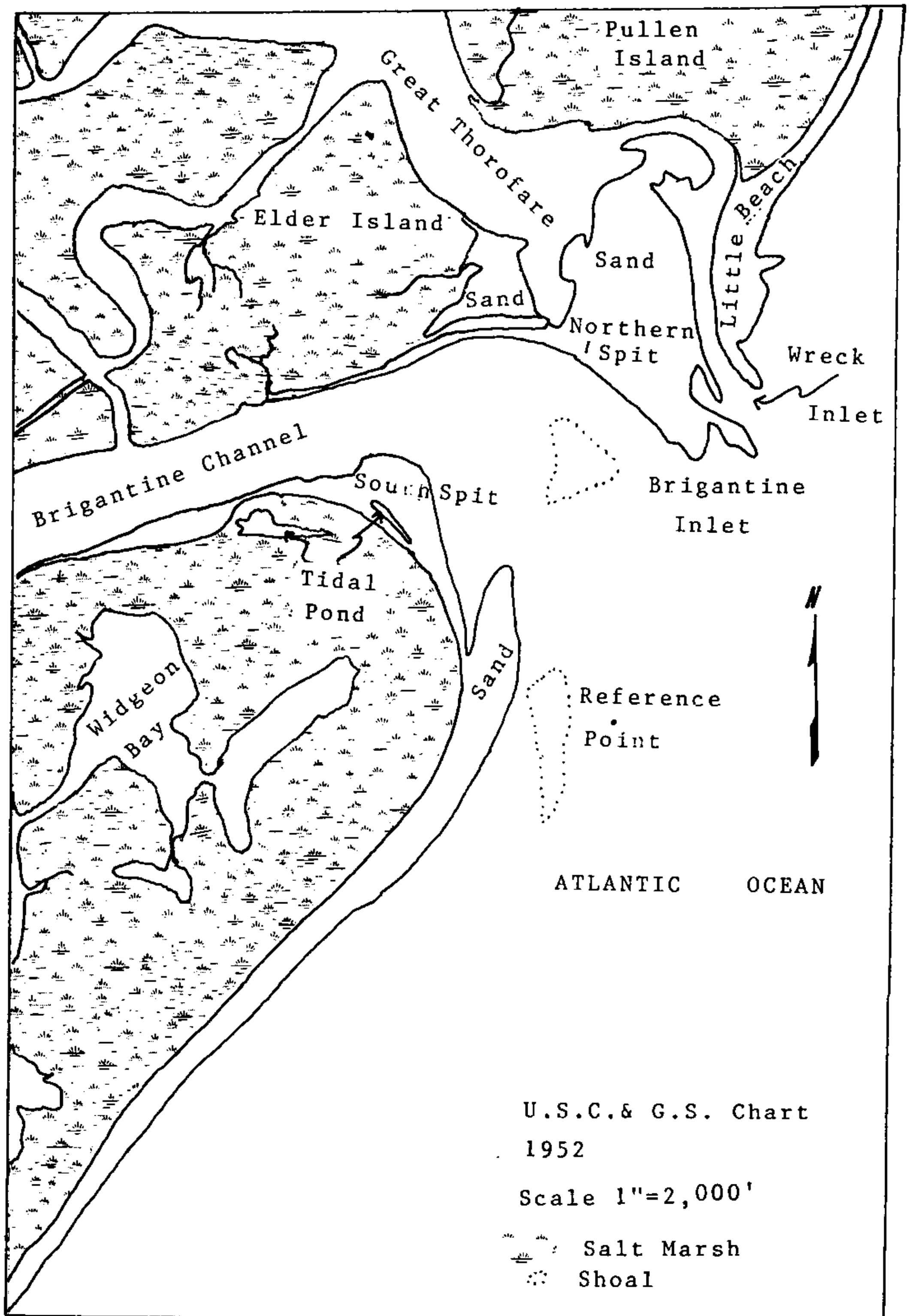

Little
Beach
Sand
Elder
Island
Wreck Inlet
Tidal Streams
Sand
Northern
Spit
Brigantine
Inlet
Brigantine Channel
Southern
Spit
Sand
ATLANTIC
OCEAN
N
Reference
Point
Widgeon
Bay
Washover
Fan
State Photograph
1930
Scale 1"=2,000'
Salt Marsh

Figure 5



Sand
Little
Beach
Wreck Inlet
Tidal
Pond
Sand
Brigantine Channel
Brigantine
Inlet
Sand
Reference
Point
Widgeon
Bay
N
ATLANTIC
OCEAN
U.S. Dept. of Agriculture
Photograph 6/21/40
Scale 1"=1,666'
Salt Marsh

Figure 6



Pullen Island
Great Thorofare
Elder Island
Sand
Sand
Little Beach
Northern Spit
Wreck Inlet
Brigantine Channel
South Spit
Brigantine Inlet
Tidal Pond
N
Widgeon Bay
Sand
Reference Point
ATLANTIC OCEAN
U.S.C.& G.S. Chart
1952
Scale 1"=2,000'
Salt Marsh
Shoal

Figure 7

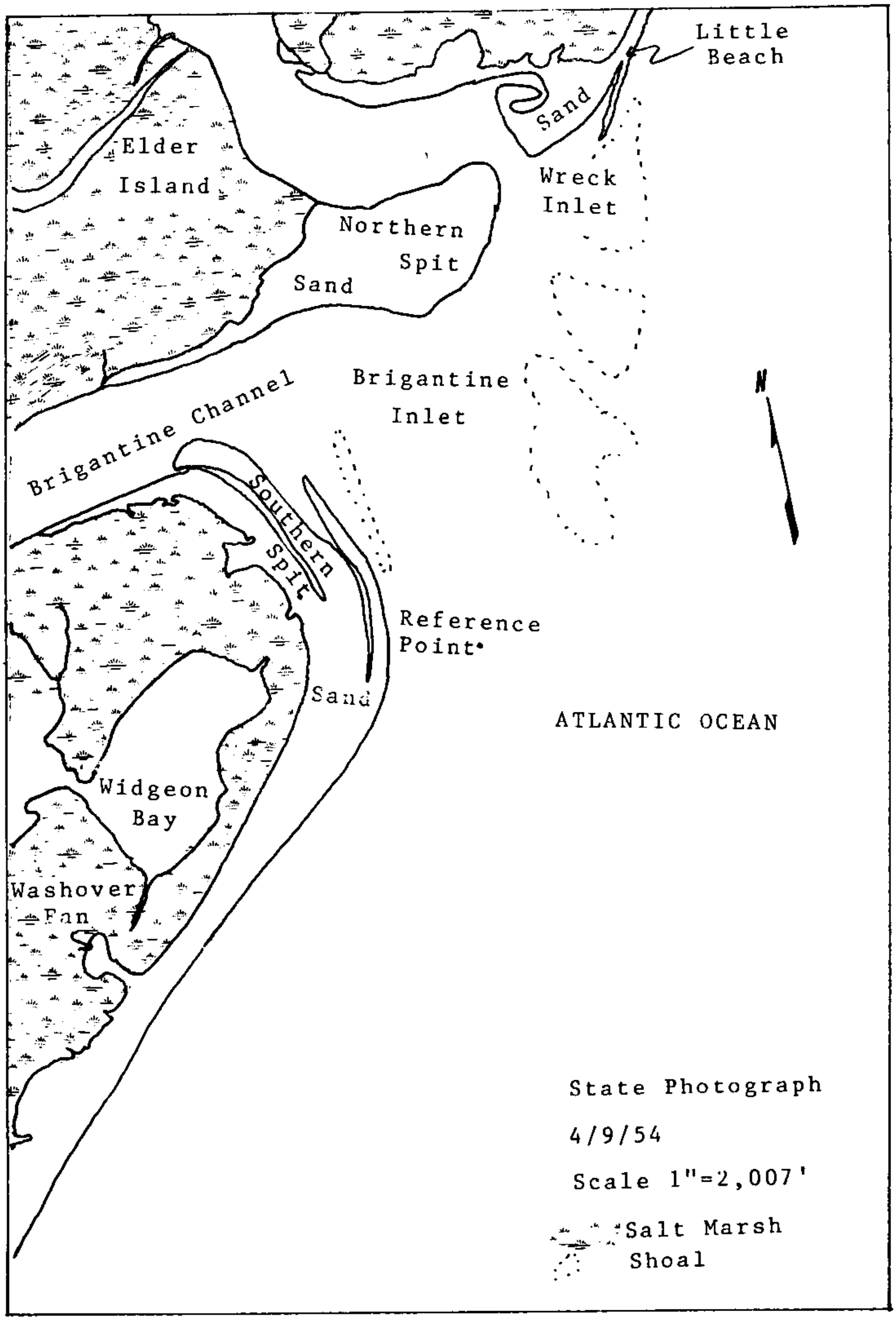

Little
Beach
Sand
Wreck
Inlet
Elder
Island
Northern
Spit
Sand
Brigantine
Inlet
Brigantine Channel
Southern
Spit
Reference
Point
Sand
ATLANTIC OCEAN
Widgeon
Bay
Washover
Fan
N
State Photograph
4/9/54
Scale 1"=2,007'
Salt Marsh
Shoal

Figure 8

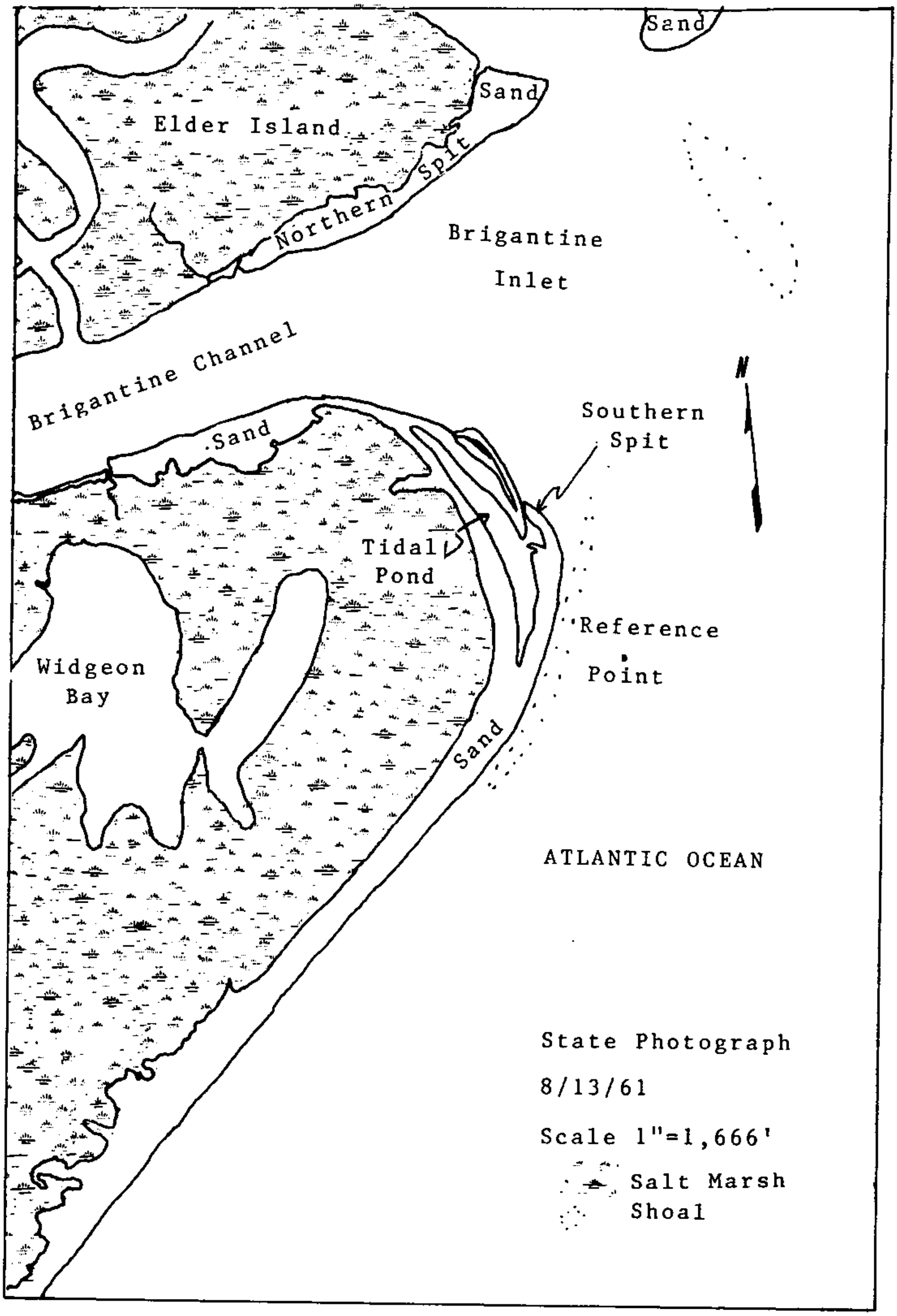

Sand
Sand
Elder Island
Northern Spit
Brigantine
Inlet
Brigantine Channel
N
Sand
Southern
Spit
Tidal
Pond
Reference
Point
Widgeon
Bay
Sand
ATLANTIC OCEAN
State Photograph
8/13/61
Scale 1"=1,666'
Salt Marsh
Shoal

Figure 9

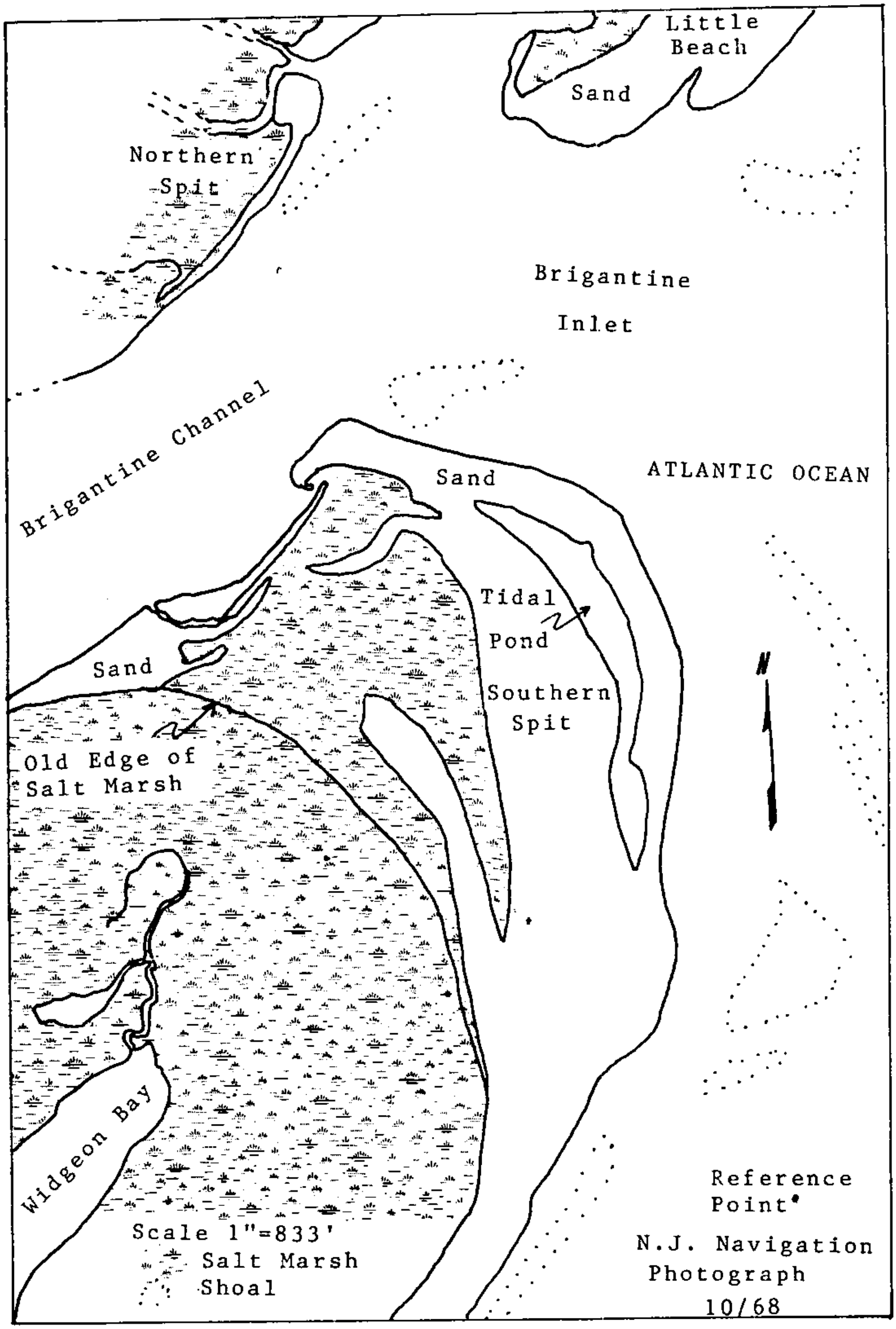

Little
Beach
Sand
Northern
Spit
Brigantine
Inlet
Brigantine Channel
Sand
ATLANTIC OCEAN
Tidal
Pond
Sand
Southern
Spit
Old Edge of
Salt Marsh
N
Widgeon Bay
Scale 1"=833'
Salt Marsh
Shoal
Reference
Point•
N.J. Navigation
Photograph
10/68

Figure 10

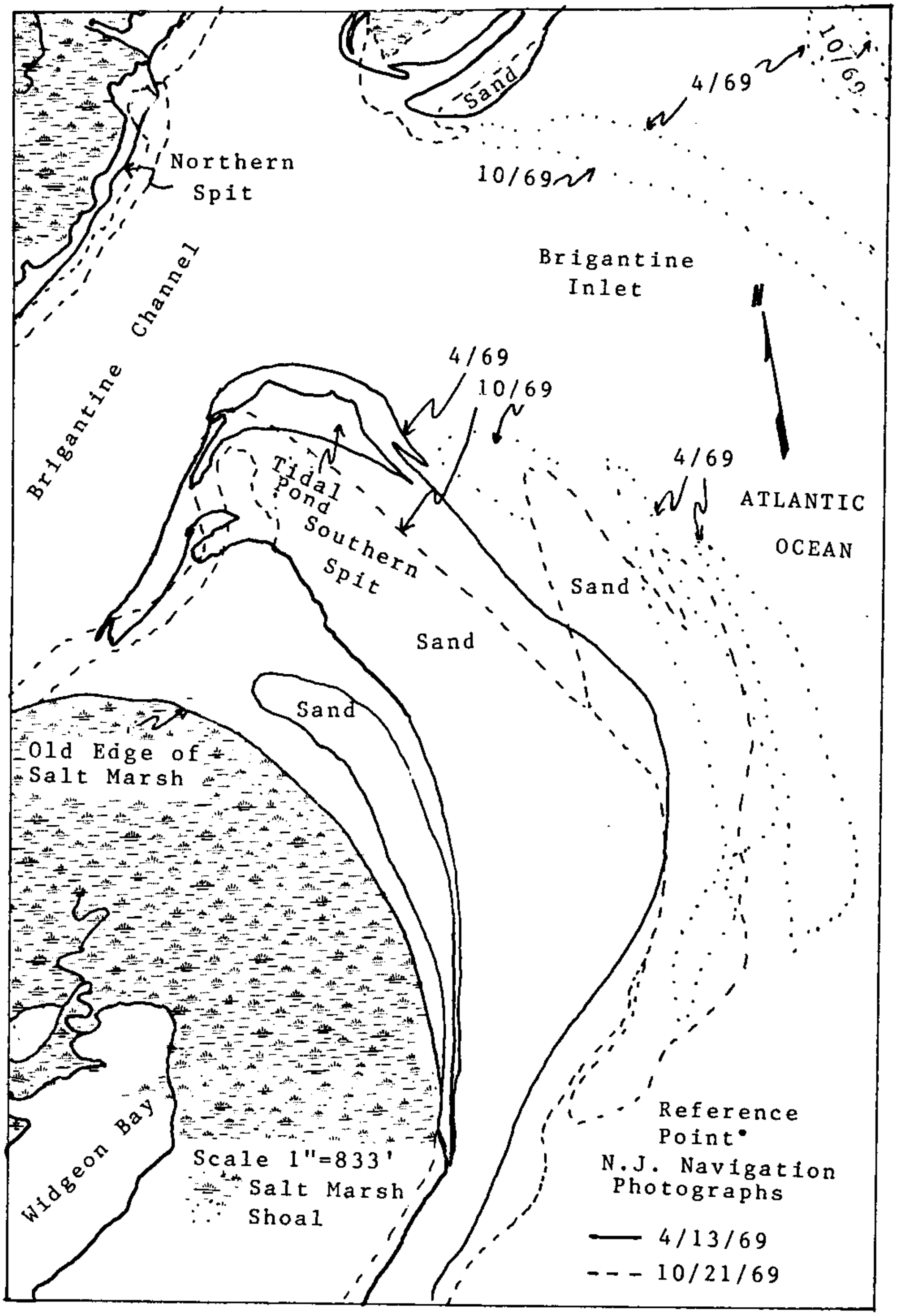

Sand
4/69
10/69
10/69
Northern
Spit
Brigantine Channel
Brigantine
Inlet
N
4/69
10/69
Tidal
Pond
Southern
Spit
4/69
ATLANTIC
OCEAN
Sand
Sand
Sand
Old Edge of
Salt Marsh
Widgeon Bay
Scale 1"=833'
Salt Marsh
Shoal
Reference
Point•
N.J. Navigation
Photographs
4/13/69
10/21/69

Figure 11

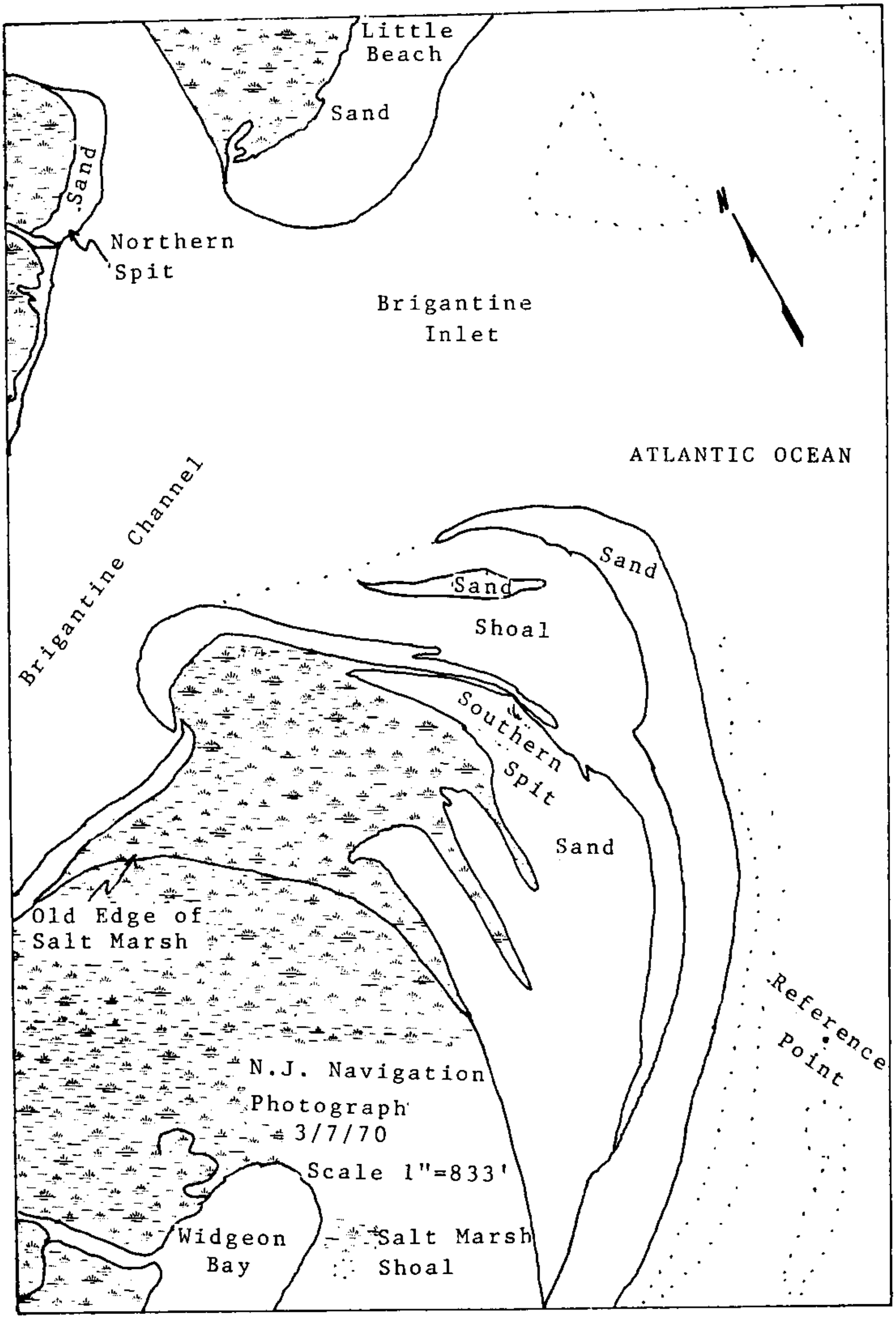

Little
Beach
Sand
Sand
Northern
Spit
Brigantine
Inlet
N
ATLANTIC OCEAN
Brigantine Channel
Sand
Sand
Shoal
Southern
Spit
Sand
Old Edge of
Salt Marsh
Reference
Point
N.J. Navigation
Photograph
3/7/70
Scale 1"=833'
Widgeon
Bay
Salt Marsh
Shoal

Figure 12

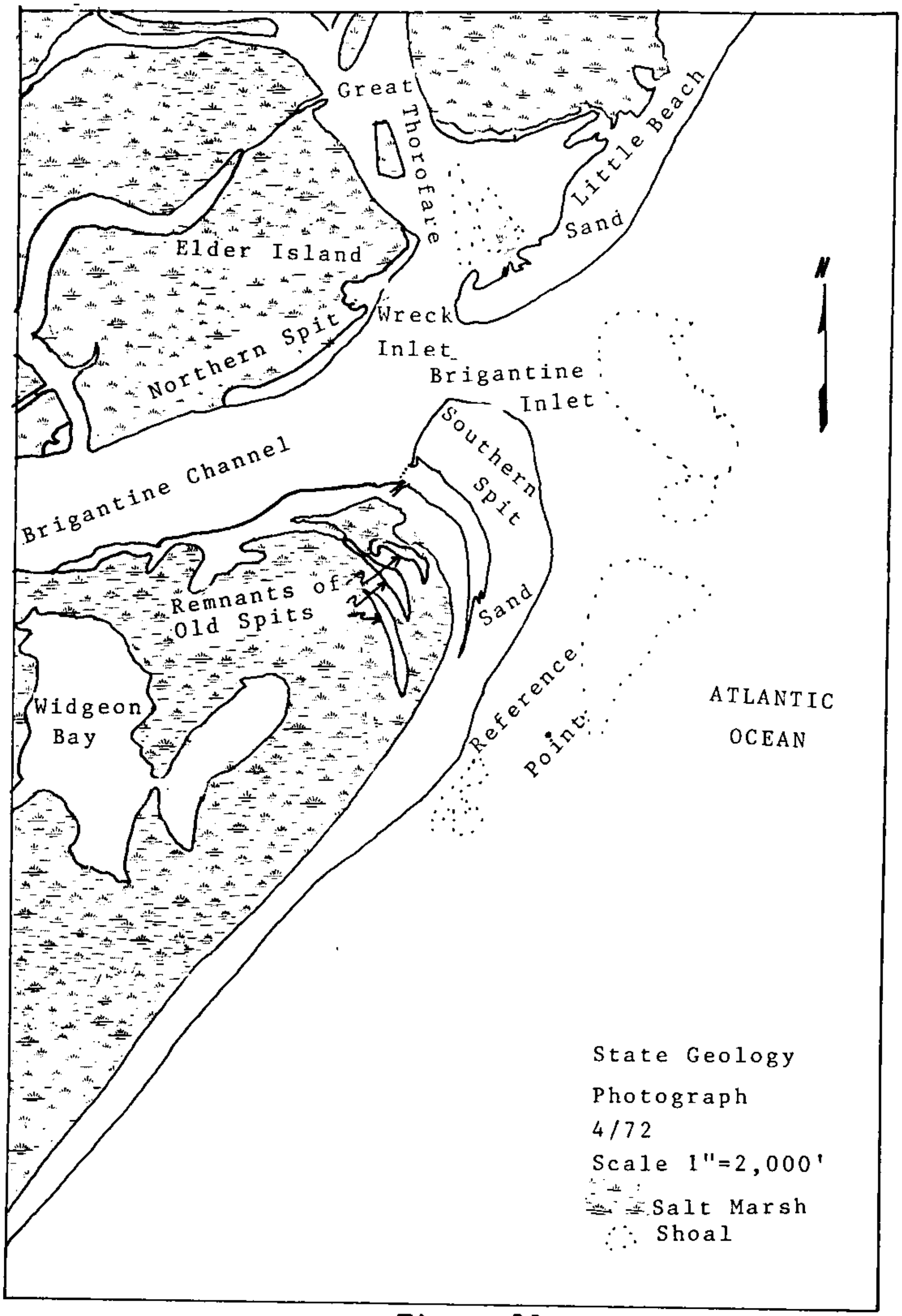

Great
Thorofare
Little Beach
Sand
Elder Island
Wreck
Inlet
Northern Spit
Brigantine
Inlet
Brigantine Channel
Southern
Spit
Remnants of
Old Spits
Sand
Widgeon
Bay
Reference
Point
ATLANTIC
OCEAN
N
State Geology
Photograph
4/72
Scale 1"=2,000'
Salt Marsh
Shoal

Figure 13

Figure 14

Distance to beach from reference point along a N90°W azimuth.

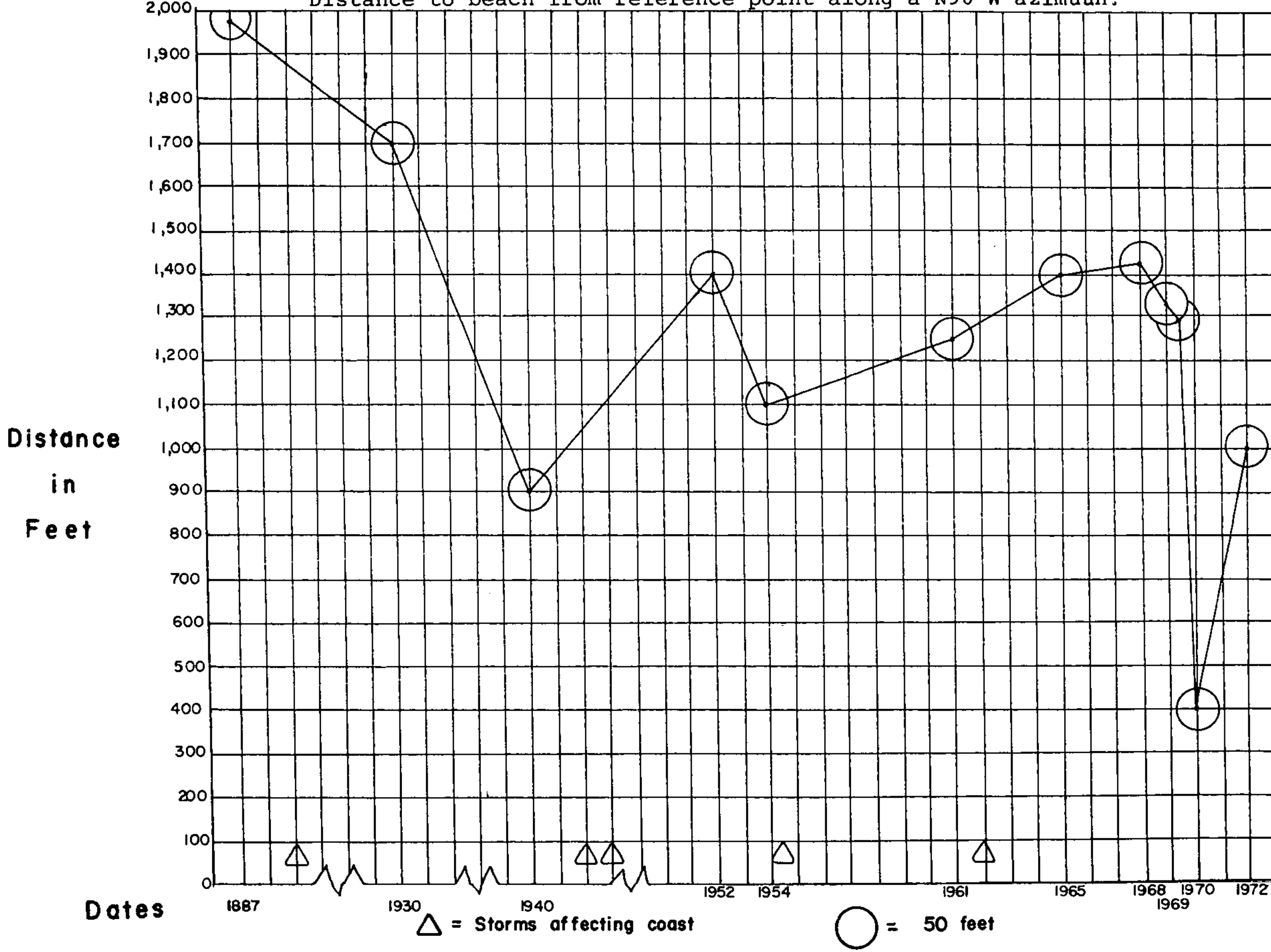


Figure 15

Channel width in a N 45°W direction

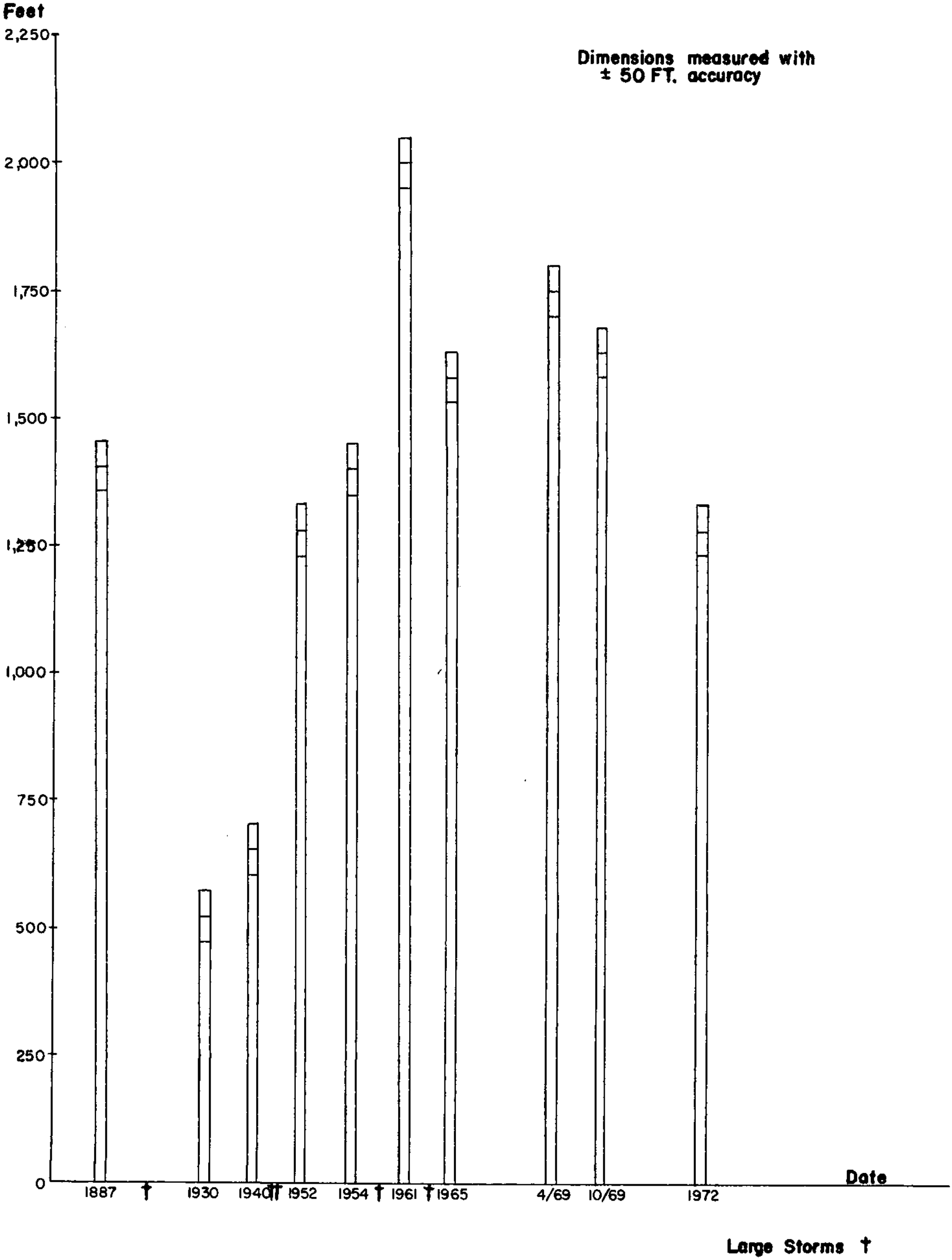


TABLE 1

Inventory of all sources used for measurements

Date	Type	Scale	Agency
1877-1887	Map	1"=1,760'	N.J. Bureau of Geology & Topography
1930	Aerial Photo Mosaic	1"=2,000'	"
1940	"	1"=1,666'	U.S. Dept. of Agriculture
1952	7-1/2' Quad.Map	1"=2,000'	U.S.C. & G.S.
4/9/54	Aerial Photo	1"=2,007'	N.J. Bureau of Geology & Topography
8/61	"	1"=1,666'	"
5/65	"	1"=400'	"
10/21/68	"	1"=833'	N.J. Bureau of Marinelands Management
4/13/69	"	1"=833'	"
10/24/69	"	1"=833'	"
3/7/70	"	1"=833'	"
4/72	"	1"=2,000'	N.J. Bureau of Geology & Topography

TABLE 2

Inventory of data not used for measurements

Date	Type	Scale	Agency	Reason Not Used
?	Map	1"=1,666'	N.J. Bur. of Geology & Topography	No date
1920	Aerial Photo	1"=840'	N.J. Bur. of Geology & Topography	No ref. pt. could be made
3/12/1940	Aerial Photo	1"=1,000'	N.J. Bur. of Geology & Topography	No ref. pt. could be made
4/13/1947	Aerial Photo	1"=1,000'	N.J. Bur. of Geology & Topography	No ref. pt. could be made
1/7/1967	Chart	1"=3,333'	U.S.C.& G.S.	Inaccurate shore profile
4/1968	Aerial Photo	1"=833'	N.J. Bur. of Marinelands Management	No ref. pt. could be made
8/15/1968	Aerial Photo	1"=1,666'	N.J. Bur. of Marinelands Management	No measurable difference from 10/1968 photo

TABLE 3

Storm data - N.J. State Climatologist
(Wind and wave intensities great enough to cause property damage)

Date	Intensity
October 23, 1878	-----
August 24-29, 1893	Great damage
August, 1933	-----
September, 1938	-----
September, 1944	Great damage
November 25, 1950	72 m.p.h. winds recorded at Atlantic City
August 31, 1954	Great damage
September, 1960	-----
March 6-8, 1962	Broke many new inlets on New Jersey coast
December 30, 1962	-----

Waves

According to Plusquellec (1966) the average wave height in the Brigantine area is 2 feet, but storm generated waves can reach the height of 11 to 12 feet and a length of 7 to 20 times the wave height. Weather Service Command (1970) indicated that the normal wave direction is from the south or southwest, with storm generated waves usually from the northwest or northeast.

The major effect of waves upon sediment transport is through longshore currents.

Longshore Currents

The direction of longshore currents on the New Jersey coast is well studied. (Wicker (1965) stated that there is a "nodal" region between Barnegat and Manasquan Inlets; north of this region, the longshore drift is to the north; to the south of this area of no drift, the current trends to the south. McMaster (1954) and MacClintock (1971) agreed with Wicker. This suggests that the dominant longshore drift direction at Brigantine Inlet is to the south.

While longshore transport is predominantly to the south, periodic northward transport cannot be ignored. The effects of northward drift are seen in the constant northward addition of digits on the southern spit (see Figs. 4-13).

Storms

Storms are the single most important factor affecting sediment transport in Brigantine Inlet. Table 3 gives the dates of the strongest storms to hit the area in question. This table was obtained from D. Dunlop, New Jersey State Climatologist (pers.com., 1972). These data are limited to newspaper accounts of the storms, used for insurance claims. Therefore, no quantitative data on direction and intensity were available.

Between 1887 and 1930 there was one large storm, from August 24 to 29, 1893. This storm probably caused the great decrease in width of the beach and the channel at Brigantine Inlet. It may have caused the washover fan seen in Fig. 5. This is what I call a destructive storm because it caused erosion of the shoreline. It probably caused a new inlet to be formed, Wreck Inlet, to the north of Brigantine (see Figs. 4 and 5). The storm was probably also responsible for depositing what I call the northern spit, on Elder Island. This sand is presumed to have been a southern extension of Little Beach before it was severed by the storm.

The next storm was in September, 1944, followed by another on November 25, 1950 (Table 3). These storms are bracketed by the 1930 and 1952 data items. Again, there was a large change in the width of the beach and channel at Brigantine (Figs.14 and 15). The net result of these storms was constructive in that both the beach and the channel were widened. Also, great amounts of sand were deposited on the northern spit (see Figs. 6 and 7), essentially closing Wreck Inlet.

The next important storm was on August 31, 1954. Photographs were available for April, 1954 and August 1961. This storm was constructive in that both the beach and channel were widened (Figs.14 and 15), but destructive in that the northern spit was all but eroded away (see Figs. 8 and 9).

The next storm is perhaps the most infamous on the New Jersey coastline. It began on March 6 and continued through March 8, 1962. Kenney (1962) described the storm as a "freak." The position of the storm gave it a 1,000 mile possible fetch and it hit the Atlantic Coast at spring tide. The result was devastating, completely destroying all the summer homes on Island Beach, just tens of miles north of Brigantine Inlet. Both the beach and channel width were decreased (see Figs.14 and 15). The beach, being directly exposed to the storm, was eroded more than the channel, which was protected by the shallower, calmer waters of the salt marsh. The shoreline receded almost 1,850 feet, whereas the channel narrowed about 420 feet (Figs. 9 and 10).

Sea Level Rise

It is difficult in this report to present any quantitative data for or against sea level rise in the Brigantine Inlet area. The 50 foot tolerance of all scalar measurements precluded detection of any of the changes due to sea level rise described by Maurice Schwartz (1965). Schwartz claimed that the dunes are eroded at the same time the sea is rising, the sand from the dunes being deposited offshore to keep up with the rising sea level. Therefore, offshore depths would stay constant, as would the shoreline. The only feature to change would be the dune topography. This information was not available from aerial photographs.

Plusquellec (1966) suggested that Brigantine Inlet is a submerging area but gave no quantitative evidence. In any case, the effect of sea level rise, at a rate of 0.25 to 0.35 centimeters per year (Mead, 1972) would be too subtle to detect.

CHANGES IN COASTAL MORPHOLOGY OF BRIGANTINE INLET

East-West Movement

Fig. 14 shows east-west movement of the southern spit. An increasing distance from the reference point to the beach demonstrates westward movement (retrogradation). A decreasing distance shows eastward movement (progradation).

Between the years 1887 and 1940, the shoreline appeared to be growing steadily eastward. This trend reversed itself in 1952 and the beach moved westward toward the mainland for a short time until 1954, when it built slightly seaward. After 1954, the 50 foot tolerance does not allow any meaningful interpretation other than that the inlet was stable until 1970. The uniqueness of the data for 1970 calls for special consideration. There are a few possibilities for this extremely wide beach and spit. The photograph may have been taken at low tide and seasonal fluctuations of the shore and tide levels may have caused this configuration. I think a more reasonable explanation is provided by Figs. 11 and 12. In these figures one can observe the landward migration of offshore shoals through time. I think that the 1970 data of Fig. 14 are best explained by the attachment of a former shoal to the coastline. This picture was taken at the climax of the prograding phase of the southern spit. After the attachment of the shoal material, the area will undergo natural erosion caused by waves, longshore drift, etc. A similar event is well documented in Fig. 11, showing erosion of a recently attached shoal through a six month period. This sequence is more difficult to see in the other sketches, due to the greater time spans between photographs.

With the data available I can make no conclusions as to the source of the shoals or sand in the Brigantine Inlet area, or the periodicity of the prograding-retrograding phases. I can just point out that they exist.

North-South Movement

The north-south movement of Brigantine Inlet is evidenced in Fig. 15, which shows the width of the channel. This has already been partially interpreted in the preceding section on storms, as the channel width is related to storms. Between 1887 and 1930, there was a trend toward closing the channel. This was reversed between the years 1930 to 1961, when the channel steadily widened. This trend was again reversed from 1961-1972, when with slight differences, the channel was again closing. The reversals and large changes in the channel width are due to major storms.

Erosion and Deposition

Erosion and deposition were studied through changes of direction of the line tangential to the easternmost extensions of the north and south spits. Any change in the directions to the east shows relative deposition. Any change in direction to the west shows relative erosion.

Between 1887 and 1930, the southern spit was eroded while the northern spit was prograding. This condition continued until 1954, when both the southern and northern spits underwent erosion. 1961 shows some deposition on the southern spit, but major erosion of the northern spit. From 1965 to 1969, there was deposition on both spits, but more on the southern than the northern. 1970 shows both spits suffering erosion, which continues on the southern spit into 1972, when the northern spit shows deposition.

There are no easily observed correlations with any of the physical factors affecting the inlet.

PREDICTIONS

I predict that: Brigantine Inlet will build eastward. This will happen if sufficient shoal areas are formed close to the shore, as appears from Fig. 13 to have happened. After these shoals become part of the shoreline, the erosional phase will begin and the inlet will erode westward.

I also predict that Brigantine Inlet will remain open. It appears that the channel is narrowing, but current velocity will increase to maintain the channel.

The pictures of Brigantine Inlet in 1887 and in 1972 are very similar. I would predict that a storm of the right intensity and direction could cut a new Wreck Inlet across Little Beach, and redeposit a new northern spit.

All of the above predictions are made under the assumption that there will be no major change in the existing conditions affecting the Brigantine Inlet area.

CONCLUSIONS

Over the short span of 100 years, Brigantine Inlet shows a cyclical pattern of sediment migration resulting in changing coastal morphology. This is due, for the most part, to the storm history of this area. These storms may be either constructive or destructive. The pattern of spit development, so dramatically seen in the southern spit of the inlet, seems directly related to the movement of offshore shoals. If the shoal areas are small and few, the spit will not be nourished. If the shoals are large and numerous, they will supply enough sediment to form a new digit on the spit and encourage northeastern migration of the inlet. From the present information, it does not appear that this process will continue until the channel is closed. Brigantine Inlet appears to "weather the storm" and remain an open, working inlet.

ACKNOWLEDGMENTS

Credit must be given to my advisor Dr. Phillip Justus for his continued inspiration and enthusiasm on this project. Dr. Naresh Kumar should also be included in this section due to his suggestions and sacrifice of time and equipment used in this study. Basic information and material such as historical maps, records and aerial photos were supplied by the New Jersey Bureau of Geology and Topography. The project was guided and supervised by Dr. George J. Halasi-Kun and David Harper, including the critical review of the manuscript.

REFERENCES CITED

Charlesworth, L.J., 1968, Bay, Inlet and Nearshore Marine Sedimentation: Beach Haven-Little Egg Inlet Region, New Jersey, Unpublished Thesis, Ph.D. for U. of Michigan.

Kenney, Nathaniel T., National Geographic, December 1962, Vol. 122, No. 6. "Our Changing Atlantic Coastline," pp. 860-887.

MacClintock, P., 1971, After an unpublished map in Leet, L.D. and Judson, S., Physical Geology, 4th Ed., Prentice-Hall, N.J., p.368.

McMaster, R.L., 1954, Petrography and Genesis of the N.J. Beach Sands, State of N.J. Dept. of Conservation and Economic Development, pp. 18-24.

Mead, R.H., July 16, 1972, New York Times.

Plusquellec, P.L., 1966, Coastal Morphology and Changes of An Area between Brigantine and Beach Haven Hts., N.J., Unpublished Thesis, M.S. for U. of Illinois.

Schwartz, M., 1965, Laboratory Study of Sea Level Rise as a Cause of Shore Erosion, Journal of Geology, Vol. 73 No. 3, pp. 528-534.

U.S. Naval Weather Service Command, 1970, Summary of Synoptic Meterological Observations, Vol. 2, pp. 475-632.

Wicker, C.F., 1965, Problems of the N.J. Beaches, Unpublished.

APPENDIX 1

Measured data

Type, Year, Scale	Direction from ref. pt.	Distance to: "Beach"	"Dunes"
Map, 1877-87, 1"=1,760'	N90°W	2,464'	4,083'
	N60°W	2,112'	3,520'
	N45°W	2,288'	3,872'
	S channel	5,456'	
	N channel	6,864'	
	N30°W	2,728'	
	S channel	4,928'	
	N channel	5,632'	
Aerial Mosaic, 1930, 1"=2,000'	N90°W	1,700'	2,000'
	N60°W	1,900'	2,300'
	S channel	4,900'	
	N channel	6,000'	
	N45°W	1,000'	
	S channel	4,280'	
	N channel	4,800'	
Aerial Mosaic, 1940, 1"=1,666'	N90°W	899'	1,083'
	N60°W	1,000'	1,166'
	S channel	3,332'	
	N channel	4,248'	
	N45°W	1,166'	
	S channel	2,749'	
	N channel	3,398'	
7-1/2' Quad. Map, 1952, 1"=2,000'	N90°W	1,400'	2,000'
	N60°W	1,400'	2,200'
	S channel	5,400'	
	N channel	6,820'	
	N45°W	2,200'	3,400'
	S channel	4,420'	
	N channel	5,700'	
Aerial Photo, 4/54, 1"=2,007'	N90°W	1,104'	2,208'
	N60°W	1,003'	2,609'
	S channel	5,318'	
	N channel	7,085'	
	N45°W	2,408'	
	S channel	4,415'	
	N channel	5,820'	

APPENDIX 1 (contd.)

Type, Year, Scale	Direction from ref. pt.	Distance to: "Beach"	"Dunes"
Aerial Photo,	N90°W	1,233'	3,398'
8/61,	N60°W	1,133'	1,999'
1"=1,666'	S channel	3,549'	
	N channel	5,493'	
	N45°W	1,249'	
	S channel	3,832'	
	N channel	5,831'	
Aerial Photo,	N90°W	1,400'	1,880'
5/65,	N60°W	1,600'	2,480'
1"=400'	S channel	4,640'	
	N channel	6,720'	
	N45°W	1,760'	
	S channel	3,940'	
	N channel	5,520'	
Aerial Photo,	N90°W	1,416'	1,666'
10/68,	N60°W	1,208'	1,833'
1"=833'	S channel	5,414'	
	N channel	---	
	N45°W	1,166'	2,499'
	S channel	4,581'	
	N channel	---	
	N30°W, S channel	4,665'	
	N channel	5,706'	
Aerial Photo,	N90°W	1,333'	1,666'
4/13/69,	N60°W	1,116'	1,833'
1"=833'	S Channel	6,497'	
	N channel	---	
	N45°W	1,083'	1,833'
	S channel	4,581'	
	N channel	6,331'	
Aerial Photo,	N90°W	1,291'	1,666'
10/24/69,	N60°W	500'	1,749'
1"=833'	S channel	5,164'	
	N channel	---	
	N45°W	583'	2,499'
	S channel	4,331'	
	N channel	5,964'	

APPENDIX 1 (contd.)

Type, Year, Scale	Direction from ref. pt.	Distance to: "Beach"	"Dunes"
Aerial Photo, 3/7/70 1"=833'	N90°W	416'	1,625'
	N60°W	350'	1,749'
	N45°W	350'	2,207'
	S channel	3,863'	
	N channel	---	
	N30°W	416'	
	S channel	3,838'	
	N channel	5,123'	
Aerial Photo, 4/72, 1"=2,000'	N90°W	1,000'	1,900'
	N60°W	920'	2,200'
	S channel	5,000'	
	N channel	7,100'	
	N45°W	1,000'	
	S channel	4,280'	
	N channel	5,560'	

APPENDIX 2

Direction of line of sight from reference point
to north and south spits

Date	South spit	North spit
1877-87	N24°W	N19°W
1930	N48°W	N5°E
1940	N32°W	N5°E
1952	N38°W	N29°E
1954	N39°W	N14°E
1961	N34°W	N6°W
1965	N30°W	--
1968	N8°W	N14°W
4/69	N1°E	N10°W
10/69	N10°E	N13°W
1970	N9°E	N10°W
1972	N3°E	N13°W

APPENDIX 3

Computed data

Date	Direction	Channel Width	Dist. to Beach	S spit Width	S beach Width
1877-87	N90°W		2,464'		2,619'
	N45°W	1,408'		3,168'	
	N30°W	704'			
1930	N90°W		1,700'		300'
	N60°W	1,100'			
	N45°W	520'		3,280'	
1940	N90°W		899'		184'
	N60°W	916'			
	N45°W	649'		1,583'	
1952	N90°W		1,400'		600'
	N60°W	1,420'			
	N45°W	1,280'		1,420'	
1954	N90°W		1,104'		1,104'
	N60°W	1,767'			
	N45°W	1,405'		1,927'	
1961	N90°W		1,233'		2,165'
	N60°W	1,944'			
	N45°W	1,999'		2,583'	
1965	N90°W		1,400'		480'
	N60°W	2,080'			
	N45°W	1,580'		2,180'	
1968	N90°W		1,416'		250'
	N60°W	---			
	N30°W	1,041'		---	
4/69	N90°W		1,333'		333'
	N60°W	---			
	N45°W	1,750'		3,498'	

APPENDIX 3 (contd.)

Date	Direction	Channel Width	Dist. to Beach	S spit Width	S beach Width
10/69	N90°W		1,291'		375'
	N60°W	---			
	N45°W	1,633'		3,748'	
1970	N90°W		416'		1,209'
	N45°W	---		3,513'	
	N30°W	1,285'			
1972	N90°W		1,000'		900'
	N60°W	2,100'			
	N45°W	1,280'		3,280'	

CURRENTS AND SEDIMENT MIGRATION IN BRIGANTINE INLET, NEW JERSEY

by

Michael A. Lynch-Blosse*

Earth Science Department
Fairleigh Dickinson University
Madison, New Jersey 07940

A study for the New Jersey Bureau of Geology and Topography in cooperation with Fairleigh Dickinson University.

*Now at University of South Florida, Tampa, Florida 33620

ABSTRACT

The tidal inlet at Brigantine, New Jersey is maintained solely by tidal currents. Not only do these currents keep the inlet open but are primary factors in determining the local flow regimen.

Tidal current flow appears to be "segregated" in Brigantine Inlet. A deep axial channel runs along the north shore inside the inlet and carries the major portion of the ebb flow. Flood currents enter the inlet as a "sheet flow." This segregated tidal flow interacting with the longshore current creates a complex sediment circulation pattern which is primarily responsible for producing a downdrift-offset and a landward net gain of sediment.

Due to the continued deflection of the longshore drift by ebb tidal currents a transverse bar develops extending seaward from shore updrift.

Brigantine Inlet is at present migrating northward and will continue to do so until there is a shift in the conditions affecting the inlet. The northern shore, inside the Inlet, is undergoing erosion, particularly at the end of the Little Beach spit and southern half of North Spit. On the southern side of the inlet deposition is favored, especially in Brigantine Channel and at the northeast end of South Spit. Digits are added to the southern barrier by tidal currents moving into the inlet near this side throughout the tidal cycle and by the landward migration of bars and shoals.

Brigantine Inlet may migrate gradually updrift during relatively stable periods but may migrate rapidly downdrift for greater distances at other times in a somewhat cyclic history. It is the latter that is best reflected in the long-term historical data.

Despite infilling of surrounding areas, as the inlet becomes narrower current velocity will increase and Brigantine Inlet will remain open.

Better knowledge of currents and sediment migration should benefit subsequent investigations on Brigantine Inlet and other inlets exhibiting similar characteristics. Furthermore, a better understanding of the nature of tidal inlets is important for scientific, engineering, and environmental purposes.

INTRODUCTION

Tidal inlets are perhaps the most dynamic part of any coastline. Brigantine Inlet is a tidal inlet representative of the kind found on the New Jersey coast. Unlike a great deal of the New Jersey coastline, however, it is unaffected by groins, jetties or other man-made obstructions. This study is concerned with the analysis of current data collected during the years 1969 and 1970 together with more recent field observations. Through the analysis of these data the somewhat complex sediment circulation patterns within and around Brigantine Inlet may be determined.

Once correlated the information allowed for near-future predictions to be made in the coastal morphology. Ultimately, those factors found to be significant should benefit subsequent investigations of Brigantine Inlet and other similar areas of the New Jersey coast. A proper interpretation of the flow regimen associated with inlets of the Brigantine Inlet variety is essential to engineers in beach maintenance as well as to the oceanside property owner and should serve as a vital tool to environmentalists. A better understanding of circulation patterns at tidal inlets is necessary for a more accurate reconstruction of paleoenvironments.

Location and Description of Study Area

The Inlet is located approximately 10 km (6 miles) north of Atlantic City, New Jersey, between map coordinates 39° 25' and 39° 27' 30" N latitude and 74° 20' 30" and 74° 20' W longitude (Rittschof).

A general description of the Brigantine area is given by McMaster (1954). The foreshore width is 30 m (100 feet) with a normal slope of 3 degrees and the backshore, when fully developed, is 30 m (100 feet) wide, having a slope of 1 degree. Remnants of dunes are present and behind the barrier islands is a lagoonal area predominantly filled by a salt marsh but cut in places by channels, streams and open water (Fig. 1). For the purpose of convenience it was necessary to give names to certain geographic areas. These names, shown in Figure 1, will apply throughout the study.

Previous Work

The entire New Jersey coastline or segments of it have been studied by many workers (Johnson, 1919, 1929; Lucke, 1934; Wicker, 1951; McMaster, 1954; Sanders, 1970; Shepard and Wanless, 1971; Emery and Uchupi, 1971; Frank and Friedman, 1973; Galvin, unpublished; Lynch-Blosse and Kumar, unpublished).

Other than the current and fathometer data provided by the New Jersey Bureau of Geology and Topography no information could be found concerning the current intensities or submarine topography of Brigantine Inlet. The history, however, of the morphology of Brigantine Inlet is very well documented by Rittschof.

Rittschof suggests that over the past one hundred years Brigantine Inlet has shown a cyclic pattern of sediment migration resulting in a changing coastline.

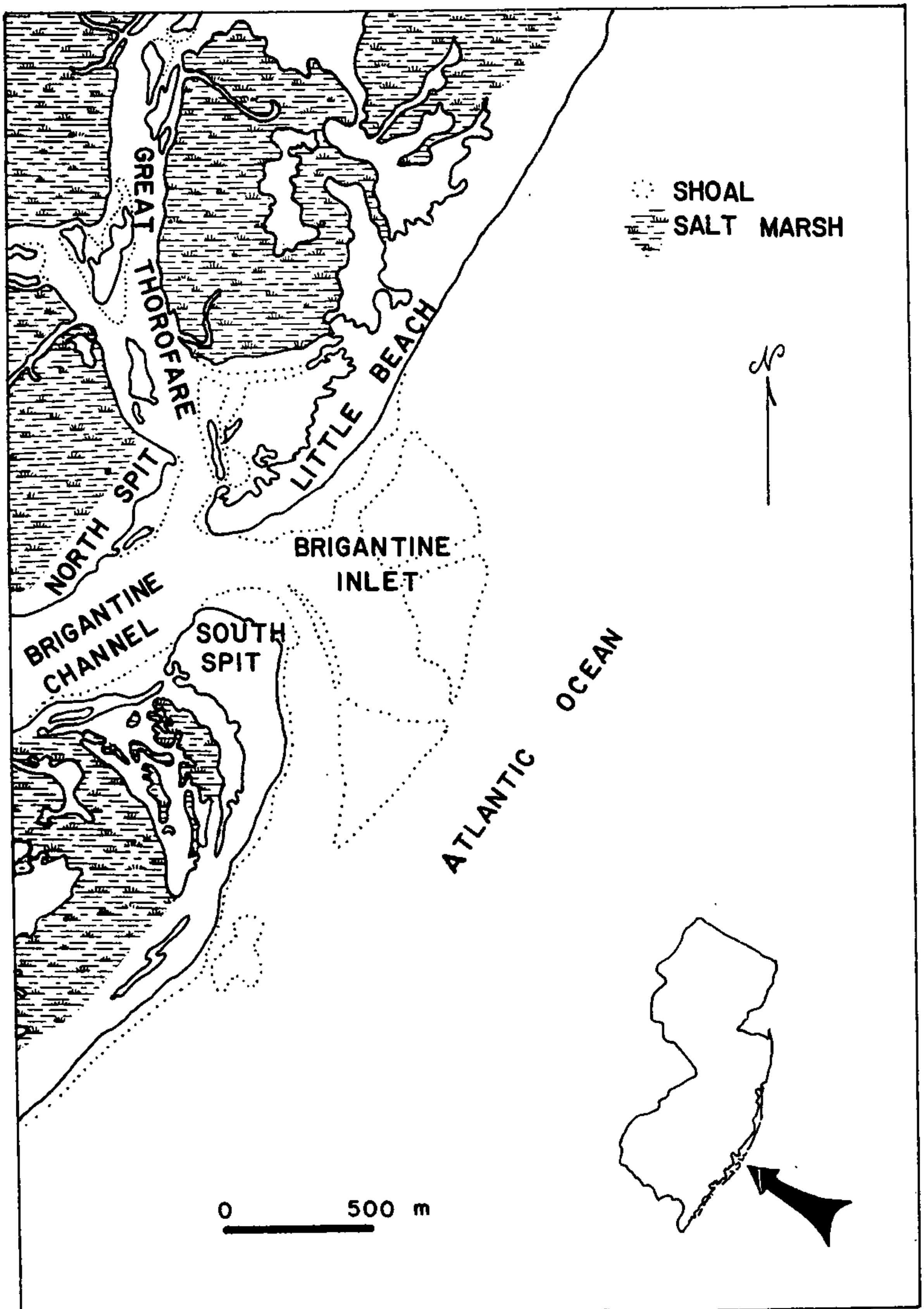


Fig. 1 Index map of Brigantine Inlet, New Jersey and vicinity; marsh areas approximated. Net longshore drift is from north to south and downdrift side of the inlet is offset seaward (after N.J. State Geol. Survey Photograph, March-April 1972).

Method of Study

Fathometer readings of the Brigantine Inlet were used to establish the submarine topography. Current profiles were studied individually and as groups along with their locations in and around the inlet. Analyses of aerial photographs were made to determine any crucial historical changes in morphology. Lastly, field work served to further substantiate findings based on the given information.

PRIMARY PHYSICAL FACTORS AFFECTING THE BRIGANTINE AREA

Tides

The tides of the Brigantine area are the semidiurnal, symmetrical type (12 hr., 25 min. period). The average height has been approximately 4.1 feet since the year 1911. However, storms have raised the ocean as much as 5.4 feet above mean high water and have lowered it 3.5 feet below mean high water (Rittschof).

Winds

The strongest winds in the Brigantine region come out of the northwest during the stormy months of January to March and October to December (Rittschof) according to a report by the U.S.N. Weather Command of Atlantic City (1970) covering the last 90 years. The calmer months of April to September, on the average, have the strongest winds coming out of the southwest. Therefore, in a given year the most frequent wind direction should be from the southwest, and the strongest winds from the northwest; however, it should be noted that the storm winds are the greatest from the northeast. The data for this study were collected in July and August when a southwest wind was dominant.

Storms

The effect of storms on a coastline like that of New Jersey can be devastating. More locally, storms are probably the biggest variables in the predictions of sand transport by various marine processes in the Brigantine Inlet area. Their significance is not to be overlooked and reference should be made to a study conducted by Rittschof in which storms of the area and their subsequent effect are discussed.

Waves

The average wave height in the Brigantine area is 60 cm (2 feet) and storm generated waves reach a height of 3.2 to 3.6 m (11 to 12 feet), with a length 7 to 20 times the wave height (Plusquellec, unpublished). According to the Weather Service Command (1970) the normal wave direction is from the south or southwest and storm generated waves are out of the northwest or northeast.

Waves can have a profound effect on a shoreline such as that of the Brigantine area and may indeed be responsible for the movement of large quantities of sediment.

Longshore Currents

Waves approaching shore at an oblique angle generate a longshore current that is predominantly (there are seasonal reversals) to the south along this section of the New Jersey coast (Johnson, 1919; Lucke, 1934; Wicker, 1951; Lynch-Blosse and Kumar, unpublished). Therefore, the net longshore drift in the Brigantine area is to the south.

DESCRIPTION AND GENERAL DISCUSSION OF SUBMARINE TOPOGRAPHY

The submarine topography of the inlet must be considered in any effort to establish current patterns. Bottom features may be a direct result of sediment movement by currents and in turn serve to indicate areas of possible deposition and erosion.

Fathometer data were available for 1969 only, so it is on this information that all hypotheses pertaining to bottom features are based. This is a significant handicap as the change in bottom features due to current movement over longer periods can not be determined.

A series of runs were made in and around the mouth of Brigantine Channel. Within the channel itself, along the southern shore, the water is shallow (Fig. 2). The depth here is not more than a few feet. Along the northern shore of Brigantine Channel the water is considerably deeper. The greatest depths recorded in the inlet were those nearest the southern end of North Spit.

The shallower expanse to the north of South Spit extends nearly halfway across the mouth of the inlet.

North of Brigantine Inlet along the entire length of the Little Beach Spit water depth is notably more shallow than it is immediately north of this point (Fig. 2).

What may be best termed a transverse bar is oriented more or less perpendicular to the Little Beach spit and bends sharply to the south further out from shore. The distinction between the asymmetrical ebb tidal delta and the transverse bar can be made by assuming that the ebb tidal delta is located along the axis of ebb flow and the transverse bar is situated updrift of this axis. A distinct channel can be traced through the ebb tidal delta. Originating within the inlet it is oriented perpendicular to the shore line and bends sharply in a southerly direction. The boundaries of both the ebb tidal delta and the included main channel become less distinct farther to the south. In Brigantine Channel bars flank the edge of the main channel. Further, within the channel the presence of shoals is suggested by the shallower depth. Near the southern end of North Spit where the greatest depths were recorded, a deep elongate hole is located within the main channel (greater than 12 m).

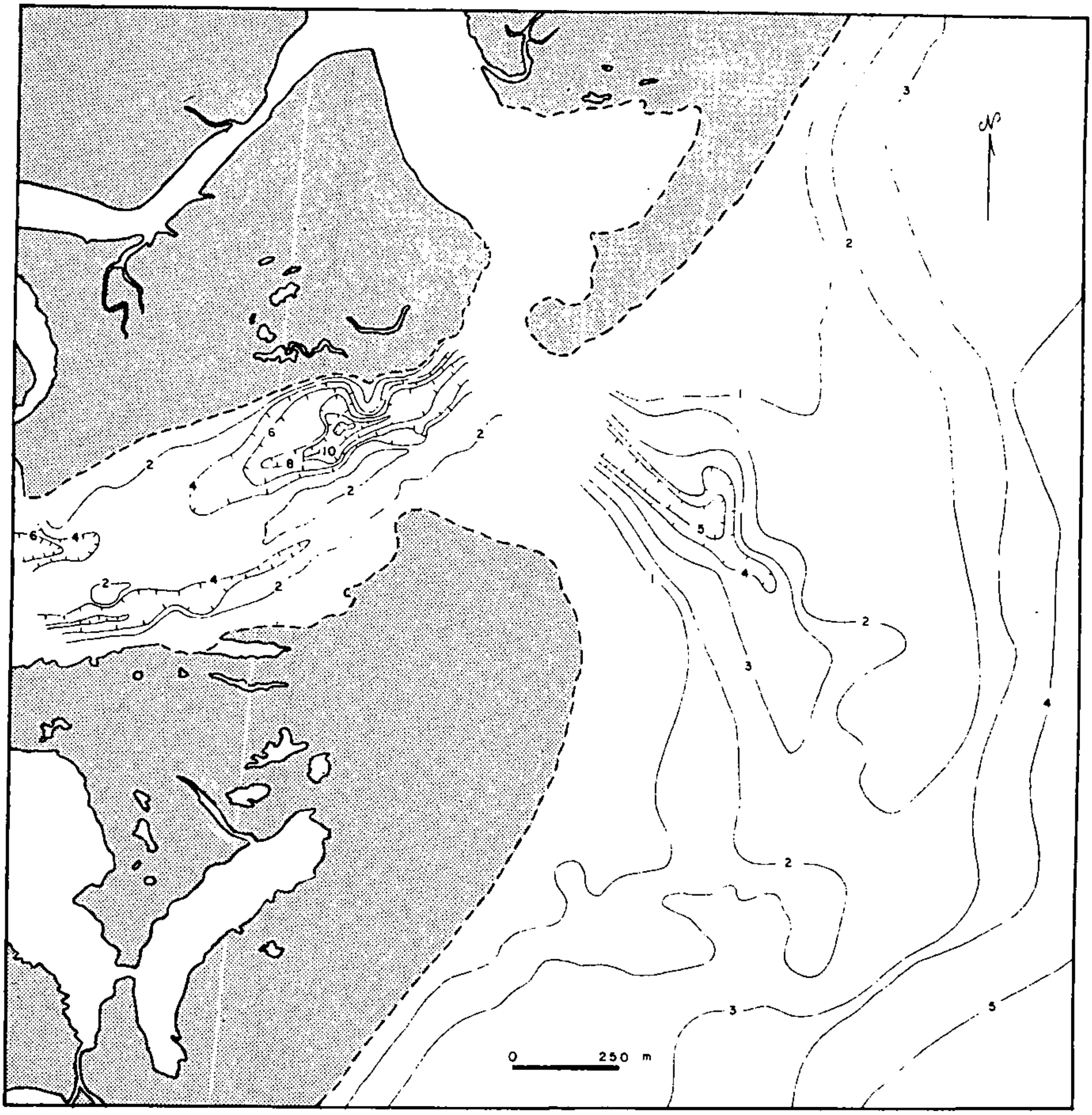


Fig. 2 Bathymetry of Brigantine Inlet, N.J., based on echogram data supplied by the New Jersey Bureau of Geology and Topography. Contour interval in meters below sea level. A deep channel located closest to the northern shore inside the inlet can be traced through an asymmetrical ebb tidal delta. Note also the transverse bar extending seaward from the updrift side of the inlet.

DESCRIPTION AND GENERAL DISCUSSION OF CURRENT DATA, 1969

Certain limitations exist with the current data available for both 1969 and 1970. The primary limiting factor is the lack of knowledge pertaining to specific current directions. The designation of current direction as "ebb" or "flood" is satisfactory enough to make this study worthwhile; however, the reconstruction of current movement in the inlet is somewhat less accurate. At a given station the readings were taken during either ebb or flood tide. Therefore, the character of the current during both ebb and flood at any one point can not be directly determined.

Data were collected each year during the months of July and August when only one set of conditions was acting upon the inlet. Throughout any given year the nature of the inlet is affected by a large variety of seasonal variations.

The geographic extent of this study is limited by the number and location of the stations.

In plan view Brigantine Inlet is offset downdrift (i.e., the downdrift barrier extends farther seaward than the updrift barrier). Hayes and others (1970) have inferred that tidal flow associated with inlets that are offset downdrift is characteristically "segregated." The author believes this hypothesis to be basically applicable to Brigantine Inlet. In segregated flow, ebb flow should be more channelized while flood waters enter as a "sheet flow."

Current data were available for the month of July, 1969. However, there were only 15 stations, all of which are located within Brigantine Inlet (Fig. 3).

Deep scour depressions in the main channel testify to the erosive power of the tidal currents. During flood tide, currents erode this area particularly, it would seem, near the southern end of the Little Beach spit and the southern half of North Spit. The overall appearance of the updrift side of the inlet as a large recurved spit is indicative of the strong transportation of sediment into the inlet. However, suspended sediment would be deposited chiefly at the mouth of Great Thorofare and around the northern half of North Spit where current velocity decreases considerably as it encounters the shallow bottom. The finer sediment is eventually deposited in the Great Thorofare and is trapped there during ebb tide resulting in the building up of backbarrier areas.

The main channel, closer to the updrift side of the inlet, apparently carries the greater portion of the ebb flow. At ebb tide deposition is probably taking place in the area of Great Thorofare, especially along the North Spit side. A strong flood current moves across the shallow expanse to the north of South Spit transporting sediment into Brigantine Channel where it is deposited due to a sudden decrease in velocity. This sediment eventually builds up along the southern half of the channel. This same flood current decreases in strength near the bottom approaching the middle of the inlet and, therefore, may be extending South Spit northward, as is indicated by the bottom topography.

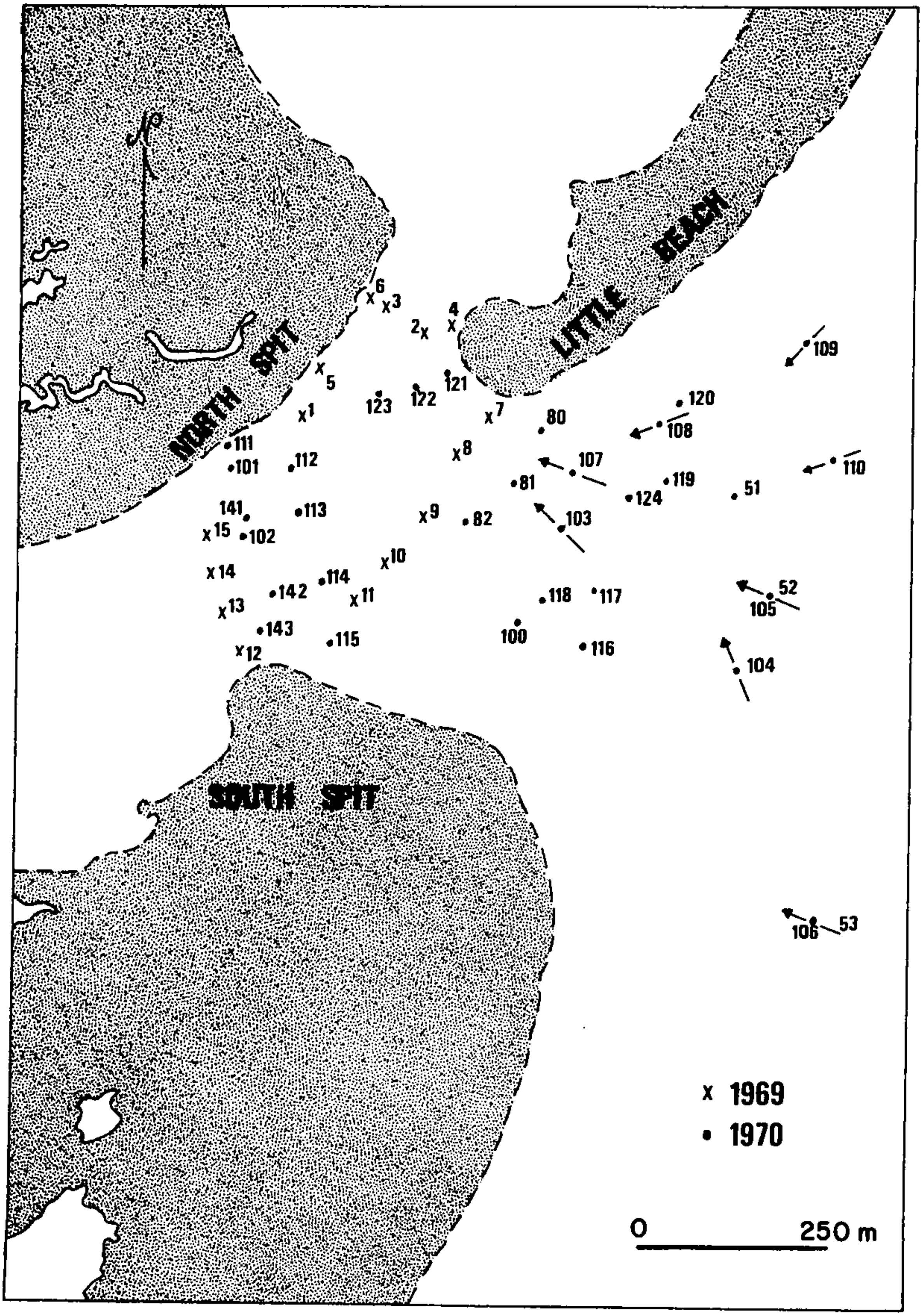


Fig. 3 Location of current intensity stations; 1969 and 1970. Arrows indicate current direction at those stations where a drogue was used.

Lastly, velocity profiles indicate that a somewhat uniform flow exists at the mid-depth range of those stations located in the main channel, enabling suspended sediment to be transported greater distances (Fig. 4). The profiles also suggest that ebb currents are fastest near the surface. Flood currents, in some cases, are about constant from surface to bottom. It would seem that for the most part bottom currents are stronger at flood tide than at ebb.

Flood Currents

Of the 15 stations 12 were flood. Stations 7 through 11 are located across the mouth of Brigantine Inlet between the Little Beach spit and South Spit (Fig. 3). Stations 9, 10 and 11 are located in shallow water. In general, the current strength increased moving toward South Spit. Some of the fastest currents recorded in the inlet were at these stations and the strongest of these were at station 11 (Fig. 4). The current velocity is lower at station 10, although still quite strong. The bottom would seem to have a greater effect on the current here as velocity decreases sharply after the 1.2 m (4 foot) depth. The situation at station 9 would appear to be similar to 10, perhaps to a greater degree.

If the above hypothesis holds true there could very well be gradual northward extension of South Spit. Sand carried along the bottom by fast moving currents would be deposited as current strength at the bottom decreases toward the center of the inlet.

At station 8 where readings were taken down to 9 m (30 feet) the velocity was highest near the surface. There is a steady decrease until mid-depths. Here the water is unrestricted by either surface or topography, consequently the velocity is more uniform. The current strength then decreases with the influence of the bottom. Sediment should be transported freely in this channel at a much greater rate. Finer sediment in suspension would be carried further into the inlet to be deposited in tidal flats. Current velocity was slowest at station 7. However, it is very characteristic of the same type of flow shown by station 8 readings. As such, material carried by the longshore current over the shallow bottom on the seaward side of the Little Beach spit would be transported into the inlet as it encounters the strong flood current.

Stations 12 through 15 are located across the mouth of Brigantine Channel (Fig. 3). Station 12 is located in an area of very shallow water near the northwestern-most tip of South Spit. Here the velocity was the slowest of the run, perhaps because its position at flood tide is more or less protected by South Spit. The decrease in current speed is a substantial one compared to stations 9, 10 and 11. The sudden decrease in velocity should result in the deposition of transported sediment in Brigantine Channel. Similarly, stations 13 and 14 show that the water is moving considerably slower than those corresponding stations at the mouth of the inlet. Velocity decreases sharply at these points as it did at stations 9 and 10. Overall, the current is much slower here and should again result in deposition in and near Brigantine Channel where depth increases.

Stations 11 and 12 both show an increase in velocity at the bottom and are both closest to shore in shallower water. Each of the remaining stations in the run shows a decrease in velocity at the bottom as the middle of the inlet is approached. Thus, strong flood currents may enter the inlet and run

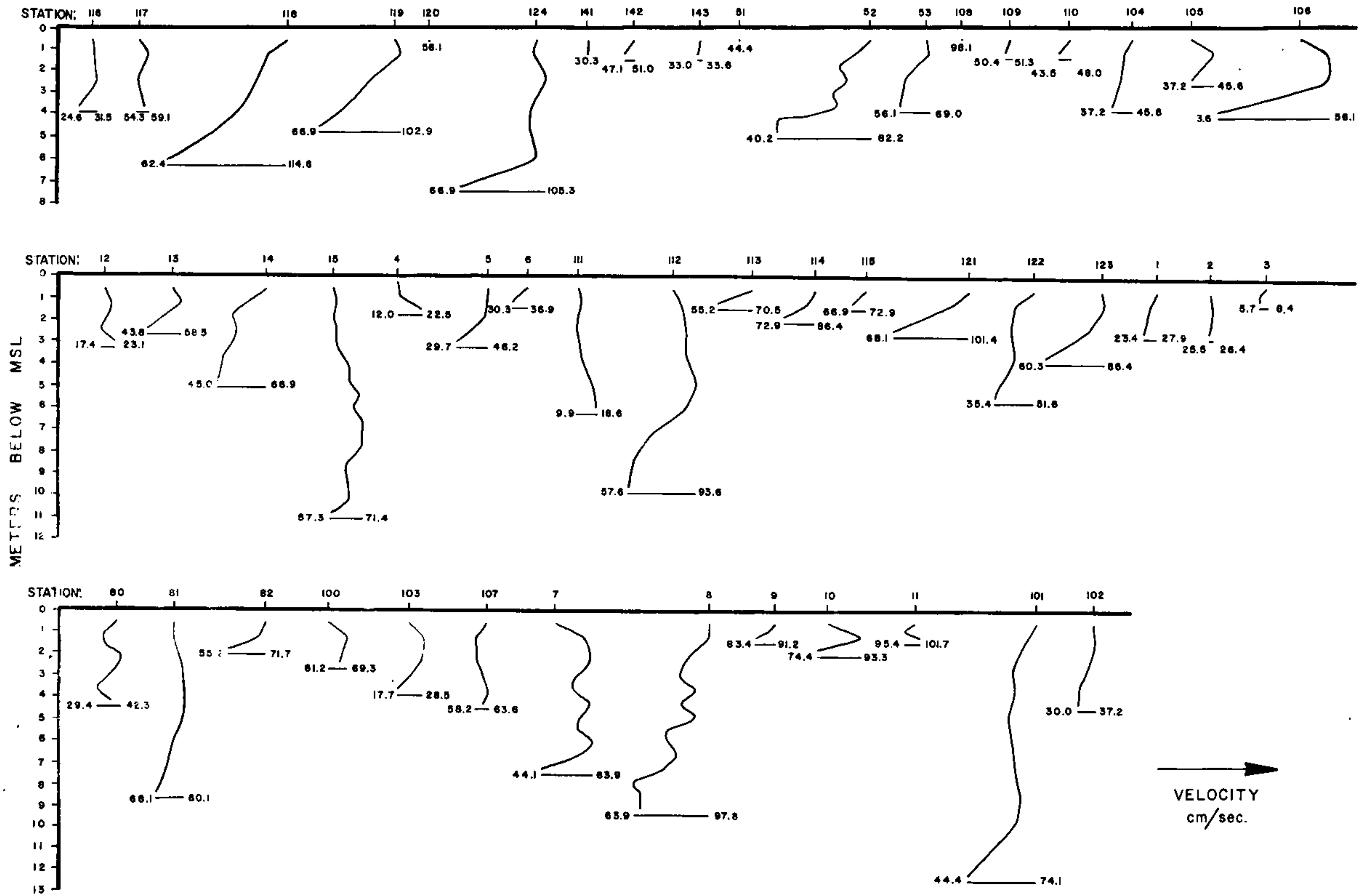


Fig. 4 Current intensity profiles for 1969 and 1970, sde figure three for station locations.

along the southern shore. Deposition would take place in the middle of the inlet as well as in Brigantine Channel. This can be best substantiated by comparing the similarities in velocity profiles at stations 11 and 12, 10 and 13, and 9 and 14 (Fig. 4).

Station 15 is located where the maximum depths were recorded in the inlet. Unlike the other stations, velocity remained constant to a depth of about 2.9 m (10 feet) and then began a gradual increase that continued to about 7.7 m (26 feet). If these readings were taken down to near the bottom, then the current velocity was similar to station 8 near the bottom. Here too, there is evidence for the uniform flow that was present at stations 7 and 8 that could transport sediment much further into the inlet. The greater depths at stations 7, 8 and 15 along with the relative uniformity of current velocity suggests the presence of a dominant current running through these points. The effect of such a current could very well result in erosion of the northern side of the inlet during flood tide.

Stations 4, 5 and 6 are located on either side of Great Thorofare (Fig. 3). The velocity at station 4 increased nearer the bottom allowing for the possibility of some sediment movement through this point. On the other hand, current strength decreased with depth at stations 5 and 6. Some of the slowest recorded velocities were at these points and it is again probably due to the portected location. Sediment in suspension would logically be deposited at the mouth of Great Thorofare as current speed suddenly decreases away from the main flow and encounters much shallower water. This finer material would gradually be moved into Great Thorofare. The build up of this sediment would be responsible for the infilling of backbarrier areas behind the Little Beach spit. The shape of the Great Thorofare where it enters Brigantine Inlet also serves to trap sediment once it has been transported inside.

Ebb Currents

In 1969 only three of the fifteen stations were designated as ebb. Unfortunately this limits an attempt to reconstruct the patterns of outgoing current.

If indeed the main ebb flow does follow the apparent channel past the southern end of North Spit and the southern tip of the Little Beach spit, then deposition could be taking place in the area of station 1 (Fig. 3). The relatively slow current recorded at station 1 suggests that this area is not influenced by the main outgoing flow. Suspended material is likely to settle out here during ebb tide. Sediment carried by an outgoing current may also be deposited near the mouth of Great Thorofare and the northern end of North Spit. The shape of the shoreline here again serves as an excellent trap for suspended sediment as shallow bottom is encountered.

Current speed at station 3 was much slower than that at 2 (Fig. 4). The protected location of station 3 along with the very low velocity reading would suggest that it receives the deposition of sediment from both within and from outside Great Thorofare at ebb tide. The higher current velocity and uniformity with depth at station 2 show that the main flow leaving Great Thorofare may pass this point.

DESCRIPTION AND GENERAL DISCUSSION OF CURRENT DATA: 1970

In July and August of 1970 there were a greater number of current readings taken within and around Brigantine Inlet (Fig. 3). At flood tide, not only does the ebb tidal delta provide a source of sediment but the littoral drift is deflected into the inlet as well. Material caught in the main flow along the northern side would be transported at a faster rate and much deeper into the inlet during flood tide. Due to this main flow entering the inlet, erosion is taking place all along the northern side, particularly at the end of the Little Beach spit and southern end of North Spit. Despite this, sediment is apparently being deposited at the mouth of Great Thorofare.

The strong current moving over the bottom to the north of South Spit results in the transportation of sediment into Brigantine Channel. At ebb tide the major portion of the ebb flow moves along the north side of the inlet carrying sediment seaward into deeper water. Deposition may again be taking place near Great Thorofare at ebb tide.

The shallow expanse to the north of South Spit is growing northward as well as seaward. This is a result of the continued deposition of sediment along its edge and/or the gradual landward migration of shoals or bars. This landward migration of shoals was recognized in the historical data by Rittschof at Brigantine Inlet. Oertel (1972) and Hayes and others (1970) have provided adequate evidence and explanations for the landward movement of sediment. In addition, the high velocity ebb currents in the asymmetrical channel create a low pressure zone in the northern half of the inlet. Applying the Bernoulli Effect (Haliday and Resnick, 1962 p.376-382, citing Bernoullis Hydrodynamica of 1738) water and sediment in the higher-pressure, southern half of the inlet would tend to be drawn toward the faster-moving water, thus aiding the northward migration of sediment (Lynch-Blosse and Kumar, unpublished).

Current profiles indicate that during flood tide currents are moving faster near the bottom than at ebb; transporting coarser as well as finer material into Brigantine Inlet. Ebb currents are fastest near the surface, favoring the transportation of suspended material. The strongest currents during both ebb and flood were at the mouth of Brigantine Inlet along the northern side. Erosion of this side of the inlet would therefore seem logical. Deposition would seemingly dominate to the south.

Bottom features developed during the flood phase of the tidal cycle are merely modified by the ebb flow. Therefore, the flood currents may be considered constructional and ebb currents destructional.

It, again, appears from the 1970 current data that the tidal flow in Brigantine Inlet is "segregated." Ebb flow is more channelized, while a "sheet flow" tends to develop at flood tide.

Flood Currents

Stations 101 and 102 are located near the mouth of Brigantine Channel. The current was much stronger at station 101 than at 102 where the water was about half as deep (Fig. 4). Current strength is decreasing in intensity as is apparently the degree of erosion moving southerly toward South Spit. Current intensity is nearly uniform with depth at stations 101 and 102.

Stations 141, 142, and 143 were taken across the mouth of Brigantine Channel (Fig. 3). The current was strongest on the southern side of the channel at stations 142 and 143 where the water is shallow. The current intensity was not as strong at 141 which is located where the depth should be greater. Sediment should be transported into Brigantine Channel and be immediately deposited just inside its mouth at flood tide. If the sediment were caught by the main flow along the northern shore it would be transported much deeper into the channel.

Located between the Little Beach Spit and South Spit are stations 80, 81, 82, 100, 103, and 107. The flood currents were recorded to be the strongest at station 8., somewhat slower at 82, and slower still at 80 (Fig. 4). Station 81, having the highest velocities, is within the boundaries of the main channel on the northern side of the inlet and station 80, closest to the Little Beach spit, is in water about half as deep and moving roughly half as fast. There is little variation in velocity with depth at 81, representing the presence of a major current entering the inlet and indicating currents that are relatively fast along the bottom. Similarities in the current behavior between this station (81) and station 101 allow the major flow to be traced further within the inlet. Much the same comparison can be made between stations 80 and 102. The current readings at stations 82 and 100 show water to be moving fast over the shallow bottom to the north of South Spit. Current speed at the bottom decreases from station 100 to 82 which indicates that the overall effect at 82 might very well be depositional. Thus, sediment coming to rest here may result in the submarine extension of South Spit.

Station 103 is one of a few stations where a drogue (a current measuring assembly consisting of a weighted parachute and an attached surface buoy) was used at the 1.2 m (4 foot) depth to indicate current direction (note arrows in Figure 3). At 103 this direction would be toward the main channel. It should be noted that the current speed at this station was very much slower than at surrounding stations. Such a sudden drop in velocity would allow for deposition, possibly resulting in the development of a shoal or bar. If it is assumed that station 103 is just about on the edge of the shallow expanse stretching out from South Spit, then it would be affected neither by the current moving swiftly over the shallower bottom to the south nor the strong flow in the deeper water to the north. In addition, if shoals or bars are present and become larger the end result could be their joining with the shallow expanse to the south. A drogue reading was taken also at station 107. The determined direction would again be approximately in the direction of the main current and deep water channel entering the inlet. Velocity remained more or less constant with depth down to 4.1 m (14 feet) where bottom was presumably encountered (Fig. 4). Current speed falls between that of stations 80 and 81. As might be expected, although they are not in a straight line, 107 does lie between 80 and 81. Transported sediment approaching this point would, therefore, be swept into the inlet as the main flow was reached.

A single reading was taken at station 108 (at the 60 cm level) showing the current to be moving at a high velocity. The combined strength of the longshore and flood currents could be responsible for the reading. Regardless, transportation of considerable quantities of sediment into the mouth of the inlet is certain. Drogue readings here indicate the current to be moving toward the dominant current and main channels. Station 109 is also located in shallow water to the east of Little Beach spit. A drogue reading was taken here also. Any transported sediment would be carried toward the end of the Little Beach spit toward deeper water and generally faster currents. Station 110 had a drogue reading that was again in the direction of the main channel.

Stations 104, 105 and 106 all fall within the boundaries of the main channel. The drogue readings are all in the direction of the inlet but stations 104 and 105 definitely indicate a direction more to the northern side of Brigantine Inlet. Stations 105 and 106, located on either side of the channel, show a stronger flow in the mid-depths. Current velocity decreases only slightly with depth at 104 that is located in the center of the channel running through 104. Perhaps most important of all is the fact that the flood current exhibits such strength outside the inlet. Several other runs where flood current readings were taken are located to the north along Little Beach. It should be sufficient to state that these stations generally show no significant variation in current speed and the velocities at these various points are substantially less than those closer to the inlet. To the south of the inlet still other runs were made. Velocities recorded here were again similar and considerably slower than those closer to the inlet but were faster than those at stations to the north off of Little Beach.

Ebb Currents

The majority of current data taken in and around the inlet during 1970 were at ebb tide. Stations 111, 112, 114, and 115 represent a run made across the mouth of Brigantine Channel (Fig. 3). At station 111 the current was the slowest but intensity increased steadily to a 5.9 m (20 foot) depth (Fig. 4). Station 112, on the other hand, lies directly in line with the main ebb flow and consequently has the greatest intensity. Sediment is being eroded as the current moves swiftly along the bottom and out of the inlet. Of the three remaining stations in this run the current was the fastest at 114, slower at 115, and the slowest at station 113. Station 115 is protected to a small degree from the ebb currents by the shape of South Spit and its nearness to shore. The slower current at 113 is a little harder to explain. It may be that there is a split in the ebb currents leaving the channel. This would mean that the flow of water follows a straight course out of Brigantine Channel through 114 or is pulled along the northern shore by the main ebb flow in deeper water. The entire area between, including station 113, might very well be filling in with sediment as the current splits or decreases in speed. If a bottom feature, such as a shoal or bar, does exist in the area of 113, sand would be deposited first on the seaward side at ebb, and then on the landward side during flood tide. This may result in an increase in size and a shifting of the feature at ebb and flood. Eventually the bar or shoal might connect with the shallow expanse to the south, further extending the submarine portion of South Spit. With the exception of 111 the current velocities at these stations were highest near the surface (Fig. 4).

Stations 121, 122, and 123 are situated near the mouth of Great Thorofare (Fig. 3). The current was the strongest at 121. This is likely due to the main flow exiting from Great Thorofare joining the major portion of ebb flow leaving Brigantine Channel. Station 121 decreases in velocity sharply with depth. The decrease at 123 is more gradual, possibly because of the influence of the main flow as it is encountered. Station 122 is relatively uniform from the surface to bottom and has an overall lower velocity than the surrounding stations. Deposition of suspended sediments could be taking place here with the sudden decrease in current intensity.

The next group of stations, 116-120, and 124, are all located just at the mouth of Brigantine Inlet (Fig. 3). Readings were taken to the greatest depth at stations 118, 119, and 124. It is here that the highest current intensities were recorded. A profile of the current intensity at 124 shows the uniform flow at mid-depths that has been characteristic of stations located in the main channel (Fig. 4). There is also a strong similarity in the profiles of 118 and 119 that are to either side of 124 and the main channel. Current strength decreased at 117 and more so at 116. The sudden drop in current strength would suggest deposition, especially near shore to the south. Station 120 is situated in very shallow water and the current speed is comparatively slower than that at 117-119 and 124. It would be in this area that the outgoing current encounters the longshore current resulting in a sudden decrease in the intensity. Similarly, deposition should also be taking place here at ebb tide.

Stations 51, 52, and 53 are located further seaward. Fathometer data indicate that 51 is near the northern boundary of the main channel outside the inlet. The current intensity here was the slowest of the three stations. In mid-channel, at 52, and where the water was the deepest, the current was also the strongest. Velocity remained about constant from 1.8 to 3.6 m (6 to 12 foot) depth and resembles the profiles of other stations in the main channel. At 53 the current was slower and the water not as deep. Apparently, the influence of the currents leaving the inlet is considerably less here.

INTERPRETATION OF CURRENT INTENSITY, BATHYMETRIC AND FIELD DATA

Field Observations

Field observations were made on several visits during the months of August and October in 1973. Relative surface movement was noted. Attention was also given to water depth at various areas in the inlet. This was accomplished by observing vessels as they navigated in and out of the inlet as well as the breaking of waves over shallow bottom. Unfortunately, the majority of observations were made at ebb tide. As a result a meaningful interpretation of water movement can be made only for this time.

In Brigantine Channel the water surface appeared uniform across the entire width. The surface water continued to be comparatively tranquil in the deeper portions of the inlet. Surface speed increased greatly as the flow passed over the shallower bottom north of South Spit. Closest to shore on this side the surface water was moving equally as fast but in the opposite direction producing a series of standing waves.

The author believes that the interaction of tidal and longshore currents causes the currents to enter this side of the inlet; during the ebb phase of the tidal cycle as well as flood. Todd (1968) referred to this as "dynamic diversion." Eddy currents also develop along the shore of South Spit, particularly in Brigantine Channel. Within Great Thorofare the water surface appeared to be very calm. Shoaling was observed in a few places indicating the presence of the suspected bars. As anticipated, waves were seen to break over a bar in the middle of Brigantine Channel. A bar connected to the Little Beach Spit stretched nearly all the way across the mouth of Great Thorofare. Sea birds were perched along the length of this bar further testifying to the shallow bottom there. A build-up of sediment was apparently taking place around the northern half of North Spit. However, along the north side of Brigantine Channel there were signs of an eroded bank. Originating at a point on the Little Beach Spit a ring of breakers all but encompassed the mouth of the inlet and tapered off to the south, substantiating the existence of the transverse bar. Bottom was visible for a considerable distance looking across from South Spit to Little Beach. This was also true on the seaward side of South Spit as well. The southern half of Brigantine Channel appeared to be generally shallower than the northern shore. As suspected, vessels traveled along the northern side of the inlet at all times. When entering Great Thorofare, vessels did so close to North Spit, indicating this to be the deeper portion. In comparing the field observations to an aerial photograph taken in 1972, major morphological changes are realized. South Spit appears to have been extended in a northeasterly direction. The tip of the Little Beach Spit has been eroded as has the southern end of North Spit. North Spit is also being built up in the north. The mouth of Great Thorofare is becoming narrower.

Current Patterns

The flow patterns of flood and ebb currents are shown in Figure 5. Without knowledge of actual current direction these patterns were determined primarily through the evaluation of current intensities and the orientation of topographical features, together with field observations. More locally, flow patterns of tidal currents around coastal irregularities result in the development of counter eddies. The large counter eddy flow that is produced during the ebb phase northeast of South Spit undoubtedly results in counter-drifting (Johnson, 1919; Kidsen, 1963; Carr, 1965; Todd, 1968; Hayes and others, 1970; Lynch-Blosse and Kumar, unpublished). Turbulent flow develops near the end of the Little Beach Spit as the tidal currents encounter the longshore current. This is reflected in the velocity profiles of surrounding stations. At flood tide counter eddies are produced along the western side of South Spit in Brigantine Channel. As the tidal currents move at greater rates within the main channel, eddy currents are produced along the northern shoreline.

Currents Within the Main Channel

Attention is given to this section of the inlet because it should be here where the greatest amount of sediment is transported at both ebb and flood tide. Briefly stated, the flood and ebb tidal currents recorded here are dynamically similar to open channel flow. At any point along the channel the current has a certain average velocity. The greatest velocities are found in the middle of the channel nearer the surface, as far away as possible from any drag on the channel boundaries. Profiles of stations 2, 10, 13, 53, 81, 100, 102, 103, 105, 106, 116, 119, and 123 exhibit the flow tendencies mentioned above to varying degrees (Fig. 4).

A relatively smooth velocity profile would indicate laminar flow and little turbidity whereas an irregular variation in velocity with depth indi-

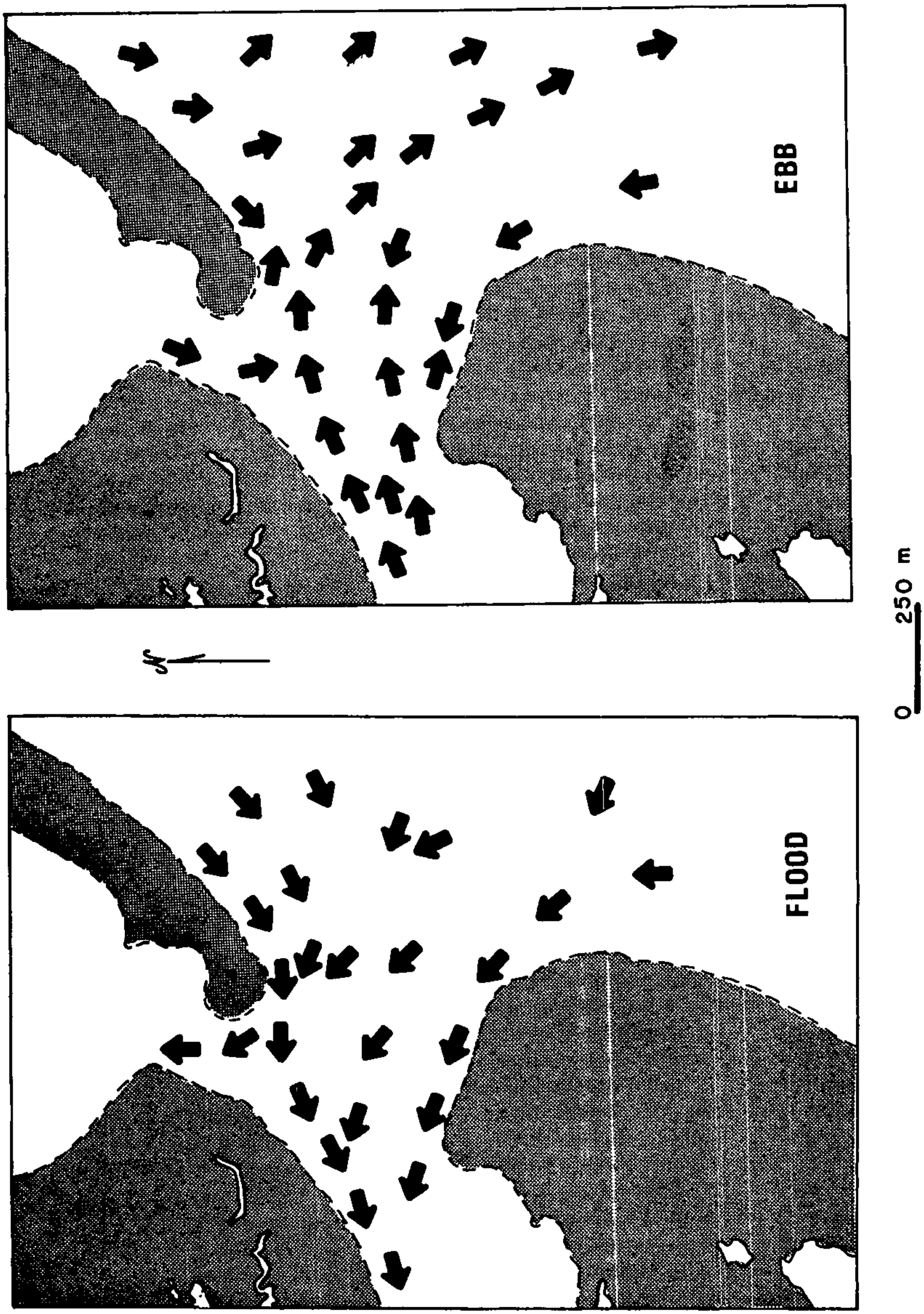


Fig. 5 Flow patterns of flood and ebb tidal currents in Brigantine Inlet as inferred from current intensity, and bathymetric data along with field observations. The major portion of the ebb flow is carried in the main channel, flood waters are less channelized and enter the inlet as a "sheet flow". Tidal currents enter the inlet close to the downdrift side of the inlet throughout the tidal cycle.

cates turbulence. Those stations actually within the boundaries of the main channel do not have the smooth profiles characteristic of laminar flow. Turbulence increases with the increase in velocity or the increase in bottom roughness and should be the greatest in the boundary layer as the current drags against the sides and bottom. Sediment thus has a tendency to remain in suspension. Consequently, those areas in the inlet that show turbulence should also be areas where sediment is chiefly being transported in suspension. Current profiles of stations 7, 8, 12, 14, 15, 52, 80, 101, 107, 112, 117, 122, and 124 exhibit turbulent flow tendencies (Fig. 4). Suspended material carried by the main flow would then be deposited at certain locations as previously suspected. At flood tide sediment would be deposited near Great Thorofare and deep within Brigantine Channel, whereas at ebb, deposition would take place again at the mouth of Great Thorofare and on the ebb tidal delta.

Possible Significance of Submerged Bars

Bedforms such as current ripples, sand waves, dunes and sand bars are created by the flow of water over the bottom at various velocities. More important in this study is the fact that these features are sensitive to flow direction of tidal currents. In areas where the ebb current is dominant the topographic structures should be oriented in that direction. Similarly, structures in flood-dominant portions of the inlet should be oriented in the direction of the flood current (Klein, 1970). Generally, the influence of the ebb current should dominate in shallower areas while the flood current dominates the orientation of topographic structures in deeper water. Many places in Brigantine Inlet are influenced greatly by both ebb and flood bottom currents. In this case the features constructed and oriented by the inflowing currents would be modified by the outgoing flow.

With the limited knowledge of bottom topography only a few bottom features can be recognized in this study. The orientation of these structures would prove to be most beneficial in determining current patterns. From fathometer data it was established that a bar exists in the middle of Brigantine Channel and is situated approximately on the southern edge of the main channel separating deep water from shallow (Fig. 2). The orientation of the bar supports the belief that the main flow in Brigantine Channel runs parallel to the northern shore. A second bar connected to the end of the Little Beach Spit stretches nearly all the way across the mouth of Great Thorofare. Here again it serves to establish the boundary of the main flow, this time on the northern side. The possibility of a third major bar being located along the edge of the shallow expanse north of South Spit has already been discussed. The orientation of all the bars is longitudinal to the confined currents within the inlet.

A transverse bar extends out from Little Beach Spit. The alignment of the submerged bar axis should reflect the angle at which the longshore current is deflected by the ebb current leaving the inlet.

Cyclicity of Transport

Sediment dispersal (sediment circulation pattern) in Brigantine Inlet follows a cyclic pattern (Fig. 6). At ebb tide sediment carried by outgoing currents is transported from within the inlet and deposited outside its mouth. The longshore drift upon encountering the outgoing currents of the

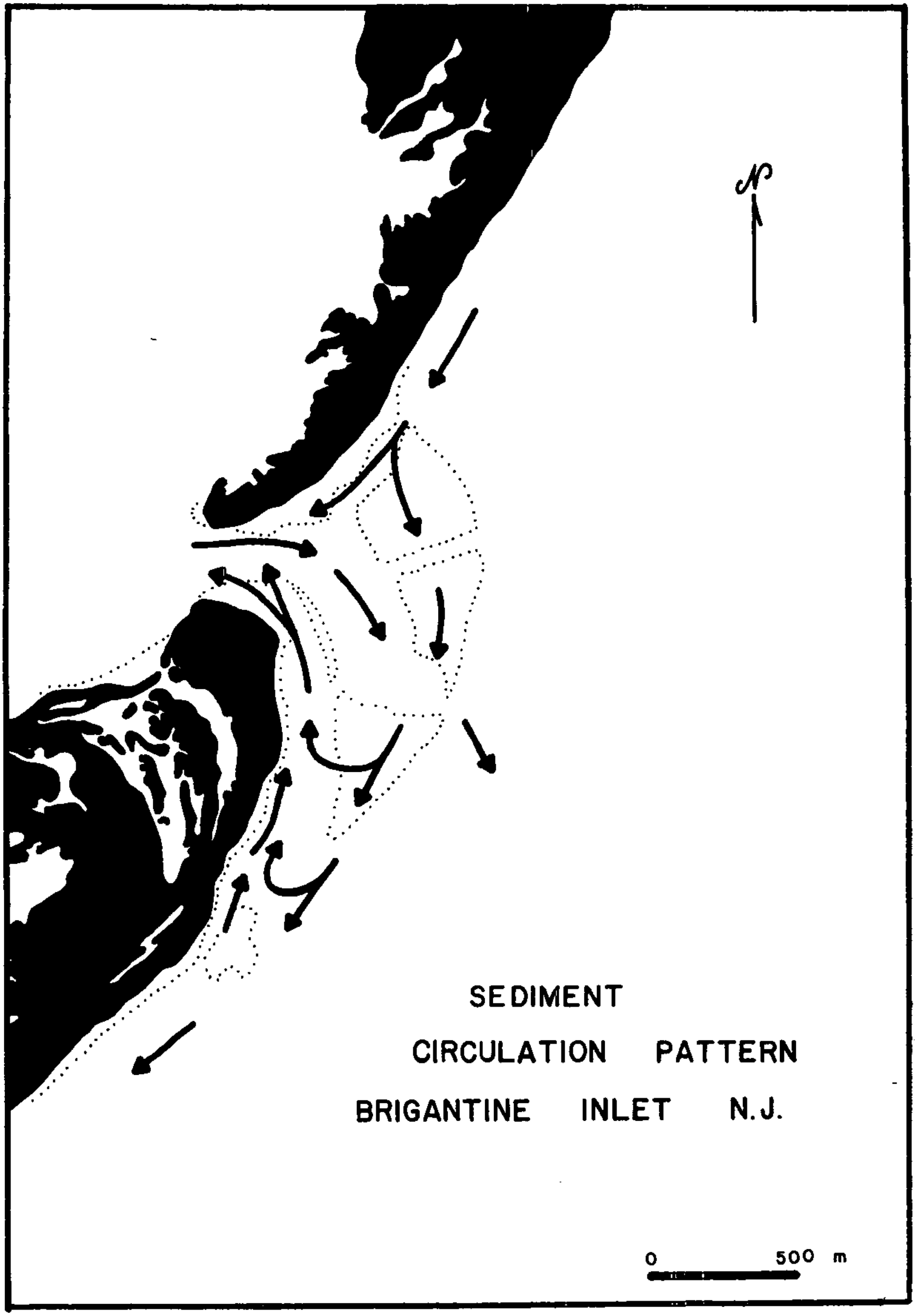


Fig. 6 Sediment circulation pattern at Brigantine Inlet, New Jersey as inferred from current, bathymetric and morphologic data. A landward net gain in the sediment budget is responsible for an infilling of backbarrier areas.

inlet is deflected seaward and deposited in deeper water. Some sediment also re-enters the inlet during this pahse of the tidal cycle. At flood tide the longshore drift is deflected into the inlet. A second source of sediment is provided by the ebb tidal delta itself. The same sediment may be transported back and forth many times, in and out of the inlet. Thus, sediment dispersal around the mouth of Brigantine Inlet is, at least in part, cyclic. Sediment lost from this cycle to the constant movement to the south is replenished by the same littoral drift from the north.

The Sediment Budget

There is a landward net gain of sediment at Brigantine Inlet. Velocity profiles show that the average bottom flood currents are stronger than those at ebb. Tidal currents entering the inlet introduce coarse sediment as well as fine. The littoral drift is also deflected into the inlet at flood tide. Ebb currents, moving faster at the surface tend to transport only the finer sediment that can be carried in suspension. Some deposition may take place during ebb flow as sediment is trapped in sheltered areas. Perhaps the most important factor contributing to a landward net gain of sediment is the continuous flow of currents (and sediment) into the inlet on its downdrift side throughout the tidal cycle. The volume of sediment should, therefore, be greater with the inflowing currents, producing a landward net gain.

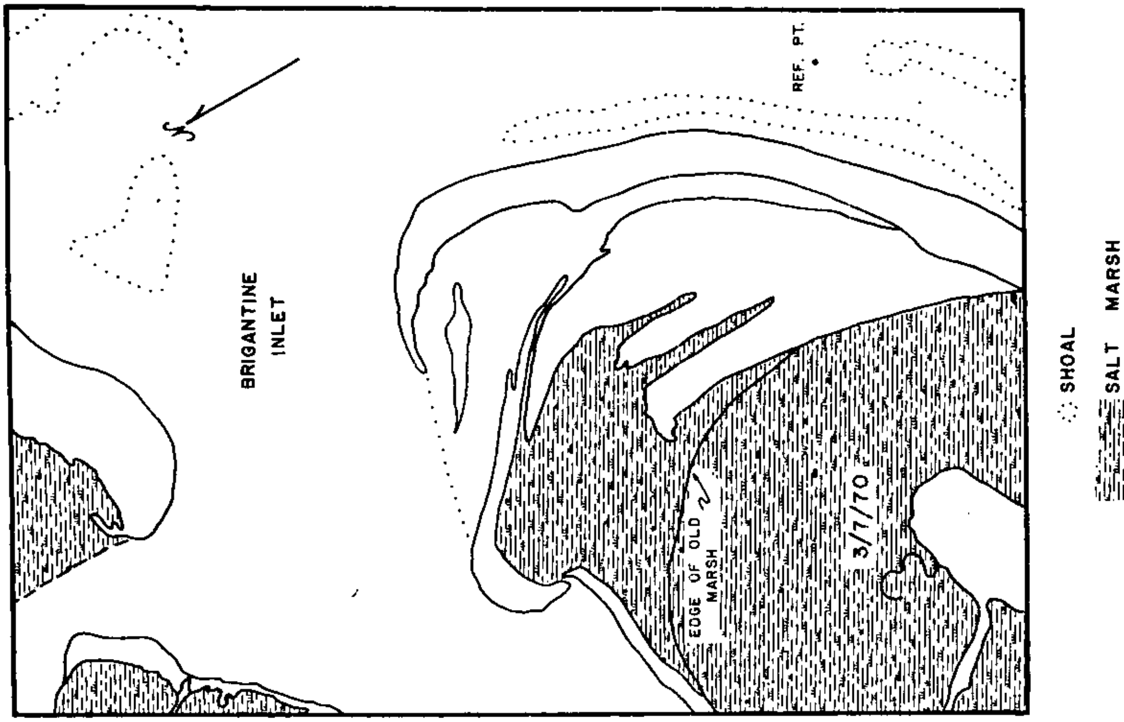
Northeastern Migration

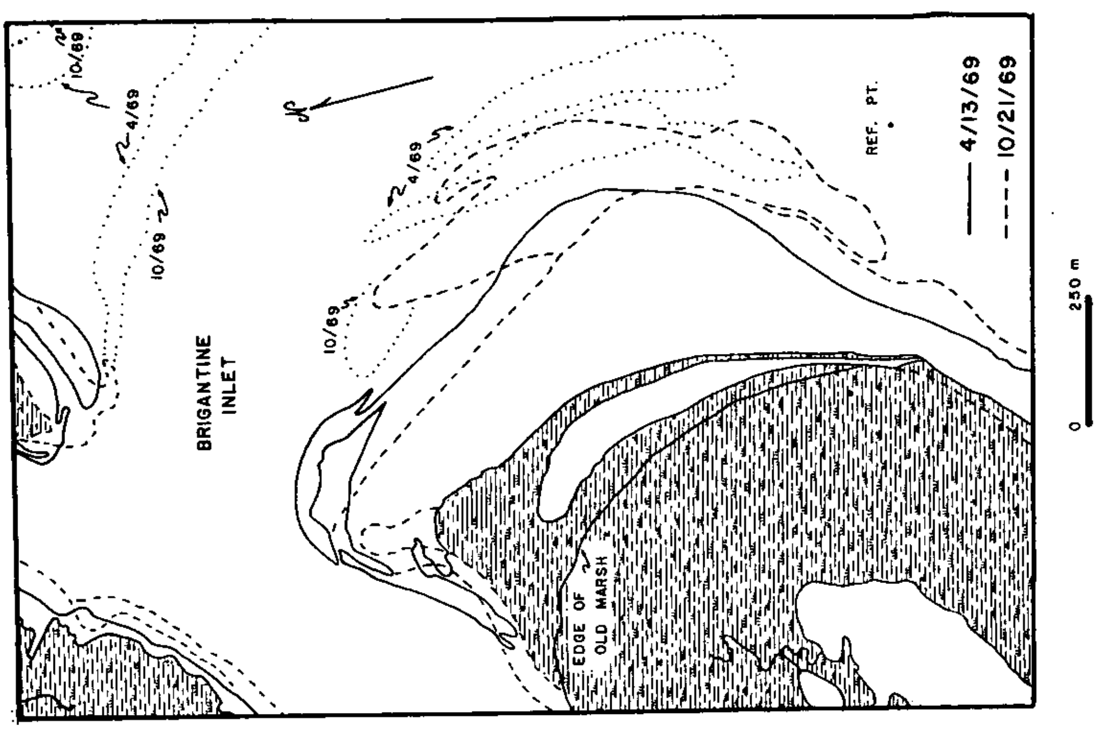
One of the interesting features of Brigantine Inlet is its migration to the northeast directly opposing the erosive longshore current. Equally as interesting is the offset of the downdrift barrier beach (Fig. 1). Hayes, Goldsmith, and Hobbs (1970) propose in their model that these phenomena can be attributed to the refraction of waves around the ebb tidal delta and subsequent accretion on the southern barrier beach. Galvin (unpublished) has also offered an explanation for downdrift-offsets. A more detailed explanation of downdrift-offsets is given by Lynch-Blosse and Kumar (unpublished).

As the longshore current encounters the ebb current leaving the inlet there is a build up of sediment and a transverse bar is created extending seaward from shore updrift. This bar protects the mouth of the inlet from the littoral drift; its full influence is not felt again until much further down shore. At flood tide the littoral drift is deflected into the inlet. Erosion of the southern barrier beach is again minimal as compared to surrounding areas where the littoral drift is constantly at work. This creates a somewhat unique situation in the area immediately adjacent and seaward of South Spit. Erosion has been retarded during ebb flow providing a plentiful source of sediment along the shoreline of South Spit. Either by gradual movement or by mass transportation during exceptionally high tides or storms, and predominantly by currents entering the downdrift side of the inlet throughout the tidal cycle, digits would be added. Historical evidence has shown this to be true (Figs. 1 and 7). The repeated addition of these digits could only result in the northeastern migration of South Spit and eventually the entire inlet.

Wave erosion is also reduced around Brigantine Inlet. The transverse bar that nearly surrounds the inlet's mouth acts as a breakwater absorbing the initial force of the waves approaching the shore. This reduces wave attack on the shoreline. The rate at which these processes occur would

Fig. 7 Brigantine Inlet; April 13, 1969, October 21, 1969, and March 7, 1970 (modified from Rittschoff, unpublished). Accretion on the downdrift barrier is the result of currents (and sediment) moving past this side of the inlet throughout the tidal cycle. Wave refraction and the interaction of tidal and longshore currents are also responsible for the landward migration of sediment.





naturally be increased by storms. Therefore, migration at times may be rapid. The areas behind the digits become washover zones and would eventually fill with sand, particularly during strong storm winds from the northeast. The filling in of these areas would tend to stabilize any migration of South Spit.

It should be remembered, however, that storms can be destructional as well as constructional. For example, during a strong storm the bar protecting the inlet may be breached. Once this protection is removed the littoral drift would be free to act upon the southern barrier beach. Simply stated, Brigantine Inlet would then migrate to the south until there is sufficient deposition to produce the protective bars and shoals.

Consequently, Brigantine Inlet may migrate gradually updrift during relatively stable periods, but may migrate rapidly downdrift for greater distances at other times. It is the latter that is best reflected in the long-term historical data.

Major Areas of Deposition and Erosion

In considering current strength and direction, topography, aerial photographs, and sediment circulation patterns of Brigantine Inlet, possible areas of deposition and erosion can be contemplated. It may, therefore, be possible to predict near-future morphological changes (Fig. 8).

These trends will continue in the same manner until there is a shift in the conditions affecting the Inlet. Storms must be considered the major variable in determining the nature of Brigantine Inlet.

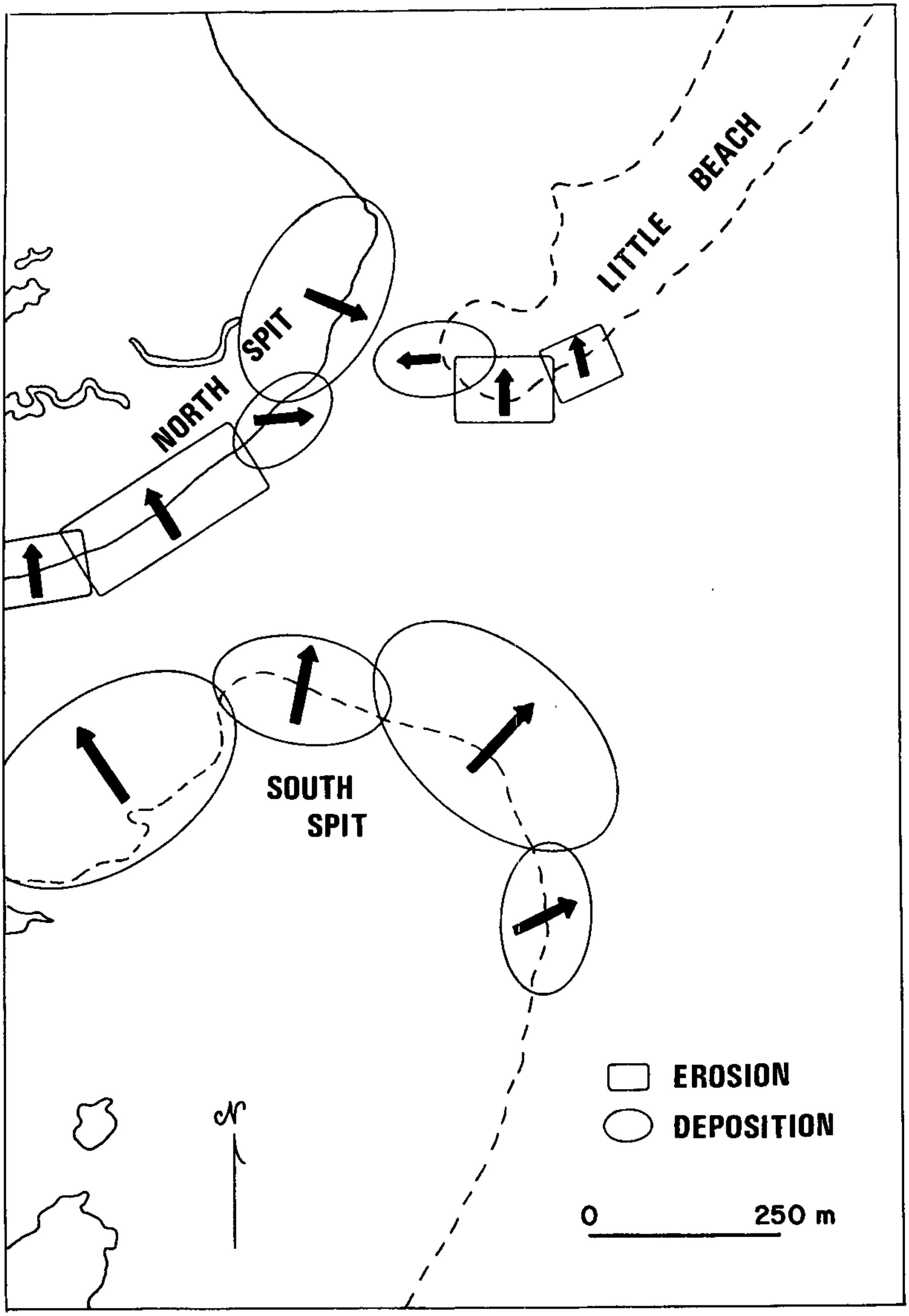


Fig. 8 Major areas of deposition and erosion; approximate directions of progradation and retrogradation.

SUGGESTIONS FOR FURTHER STUDY

The amount of material transported by currents within Brigantine Inlet would naturally depend on two primary factors; current intensity and grain size of the sediment. No data pertaining to the analyses of the local sediment were available. Therefore, the volume of sediment, transported in any size fraction, can not be determined. With only the current intensity and fathometer data at hand sediment movement could be evaluated only in a relative sense from one section of the inlet to another.

To date, the geologic study of Brigantine Inlet has been limited to topographic features of the area. A better reconstruction of the sedimentary record is needed. Attention should be given to the distribution of sedimentary facies to see if there is agreement with topography and the distribution of flood- and ebb-dominant velocity zones. An understanding of bedform morphology is extremely useful in determining the nature of flow as well as current direction. The internal organization of sedimentary bedforms should be examined to see if their orientation agrees with that of sedimentary facies and related topography.

CONCLUSIONS

A complex interaction of tidal and longshore currents is responsible for maintaining Brigantine Inlet. This interaction is the dominant process in sediment transportation from one area of the inlet to another.

Tidal flow in Brigantine Inlet is "segregated." A main channel runs along the northern shore inside the inlet, and cuts through an asymmetrical ebb tidal delta. This channel carries the major portion of the ebb flow. While ebb flow is more channelized, flood waters enter the inlet as a "sheet flow."

During the ebb phase of the tidal cycle the littoral drift is deflected seaward. As a result there is a build up of sediment, and a transverse bar is created extending seaward from shore updrift. The alignment of the submerged bar axis reflects the angle at which the longshore current is deflected by the ebb flow.

Zones of ebb- and flood-dominant currents as well as the topography control the orientation of sand bars. A series of bars flank the main channel within the inlet separating deep water from shallow.

The downdrift barrier is offset seaward at Brigantine Inlet. This downdrift offset is the result of several factors. Wave refraction around the ebb tidal delta, and the interaction of currents over the bottom cause a landward migration of sediment and subsequent accretion along the downdrift barrier beach. Circulation is such that currents enter the inlet close to its downdrift side throughout the tidal cycle. Digits are added by currents transporting sediment past the end of the downdrift barrier and/or the landward migration of bars or shoals. The areas in back of these digits become washover zones, and eventually filled by sediment, thus stabilizing the shoreline. The transverse bar tends to reduce wave attack on the downdrift barrier and further protects it from the erosive longshore currents.

The overall effect of the tidal currents along the northern side of Brigantine Inlet is erosive; particularly at the end of the Little Beach Spit and the southern half of North Spit. Despite erosion taking place along the northern shore deposition occurs near Great Thorofare, and, as a result, there is a narrowing of the entrance itself. Some of this sediment is eventually redeposited within Great Thorofare. Deposition is favored along the southern side of the inlet, especially in Brigantine Channel and around South Spit.

Brigantine Inlet is at present migrating northward and will continue to do so until there is a shift in the conditions affecting the nature of the inlet. Brigantine Inlet may migrate gradually updrift during relatively stable periods, but may migrate rapidly downdrift for greater distances at other times in a somewhat cyclic history. It is the latter that is best reflected in the long-term historical data.

Despite a cyclical pattern of sediment dispersal there is a landward net gain of sediment within Brigantine Inlet. Consequently, surrounding lagoonal areas are being filled in. However, as the inlet becomes narrower current velocity will increase, and Brigantine Inlet will remain open.

A better understanding of the nature of tidal inlets is essential for scientific, engineering, and environmental purposes.

Brigantine Inlet remains as one of the few natural inlets in the region. I sincerely hope that its educational and research value will be recognized by others, and the task of maintenance will be left to nature alone.

ACKNOWLEDGMENTS

Appreciation is extended to Dr. Naresh Kumar and Dr. Phillip S. Justus for their exceedingly valuable suggestions and sacrifice of time. Gratitude is expressed to Dr. Paul S. Boyer for his inspiration and consultation while conducting this study. Research conducted by the author's peer, William Rittschof, proved to be of vital importance and is an essential reference in future study of Brigantine Inlet. Basic information and material such as historical maps, records and aerial photos were supplied by the New Jersey Bureau of Geology and Topography. The project was guided and supervised by Dr. George J. Halasi-Kun and David Harper, including the critical review of the manuscript. The author especially wishes to thank Barbara L. Haberthur for typing this manuscript in its final stages.

REFERENCES CITED

Carr, A.P., 1965, Shingle spit and river mouth: short term dynamics: Inst. British Geographers Trans., V. 36, p. 117-129

Emery, K.O. and Uchupi, Elazar, 1972, Western North Atlantic Ocean: topography, rocks, structures, water, life, and sediments: Memoir 17, Amer. Assoc. Pet. Geol., 532 p.

Frank, W.M. and Friedman, G.M., 1973, Continental shelf sediment off New Jersey: Jour. Sed. Pet., V. 43, p. 224-237

Galvin, C.J., unpublished, Wave climate and coastal processes: Paper delivered at Symposium on Water Environment and Human Needs, Oct. 1, 1970, Mass. Inst. Technology, Ralph M. Parsons Laboratory, 44 p.

Hayes, M.O., Goldsmith, V. and Hobbs, C.H., 1970, Offset coastal inlets: Proc. 12th Coastal Engineering Conf., p. 1187-1200

Johnson, D.W., 1919, Shore processes and shoreline development: New York, John Wiley & Sons, 504 p.

Kidson, C., 1963, The growth of sand and shingle spits across estuaries: Zeitschrift für Geomorphologie: New Series V. 7, p. 1-22

Klein, G.D., 1970, Depositional and dispersal dynamics of intertidal sand bars: Jour. Sed. Petrology, V. 40, p. 1095-1127

Lynch-Blosse, M.A. and Kumar, Naresh, unpublished, Evolution of downdrift-offset tidal inlets of the east and Gulf coasts of the United States; 57 p.

McMaster, R.L., 1954, Petrology and genesis of the New Jersey beach sands: State of New Jersey Dept. of Conservation and Economic Development, Geol. Sur. Bull. 63, 239 p.

Plusquellec, P.L., unpublished, Coastal morphology and changes of an area between Brigantine and Beach Haven Hts., N.J.: M.S. Thesis for U. of Illinois

Rittschof, W.F., unpublished, Coastal morphology of Brigantine Inlet, New Jersey: history and prediction, 1877-1977: Report for New Jersey Bureau of Geology and Topography, Trenton, N.J., 44 p.

Sanders, J.E., 1970, Coastal-zone geology and its relationship to water pollution problems, In Johnson, A.A. (ed.), Water pollution in the greater New York area: New York, Gordon and Breach Science Publishers, p. 23-35

Shepard, F.P. and Wanless, H.R., 1971, Our changing coastlines: New York, McGraw-Hill Inc., 579 p.

Todd, T.W., 1968, Dynamic diversion: Influence of longshore current-tidal flow interaction on chenier and barrier island plains: Jour. Sed. Pet., v. 38, p. 734

U.S. Naval Weather Command, 1970, Summary of synoptic meterological observations, v. 2, p. 475-632

Wicker, C.F., 1951, History of the New Jersey coastline: 1st Coastal Eng. Conf. Proc., p. 229-319

PARAMETERS OF MARINE POLLUTION

by

William Jamieson, Ph.D.

Columbia University Seminars on
Pollution and Water Resources

INTRODUCTION

Large sums of money, both private and public, are going to be spent in the coming years to abate and control water pollution. A sizeable share of such expenditures will be used to gather water quality data which will be used to give direction to the abatement efforts and to measure their effectiveness. In order to assure maximum value from such expenditures it is important to consider carefully what data are desired and how they will be gathered and analyzed. The nature of the measurements to be made will be keyed to several factors -- a major factor being whether the water is classified as fresh or marine.

Probably because, up until very recently, only fresh water has been used as a source of municipal water supply, much thought has been given to the gathering and analysis of fresh water data, but relatively little to saline (or marine) water. It is the intent of this paper to examine some of the aspects of the water quality data required to evaluate and control the latter category of water resources.

Since each of the key words in the title, Parameters of Marine Pollution, is currently open to a degree of interpretation, it is desirable to briefly discuss the meanings ascribed to them in this paper.

A parameter has been defined as being a quantity used to describe a statistical population. It is a means of measuring, a type of yardstick. It is quantitative -- a number must be involved. Qualitative, descriptive phrases cannot qualify as parameters.

The second key word, "Marine," pertains to the oceans or seas and is applied only to saline waters. The marine environment is usually considered to include the estuarine waters.

Pollution can be and has been defined in a great many ways. For the purposes of this paper, the definition given by the California State Water Control Board will be used. This Board defines pollution of water as any impairment of qualities that adversely and unreasonably affect the subsequent beneficial use of such water. It is important to note that the change must be both adverse and unreasonable. Implicit in this definition is the belief that a change from the natural state need not be adverse but may actually be beneficial. Also implied is the fact that every substance in the water can be considered to be a potential pollutant. If a substance is concentrated to the extent that it affects the subsequent beneficial uses of the water, it is a pollutant; if sufficiently diluted, it is no longer considered to be a pollutant.

SELECTION OF PARAMETERS

Beneficial Uses

Since, by definition, a condition of pollution is dependent upon the subsequent beneficial uses to which that water will be put, it is necessary to establish the beneficial uses for each specific body of water prior to establishing pollution parameters for it.

Some of the uses usually considered to be beneficial are:

- Esthetic enjoyment
- Swimming
- Beach picnicking
- Surfing
- Skin diving
- Boating
- Water skiing
- Sports fishing
- Commercial fishing
- Propagation of fish, shellfish
- Propagation of algae
- Industrial cooling water
- Municipal water supply (after desalinization)
- Dilution and transport of wastes

In some cases the uses may be compatible or synergistic; in most cases they are antagonistic. The relative importance of the uses varies with the season and often depends upon the viewpoint of the user.

Monitoring Programs

Too often in the past, surveillance programs have been cumbersome data-collecting operations with a pronounced deficiency in the analysis of the acquired data. Little has been done in the way of relating the data to the beneficial uses to which the water is being applied. Also, water data are usually gathered for a particular study with little thought given to other possible uses. Uniformity of sampling and analysis technology do not often exist.

We are at the beginning of a vast effort to control water pollution. Modern tools in the forms of computers and data reduction equipment are available. A national system for the storage and retrieval of data for use in water control (STORET) has been initiated. The compilation of a national estuarine inventory has been authorized and funded. If maximum benefit is to be gained from these expenditures of money and manpower, care must be taken to assure uniformity in the selection of the pollution parameters to be measured and in the sampling and analytical procedures. Such parameters must be selected which will provide the most meaningful information for the widest possible use.

CLASSIFICATION OF MARINE POLLUTION PARAMETERS

The many parameters of pollution may be placed in one of the following four major categories:

(1) Physical
(2) Chemical
(3) Biological
(4) Radiological (sometimes included in physical category)

Each parameter must be further categorized according to the zone in which the data are to be taken, i.e., pelagic, benthic, littoral or intertidal. Also, consideration must be given to whether the pollutant floats, dissolves, settles out, or becomes interminably suspended.

Physical Parameters

In the pelagic zone, physical parameters include, but are not limited to, temperature, salinity, turbidity, transparency, color, odor and current flow.

Physical parameters peculiar to the benthic zone include various aspects of the geology of the bottom, such as grain size and distribution.

As a rule, physical parameters are not used to measure the concentration of a pollutant. They aid in the description of an environment and in the prediction of changes that will occur in the environment as a result of an increase or decrease in the rate of discharge of pollutants into the waters of that environment.

In the design of ocean outfalls, physical parameters such as the velocity of the water mass, water temperature, the eddy diffusivity coefficient and the amount of floatables in the wastes discharged are required. The latter parameter has been receiving more attention in recent years. Even if the concentration of floatables is low, they float to the ocean surface and are eventually transported by the prevailing winds to some point of land or structure where they continue to pile up. With the plastic and aluminum containers in current use the rate of degradation is very slow and the concentration becomes objectionable.

Chemical Parameters

The number of different chemicals discharged into the waterways is great and the changes which they often undergo due to reaction with other substances in the water further complicate an already complex situation.

Chemical parameters in the pelagic zone include but are not limited to the following:

(1) Biochemical oxygen demand (BOD)
(2) pH
(3) Dissolved oxygen (DO) and carbon dioxide
(4) Chemical oxygen demand (COD)
(5) Nutrients - phosphates, nitrates
(6) Pesticides - insecticides, herbicides
(7) Synthetic detergents
(8) Heavy metals - lead, zinc, copper, nickel, chromium

Sodium, calcium and magnesium are not monitored, as they usually are in fresh water, due to the high concentrations of these elements found in sea water.

Although the assay of chemical parameters in estuaries is useful, in the open marine environment the quantities found are so small that their effect on beneficial uses is hard to determine.

Chemical analysis of bottom deposits are essential because of the tendency of some pollutants to interact with the sediments and also with benthic marine life. Thus the presence of a pollutant can often be noted by examining the bottom-dwelling organisms even though the waters show no trace of it. Pringle et al. (1968) reported on the ability of mollusks to concentrate trace metals up to many hundred times the level found in the natural environment.

Total nitrogen, organic carbon and sometimes BOD are measured in bottom deposits.

A new parameter of organic chemical pollution has been proposed (Parker 1967) using the stable carbon isotope ratio $^{13}C/^{12}C$ in combination with the carbon-14 dating technique. By means of this new method it is possible to distinguish between natural and industrial organic pollution. In many cases it can identify specific carbon wastes.

Biological Parameters

In the pelagic zone biological parameters may include enumeration of the principal species of plankton, statistics on fish catches, the assay of coliform organism, and the determination of primary production.

Biological parameters in the benthic zone are especially useful because most of the organisms to be found there are sessile. Thus, it is possible to periodically enumerate the species of benthic animals and plants. Sometimes the density of coliforms and other bacteria are measured at various depths below the surface of the bottom deposit.

The littoral (or intertidal) zone is an area where the pollution parameters deal with attached algae, invertebrates, and bacterial densities.

The basis of evaluation of water pollution in Europe has been the "Saprobien System" devised by Kolkwitz and Marsson (1908). Lists of indicator species said to occur characteristically at certain levels of water pollution were made. Four levels of water quality were established:

(1) Olygosaprobic - no trace of pollution
(2) Beta-mesosaprobic - water not directly polluted by man, possibly seepage and fecal matter of animals, no intentional pollution
(3) Alpha-mesosaprobic - intentional seepage, due to cesspools
(4) Polysaprobic - raw sewage, quantities of fecal matter

Much work has been carried out towards adapting this basic saprobic system to the marine environment. Garber (1960) studied the correlation between free-floating plankton populations and the degree of pollution. Resig (1960) related foraminiferal ecology to ocean outfalls. Stein and his associates (1963) investigated the use of quantitative samples of marine fishes. Beck (1964) recognizing the need for a concise expression of populations, developed a method of biological scoring which is based on a frequence of occurrences of certain macroscopic invertebrates.

Sessile organisms have been found to be generally the best indicators since they cannot move to avoid the polluted water. Worms, mollusks, arthropods and algae have all been used.

Probably the most complex facet of marine pollution is the effect of the pollutants on the biota. Various organisms have different environmental requirements and sensitivity to pollutants. The problem is further compounded by the interactions and associations between the organisms and by the phenomenon expressed in one of the basic rules of ecology which says "two limiting factors, acting together, will create conditions as one would at its maximum." In the laboratory one factor can be varied at a time -- in nature this seldom happens. The choice of parameters to assay under such conditions is a difficult one.

In recent years, methods for defining the concept of a biological community and determining the form of statistical distribution functions to describe biological populations have developed. Margalef (1957) proposed a diversity index expressed by the equation

$$I = p_i l_n p_i$$

where I is the diversity index, p_i is the number of organisms in the species i, divided by the total number of organisms in the sample and $l_n p_i$ is the natural logarithm of that function. This index recognizes the accepted ecological principle that an adverse environment will result in a decrease in the number of species although the total number of organisms of a given species may increase due to reduced competition. This index may be applied to both plant and animal life.

Bray and Curtis (1957) developed a mathematical method for comparing forest communities and soil characteristics. Their technique (similarity coefficient) has since been used to determine which physical or chemical parameter of water and sediments were most closely associated with differences in benthic populations at various locations in San Francisco Bay.

By the use of such techniques as diversity and similarity indexes and modern computers, it has become possible to understand, to a greater degree, the relationship between the various chemical and physical parameters and the biotic populations.

Radiological Parameters

Radioactivity, long a water contaminant from natural sources, has grown in importance and health significance with the development of nuclear energy. Consequently, the United States Public Health Service has been monitoring, since 1957, the radioactive levels of:

(1) Gross alpha
(2) Gross beta
(3) Strontium 90

The disposal of radioactive wastes is controlled by the Atomic Energy Commission and by state governments. However, periodic surveys are indicated to determine the gross radioactivity of plankton, attached algae, fish, and benthic animals. In certain cases it may be desirable to measure the activity of specific radionucleides, for example, zinc -65 in oysters. Some of the radioisotopes can be concentrated in marine plants and animals by a factor of 1:100. (McKee 1967.)

BIBLIOGRAPHY

Beak, T.W., 1964, "A biotic index of polluted streams and its relationship to fisheries," 2nd Int. Conf. Water Pollution Research, Paper No. 10, p. 20.

Bray, J.R. and J.T. Curtis, 1957, "Ordination of the upland forest communities of southern Wisconsin," Ecol. Monogr. 27:325

Camp, T.R., 1963, Water and its impurities, Reinhold.

Garber, W.F., 1960, Receiving water analysis, Proc. 1st Int. Conf. Waste Disposal in the Marine Environment, Pergamon Press.

Greene, R.S., The storage and retrieval of data for water quality control, U.S. Dept. of Interior, Federal Water Pollution Control Administration.

Ingram, W.M. and K.M. Mackenthum and A.F. Bartsch, Biological field investigative data for water pollution surveys, U.S. Dept. of Interior, Federal Water Pollution Control Administration, Wash., D.C., 139 pp.

Kolkwitz, R.and M. Marson, 1908, "Okologie der pflanzlichen saprobien," Ber. Deut. Bot. Ges., 26:505-519

Margalef, R., 1957, La teoria de la informacion en ecologia, Memorias della real academia de ciencias y artes, Barcelona.

McDermott, J.H., 1968, Water quality surveillance in water resources planning and control, U.S. Dept. of Interior, Federal Water Pollution Control Agency.

McKee, J.E., 1967, "Parameters of marine pollution - an overall evaluation," Proceedings of the Conference on the Status of Knowledge, Critical Research Needs and Potential Research Facilities Relative to Ecology and Pollution Problems in the Marine Environment. Held at Texas A&M, Galveston, Texas, T.A. Olson and F.J. Burgess, Eds., pp. 259-266.

Parker, P.L., 1966, "Chemical parameters." Proceedings of the Conference on the Status of Knowledge, Critical Research Needs and Potential Research Facilities Relating to Ecology and Pollution Problems in the Marine Environment. Held at Texas A&M, Galveston, Texas, T.A. Olson and F.J. Burgess, Eds., pp. 317-321.

Pringle, B.H., D.E. Hissong, E.L. Katz, and S.T. Mulawha, 1968, "Trace metal accumulation by estuarine mollusks," Journal of the Sanitary Engineering Division; Proceedings of the American Society of Civil Engineers, Vol. 94, No. SA3, June 1968, pp. 455-475.

Resig, M.J., 1960, "Foraminiferal ecology around ocean outfalls off southern California." Proceedings of the 1st International Conference on Waste Disposal in the Marine Environment, Pergamon Press, p. 104.

MEMBERS OF THE SEMINAR, 1972-1975

Chairman of the Seminar:

George J. Halasi-Kun
Hydrologist
Columbia University

Steering Committee:

Charles H. Behre, Jr.
Professor Emeritus of Geology
Columbia University

Courtney C. Brown
Professor Emeritus of Business
Columbia University

Laszlo Czirjak
International Financial Research
633 W. 115 St., New York City

Wesley J. Hennessy
Dean of School of Engineering and Applied Science
Columbia University

Kemble Widmer
State Geologist of New Jersey
Trenton, N. J.

Members:

Thad P. Alton
International Financial Research
633 W. 115 St., New York City

Charles G. Amato
Nuclear Engr. of Dames & Moore, Consultants, Cranford, N. J.

Conrad M. Arensberg
Professor of Anthropology
Columbia University

Armando Balloffet, Consultant
Tippetts-Abbett-McCarthy-Stratton
Engineers & Architects, N. Y.

Joseph Barnea, Director
Dept. of Economics & Social Affairs,
Resources & Transportation Div.,
United Nations, New York City

Byron Beattie
Expert on Forest & Watershed Management, United Nations,
Manila, Philippines

Jeanette A. Behre
Retired Asst. Professor of Biochemistry
Columbia University

Chaba Benedek, Chief Engineer
Swindell-Dressler Pan American Co.
Washington, D.C.

Paul Bock
Professor of Hydrology
University of Connecticut

D. Joseph Bollyky
Pollution Control Industries
Stamford, Conn. 06902

Stephen K. Breslauer
NUS Corp. Environmental Safeguard Div.
Rockville, Md. 20850

Wallace S. Broecker
Professor of Geology
Columbia University

Joseph H. Butler
Professor of Geography
State University of New York at Binghamton

David L. Campbell
Asst. Professor of Mining
Columbia University

George Claus
Faculty of Medicine
University of Vienna, Austria

Bertrand H. Chatel
United Nations
New York City

Joseph S. Cragwall, Jr.
Chief Hydrologist
U.S. Dept. of the Interior
Geological Survey, Reston, Va.

Donald V. Dunlap
State Meteorologist of N. J.
New Brunswick

Augustine O. Esogbue
Professor of Industrial & Systems Engineering
Georgia Institute of Technology

John T. Egan
Water Quality Control
Dept. of Water Resources of N.Y.

John Fabianek
Professor of Life Sciences
N.Y. Institute of Technology

Rhodes W. Fairbridge
Professor of Geology
Columbia University

Ella F. Filippone
Environmental Research Association
Basking Ridge, N. J.

James J. Geraghty
Groundwater Geologist
Port Washington, N. Y.

Robert D. Gerard
Research Associate in Physical Oceanography
Columbia University

Samuel Gofseyeff
Civil Engineer
Whitestone, N. Y.

Alvin S. Goodman
Professor of Civil Engineering
Polytechnic Institute of N. Y.

Harry P. Gregor
Professor of Chemical Engineering
Columbia University

M. Grant Gross
Professor of Oeeanography
The Johns Hopkins Universtiy

Isadore S. Grossman
Board of Water Supply of
New York City

William A. Hance
Professor of Geography
Columbia University

John E. Harrison
Environmental Quality
Dept. of Health, New York State

Steve Hartman
Biologist Consultant
Sea Cliff, N. Y.

Ernest LeRoy Hendricks
Retired Chief Hydrologist
U.S. Dept. of the Interior
Geological Survey, Reston, Va.

Colin High
Asst. Professor of Geography
Columbia University

Allan Hirsch
U.S. Dept. of the Interior
Fish & Wildlife Service
Washington, D.C.

Raphael Hurwitz
Board of Water Supply of
New York City

William Jamieson
Consultant
Amityville, N. Y.

John A. Jones
Professor of Earth Sciences
Miami-Dade Junior College

William C. Kennard, Director,
Institute of Water Resources
University of Connecticut

Walter Kiechel, Jr.
Deputy Asst. Attorney General
Land & Natural Resources Div.
U.S. Dept. of Justice
Washington, D.C.

Jack Koczan, Consultant
Dames & Moore
Cranford, N.J.

Adolfo Korn
Mining & Mechanical Engineer
United Nations, New York City

Martin Lang
First Deputy Administrator
Environmental Protection Agency
New York City

Gregory Lazarcik
Professor of Economics
State University of New York
at Genesee

Robert A. Lewis
Professor of Geography
Columbia University

Richard LoPinto
Director, Marine Biology Program
Fairleigh Dickinson University

Daniel P. Loucks
Professor of Water Resources Eng.
Cornell University

Ulrich A. Maniak
Professor of Hydrology
Tech. University of Brunswick
F.R. Germany

Vincent E. McKelvey
Director of U.S. Geological Survey
U.S. Dept. of the Interior
Washington, D.C.

Everett L. McLeman
Public Health Service
U.S. Dept. of Health, Education
& Welfare, New York City

Seymour L. Meisel, Vice President
Mobil Research & Development Corp.
New York City

David Miller
Groundwater Geologist
Port Washington, N. Y.

Francis C. Monastero, Oceanographer
U.S. Dept. of the Interior
Bureau of Land Management
Washington, D.C.

Norbert Psuty
Director, Marine Sciences Center
Rutgers University

Habib S. Rahme
Consultant
Syosset, N. Y.

George Redey
Civil Engineer
Englewood, N. J.

Peter P. Remec
Professor of Political Sciences
Fordham University

Roland Renne
Associate Dean
University of Illinois

Hugh B. Ripman, Dir. of Administration
International Bank for Reconstruction
& Development
Washington, D.C.

Gerald W. Robin
State University of New York
Stony Brook, N. Y.

Oswald A. Roels
Sr. Researcher in Marine Biology
Columbia University

Virginia Scrocco
Orange, N. J.

Harold R. Shipman
Head of Water Supply Division
International Bank for Reconstruction
& Development
Washington, D.C.

H. James Simpson
Asst. Professor of Geology
Columbia University

Richard Skalak
Professor of Civil Engineering
Columbia University

Lawrence Slote
Consultant
Kings Point, N. Y.

Victor T. Stringfield
USGS Water Resources Div.
U.S. Dept. of the Interior
Washington, D.C.

Nocolay P. Timofeeff
Professor of Geography
State University of New York at Binghamton

Michael A. Tirabassi
Asst. Professor of Operations Research
Stevens Institute of Technology

John Volkert
Associate in Geography
Barnard College

Grant F. Walton
Professor of Environmental Sciences
Rutgers University

Leon Weinberger, Vice President
Environmental Control Management
Rockville, Md.

George W. Whetstone
Asst. Chief Hydrologist
U.S. Dept. of the Interior
Geological Survey
Reston, Va.

Gordon R. Williams
Professor Emeritus of Civil Engineering MIT
c/o Tippetts-Abbett-McCarthy-Stratton
Engineers & Architects
New York City

Lamar J. Worzel
Professor of Geology
Columbia University

Akhtar Yaseen
Chief of Laboratories
New York Medical College

Warren E. Yasso
Professor of Natural Sciences
Columbia University

Leonard B. Zobler
Professor of Geology and Geography
Columbia University

Guest Members:

Frank Basile
Bureau of Land Management of U.S. Dept. of the Interior
New York City

E. L. Bourodimos
Professor of Civil Engineering
Rutgers University

Gerardo Cruickshank
Undersecretary of Water Resources
Government of Mexico, Mexico City

Nicholas de Kun
Consultant
Bruxelles, Belgium

Nicholas Domokos
Water Resources Management
Budapest, Hungary

Michael J. Passow
Asst. Professor of Geology
Fairleigh Dickinson University

Charles Szesztay
United Nations
New York City

Edith B. Weiss
Asst. Professor of Civil Engrng. & Political Sciences
Princeton University

Junior Members:

from Columbia University

Lawrence A. Buck
David Harper (also Rutgers University)
Kathy Hartman (also New York University)
Peter P. Madri (also University of London)
Yeshwant K. Purandare (also State University of New York)
Frank Pecenka (also New York University)
Charles Szilagyi

from City University of New York

Michael Dicken (Queens College)
Richard Krauser (Queens College)

from Fairleigh Dickinson University

William Rittschoff
Michael Lynch-Blosse