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REPORT BY

BOARD OF COMMERCE AND NAVIGATION

NEW JERSEY

ON THE EROSION AND PROTECTION OF THE

NEW JERSEY BEACHES

1922

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LETTER OF TRANSMITTAL

TRENTON, N. J., January 10th, 1923.

To the Legislature:

GENTLEMEN—For a number of years past, in its annual reports to the Legislature, this Board has stressed the importance of the protection of the New Jersey beaches, realizing their tremendous value to the State and to the nation at large.

We would respectfully bring to your attention that those sections of the coastal strip from Keyport to Cape May which lie next to the ocean and bays were assessed in 1899 at Fifty-Seven Million Dollars. The same territory in 1922 was assessed at over Three Hundred Million Dollars. This is more than the assessed valuation of the farms and farm property in the whole State; this increase is 425 per cent., while the total State ratables only increased 310 per cent. in the same period.

The ocean, as will be seen in the accompanying report, has caused some accretion as well as loss of land, but the net loss since 1835, the earliest record available, is over two thousand acres, and unfortunately the ocean does not always select the least valuable points for her attack.

The erosions are still in progress and unless checked will not only result in further loss of physical property but discourage investment of capital in seashore property. Thus it is of prime importance to protect this valuable contribution to the State's growth.

At the last session of the Legislature this situation was appreciated and an appropriation was made for an investigation and a study of the changes on the New Jersey coast and to determine, if possible, the best means of preventing further encroachment, and the work was assigned to this Board.

With enthusiasm the Board undertook the work, and entrusted the gathering together of the materials and the formulation of conclusions and recommendations to its Committee on Coast Erosion, and that Committee turned over the details of this work to an Engineering Advisory Committee which it appointed with the sanction of the Board.

Realizing that the United States Government, through several of its departments, had valuable records, information and knowledge, a request was sent to the Department of Commerce, and to the War Department for co-operation and aid, and both Senator Edge and Senator Frelinghuysen personally took up with these Departments the assistance and kind of assistance we wanted, and we have had the very fullest co-operation and aid from the United States Government Departments to whom we have applied. The Department of Commerce, through Secretary Hoover, and Colonel Jones, Director of the United States Coast and Geodetic Survey, permitted Commander R. S. Patton, Chief of the Division of Charts, not only to prepare maps showing the relative condition of the coast line at various periods for a hundred years back, but also permitted Commander Patton to sit as a member of the Engineering Advisory Board and to make physical inspections and to report his conclusions and recommendations. We received also from this Department information concerning wind velocities and current tendencies.

The War Department offered us for use the records of coast changes filed at the offices in New York, Philadelphia and Wilmington, and further permitted Colonel E. Eveleth Winslow, Colonel Earl I. Brown, and later on the retirement of Colonel Winslow, Colonel H. C. Newcomer, to sit at the meetings of the Engineering Advisory Board and to give exceedingly valuable aid, not only in the consideration of the causes of erosion, but also in the best means of protection against further erosion.

The Board also secured the services of Mr. Charles W. Staniford, formerly and for many years Chief Engineer of the New York City Dock Department, with much knowledge of coast erosion and coast protective devices, to sit as a member of the Board; and it employed Captain H. V. Campbell, an engineer with local knowledge of the New Jersey beaches, to make physical examinations of the coast from end to end, a large part of this being made under the direction of Mr. Staniford and a portion with Commander Patton.

The make-up of the Engineering Advisory Board and its Associates was therefore as follows:

Commander R. S. Patton,

Mr. C. W. Staniford,

Mr. Victor Gelineau, Director of the Board of Commerce and Navigation;

Mr. Harrison P. Lindabury, Special Counsel of the Board of Commerce and Navigation;

Mr. Henry J. Sherman, Assistant Engineer, Board of Commerce and Navigation;

Mr. Edward J. Murphy, Assistant Engineer, Board of Commerce and Navigation;

Mr. B. F. Cresson, Jr., Consulting Engineer, Board of Commerce and Navigation; the latter acting as Chairman.

On behalf of the War Department, not as members of the Board, but sitting with it and aiding it, were:

Colonel H. C. Newcomer,

Colonel E. Eveleth Winslow,

Colonel Earl I. Brown.

Mr. Edward H. Russell, Chief Clerk of the Board of Commerce and Navigation, acted as Secretary.

The Board organized, held a preliminary meeting, laid out the work as described in the general report, and carried it forward as far as it could be carried with the funds and time at its disposal. Then it held meetings and formulated its conclusions and recommendations.

The Board of Commerce and Navigation has followed closely the work of this Engineering Advisory Board and has been kept informed as to the progress of its work, has considered its tentative conclusions and recommendations and has accepted and approved the final recommendations and conclusions contained in the engineers' report.

Under recent legislation and appropriation the State is now, through the Board of Commerce and Navigation, lending its aid to municipalities in the protection of beach fronts, and structures are now in course of construction. Some of these structures are rather radical in theory and design. These works should be followed up, the State should continue the work of this Engineering Advisory Board to further extend its investigations

and to keep track of the effect of the structures that have been recently erected along the coast front; and it is confidently believed that this report will indicate to the State the effectiveness of the investigation so far carried forward and the desirability of making it possible to continue for further conclusions and recommendations.

The Board of Commerce and Navigation cannot too gratefully express its appreciation of the services rendered by its staff with Mr. Staniford added, and especially by the representatives of the Federal Government in the persons of Commander R. S. Patton, Colonel H. C. Newcomer, Colonel E. Eveleth Winslow and Colonel Earl I. Brown, and to the broad-spirited action of Mr. Herbert Hoover, Secretary of Commerce, and Mr. John W. Weeks, Secretary of War, of Colonel E. Lester Jones, Director of the United States Coast and Geodetic Survey, and General Lansing H. Beach, Chief of Engineers, United States Army, for making this possible.

Acknowledgment is also made of the aid and co-operation rendered by Mr. B. F. Cresson, Sr., who read the entire report with great care and supplied a statement of conditions at Atlantic City as he observed them during the last fifty years.

To Senator Edge and Senator Frelinghuysen, the Board also expresses its thanks for their assistance in bringing the desires of the Board before the Federal Authorities and in securing the co-operation that the Board so greatly needed.

Respectfully yours,

ROBERT F. ENGLE,

Chairman Committee.

REPORT

BY

ENGINEERING ADVISORY BOARD ON COAST EROSION

TO

BOARD OF COMMERCE AND NAVIGATION

MAIN REPORT

The Atlantic Ocean, during the last century, has encroached and robbed New Jersey of some 2,200 acres of its beach front. This is the net result of erosion and accretion. Future loss can best be prevented by constructing series of low straight groynes at localities where erosion is evidently in progress. These, in simplest terms, are the findings of the Engineering Advisory Board on Coast Erosion appointed by the Board of Commerce and Navigation.

Dr. Elmer L. Corthell, past President of the American Society of Civil Engineers, and for many years and until his death esteemed as one of the great authorities on coast protective works, most aptly said: "Between land and sea an endless battle is being waged. Night and day the waves are continuing their assault upon the shore and for centuries past engineers have been struggling against the powerful invader."

Coast lines are continually changing; in some localities where accretions have been occurring for many years the situation may suddenly change, and for reasons that are undetermined erosion sets in. It is the problem of the engineer to devise means whereby damaging erosions may be arrested, and to do this in such a manner as not to promote erosion at other localities.

Structures placed to control erosion many times have their effect on localities far distant, and it is most important in the designing and in the consideration of shore protection to consider most carefully the possible effect of structures upon the coast lines within the entire zone of their influence.

A paper prepared for the Second Pan-American Scientific Congress states:

"There are two general principles which the engineers have adopted in plans for arresting coast erosion. First, to build structures whose principal purpose is not to oppose the action of the sea but to control it and direct it, so that by changing the forces which are causing erosion they may direct these forces in such manner that the erosions will cease. This principle appears to be the logical one to adopt where possible, but in some cases and in some instances it is impracticable and impossible to so change and control the forces of the elements by directing them that damaging erosions can be prevented. In these cases the second principle must be adopted, and that is to build structures to resist the action of the elements. This is most difficult and usually expensive, as the power of the ocean is limitless and any structure set up by man to oppose the action of the sea must necessarily be massive, and in spite of what can be done in the way of building masonry bulkheads, walls, jetties and breakwaters, where they are to oppose the action of the elements, there are continued records of failure and needs for reconstruction and renewals. It is far better to devise protective works with a view to directing the forces of the elements rather than designing them with a view to resisting the elements."

Coast Protection in Europe

In Holland, in England and in various other of the Old World countries this problem of coast protection has been a vital one for centuries. In Holland the very life of the country depends upon it. Most of that country lies below sea level, and were it not for the dykes and the means of protecting and maintaining the dykes against the attack of the elements, great sections of Holland might be submerged. Great engineering skill has been exhibited and remarkable results have been obtained, but the cost has been enormous

and means have been taken and structures erected which would have been impossible in this country owing to the great expense involved.

The great tidal variations in the North Sea and in the English Channel, and on the ocean fronts of Great Britain and France have rendered the problem more difficult than that which exists along the coast line of the Middle Atlantic States. But the Old World with its thoroughness and with the willingness of the people to spend large sums of money to accomplish results, and with their ability to see far enough ahead to cause a general study to be made and a general plan to be worked out and carried out, may be said, generally, to have succeeded.

Erosion of New Jersey Coast

There is no State in the Union whose waterfront, as a whole, is of more importance to it than New Jersey, and there is no oceanfront that is of more importance to a country than is New Jersey's waterfront to the United States. It is the playground, the principal recreation and health resort of the Nation.

Great damages have occurred during the last two decades to New Jersey's oceanfront. The beach has retreated in many sections and vast sums of money have been spent, not only by municipalities but also by private individuals, in the construction of coast protective devices. Inlets, too, have changed; some have closed, some have opened, new ones have appeared, and they have all, unless controlled by expensive works, been in a constant state of instability, not only as to depth and bars but as to the location with respect to the beaches on the north and south.

Under the stress of this situation, New Jersey, as a State, took cognizance of the danger threatening its most valuable asset. It appreciated the importance of certain municipalities devising, by themselves, the necessary protective works, and it realized the danger of leaving unprotected certain beaches, in view of the possible effect on their localities which might be caused by their erosion.

Legislation

New Jersey passed a law under which the State could make appropriations of moneys to be spent in conjunction with a like amount of money appropriated by local municipalities for the construction of defensive works, such work to be done under the direction of the Board of Commerce and Navigation. This law has been availed of, and the State is now participating in the protection of beach fronts along lines approved by the State body in order that too great a burden should not be placed against local communities.

One section of the beach cannot be eroded without the effect of the change being felt on other beaches—no section of the beach can be added to by artificial accretions without the effect of this being felt on beaches nearby. The State, therefore, with full appreciation of the relation of one beach to another and of the inlets to the beaches and of the importance of preserving the beaches as a whole, directed the State Board of Commerce and Navigation to make an investigation and a recommendation covering the works that had been done in coast protection and their effects, and it further directed that at the conclusion of such an investigation the Board prepare recommendations as to the general form that coast protective devices could take.

Engineering Advisory Board

The Board, as soon as the appropriation was available for this work, commenced its study. It first placed the matter in the hands of its Committee, made up of members of the Board particularly familiar with coast protection works. This Committee appointed an

Engineering Advisory Board, made up of certain members of the staff of the Board, and in addition Commander R. S. Patton of the U. S. Coast and Geodetic Survey who was intimately acquainted with the coastal changes as shown on the maps of the U. S. Coast and Geodetic Survey and who had been studying coastal changes, their causes and means of prevention.

On the Engineering Advisory Board the United States District Engineers were invited to serve, and, while Colonel Winslow, Colonel Newcomer and Colonel Brown were unable to accept appointment on the Board, they agreed to sit in with the Engineering Board and give it the benefit of their suggestion and advice.

In addition to the above members of the Engineering Advisory Board, Mr. C. W. Staniford was appointed in order to secure the benefit of his experience as Chief Engineer of the New York City Department of Docks for many years, and as an engineer experienced in coast protection works.

This Engineering Advisory Board met and determined on a course of procedure. It determined that the first thing to get was as much history of the New Jersey Coast as was available, and as much history of coast protecting devices wherever they may exist as could readily be obtained, and determined therefore that the following work should be done:

First—That an examination should be made in the engineering libraries and various articles and reports written on the subject of coast protection, and Mr. E. J. Murphy, Assistant Engineer of the Board, was assigned to this work. Mr. Murphy visited the Library of the United Engineering Societies in New York and abstracted a large amount of material, and a portion of this has been summarized in the appendix of this report.

Second—An examination on the ground of the entire New Jersey Coast. Mr. Staniford and Captain Campbell, employed for this purpose, have made an inspection of the entire coast of the State, have made sketches of the types of structure that have been placed to control erosions, and have gotten together maps showing sections of the beach where extensive work has been done. While all of the sketches and maps have not been reproduced, those that have not been included are in the files of the Board.

Third—A tour of inspection covering the life saving stations and the light houses along the New Jersey beach, with interviews at the coast guard stations and light houses to get as much as possible of the history of the changes in the beaches from men who have been observing the beaches for many years. This work has been covered by Commander Patton and by Captain Campbell.

Fourth—A study of the movements of the inlets and the changes in them has been prepared in part by Commander Patton, by Director Gelineau, by Assistant Engineer Sherman and by Captain Campbell. Realizing the importance of considering the effects of the inlets, this is of exceedingly great interest.

Fifth—Appreciating the effect that is exerted upon the beaches by the wind, we have secured a statement from the United States Weather Bureau showing the velocity and direction of the winds during certain periods and at certain localities upon the New Jersey coast.

Sixth—The best records of the changes in the coast line are undoubtedly in the office of the U. S. Coast and Geodetic Survey, and through the courtesy of Colonel E. Lester Jones, Director of the U. S. Coast and Geodetic Survey, and Commander Patton, the Board has had prepared for it a map of the New Jersey coastal frontage showing conditions at various times since 1835. These maps are made a part of the report.

Seventh—Mr. Cresson, the Consulting Engineer of the Board, made a trip to Europe during the summer of 1922, and among the purposes of his trip was that of observing on the ground certain coast protective works that had been put in place, and a portion of

his report of Coast Protection Works in Holland and on the Southern Coast of England is included.

Eighth—Mr. Lindabury, Special Counsel of the Board, was requested to prepare a statement on the legal aspects in the matter as it referred to the protection of the beaches by the State or municipalities or private interests, and as it referred to riparian rights and ownerships.

The question has been frequently raised in the past as to whether the elevation of the New Jersey beach is lowering. Mr. George Otis Smith, Director, U. S. Geological Survey, in a letter dated June 12, 1922, says in part in respect to this subject:

"There have undoubtedly been oscillations of this coast during the later geological periods which geologists have called Pliocene, Pleistocene, and Recent, but there has not been unanimity of opinion as to the detailed manner in which these oscillations have taken place.

"Geologists are not in perfect agreement as to the stability of sea level with respect to the land at the present time, although there is fairly reliable evidence that within a relatively recent time sea level has risen. This is shown by the stumps and roots of trees that are in places exposed at extreme low tide below mean sea level. I believe, however, that no one has been able to demonstrate by actual measurement that there has been a change of sea level within historic times.

"The sands that compose the present beaches were probably derived chiefly from the shore of Monmouth County, where the waves appear to be cutting away the mainland. The materials thus derived are distributed southward along the coast forming the barrier beaches, and northward into Lower New York Bay, forming Sandy Hook."

With these conclusions as to the relative level of the sea and the land this Board is in agreement, *i. e.,* that there has been no material change in sea level within historic times.

Fundamental Questions

There were two fundamental questions submitted to the Engineering Advisory Board for its consideration: First, have there been changes in the conditions that are tending to erode the coast either along its entire length or locally? And, second, are there any key works such as heavy riprap jetties that could be placed at localities that would tend to correct any destructive currents along the coast? These questions were considered by the Board with the following conclusions:

In so far as can be seen we have no evidence of such changes if we consider the word change to mean a definite and permanent transition from one state to another, traceable to some clearly defined cause. We do have ample evidence of what may be called fluctuations, that is, changes in the rate of progress of erosion or accretion, erosion going on at some point for a greater or less time and then seeming to be followed by accretion, changes in the rate of inlet movements, etc. These fluctuations, however, should be attributed to variations in the attacking forces and to the resistance encountered at the point of contact rather than to any permanent change in the conditions producing erosion. For an example, an unusual succession of northeasterly gales during any short period may produce a result which will make that period stand out for years in the minds of local observers, yet the effect is produced by forces identical in kind and only differing in amount from the ordinary.

Theoretical considerations point to the conclusion that as the high water line recedes its accessibility to attack by the waves is reduced unless that recession is accompanied by such a planing down of the shoal area alongshore that a constant profile is maintained.

There is, however, a total lack of evidence to indicate what has actually gone on in this respect.

It seems obvious that the major part of the erosion is caused by wind-driven waves which, striking the beach obliquely, cut deeply into it and produce an alongshore current to carry away the material. Protection, then, demands at least partial protection from these waves and a breaking up of the continuity of the current produced. In general, this could not be accomplished by a few extensive widely separated groynes or breakwaters. Any structures to be effective should be sufficiently close together to divert wave accessibility to any considerable extent of beach. In other words, the forces producing erosion are being constantly renewed from seaward, thus differing, for example, from a hydraulic or tidal current flowing along a beach, which, if checked at one point, has no means of renewing itself to leeward of that point.

The actual distance apart of the structures will be a function of the direction from which the waves strike the beach, but any protective measures taken can properly be described only as local structures designed to produce local effects.

The Engineering Advisory Board held a meeting in Trenton on October 30th. At this meeting all material at hand was considered and each member of the Board was requested to take a subject under consideration and to prepare it from the material at hand for consideration by the Board at its meeting on November 13th. This was done and in this each member was asked to present his conclusions and recommendations as to the most effective means of coast protection for the New Jersey beaches. These latter were considered by the Board at its meeting on November 13th in great detail and with great care and the conclusions and recommendations stated below represent the unanimous opinion of the Engineering Advisory Board and its associates, Colonel Brown concurring.

Conclusions and Recommendations

1. Neither bulkheads nor groynes can be recommended for use singly except in special cases.

2. The use of concrete for bulkheads is not recommended except for those heavier and more permanent types that may be classed as sea walls.

3. Timber bulkheads should always be provided with riprap protection. To be most effective, there should be added to the timber jetty or groyne a bank of riprap on each side. The riprap should be of substantial size and the whole bank of riprap with the timber groyne should have a width at top of from twelve to twenty feet, dependent on the locality; the purpose of the riprap being to add substance to the groyne, the purpose of the timber work to constitute a tight core, and the purpose of the riprap also to decrease the scour of the receding waves.

4. The construction of bulkheads seaward of high water line should not be permitted except for urgent reasons to the contrary.

5. The groynes must be spaced dependent on the slope of the beach, and the location of the inlets; the steeper beach necessitating groynes closer together than the flat beach, and it is not believed that any benefit, except in isolated cases and under particular conditions, will result in the groynes being otherwise than straight and generally normal to the beach.

6. Groynes should always be securely connected back to a bulkhead, or lacking that to the line of sand dunes or other points well above the high water line.

Sheet piles should be never less than ten feet. Riprap should not be less than one-man stone, pieces weighing about one hundred pounds. The larger the stone the less the effect of wave action upon it.

The most effective coast protective works for the New Jersey coast are a combination of bulkheads and groynes. The bulkheads should be substantial and should be built well inshore of high water line. They should extend into the sea as far as practicable below low water line. This may be defined as a point about three feet below mean low water. The jetties or groynes should be of tight construction, preferably of tongued-and-grooved sheet piling, rigidly held in place by wales and piles, the latter having a penetration of at least twenty-four feet; and it is desirable that all timber shall be treated with creosote, and all bolts, rods, spikes, etc., shall be galvanized.

7. Groynes for purposes other than that of holding the beach should be permitted only for special reasons and after careful study.

8. A sand-tight core should always be provided for groynes. Either sheet piling or a compact one of gravel, quarry refuse, etc., may be used.

9. The core should always be solidly protected by piles or by riprap or by both.

10. Groynes more than three feet above the normal profile of the beach should be permitted only for special reasons. The top of the groyne should conform to the general slope of the beach and should be on an average three feet above the level of the beach, and where erosions have occurred in the past and it is desirable to recapture the beach and restore it, the groynes should be designed with the piles projecting up so that additional boards may be added between the vertical piles if the beach rises.

11. Care should be exercised in permitting the construction of curved groynes.

12. Groynes should be spaced roughly a distance apart equal to their length.

13. When State aid is given in connection with coast protective works, means should be taken to provide for the maintenance of such works in good repair. Such works not in good repair cannot be expected to have beneficial results.

14. The growth of sand dunes along the coast should be encouraged and promoted. They are best promoted by promoting the growth of beach-building vegetation, such as sea oats, sea wheat and other beach plants.

15. That littoral drifts are not of sufficient volume and velocity to warrant the construction of any key works in the way of heavy outshore jetties or current deflectors; that such works are not considered necessary, desirable or justified.

16. That to control the location and navigable depth of inlets, tight jetties are necessary, and that in the case of many inlets two parallel jetties are needed to carry the current into deep water.

17. These jetties may be straight where the tidal prism of the lagoons or bays is large, but may be curved in order to increase velocity where the lagoons or bays are small.

18. In the construction of jetties to control the entrance to inlets, great care must be exercised that such works do not cut off the supply of sand on which beaches adjacent to the inlet depend.

19. The public authorities should discourage, as far as lies within their power, the construction of sand catchers or arrestors designed and placed for the purpose of extending the high water line or the low water line toward the sea. Whatever is done in the way of coast protective works should be as coast protective works and not as coast extension works.

20. There are certain locations where particular treatment is necessary—the heavy riprap jetty at Sea Bright being an instance—where an inlet was endeavoring to open, and here the heavy riprap jetty to resist northeast storms and to trap sand on its normal movement to the north, appears justified, and there are inlet openings which are seeking to move and which must be controlled by substantial riprap jetties.

21. There is no hard and fast rule in coast protective works. Every locality must itself be studied, but the type of construction recited above appears generally to be a type which

has been used in this country and abroad, which has gotten beyond the stage where it is experimental, and appears to be backed by sound opinion, and for the New Jersey beaches it seems to be the type that should receive first consideration in the study of protection for any beach front.

Respectfully submitted,

ENGINEERING ADVISORY BOARD ON COAST EROSION;

COMMANDER R. S. PATTON,
CHARLES W. STANIFORD,
VICTOR GELINEAU,
HARRISON P. LINDABURY,
HENRY J. SHERMAN,
EDWARD J. MURPHY,
B. F. CRESSON, JR., *Chairman;*
EDW. H. RUSSELL, *Secretary.*

Concurred in by
COL. H. C. NEWCOMER,
COL. E. EVELETH WINSLOW,
COL. EARL I. BROWN,
B. F. CRESSON, SR.

APPENDIX "A"

HISTORICAL

Changes in the New Jersey Beach Front—In the Condition and Location of Inlets

A moment's consideration of the complexity of the factors concerned in the evolution of the shore forms, and of the difficulty of properly evaluating the various components involved, will make it clear that everything we can learn regarding the actual past results of the working of these forces will add to our knowledge of the forces themselves and of their relative importance in the problem of shore protection.

In other words, having stated in general terms the nature of the forces involved in coast erosion, our next step is to see what has been the actual result of their continued action over as long a period as possible.

We must also remember that these changes are in the nature of fluctuations rather than a constant, gradual change in a fixed direction, since the principal forces producing them have been traced to the winds, which differ greatly in both strength and direction during different seasons, and from year to year.

Therefore it is not sufficient to ascertain the facts as they existed at two widely separated periods. On the contrary, our knowledge of the subject will be increased by everything we can learn regarding conditions at as many intermediate periods as possible.

MAPS

The earliest published maps of this coast of an accuracy sufficient to permit of their being used even in the most general way for purposes of comparison were made at about the time of the Revolutionary War. Even these maps, however, are on such a small scale, and so generalized as to local details that they may be described as interesting for a general visual comparison rather than useful in the determination of quantitative results.

The earliest surveys made on a sufficiently large scale, and with sufficient detailed accuracy to justify the engineer in utilizing them in an effort to determine the nature and extent of the changes along the coast, were made by the U. S. Coast and Geodetic Survey. (Plates 1 to 13 and Index Map.)

These surveys were begun in 1835, and have been repeated at intervals since that date, so that at the present time that Bureau possesses records of four surveys each covering practically the entire coast, with additional surveys made at various intermediate times at various places where the changes were most rapid.

These surveys were all based on a closely-spaced network of geodetic control, by means of which a high degree of accuracy in the field work was maintained, and which now permits of an exact coordination between the surveys of different dates.

These records were placed at the disposal of the Board of Commerce and Navigation, which has compiled from them a composite map showing by means of distinctive colors or symbols the different surveys of the various sections. The map is in 12 sheets, drawn to a scale of 1/20,000 (3.17 inches to the mile) which is the scale to which the majority of the original surveys were made, and which is large enough to permit accurate quantitative measures of the changes which have occurred.

Constant use of this map has been made in arriving at the conclusion which will be stated in a later section of this report, but which need not be set out in detail at this point. We may, however, note some of the facts of major interest thus revealed.

MEASUREMENT OF EROSION AND ACCRETION

A measure of the areas of erosion or accretion between the dates of the earliest and latest surveys gives the following results. The measurements were made with a planimeter, and check measurements indicate a probable error of about one per cent.

Plate No.	LOCALITY	Accretion (Acres)	Erosion (Acres)	Surveys (Dates)
1	North of 40° 25′ 25″	63.4	37.5	1835-1885
1	40° 23′ 52″ to 40° 21′	.....	152.5	1836-39-1899
1	South of 40° 21′	.....	195.8	1839-1920
2		.....	390.0	"
3		31.3	388 3	"
4		86.4	604.5	"
5	North of Barnegat Inlet	240.7	87.0	"
5	South of Barnegat Inlet	.....	1096.6	
6		203.7	388.5	1839-40-1920
7	North of Little Egg Inlet	245.2	61.8	1840-1920
7	Little Egg Inlet to Brigantine Inlet	136.5	35.5	1841-1920
7	South of Brigantine Inlet	91.5	342.7	"
8	North of Absecon Inlet	125.1	272.4	"
8	South of Absecon Inlet	374.2	58.0	"
9	North of Great Egg Inlet	50.0	114.6	
9	South of Great Egg Inlet	397.8	10.9	1842-1920
10	North of Corson Inlet	.....	147.1	"
10	Corson Inlet to Townsend Inlet	148.5	146.6	"
10	South of Townsend Inlet	106.8	40.3	"
11	North of Hereford Inlet	242.1	41.2	"
11	South of Hereford Inlet	259.5	41.2	"
12	North of Turtle Gut Inlet	92.2	3.0	"
12	Turtle Gut Inlet to Cold Spring Inlet	22.5	244.0	"
12	Cold Spring Inlet to Cape May	107.6	320.5	"
		3025.0	5220.5	

As was to be expected, the greatest changes have occurred in the immediate vicinity of the inlets. These inlets show persistent fluctuations, as well as radical variations along adjacent sections of the outer coast.

The shore line along the outer coast, excluding that part in the immediate vicinity of the inlets, shows some tendency toward fluctuations, but on the whole, a rather steady recession. The changes, in a direction at right angles to the shore line, between the surveys of 1839 and 1920, are as follows at various points:

LOCALITY	Recession (Feet)	Accretion (Feet)
Seabright	440	....
Long Branch	280	....
Asbury Park	180	....
Belmar	70	....
Como	....	60
Manasquan	230	....
Bay Head	300	....
Mantoloking	220	....
Lavallette	....	140
Seaside Park	400	....
Latitude 39° 51′	780	....
South of Harvey Cedars	1260	....
Latitude 39° 36.5′	00	00

LOCALITY	Recession (Feet)	Accretion (Feet)
Beach Haven	....	600
Brigantine Beach, north end	1200	....
Brigantine Beach, south end	....	1470
Atlantic City	....	1450
South Atlantic City	540	....
Ocean City	....	1350
Peck Beach	200	....
Sea Isle City	360	....
Avalon	....	1000
Stone Harbor	....	600
Wildwood	....	680
Two-Mile Beach	1120	....
Cape May, south face	900	....

CHANGES AT INLETS

It will be noted that most of the points at which accretion is shown in the above table are adjacent to inlets.

The changes at the various inlets are as a rule so complicated that they can be comprehended only by a critical study of the map. Without attempting to discuss these changes in all their details, we may touch briefly on some of the more conspicuous features.

For the sake of brevity, we will use the term "normal position" of the channel to indicate that position which is a prolongation seaward of the shore lines of the adjacent inland water.

SHARK RIVER INLET

Shark River Inlet joins the ocean with a relatively large shallow bay known as Shark River. (Plate 2.) This inlet fluctuates north and south, the axis of the river channel at times changing its direction sharply inside of the beach, and seeks an outlet several hundred feet north of the normal position. The charts would indicate a persistent southerly migration, each survey showing inlet further south than the preceding one. The topography, however, shows hooked spits extending northward from the southerly shore, a fairly sure indication of northerly movement. The surveys show migrations both to the north and to the south, with a predominant tendency to the north.

Under joint action by the State and local authorities curved jetties have been constructed in this inlet for the purpose of fixing its location and increasing its depth.

SEA GIRT OR WRECK POND INLET

This inlet shows variance similar to Shark River Inlet, with no decided migration in either direction (Plate 3). The movement of the inside channel by seasonable flow would account for the movements shown.

It is frequently closed by the beach forming across its mouth and remaining so until opened by a storm or drainage from the upland.

MANASQUAN INLET

The surveys of 1839 and 1867 both show this inlet at a point well north of its normal position, and in each case various features revealed by the surveys strongly support a supposition of northerly migration (Plate 3). Thus, although in 1867 the inlet was south of its 1839 position, the form of the inlet at the latter date is by no means what we would expect as a result of southerly migration. On the contrary, the evidence is fairly conclusive that at some time subsequent to 1839 a new outlet broke through the beach, probably about at the narrow neck between the beach and the southeast arm of the 1839 survey. In addition to the two hooks shown on the south spit in 1867, which of themselves afford strong presumptive evidence of a northerly growth, the extreme youth of this south spit as compared with that of the beach to the southward, is indicated in the original surveys, although not on the map, by the fact that the ridge of sand hills which fringes the coast terminates abruptly just below latitude 40° 06′, its northerly extremity being abruptly sheared off in a NW-SE direction precisely as must have resulted had an opening broken through at the position indicated. North of this point the survey shows a low flat beach or spit without dunes. There is a gap of about two miles at this locality in the 1899 survey, so we lack data regarding the migration of the inlet between 1867 and 1920, at which time it was subjected to artificial control.

Thus, the available data point to a prevailing set to the northward in this locality.

CRANBERRY INLET

This inlet was situated opposite the mouth of Toms River and the southerly boundary is the present north line of the Borough of Seaside Heights (Plate 3). The inlet has been closed for at least 100 years, closing probably about the year 1812. There is some evidence to the effect that it was used during the War of the Revolution. The principal significance in connection with it rises from a statement found in a description of the New Jersey coast, published by Woolman and Rose in 1879, that this inlet moved nearly a mile northward during the 60 years of its existence. If this statement is true, it is of the greatest interest considered in the light of the persistent southerly migration of Barnegat Inlet, 10 miles to the southward.

BARNEGAT INLET

Here we have a beautiful example of apparently persistent migration in one direction (Plate 5). The five surveys show a continuous advance of the north point to the southward, and an equally steady, but slower, recession of the south point to the southwestward. The advance and retreat of the two shores in the direction indicated between the dates of successive surveys is given in feet in the following table:

	1839–1874	1874–1899	1899–1915	1915–1920
North Shore	2200	660	1520	260
South Shore	1730	700	100	500

The net result between 1839 and 1920 is that the north point has grown to the southward, a distance of 4,640 feet, and the inlet has narrowed to only a trifle over half its width at the earlier date.

We should also note that the rate of change of both points varies greatly for different periods, and that there is no fixed numerical relation between the changes of the two points during the same period.

If we now turn our attention from the topographic surveys to the hydrographic we will note certain additional points which must have a vital bearing on this subject. A copy of a typical hydrographic survey is furnished to illustrate the following discussion.

The rise and fall of the ocean tides produces a hydraulic current flowing alternately into and out from Barnegat Bay, by means of which an attempt is made to equalize the water surface of the bay with that prevailing on the ocean side at any given moment. We have seen that the tidal wave approaches the coast from a direction at right angles to the line of the beach, and are therefore justified in assuming that the theoretical normal position of the axis of the currents through the inlets, if undisturbed by forces tending to modify it, should be through the middle of the inlet in a direction at right angles to the line of the beach.

If sand is being carried by the along-shore currents past the mouth of the inlet some of it will be seized upon by these hydraulic currents. The flood



Hydrographic Survey Map, Barnegat Bay and Inlet.

will carry it into the bay, depositing most of it just beyond the end of the gorge, where the currents are dissipated in the open waters of the bay. Similarly, the ebb current will tend to carry material seaward a short distance and there deposit it. The result is to form a more or less symmetrical "delta" at each end of the inlet; such deltas can be observed at every inlet where the body of inland water is sufficient large to result in appreciable currents through the inlet.

If an exact balance were maintained between the along-shore forces approaching the inlet from opposite directions we would expect these deltas to be symmetrical with respect to the current axis, while if there is a preponderence in the forces from one direction, we would expect that symmetry to be disturbed.

At Barnegat Inlet that disturbance is most pronounced. The deep water channel through the inlet does not follow a straight line, but forms a letter "S". The eastern half of the bay north of the inlet is filled by an extensive shoal, extending so far south that it overlaps the south point and almost blocks the entrance.

The main channel through the bay lies westward of this shoal, curves around its southern end, where it is crowded close against the shore southwestward of the south point of the inlet, and trends northeastward toward the north point of the inlet. Here it is deflected to the southeastward by that point and by a bar of exceptional shallowness extending in that direction from the point.

The characteristics here briefly stated are in general common to all the hydrographic surveys available. The only important difference between the survey chosen for this purpose and the others examined is with respect to that portion of the channel extending seaward from the north point. In general the direction of this channel is more to the southward than that shown on the survey of 1866-7. We may complete the record at this point by stating the fact, which seems amply established, that this channel goes through a fairly regular cycle, breaking through the crest of the bar at or north of its middle point and immediately starting to shift gradually to the southward until it trends about south-southeast, favoring the south shore. Here it will remain fixed for some time, but eventually breaks through again and starts a new cycle.

It appears that the bay shoal above described is one of two elements of first importance in determining the direction and rate of inlet migration, the other element being an excess of along-shore drift to the southward.

We have seen that the shoal keeps advancing ahead of the north point, and that it is responsible for a trend of the channel to the northeastward. The direction thus given to the ebb currents places them in opposition to the along-shore drift from the northward, which is encountered as soon as the ebb enters the area seaward of the north point. This opposition results in slowing up both currents, which in consequence the more readily deposit their burden of material on this portion of the bar crest, assisting in the formation of the shoal which deflects the channel to the southeastward.

Thus we have a shoal on either side of the north point, both working to the southward; the inner one in advance and responsible to some extent for an acceleration in the progress of the outer. We must infer that these conditions materially assist in the southward growth of the north point, without forgetting that that southward growth is due primarily to the action of the predominant currents outside, laden with sand and setting to the southward.

We may suggest, as a probable approximation to the truth, that had it not been for the modifying effect of this bay shoal the inlet positions would have fluctuated, with a prevailing component to the southward, but that the exceptionally constant movement in that direction is due in large measure to the pronounced advance of the shoal ahead of the point.

The importance of this phenomenon is sufficient to justify an attempt to ascertain its cause.

The records of the hydrographic surveys show that the flood tide spreads out over this shoal area, whereas the ebb skirts it to the westward, following the deeper water of the main channel. Thus the flood is permitted to deposit its burden of sand without a great deal of opposition from the ebb, and in consequence the shoal is built up.

By far the greater part of Barnegat Bay lies to the northward of the inlet. The extent and depth of open water in this direction are adequate to permit the formation of sizeable waves which, in northerly weather, roll south to break on and across the shoal, resulting in a southward movement of material which is not appreciably affected by wind or sea from any other direction, since the latter have not sufficient breadth or depth of water to enable them to become effective.

That the flood tide delivers more material to this shoal than the erosive agents can carry away is indicated by the fact that the shoal is building up. The resulting westward extension of the extremity of the north point is imperfectly indicated on the map. Therefore we may assume that the rate of southward progress of the shoal will be measured by the relative prevalence of northerly weather and its consequent ability to crowd the ebb tide channel to the southward against the resistance of the banks on that side..

While the above conclusions depend on theoretical deductions from an insufficient body of observed facts, they justify us in formulating a tentative rule, to be tested at subsequent inlets, that where the inland waters are extensive and unequally dis-

tributed with respect to the inlet, they may exercise a pronounced effect upon the changes in progress at the inlet.

The amount of erosion of the south point has already been stated. This erosion has occurred chiefly at the western extremity of the point, due to the action of forces already noted, and along the northeast face. Local observers state that the latter cuts away during easterly weather and on the flood tide only, when waves and currents are working in conjunction instead of in opposition, as is the case during the ebb.

BEACH HAVEN INLET—LITTLE EGG INLET

Since the charts apply the name "Little Egg Inlet" to the inlet opposite Great Bay instead of the name "New Inlet," by which it is known locally, in this description we will call the upper inlet "Beach Haven Inlet" and the lower or new inlet "Little Egg Inlet" (Plates 6 and 7).

The earliest record of the position of this inlet is given in the determination of the Province line between East and West New Jersey, by George Keith, in 1687. The description calls for "the first north point of beach north of Brigantine Inlet," and since Beach Haven Inlet was the first inlet north of Brigantine Inlet at that time this survey fixes the north side of this inlet.

The West Jersey Proprietors made an ex parte location of this line and set a substantial monument therein. It is situated near an ancient hostelry known as "Bond's" and about 3,000 feet north of the present inlet, opened in 1920.

John Lawrence resurveyed the boundary between the Provinces in 1743, and in this connection it is interesting to note that his location of the north side of Little Egg Harbor Inlet is the same as that made by the present inlet when it broke through the beach in 1920, 177 years later. This location also agrees with the Coast Survey of 1840.

The location of the south shore of this inlet is given in the Proprietary Survey to John Alvord in 1737, this survey extending from Little Egg Inlet to Brigantine Inlet. The northerly end of this survey was situated about 1,000 feet north of Little Egg Harbor Light and using the Alvord survey for the south side and the Lawrence survey for the north side (there being a difference in time of only six years in the two surveys). Little Egg Inlet was then about 9,000 feet wide.

According to a survey in 1818, for a division of Long Beach, the inlet appears to have worked south about 1,000 feet, and a survey in 1875, subdividing the property into building lots, shows the north side of the inlet 15,000 feet below Lawrence's line. A survey in 1882 shows the inlet entirely closed. In general the Coast Survey records agree with those from private sources. Between 1840 and 1871 the north point grew a distance of about 13,000 feet, and during the same period the south end of Tucker's Island, which separates the two inlets, receded 5,500 feet, so that in 1871 the end of the point was abreast the south end of the island.

Between 1871 and 1899 the point advanced 5,400 feet more, reaching the location occupied by the south end of the island in 1840. About this time conditions were becoming stabilized, for in the period between 1899 and 1915 the point advanced only about 2,000 feet, while between 1915 and 1920 it moved back somewhat.

The movements in this territory have been the most extensive of any section of the coast, and due to the fact that Beach Haven Inlet happens to be an important division line established at an early date, we have the longest reliable record of its changes. For instance, it is known that the inlet existed in 1687, 1743, 1840 and 1920, and in exactly the same place, except at the earliest date, when it was 3,000 feet further north. There have been rapid changes since the inlet reopened in 1920, and it is still eroding to the northward, pending the establishment of its regimen. It has worked southward before and undoubtedly will do so again.

Reduction in its volume of water by reason of the flow from Great Bay through Little Egg Inlet (New Inlet) will assist its southerly migration, especially since there will be no movement on the ebb tide to the north from that bay.

Examination of the charts shows the channel of Great Bay north of Anchoring Islands, the area south of them being filled by extensive flats. This situation is a survival of the time when Beach Haven Inlet was the principal outlet.

As late as 1903, long after Little Egg Inlet had become established, we still find the channel north of those islands instead of the direct route south of them.

This shows that the seaward forces at this inlet are stronger than the landward, a fact which is further attested by the migration of the Anchoring Islands northwestward while being worn away.

The beach making the south side of this inlet has receded at least 1,700 feet, the material having been deposited on the ocean front. The east line of the beach at this time is a continuation of the line of Brigantine Beach.

The most radical change of any beach along the coast has taken place in the territory between Brigantine and Little Egg Inlets, known as Little Beach or Island Beach. It has not only moved up and down and back and forth hundreds of feet but its entire shape has been greatly altered, and marsh islands separated by intervening thoroughfares have been joined to the beach by the filling of those thoroughfares.

The changes in this locality suggest the following tentative rules:

(1) That the alongshore drift of material is not continuous for the whole coast. It is more or less seriously interrupted at each inlet, the amount of such interruption depending on the volume of water passing in and out through the inlet, and on the direction of the resulting currents with respect to that of the drift.

(2) The erosive alongshore forces must therefore, to a greater or less extent, begin anew at the leeward side of each inlet to build themselves up and acquire a new burden of material. Therefore, for any given weather conditions, the amount of material passing any selected point on the beach will depend, within reasonable limits, on the length of beach between the selected point and the adjacent inlet to windward.

(3) While in general the dominant drift is toward the southwestward, its preponderance is not so great that it cannot be reversed locally by other factors. It would be a serious mistake to assume that at all points below the node between Manasquan and Barnegat the actual prevailing movement of material is to the southwestward. This applies particularly to material in transit between the high and low water lines.

BRIGANTINE INLET

This inlet is so close to Little Egg Inlet that it is profoundly affected by it. (Plate 7.) Its earliest position is defined in the Alvord survey of 1737, which shows its north shore a mile above the 1841 position of the Coast Survey.

The north point grew southwardly 2,000 feet and swung southwestwardly about 1,600 feet between 1841 and 1871. Evidently the long north spit was breached, for in 1920 we find the north line had receded 3,700 feet and the ocean front had moved out 2,000 feet.

Turning now to the south shore, the Ladd survey of 1742 shows it in the same position as the 1871 survey.

The earliest record of the Coast Survey, that of 1841, indicates this shore as extending in a southwesterly direction, and a continuation of the north beach line. The opening is narrow and well defined, being only 1,000 feet wide. By 1870 it has swung from northeast to northwest, eroded 3,500 feet in the southwesterly direction and changed to the familiar hook and rounded contour on the ocean front. The 1899 survey shows the same formation with an accretion in a northeasterly direction of a maximum width of 1,500 feet.

By 1903 it had receded one-half way to the 1870 location, and in 1920 it had gone back of the 1870 position a distance of 600 feet. In other words, the south shore of the inlet is now the farthest south and west of any position of which we have an authentic record.

The survey of 1869–70 shows an inlet in Brigantine Beach a mile and a half north of Absecon Inlet. It was not there when the survey of 1841 was made, although the beach was then only 500 feet wide at that point. The surveys of 1899 and 1920 also show the beach as continuous across this old inlet.

ABSECON INLET

Owing to the immense land values in Atlantic City which lies on the south side of this inlet, the changes here are of the greatest importance to the city and property owners. (Plate 8.)

The Ladd survey of 1742 shows the north shore of Absecon Inlet 9,000 feet north of the present lighthouse. Later surveys show the inlet gradually migrating southwardly, and by 1869, in a survey to Charles H. Tatem, the north line was 5,500 feet below the Ladd survey, or 3,500 feet from the Light.

The earliest record of the south shore is contained in the Proprietary Grant to Thomas Budd in 1695, which grant places the inlet 2,500 feet north of Absecon Light.

On the survey to John Scott, in 1714, it is shown 1,500 feet north of the Light.

Looking at the charts we see a well-defined trumpet-shaped opening by the 1841 survey, the minimum width being 700 feet. By 1864 the oceanward side of both beaches had eroded, Brigantine having receded 1,400 feet and Absecon 600 feet. In 1899 we find Brigantine Inlet had migrated westwardly 2,800 feet, and we observe that in 1920, while the ocean side of the beach had receded a further distance of 350 feet, the point had started to work southwardly, reaching a distance of 700 feet below the position in 1899, and the bar in extension of the beach reached a point abreast the lower end of the middle ground inside the inlet.

On the south or Atlantic City side the line receded 300 feet between 1841 and 1864, while just below on the beach front there was an accretion of 1,200 feet wide in the same period.

In 1920 the beach had still further receded at the inlet, varying from nothing on the inside to a maximum of 350 feet at the ocean end; thence the line turned sharply east, making a large accretion.

The irregularity of the present line may be partly accounted for by the large number of regulatory works which have been built to hold the front, although the early lines do not show the well-rounded form one would expect to find, but are quite irregular.

In 1899 the inlet was 4,000 feet wide at its narrowest point. In 1920 it had decreased to 3,400 feet. The 1841 survey shows the characteristic hook

on the Brigantine side, and this, too, appears in less marked fashion in 1864 and 1869–70, but does not show in the later surveys owing to protective works built across the point.

In connection with this inlet, it should be borne in mind that the northerly component of the tidal flow has been somewhat diverted by the construction of the Inland Waterway cut through the meadow and across the bar and the filling of the beach channel back of Brigantine Beach.

GREAT EGG INLET

The changes at this inlet warrant the utmost thought and consideration. The Board has recently made calculations which showed that between 1880 and 1920 some 184 acres of beach had been lost from the lower end of Longport. (Plates 9 and 22, Fig. 4.)

In 1841 there was a distance of 2½ miles between the north and south points of the inlet. Midway of this distance and on a line between the two points was an island, its main body roughly rectangular in shape with its major axis coinciding with the axis of the beaches on either side of the inlet. Each corner of this rectangle was modified by a characteristic hook. The two on the landward side of the island pointed to the northwestward, indicating building by the flood without much opposition from any ebb current between the island and the main shore northwestward. The two points on the seaward face pointed to the southwestward, suggesting the combined action of ebb currents and dominant southwestward drift. At that date the two openings through the beach through which the tidal flow passed aggregated 8,500 feet in width.

Between 1841 and 1886 the northeastern or Longport point had grown southwestward a distance of 7,600 feet, annexing whatever may have been left of the island and extending slightly beyond the position of its southwestern end in 1841. During the same period the south point of the inlet grew to the northeastward a distance of 1,200 feet, so that on the later date the width of the gorge was 3,600 feet.

Subsequent to 1886 we find a steady wearing away of the northeast point. While this receded more rapidly at the extremity of the point, which retreated 2,100 feet between 1886 and 1904 and 1,800 feet between 1904 and 1920, or at the rates of 117 and 113 feet per year respectively, the erosion was also pronounced on both the ocean and bay shores for considerable distances northeast of the point.

Serious damage has occurred at Longport owing primarily to the fact that a considerable proportion of the waterfront attacked during this period has been improved and built upon. The gravity of the situation was not realized in the early days, and as a result concerted action was not taken at a time when such action would in all probability have promised far more effective results than when undertaken after tremendous damage had occurred.

While this recession of the northeast point was in progress the southwest point underwent growth modified by some fluctuations, but on the whole persistent. Thus during the entire period between 1842 and 1920 the point grew to the northeastward some 3,100 feet, and its seaward face advanced to the southeastward an average distance of 1,200 feet. The peculiar characteristics of a broad, blunt-ended point seen in the 1842 survey are duplicated on an enlarged scale in 1920. The intermediate surveys, however, show radically different features. The most pronounced characteristic is for the inlet face to persist as a long, straight beach which swung back and forth as though on a pivot at its northern end.

It is interesting to note that between 1886 and 1891 while the north point was receding 500 feet the south point advanced some 1,700 feet, narrowing the inlet to a least width of 2,400 feet. This is the minimum width shown by any of the surveys. Thereafter, while the northern tip of the south point fluctuated somewhat the northern point receded steadily and the inlet widened in consequence.

The data available are not sufficient to furnish a satisfactory explanation of the erosion of the north point. We lack adequate information regarding the hydrographic features and the inlet currents. Such hydrographic surveys as have been made, however, in 1891, 1901 and 1904, show that whereas the main channel through the inlet is to the southward of the center line, there is a pronounced secondary channel close around the end of the north point. This indicates existence of currents available to carry away any material loosened from the point by wave action. Local observers state that the point has been eroded by the waves of northeast gales which sweep close around it.

It is worthy of note, however, that the extent of inland waters to the south of the inlet materially exceeds that to the north, indicating the possibility of a dominant ebb flow directed toward the north point. We should not lose sight of the possibility that this feature may have some bearing on the erosion of that point.

It is also interesting to note that between 1842 and 1886, while the Longport point was undergoing rapid growth, the accretion to the Ocean City side was very slight. By 1886 the north point had reached its southernmost extent and thereafter began to erode. This erosion was accompanied by a material increase in the rate of accretion to the south point, suggesting some connection between the growth of the latter point and the prevailing southwestward drift. It is as though in the earlier period, while that drift was being utilized to build the north

point, there was no material available to build the south one, but after the north point had taken all it could carry, the material which continued to arrive was transferred across the inlet and eventually found its way to the south point.

The beach between Great Egg and Corson Inlets affords an interesting example of oscillations about a fixed point. (Plates 9 and 10.) Near the present site of Coast Guard Station 127, 4½ miles southwestward of the south shore of Great Egg Inlet as it existed in 1920, we find a fulcrum, where the surveys of 1842, 1886, 1899 and 1920 all intersect in a common point. Northeastward of that point we find accretion; southwestward of it, erosion. The accretion considerably exceeds the erosion, indicating a tendency of the beach to the northeastward of the fulcrum to conform to the growth on the seaward face.

CORSON INLET

The surveys of the high-water line afford a very inadequate picture of the conditions in this locality due to the fact that so much of the area between the two points is filled by sandbars which are bare a considerable portion of the time and through which wind shifting and shallow channels. (Plate 10.)

The north point of the inlet has undergone radical fluctuations. In 1842 it occupied its southernmost position. In 1883 we find it 3,100 feet northeastward of the 1842 position, due probably to a flank attack on the bay side by the currents through Weakfish Creek, which on the ebb particularly are directed against the beach shore producing constant erosion and thus facilitating a break through the beach under favorable conditions. By 1899 the point, apparently following such a break, had grown to the southward 2,500 feet. In 1920 we find a recession of 3,200 feet from the 1899 extremity, due apparently to another break at the point of attack by Weakfish Creek. In 1842 the inlet was 3,000 feet wide; in 1920 the width between points was 5,200 feet.

The surveys of the south point suggest changes depending to a considerable extent on the fluctuations of the north point. Thus between 1842 and 1883 the south point grew to the northeastward 700 feet. Between 1883 and 1899 it receded 250 feet and between 1899 and 1920 it grew 1,400 feet.

The seaward face of the south point of this inlet does not show the accretion which we find at most of the other inlets. All surveys show the beach essentially straight, and the indications are that the growth of the south point has resulted from drift to the northeastward at such times as this secondary drift was able to dominate as a result of recessions of the north point. Here as in the case of Great Egg Inlet it is interesting to note that the ebb tide flow is directed toward the north point.

The beach between Corson Inlet and Townsend Inlet has in general receded since 1842, the maximum recession amounting to 900 feet at a point about half way between Strathmere and Sea Isle City.

TOWNSEND INLET

An inspection of the charts shows a steady migration southwestwardly of the north shore between 1842 and 1920, a distance of 1,700 feet, with a tendency to narrow at the point until the railroad trestle was built, after which the point began to widen, filling nearly all the space between its position in 1899 and the bridge. (Plate 10.)

The south shore line juts out 3,000 feet from the beach line to the north, the 1885 line making a right angle turn to the south. There was a gradual erosion on the south side of 700 feet until checked by the bridge. The material has been deposited on the ocean front, causing a sizable accretion there. The anomalous 1885 shore line was probably caused by the diversion of the ebb flow after the first railroad bridge was constructed, this bridge having extended straight across the inlet and concentrated the channel at a single point.

HEREFORD INLET

In 1842 this inlet was over a mile wide measuring the shortest distance between the shore lines. (Plate 11.) In 1881 we find the north line had moved oceanward 2,000 feet and southwardly 1,300 feet. By 1899 it had migrated back near the line of 1842, and 1,300 feet back of the point at that time. In 1920 it had receded a further distance northeasterly of 700 feet. On the lower side the shore line in 1881 is 1,300 feet back of the 1842 line on the ocean front and has moved into the inlet slightly. The 1899 line shows most of the beach front regained but the inlet proper has receded 1,000 feet, and in 1920 a portion of the beach was cut off leaving an island in the inlet 3,800 feet long and 1,500 feet wide.

This inlet is peculiar in that all the flow is from the north and taken into consideration with the islands on the inside the whole ebb current is projected against the lower beach.

TURTLE GUT INLET

This inlet displays the same characteristics as other inlets south of Barnegat, viz: the north shore has migrated southwardly since the earliest survey in 1842, though not regularly as in 1880 it was below the line in 1899 by 200 feet. (Plate 12.) In the last-named year the shore line was 1,300 feet below

that found in 1842. This inlet was always small and unimportant. About 1902 it breached a new opening three-fifths of a mile north of the old one which gradually closed.

An artificial closing of this has now been effected, so that this inlet need not be further considered in the study of the problem of coast erosion.

COLD SPRING INLET

Great changes have taken place in the line of the beach on the northeast (Two-Mile Beach) and on the southwest (Cape May). (Plate 12.) To what extent these changes have been influenced by the construction of the Cold Spring parallel jetties, constructed by the United States in the establishment of a harbor at Cape May, is an interesting and pertinent question. The possible effect of these jetties is indicated by the fact that on the line of the northeast jetty we find an accretion of 1,500 feet between 1899 and 1920.

The history of this inlet prior to the construction of these jetties is not now important from the point of coast erosion, excepting, of course, to show conditions and tendencies existing just prior to their construction. Obviously, structures of the extent of these jetties, placed on a sandy ocean beach, are certain to operate powerfully upon the forces that mould that beach. Coastwise currents are inevitably deflected, and otherwise modified.

It seems safe to say that in general the Cape May Beach has been eroded during the last few years and that this unfavorable tendency persists.

Every inlet from New Inlet to Turtle Gut Inlet shows this one interesting feature—the southwest point is of full or rounded contour and sets much farther out to sea than does the northeast point, which is usually narrow. This is not a mere coincidence but is a circumstance of the utmost significance, full of meaning for the student of the movements of our coast line.

The opposite condition now exists at Cold Spring Inlet, the high water line of 1920 at the northeast jetty being 500 feet oceanward of the high water line of 1920 at the southwest jetty.

APPENDIX "B"

Condition of Beaches, General Principles of Coast Protection, Beach Protective Devices

CONDITION OF BEACHES

The New Jersey ocean front proper extends from Sandy Hook to Cape May Point, a distance of approximately 134 miles. At Barnegat Inlet the direction of the shore line deflects through a large angle. The general tendency on the entire shore line has been in the direction of recession, though there are points where very considerable accretion has occurred in the last one hundred years.

Sandy Hook to Monmouth Beach

Sandy Hook, the most northerly point of the ocean beach has extended a great distance to the northward in the past one hundred and fifty years. At the entrance of Sandy Hook Bay, the mouth of Shrewsbury River, that is, at the neck of Sandy Hook Peninsula, the sea broke through in 1896-1897. This breach was closed by the Federal Government in 1900-1901 by the deposit of stone along the government railroad trestle and the placing of dredged sand immediately adjacent thereto. Within the last four or five years the Federal Government has placed additional structures consisting of a large rock sea-wall immediately on the ocean front.

From Highland Beach southward through Normandie almost to Sea Bright, the erosion became so severe that the Central Railroad Company of New Jersey constructed a sea-wall of heavy rock on the ocean front and in front thereof a series of timber groynes. (Plate 14, Fig. 1.) These groynes are not reinforced by rock, but the Central Railroad Company periodically replaces the rock in the sea-wall which suffers to some extent from the battering of the seas. It is not apparent that these groynes have built any beach. There is over the greater part of this front a sand bar running parallel to the shore line almost immediately outshore of the outer end of the jetties. Apparently there is a pronounced beach channel between the outer end of the groynes and the said sand bar. Whether the extension of these groynes to the present location of the sand bar would tend to bring the sand inshore and thereby form a beach is an interesting question.

The beach in the vicinity of Sea Bright has suffered severely from erosion. Many structures consisting of wooden jetties and bulkheads were built to resist this erosion, but for some reason or other in general have proved ineffectual. The Borough of Sea Bright has constructed a large stone breakwater jetty extending at an angle of approximately thirty degrees from the shore line looking south. (Plate 15.) This breakwater jetty, approximately 400 feet long, was designed on the principle that the waves generated by the northeast gales constituted the real destructive agency and should be repelled by means of a structure sufficiently massive to repel these seas and sufficiently high to prevent the seas from washing over it. Furthermore that the axis of the jetty should be placed at the normal to the northeast wind. From a point approximately 400 feet south from the outer end of this jetty and over 200 feet inshore therefrom, a sea-wall of rubble construction extends southwardly for several hundred feet. The sea-wall and jetty combined form in effect a sand trap. This construction has been effective in gathering a large amount of sand to the south of the jetty, both by extending the shore line seaward and raising the level of the beach for a considerable distance inshore. It is not clear as yet whether this piling up of the sand on the south has been accompanied by any extensive erosion on the north of the jetty. The beach for several hundred feet northward from the inshore end of the jetty is bulkheaded and protected by two groynes in front of the Peninsula Hotel property. The northeast or oceanward side of the breakwater jetty deteriorated to a slight extent either as a result of dislodgement from the impact of the seas or from under scour. The influence of this jetty is strongly marked, the sand at its southeast end being at a steep incline.

It is submitted that in a section like that at Sea Bright where it is essential that the recession of the shore line be arrested, rock structures are necessary both to absorb the impact of the seas and to prevent the littoral drift. We are now dealing with a front that is exposed to the sweep of the open sea, the deep water being relatively close inshore, the great inlet, of which Coney Island and Sandy Hook are the two spits, being only a short distance to the north. The theory has been advanced and seems entirely reasonable, that the flood tide, entering the waters inshore of Sandy Hook and Coney Island, attack this shore, and, in addition, that eddies are

generated from the efflux of the ebb tide from Lower New York Bay which in turn erode the beach, transporting the sand northward. Again, the beach is low in places where the tides have in the recent past crossed from the ocean to the bay. With an abnormal difference of level between the waters of the ocean and of the Shrewsbury River, we have a situation exceedingly favorable for the cutting through of new inlets.

Here then is a situation that calls for structures that will oppose immovable masses to the forces of the sea, and in addition we require structures not necessarily heavy, but so designed as to block the transportation by the northward current of sand from this beach to Sandy Hook Point and the waters inshore thereof. Neither type will of itself be effective. It is believed that in more favored locations the northeast storms beat down the beach, washing the sand outshore varying distances, which sand is, with favorable weather, gradually returned to the beach. Here the sand so washed from the beach is taken into deep water and continually transported by the alongshore currents to Sandy Hook Point and the waters inshore thereof. That is, that any movement of the sand from the beach at the Sea Bright front represents a net loss.

From Sea Bright south through Monmouth Beach we find structures of almost every conceivable type and of varying degrees in effectiveness. (Plate 14, Figs. 2, 3, 4; Plate 16, Figs. 1 and 2.) These structures, however, can not be said to have been designed with a view to fitting into any general plan, but have been constructed for the protection of particular properties, usually by individuals.

At Monmouth Beach (Plate 16, Fig. 3) a representative construction consists of a planked deck structure approximately 24 feet in width, supported on piling and at its outer face protected by the usual form of bulkhead and sheet piling. Immediately out-shore of the bulkhead is a dyke approximately 15 feet in width, composed of loose stone, the top of which is approximately at high water level, a row of piling forming the outer face of this rock fill. This type meets the objection that the breaking of the northeast seas washes down the beach above normal high water line. But it is submitted that in any event such a structure should be supplemented by groynes extended out approximately normal to the beach or pointing somewhat to the windward if deviating from normal, in order to arrest the alongshore drift of sand.

Long Branch to Manasquan

At Long Branch the municipal government some fifteen to thirty years ago constructed a number of groynes on the ocean front. These, however, without any question as to their correctness of design, have not been adequately maintained and the beach has suffered to a considerable extent and with particular severity on the front extended northward from Sea View Avenue, the existing jetties all being located to the south from Sea View Avenue. At Sea View Avenue, the city, perhaps fifteen years ago, constructed a reinforced concrete jetty. This to-day is in a sadly dilapidated condition, though it has arrested some sand on its south side close inshore. As above noted, however, the erosion northward therefrom has been severe. The upper ends of the vertical reinforcing rods are practically entirely exposed.

In sections through Long Branch, West End and Elberon (Plate 16, Fig. 4) there are splendid residences on the ocean front, the owners of which have in the aggregate expended large sums upon structures designed to protect their front. These structures follow no well defined general plan, but represent the ideas of the particular owner or his engineer. In some cases masonry gravity retaining walls have been constructed with groynes extending out normal to the beach; in others timber bulkheads at the high water line have been supported with groynes and backed with braced piling, between which latter and the outer bulkhead plank deck has been constructed. In some cases the planking has been carried upward at an acute angle back from the deck to prevent the washing down of the bluff. The same description applies to a number of structures varying only in their details from the above, but representing the same general idea, found in Deal Beach. (Plate 17, Fig. 1.)

At Asbury Park the general principle heretofore relied upon has been the construction of groynes extending out normal to the beach. These groynes have usually picked up considerable sand on the south side. Some of these groynes have been constructed of concrete with vertical reinforcing rods of steel. Others have consisted of the vertical sheet piling timber construction with piling and waling strip bracing. The greater part of these jetties on the Asbury Park front are now in a more or less serious state of depreciation. Some of the timber structures have been, as above stated, successful in collecting a considerable amount of sand on the southerly face, the level thereof reaching to the top of the groynes. But this action on the south face has been accompanied in several instances by erosion on the north face, and the criticism has been offered that the groynes were constructed at too high an elevation.

The city has recently let a contract for the construction of a large stone breakwater jetty, to be placed at the northerly limit of the city, to extend out at least 800 feet beyond the high water mark at an angle of about sixty degrees with the line of

the beach to the south. This adopts the principle heretofore referred to in the Sea Bright breakwater jetty.

We have at Asbury Park and at Allenhurst, immediately to the north, splendid examples of the worthlessness of groynes which have been breached. Almost side by side we can find groynes which are tight, building up the beach and other groynes which have been breached, showing practically no effect upon the level of the beach even though the breach is not very wide. The destructive effect of the inrushing waves pouring its waters through a breach in the groyne can be readily visualized.

Through Ocean Grove and Bradley Beach are found various structures, principally groynes and bulkheads.

The erosion north of Deal Lake (the north boundary of Asbury Park) has been serious, but through Asbury Park and Ocean Grove to Avon has not been so serious between 1867 and the present day. The erosion on the Avon front has been pronounced in this interval, primarily, apparently, by reason of its proximity to Shark River Inlet. The situation has been complicated at Shark River Inlet through the construction by the State of New Jersey of a reinforced concrete retaining wall extended seaward from the northerly point of Shark River. This was built under the direction of the State Geologist of New Jersey, under Chapter 305 of the Laws of 1911, entitled "An act making an appropriation for the survey of the mouth of Shark River and for the further purpose of securing plans for and estimates of the cost of making a permanent inlet or mouth to the said river."

In considering the ocean front of Avon (the north side of Shark River) conditions obtaining prior to the construction of this retaining wall are of secondary importance, the construction of this wall introducing a complete change of base from which all important tendencies must be considered. Prior to the construction of this wall Shark River manifested a tendency to shift its mouth, which traveled northwardly and occasionally closed entirely. A breach would then be made through the beach, either through the breaking over of the seas or in some other manner, as when the waters in the river obtained a level far higher than the ocean waters. Occasionally even artificial means were resorted to to form the opening which the water would then maintain for an indefinite period. The river, however, would gradually manifest the above described tendency of shifting its mouth to the north. This tendency, owing to the construction of the above described work, has been blocked.

Manasquan Inlet to Barnegat Inlet

Manasquan Inlet lies between the Borough of Point Pleasant on the south and the Borough of Manasquan on the north. The history of this inlet is of the utmost interest. It presents characteristics closely similar to those of Shark River Inlet above described. It has closed entirely at times. The inlet has occupied positions many hundreds of feet north of its present position. In 1878, at the time of the survey by the United States Corps of Engineers, it was fully 1,100 feet north of its present position. A severe storm occurred on October 25, 1878, which broke through the beach at a point approximately where the inlet now exists. A jetty was built by the War Department under contract of July 1, 1881, on the north side of the inlet. (Plate 17, Fig. 3.) On September 26, 1882, a contract was entered into with S. A. Kelly for a portion of the south jetty (see report of Chief of Engineers, U. S. Army, 1882-1883). A bar has formed entirely across this inlet within the last three years, the opening having been effected artificially by dredging a cut across the beach.

The tendency at this point is for the beach sand to travel northwardly. It is submitted that the outflowing waters of the Manasquan River checked the sand being transported to the north, thereby causing a gradual growth northward of the south point. Manasquan Inlet has never been of any importance from a navigation standpoint within recent years. Since February, 1921, a reaction jetty has been constructed by Mr. Lewis M. Haupt, Civil Engineer, on the south side of the inlet. This is of timber pile and sheet piling construction, curving to the left (northeastwardly), looking oceanward; a greater part of the structure being out-shore of the straight bulkhead on the northerly side. A considerable amount of sand has collected on each side of this curved reaction jetty, the south point on the south side of the jetty having extended rapidly as construction thereof progressed. This jetty was designed not for the purpose of building up the beach, but primarily to form a navigable entrance to Manasquan River. This object has not as yet been attained, the bar immediately out-shore being very troublesome. The bar at the mouth of the inlet shows a very high degree of instability.

At Bay Head (head of Barnegat Bay) a number of high wooden groynes have been constructed. The tendency is for the sand to pile up to the top of the groynes on the south, which is accompanied by lowering of the beach on the north side of the groynes. Here again the necessity for preserving the groynes from being breached is apparent. Some of the groynes have been breached and are apparently worthless. Other groynes in the immediate vicinity have been very effective, as above stated, in gathering sand on the south side.

At Sea Side Park a timber groyne was constructed on the ocean front at 12th Avenue, the inshore end of which was normal to the shore and the outer end formed a curve to the north. (Plate 18, Fig. 1.) A section of the straight part of the

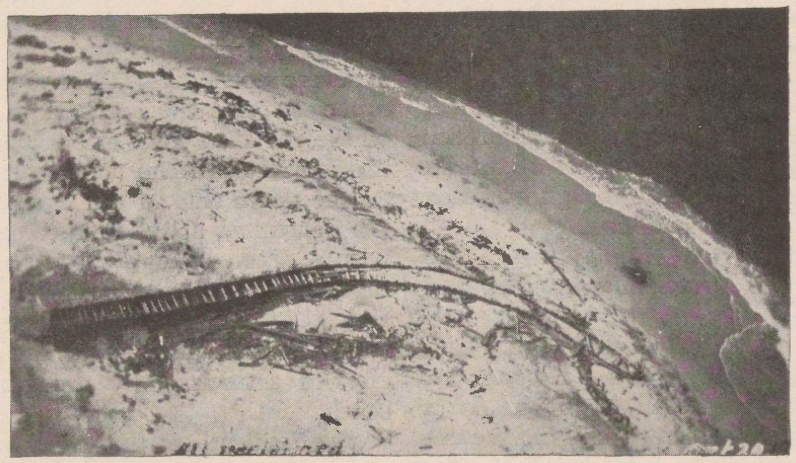
groyne was washed away and a row of piling was driven parallel to the beach within the lines of Ocean Avenue. This construction has been followed by considerable accretion. From Sea Side Park to Barnegat Inlet there is a stretch of beach of approximately nine miles in length that is uninhabited except for a few fishermen's shanties and the U. S. Coast Guard Stations.



Barnegat Lighthouse and Keeper's House, Before Erosion.

Barnegat Inlet to Absecon Inlet

Barnegat City. This is on the south side of Barnegat Inlet. The ocean and inlet front has been subjected to very serious erosion. A number of jetties, approximately normal to the beach, have been constructed by the borough and some additional work has been performed by the Federal



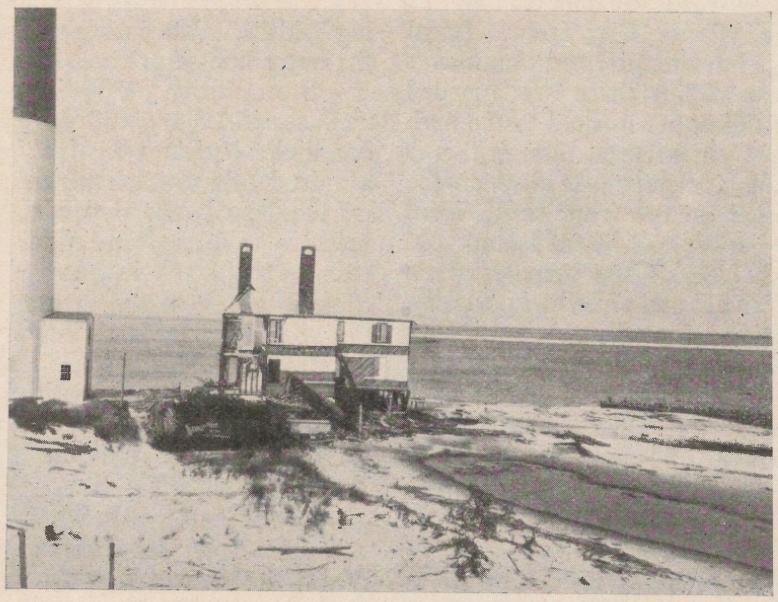
Timber Jetties, Barnegat City.

government in the vicinity of the lighthouse. (Plate 19, Fig. 1.) The timber jetties to the southeast of the lighthouse gathered a very considerable amount of sand, but the southeast and northeast storms have attacked the beach to the north and south of the jetties. The flood tide on the northeast and the southeast storms have caused the major damage.

The Borough of Surf City has constructed on the ocean front a timber jetty consisting of two rows of timber piling with waling strips well braced to each other with iron tie rods and transverse timbers. (Plate 18, Fig. 2.) Parallel to the beach has been laid a row of brush protection and an additional protection consisting of a row of piling extending northwest from the inshore end of the aforesaid jetty.

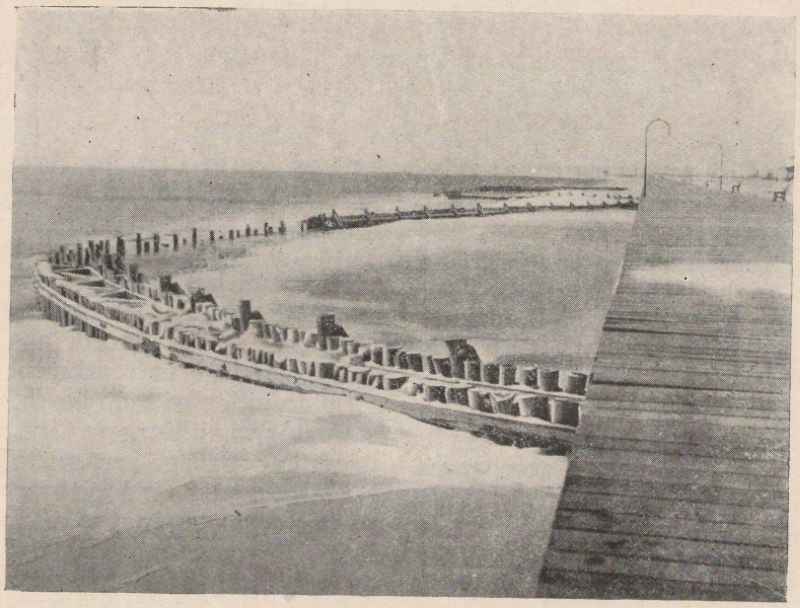
At Beach Haven the Borough, a few years since, constructed timber protective works locally known as hurdles. (Plate 18, Fig. 3.) There are two of these hurdles and each consists briefly of two double rows of open piling braced to each other with transverse timbers. The first of these structures extends out from the beach at an acute angle and the other extends out to sea on a sharp curve. The outshore ends of the two are then connected with two rows of sheet piling braced by staggered piles. These hurdles were effective in arresting the scour in the immediate locality and building out a certain amount of beach. However, within the last three or four years some erosion has taken place at the north and south of the hurdles. Studies of the beach for a considerable distance north and south of Beach Haven will require consideration of the change of conditions resulting from the formation of the inlet which broke through in 1920 at the site of old Little Egg Inlet of 1840. The beach from Little Egg Inlet or Beach Haven Inlet to Absecon Inlet is not at

this time of great importance to our subject excepting in so far as it shows the tendency to affect more settled sections. This is primarily so because of the fact that there are no improvements on this beach except the Coast Guard stations and a few houses at Brigantine.



Light-keeper's House, Barnegat, After Erosion.

Brigantine has lost what importance it once possessed as a seashore center for the reason that it is not now accessible from the mainland by railway or by highway and only in the most restricted sense by water. Only small motor boats on high tide can reach this beach at this time. The destruction of the railway bridge crossing the bays from the mainland was disastrous for Brigantine. The ferry from Atlantic City and trolley line connection from the point of Brigantine to the settlement have been out of service for many years.



Hurdles, Beach Haven.

Atlantic City to Longport

Absecon Island. On this island are the City of Atlantic City; the Borough of Ventnor, the City

of Margate and the Borough of Longport. The beach on the Atlantic City front, particularly at the northerly end, has built up tremendously in the past eighty years, and there is no appearance at this time of any seriously unfavorable tendency, that is, toward erosion, on the Atlantic City front. Local lowerings in a few spots have manifested themselves within the past few years, but these are guarded against by groynes extending out normal to the high water line. The tendency in general, though this is not without exception, is for sand to collect on the north side of the groynes on the front south from Maine Avenue near the upper end of the island; and to collect on the south side of the groynes from Maine Avenue northward and northwestwardly. The method of protection adopted at Atlantic City consists of groynes running perpendicular to the shore line. Certain of these groynes consist of a double row of piling between which are placed heavy plank or sheet piling, this timber work serving as a core for a wide low rubble wall. Plate 19, Fig. 2.) Another type used at Atlantic City has consisted of a double row of piling and waling strips between which has been placed a core of rock and brush. These groynes are of relatively low elevation and in general have proved highly successful. We do not find, with these structures, the great difference in elevation between the sand on the north side and the sand on the south side so often found where high groynes are employed.

The situation at Atlantic City is such that neither erosion nor any great accretion is desired. The City has constructed, parallel to the shore line, a boardwalk which is universally known, between which and the shore line there is a strip of beach of varying widths. The inshore edge of this boardwalk is the outer line of private property ownership, excepting two or three properties as Young's Old Pier at Tennessee Avenue and the Garden Pier. The City has under legislation, with the aforesaid exceptions, acquired title to all lands outshore of the inner line of the boardwalk under agreement with the proprietors of these former waterfront properties. The title to the lands inshore of the boardwalk immediately passes to the owners of the property abutting on the boardwalk upon the extension oceanward of this boardwalk. The property fronting on the boardwalk has been highly developed and has attained great value, and therefore any shifting of the boardwalk at this time would be almost impracticable.

A good bathing beach is absolutely essential to Atlantic City. Its summer population is stated to attain the figure of 350,000 to 400,000 people at times, and the bathing is one of the principal attractions. It is desirable, therefore, that the bathing beach be close to the boardwalk and essential that the erosion does not destroy the beach or reach the improved property fronting on the boardwalk.

Personal Recollections of Beach Changes at Atlantic City

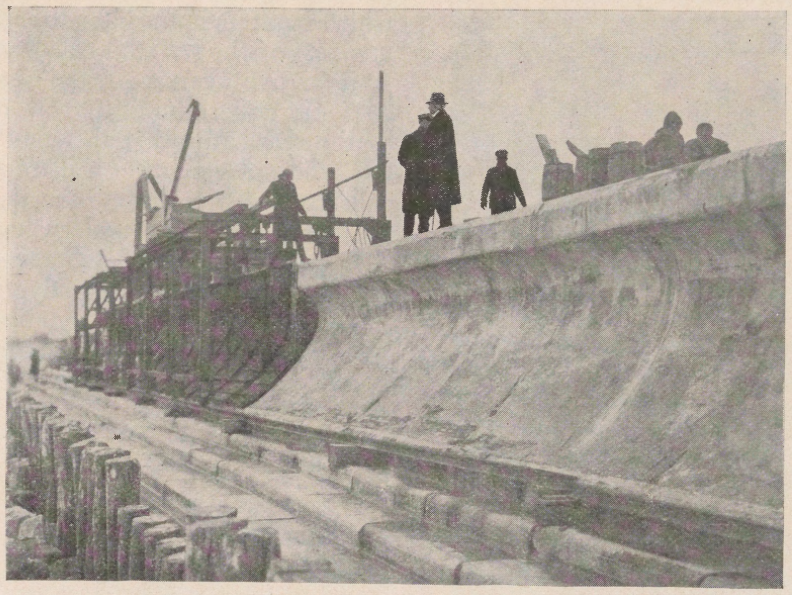
BY MR. B. F. CRESSON, SR.

The beach at Atlantic City was being cut away at the mouth of Absecon Inlet, so that the Light House was in danger, water surrounding it at times, and the northeast end of Pacific Avenue was being submerged. To save the Light House the U. S. Government, some time about 1875–1876, built a breakwater out into the inlet on the Atlantic City side, about one-quarter mile above the Light House—built straight out into the water at right angles to the beach some 200 feet in length, which brought about prompt and apparently permanent results, the beach having extended out to the north and east continuously until there is at present a half mile or more increase, pushing the beach front along the whole city (in 1858 Atlantic Avenue was the beach front street), seeming to show that the breakwater had changed the flow of sand. So that the beach for a long distance below the inlet has gained and without encroachment nearby. There has been encroachment at Longport and at some points above, but for a long distance the beach steadily extended south from Absecon Inlet by reason of the breakwater, helped no doubt by smaller ones built at the foot of North Carolina Avenue and nearby. Six piers run out into the sea have also helped in stabilizing the beach.

At Longport there has been considerable encroachment, but for several miles north the protective work, particularly the U. S. Government breakwater before mentioned, appears to have permanently checked encroachment and brought about great accretion of sand beach.

Ventnor and Margate City. The City of Ventnor about ten years ago constructed a number of groynes to protect and extend the beach. A large proportion of these groynes consist of the familiar hook type, that is the inshore end extending out normal to the shore and the outer end extending northeastwardly on a curve to the left. (Plate 19, Fig. 4.) The lower end of Ventnor, particularly, suffered heavily eight or ten years ago during severe storms which eroded the beach and destroyed a considerable section of the boardwalk. The situation was complicated by the construction by land companies at the southerly end of this Borough of concrete walls at or near the edge of the boardwalk. (Plate 19, Fig.

3.) In back of these walls sand filling was pumped from the bays westward of the island and the land so improved was subdivided and placed on the market. In the storms above mentioned extensive sections of this concrete wall were utterly destroyed and the sand filling eroded. As a result of the above-described developments and other improvements similar thereto there was very little natural beach left within the City of Ventnor.



Reinforced Concrete Jetty, Longport, During Construction.

Margate City has also suffered from the inroads of the sea within the past fifteen years. Long stretches of the boardwalk have been utterly destroyed, and the concrete wall and fill construction described in the Borough of Ventnor, a counterpart of which was built in Margate, was almost entirely obliterated. (Plate 20, Fig. 2.)

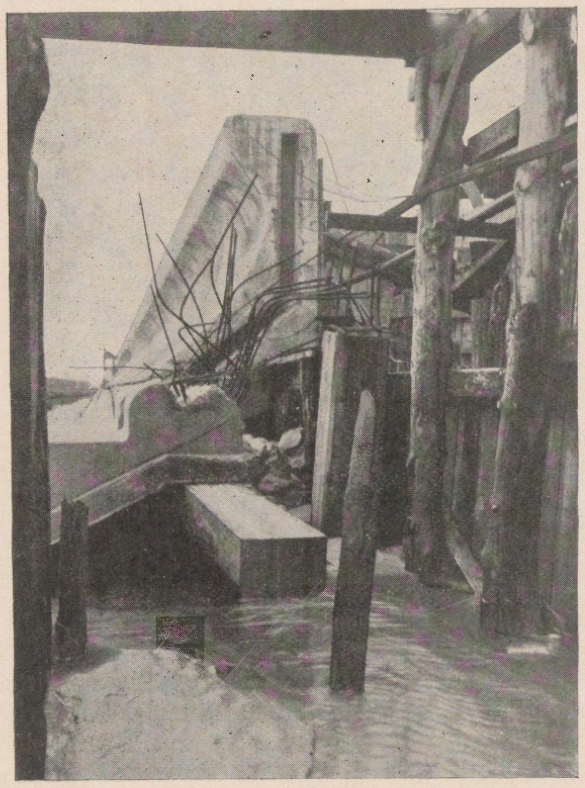
Longport. The Borough of Longport has suffered more than any section of the beach except probably Sea Bright. The changes in its littoral have been even more pronounced than at Sea Bright. A calculation recently made by this Board shows that between 1880 and 1902 some 184 acres of beach had been lost from the lower end of Long-



Reinforced Concrete Sea Wall and Groynes, Longport.

port. (Plate 22, Fig. 4.) Not much change has occurred at this site within the last two years. The lower end of Longport, which is the north point of Great Egg Inlet, has receded at least 4,000 feet between 1886 and 1920. Residences on the ocean

front and inlet and bay have been utterly destroyed, and many others seriously damaged. Groynes and bulkheads of almost every conceivable type have been built on the ocean front, and the Borough has



Breach in Reinforced Concrete Sea Wall, Longport.

constructed a reinforced concrete sea wall along the greater part of this front (Plate 20, Fig. 3), and in addition a stone and slag jetty extending out normal to the shore line at Eleventh Avenue, but conditions remain very unfavorable to-day. The stone and slag jetty has collected some sand on its northeast face at the inshore end, but requires very considerable extension seaward. Considerable erosion has taken place at one section in front of the sea wall which requires immediate attention. Approximately 400 feet of the sea wall was destroyed in a storm of four or five years ago, the seas breaking over the wall and undermining it from in back. As a result of the seas saturating the sand in back of the wall, the sand on which the wall rested was washed out, causing a collapse of this section of the wall. The State of New Jersey, under Chapter 318 of the Laws of 1920, has appropriated the sum of $50,000 for the construction of protective works at Longport. Under this statute any expenditure by the State must be at least equalled by an expenditure by the Borough.

The destruction of the beach at Longport until comparatively recently was not met by any general plan of defense. Perhaps the gravity of the situation was not realized by the residents. As a property was attacked its owner devised some plan to protect his particular holding. This in some cases was effective for a short time, but the great forces at work would attack neighboring properties, thereby creating a change of conditions which in time resulted in the destruction of the property attempted to be protected. That is, the land owners were defeated separately in their efforts at protection despite the expenditure of sums that are very large in the aggregate.

The concrete sea-wall structure above described consisted essentially of a series of steps, the lower end of which abutted on a system of sheet piling laid at low water mark. These steps consisted of concrete reinforced with steel rods, the ends of



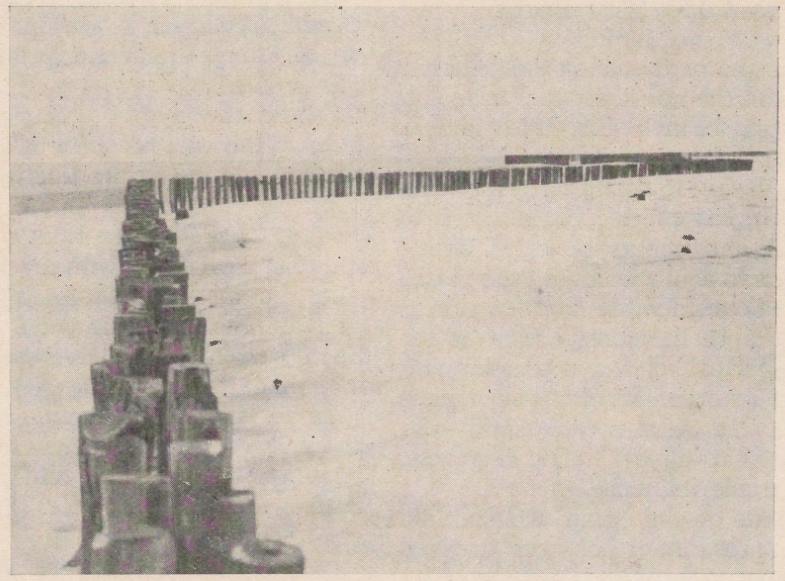
Stone and Slag Jetty, Longport.

which protruded upward. These steps were built in sections on the beach and placed in position on concrete piles. A concrete coping, which presented a curved outer face and was constructed in place, was joined to the steps by means of the protruding steel reinforcing rods. Sand was thereafter pumped from the bay in back of the wall to form a support and base on which the wall could rest. Later a concrete walk was built in back of the wall.

Ocean City to Stone Harbor

Ocean City is bounded on the northeast by Great Egg Inlet and extends southwestwardly to Corson Inlet. There has been notable accretion at the northeasterly end of Ocean City on the inlet and on the ocean front, for a considerable distance southwest from the inlet, but this has been accompanied by certain erosion on the Great Egg Harbor Bay side of the point of beach. Recent changes at the inlet and on the ocean front have not been notable but conditions are apparently still favorable, that is, point toward increased growth. Along the lower end of the island the storms of four or five years ago caused considerable erosion on the ocean front and serious cutting away of the southwesterly point of the beach fronting on Corson Inlet. Many bulkheads and jetties were constructed by private owners at various points on the front. The city during the past three years, constructed, at the northeasterly section near Great Egg Inlet, approximately at low water mark, a line of piling designed to prevent any erosion and to aid in building up the beach. (Plate 20, Fig. 4.) Inasmuch as conditions here are favorable it is difficult to state precisely what effect the row of piling has had, but where considerable beach has made out the sand has piled up along sections of this piled barrier and formed low sand hills. A similar pile barrier was built along a considerable front toward the southwest end of Ocean City's beach and has been apparently successful. It should be stated, however, that since the construction of this barrier the beach, as a rule, has not suffered, no seriously destructive storms, except the abnormal high water of the past winter, having occurred. Of the sand washed away from Longport, it is believed that a large proportion has found a resting place in the bay, but a great proportion has gone to extend the beach at the northeasterly end of Ocean City.

Sea Isle City is the principal settlement situated on Ludlam Beach, which extends from Corson Inlet on the northeast to Townsend Inlet on the southwest. Sea Isle City is situated on a low strip of beach which has suffered considerably from erosion and abnormal high tides. Conditions here are in general unfavorable, but the municipality has recently sought protection through the construction of the familiar hook type of jetty, the inshore end extending normal to the beach on a tangent, the outshore end curving to the northeast. (Plate 21, Fig. 1.) This consists of two rows of piling with waling strips, the two rows being connected with tie rods and diagonal timber braces. Some bulkhead and concrete retaining wall has been constructed by owners of the properties lying to the northwest of the boardwalk.



Pile Barriers, Ocean City.

Seven Mile Beach extends from Townsend Inlet on the northeast to Hereford Inlet on the southwest.

Avalon is the municipality nearest Townsend Inlet. An old jetty consisting of two rows of piling

between which rock has been thrown extends out almost at right angles from the boardwalk, deflecting first to the southwest, then to the southeast, at angles of approximately 90 degrees. (Plate 21, Fig. 2.) The erosion on the northeast of this jetty is considerable.

Stone Harbor is the most southwesterly of the municipalities on this beach. A jetty consisting of a double row of piling with rock between, the two rows of piling being braced by wooden tie rods, has been constructed. (Plate 21, Fig. 3.) This jetty extends for a considerable distance shoreward of the boardwalk where it encounters a bulkhead of timber in front of which sheet piling has been driven. In front of this bulkhead is a course of rubble and outshore of the rubble a row of piling.

Wildwood to Cape May Point

Five Mile Beach is the next section and extends from Hereford Inlet on the northeast to Turtle Gut Inlet on the southwest. Turtle Gut Inlet is now closed.

North Wildwood, the most northeastwardly municipality on this beach, has experienced all sorts of changes, including the shifting of an island in the inlet from that position to a junction with the beach. Wildwood has suffered considerably from erosion in the past, but as least since the construction of the jetties at Cold Spring Harbor, has witnessed considerable extension of its ocean front. The same is true of Wildwood Crest, next to the southwest. It is believed that the closing of Turtle Gut Inlet has exerted a considerable influence.

Cape May City fronts on the ocean and on Cold Spring Inlet. Cold Spring Inlet has been dredged to a depth of 25 feet within the last fifteen years, and the Federal Government has constructed two parallel rows of rock at the entrance to Cold Spring Inlet. The inland waters back of the inlet have been extensively modified as a part of the improvements at the upper end of Cape May. Since the construction of these two jetties or breakwaters by the Federal Government, the oceanfront of Cape May has suffered severely. The beach on the northeast side of the northeast breakwater has extended 1,500 feet, but the Cape May front southwest from the southwest breakwater has experienced severe erosion in recent years. The City of Cape May and, probably, private owners, have sought to protect Cape May front and have employed many types of structures. (Plate 22, Fig. 1.) The bulkhead and fill have been extensively resorted to. On a considerable frontage a stone dyke or wall, of the crib type, parallel to the shore line has been employed.

Cape May Point, which is at the junction of the ocean and Delaware Bay, has also suffered severely from erosion. Private owners and the municipality have sought to arrest the scour and the municipality has recently constructed a hurdle of the type above described at Beach Haven. (Plate 22, Fig. 3.)

GENERAL PRINCIPLES OF COAST PROTECTION

The effect produced at any point along the shore is the result of attack by the ever-changing forces of the sea upon a shore whose power to resist is determined by local conditions at the point of contact, which conditions are themselves constantly changing.

The attacking forces consist of waves and currents produced by the winds, and chiefly by the local winds.

No evidence of other forces has been discovered. Ocean circulation, as exemplified by the Gulf Stream or the Labrador current, probably has no bearing on this problem.

While the hydraulic currents produced by the tides at the various inlets are of first importance in shaping the inlets, the tide has no perceptible effect upon the outer coast remote from inlets. It can be demonstrated that the tidal currents along the coast set on and off shore with a velocity of approximately 0.04 knot at the 18 foot depth curve, which velocity decreases as the tidal wave approaches the beach. Such currents can have no appreciable effect in moulding the beaches.

In so far as the attacking forces on an unbroken shore is concerned, therefore, we may confine our attention to the winds and to the waves and currents which they produce.

Types of Waves

Assuming a beach of fixed resistance, the work accomplished by a wave will depend (1) on its physical characteristics, and (2) on the direction of its approach to the beach.

1. Beaches are attacked by two radically different types of waves; the wave of oscillation and the wave of translation.

The wave of oscillation is the ordinary wind wave or subsequent ground swell of the open ocean. It is characterized by alternate crests and troughs, and by the fact that as the wave form progresses the water particles of which it is composed move forward on the crest and backward in the trough, travelling through closed orbits, either circular or elliptical. The ellipses flatten with increasing depth of the particle, until at the bottom they are reduced to straight lines, the particles simply oscillating forward and backward.

The time required for the water particle to complete its oscillation is that required for the wave form to advance one wave length.

The size of the orbit decreases rapidly with an increase in the depth of the particle below the surface. For each additional 1/9 of the wave length below the mid-height of the surface wave, the diameter of the orbit is decreased one-half.

It is obvious that the height of the wave determines the diameter of the orbit of the surface water particles, and that the velocity of the wave determines the speed of the particles in that orbit. Therefore, the effect which any wave will have on the bottom at any given point is determined by the length, height and velocity of the wave. These characteristics are determined by the velocity and duration of the wind and by the extent and depth of the water over which it blows.

The ground swell of given height is usually much longer than the forced wind wave of equal height. Its effect on the bottom is therefore correspondingly greater.

When the wave enters shoal water the forward motion of its particles becomes quicker and shorter, and their backward motion slower and of longer duration. A wave may therefore transport heavy material shoreward, and lighter material seaward, at the same time.

The wave breaks when the depth below the undisturbed water surface is approximately equal to the height of the wave.

The Wave of Translation—When the oscillatory wave breaks a wave of translation is formed and continues shoreward in the direction of wave propagation. In this type of wave the wave form is entirely above the still water surface. The surface water particles rise, move forward, descend and come to rest in an advanced position, there being no corresponding backward motion. The particles below the surface move forward the same distance, but through paths that become progressively flatter until at the bottom they are reduced to straight lines.

The inherent tendency of the wave of translation is therefore to move material shoreward. It should be noted, however, that the accretion to beaches which might be expected to result from the arrival of these waves is more or less effectively prevented by the simultaneous operation of other forces, such as the undertow and alongshore currents, which are produced under the same conditions as heavy breakers.

Effect of Wind on Waves

If the wind direction is at right angles to beach line we have three possible conditions:

(a) With calm or prevailing light airs the only waves consist of the ground swell. These always come in broadside, or nearly so; their inherent tendency is to move material in shoal water shoreward, and they may either build up or erode the beach, depending largely on its slope.

(b) With a gale blowing on shore the waves are heavy and confused, the water level at the beach is appreciably raised, permitting larger waves to reach it, and the undertow is heavy so that the usual result is erosion. Most of the eroded material, however, is probably carried seaward but a short distance, leaving it in a position favorable to subsequent return.

(c) With an offshore gale, the ground swell approaching the beach is flattened down; the water is blown seaward, producing a counter current shoreward along the bottom. It is axiomatic along this coast that "a west wind builds up the beach."

Processes of Erosion and Accretion—General Principles

The most rapid erosion is produced by a wind-driven sea striking the beach obliquely. These seas rush diagonally up the beach, curving gradually, and retaining considerable velocity at the apex of their parabolic paths, and down again. Without going into details it is sufficient to state that they cut much more rapidly than a sea of equal size which strikes the beach broadside on. With only a fresh breeze and choppy sea, erosion under these conditions may be so rapid that even the plastic materials of a sand beach cannot maintain their profile. The slope of the beach will be reduced to the horizontal, leaving a vertical cliff in the sand to mark the limit of accessibility to attack. It was observed that such a step was cut in the sand by a fresh northeast breeze of some four days' duration. To complete the story it may be added that this breeze was succeeded by good weather with light variable airs and in three or four days the beach was built up again to approximately its former profile.

This oblique wind and sea also produce an agency to carry away the eroded material. This agency consists of a current setting to leeward close along the shore, which is produced by the following causes:

(1) The wind produces a current which sets shoreward until it strikes the beach and is deflected.

(2) The wind backs the water up against the shore, raising the mean water surface there, creating a current flowing seaward along the bottom.

(3) The excess of water reaching the beach in the crests of the incoming waves must escape. The progressive motion of these waves to leeward has already been indicated.

The tendency of the excess of water, if unopposed, would be to leave the beach diagonally in

approximate obedience to the law of equality between the angles of incidence and reflection. That opposition, however, is encountered in an attack on the seaward flank by the masses of water in the incoming waves, which deflect the current and causes it to flow away along the line of least resistence closely adjacent to the water's edge. Undoubtedly much of this water near the bottom does escape seaward also, carrying with it its burden of material.

The velocity of this alongshore current becomes very considerable during gales. An estimated maximum exceeding 6 knots has been reported by observers. The transporting power of such a current is obvious.

Throughout most of the coast we find a bar about 75 to 150 feet offshore with a slough between bar and beach. This slough probably defines the width of maximum current, although we would expect some drifting of the kind indicated as far seaward as the outermost line of breakers.

Assuming attack by waves and currents of fixed characteristics, the work which they accomplish upon the beach will be determined by the physical characteristics of the beach and of the belt of shoal water adjacent. Stated briefly, each oncoming wave contains a certain amount of energy which it must expend. If the shore is bordered by an extensive area of shoal water, that energy will be expended gradually, and the amount reaching the beach itself may be negligible. Conversely, if deep water exists close to the shore, the entire energy of the wave may be expended on the beach, with appropriately effective results.

It should be noted, however, that neither of the abnormal conditions here assumed can exist permanently in nature. In the first case, the expenditure of wave energy on the shallow bottom offshore must result in its deepening, and consequently in increasing the accessibility of the beach to attack. Conversely, if we start with deep water close to the beach, the rapid erosion thus rendered possible results in shoaling the water to seaward, to a point where it results in partial protection to the beach. Thus, the actual tendency is to establish a profile of equilibrium which represents an approximate mean between these two extremes. This profile must shift constantly, for it must be different for each set of waves.

An excellent example of the actual operation of this law will be seen at the new inlet south of Beach Haven, where the abnormally rapid changes now in progress are due to the effort to establish such an equilibrium. The inlet is now adjusting itself to conform to local conditions at that point. Once that adjustment is completed, the changes will not cease, but they will assume a radically different character from those which are the most striking at the present time.

The foregoing conclusions, while general in character, are necessary to a proper grasp of the problem under consideration. The next step is to apply them specifically to the New Jersey coast.

Local Winds

No attempt will be made to analyze in detail the local winds. The general statements by the Coast Guard officers simply confirm the data furnished by the U. S. Weather Bureau. It should be noted, however, that certain amplifications of those data, if obtainable, will render the whole much more valuable for this purpose. For example, a particularly interesting tabulation is that of the "average hourly wind velocity and average number of hours from each direction" at Sandy Hook. The diagram on p. 41, prepared from this tabulation, affords an excellent visual indication of the relative effectiveness of the actual winds from different directions. Similar tabulations for Atlantic City and Cape May are desirable.

A surprising dissimilarity in weather conditions at Sandy Hook and Cape May is indicated by the statements of maximum hourly wind velocities, which show very few gales occurring simultaneously at the two places. If this apparent fact is verified by further investigation, a study of the weather at intermediate points, which will show further details of the transition between these two extremes will be desirable. Should the Board desire to make such a study the necessary data can be obtained from any number of selected Coast Guard stations. These stations keep a log of weather conditions which, while not so detailed or accurate as that of the Weather Bureau, will yet be sufficient, if studied over a considerable period, to meet the requirements of the Board.

Passing now from the weather to its effect upon the beach; each wind will have its own individual effect at any particular point, so that the condition at that point is a state of constant fluctuation. The effect produced will depend, not directly on the wind itself, but on the character of the waves which that wind generates. It must not be assumed that the dominant effect will be produced by the prevailing winds; in fact, along the New Jersey coast that is emphatically not the case, since the prevailing winds blow from off the land and do not produce the sea required for erosion.

Direction of Littoral Drift

Save for an exception, which will be noted later, the northeast wind is the most effective erosive agent. It may not blow any harder than a south-

easter, but it lasts very much longer and the seas which it produces strike the beach obliquely instead of almost broadside on as in the case of the southeaster. Practically all persons interviewed attributed the damage suffered by the coast to northeasters and their opinions are confirmed by the evidence deduced from the comparative surveys which show a net drift of material to the southward along the coast.

The exception above noted occurs along the northern part of the coast. Here the net drift is to the northward. This northward drift is fairly constant along Sandy Hook and apparently it diminishes gradually as we proceed southward from the base of the Hook. The evidence of the surveys is rather conclusive that at Manasquan Inlet the dominant drift is to the northward, whereas at Barnegat it is distinctly in the opposite direction. Somewhere between these two inlets must be a neutral point which is probably nearer to Manasquan than to Barnegat. The evidence at present available does not permit of closer approximation of its position.

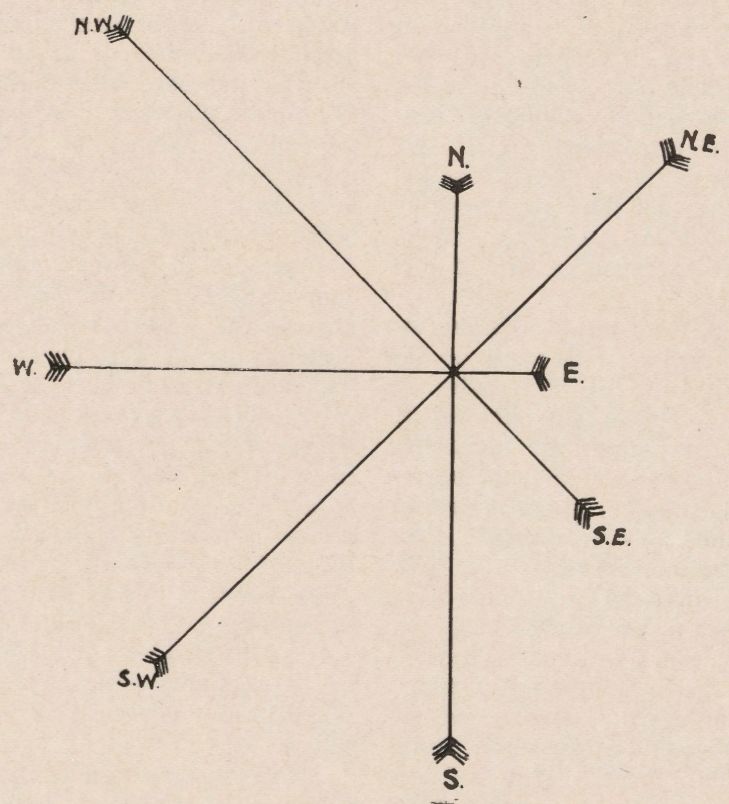
We can only theorize as to the cause of this exception. By some it has been ascribed to a tidal effect. We are not prepared to assert that the tidal currents in and out of New York Bay do not have some bearing on the problem in the vicinity of Sandy Hook and possibly for some unknown distance south of the Hook. But we can find absolutely no evidence of such a cause operating as far south as Manasquan Inlet. In the absence of any other plausible explanation, it seems not wholly unreasonable to assume that the effect produced is a result of the shelter from northeasterly weather afforded by Long Island. This shelter undoubtedly limits the wave effect produced by northeasters on account of the limited length of fetch over which that wind blows, and in consequence it seems not unreasonable to assume that this shelter swings the balance in favor of the waves produced by southerly winds, which thus become the dominant modifying force. However, collection of additional data is necessary before we are justified in urging any final conclusion on this point.

From some point north of Barnegat to the immediate vicinity of Cape May the prevailing drift indicated by the surveys is to the southwestward We should not be misled by the fact that at certain inlets the north point has suffered considerable erosion. The latter is produced by certain local

Diagram of Relative Wind Effects

sandy hook, new jersey, 1918–1921.

The length of each component is determined by multiplying the average hourly wind velocity from each quarter by the number of hours of its duration.



modifying effects frequently chargeable to the inlet waters themselves, whereas the dominance of the southwesterly drift alongshore is indicated by the fact that in the case of each inlet there is a constant tendency for it to crowd the channel in that direction.

Littoral Drift at Inlets

The continuity of this drift appears to be broken at each inlet by the currents flowing in and out. No quantitative statement is possible, but we may safely assume that the amount of alongshore drift passing the seaward face of the south point of any inlet is much less than the amount of material passing the north point.

Furthermore, the amount of material passing the north point will, within certain limits, be a function of the length of beach between adjacent inlets. For example, the excessive erosion of the south end of Tucker's Island, which is now in progress, is probably traceable in considerable part to the diversion elsewhere of material which had previously come down the beach from the northward to take the place of material eroded from the point by the action of local forces, and to the fact that the length of beach between the New Inlet and Little Egg Inlet is not adequate to permit the alongshore drift to become charged with material.

A similar illustration is furnished by Brigantine Inlet. Here we have no characteristic point on the north side, due to the inability of the southward drift to supply material to replace that removed by local forces. On the other hand, the successive hooked spits of the south point show that the northward drift, elsewhere subordinated to the dominant southerly one, here becomes the major agent. This reversal is due alike to the interruption of the drift from northward by the currents from Little Egg and Brigantine Inlets, and to the limited length of beach between the two. Since the north point of Brigantine Inlet cannot grow southward through lack of material, but on the contrary, has eroded, the pressure against the south point which would result from that growth is absent, and the latter is therefore that much freer to grow to the northward.

Other Factors of Change at Inlets

Some other factors which are probably effective in determining the changes at the inlets are the following:

The size of the body of inland water is important, as such size is a factor in establishing the width and, to some extent, the depth in the gorge through which waters enter and leave the bay as the tide outside rises and falls.

Where the inland waters are extensive, as in the case of Barnegat Bay, the position of the bay with reference to the axis of the inlet may be of importance. One factor in the exceptionally constant migration of Barnegat Inlet to the southward is probably traceable to the existence of an extensive body of open water to the northward of the inlet with only a limited water area south of it. This inequality has resulted in building the bay shoal abreast the inlet to the southward always ahead of the point itself. The effect is so pronounced that it may not be too much to say that the point has followed the shoal southward.

Another interesting feature noted is the bulging seaward of the south point of most of the inlets. Local informers state that this building occurs after the ebb tide channel, having been dredged to its southern limit by the alongshore drift, has broken through the crest of the bar and begun a new cycle. Apparently the barrier imposed by the ebb current being thus removed, greater opportunity is then afforded the material in the bar to work shoreward. We should also note that the southern deflection of the ebb tide channel out of the inlets must result in the deposit of material seaward abreast the south point, in a position favorable to its accretion to the beach when building forces are in operation.

This building of the south point probably has an appreciable effect on the north point of the adjacent inlet to the southward, since the building gives a different direction to the alongshore forces, producing an effect as though the shoreline between inlets were swung on a pivot near its central point. Thus whenever this phenomenon occurs we find the north point of the inlet to the westward of the position which it would occupy if the south point of the inlet above had merely built out seaward from a beach of fixed and constant curvature. The tendency of the alongshore forces is to flatten out beach curves to a tangent, and thus, the curve which tends to be formed by the seaward advance of the north end of a beach, and particularly of a short one, is partly neutralized by a retreat of the south end of the same beach.

If this supposition can be definitely established it follows that Atlantic City (for example) cannot by artificial means secure accretions to its beach without producing erosion at Longport. Therefore, the jurisdiction of the State in this matter should include authority to forbid the erection at Atlantic City of structures designed to produce further accretion, even when the cost of such structures is defrayed entirely by the municipality, unless Atlantic City agrees to afford Longport such protection as the State considers adequate. The question thus opened admittedly is difficult to handle to the mutual satisfaction of the communities involved, but it should not be ignored on that account.

Net Result of Action at Inlets

The net result of the action of these various factors has been that in general, from Little Egg Inlet south to the vicinity of Cape May, the north points of the various inlets have suffered very considerable erosion, while the south points have gained. Nor have the inlets migrated appreciably. The changes should rather be described as local fluctuations.

It would seem that, while the southwestward alongshore drift will always erode, its effectiveness in building the north inlet points is chiefly discernible during the period following some unusual disturbance of the existing equilibrium, as when a new inlet breaks through the beach. Under these conditions it becomes very effective in restoring the previously existing balance between the alongshore forces and those in and out of the inlets. Once that balance is restored, however, the building ceases, and is usually followed by a retreat of the point.

It is also interesting to note that whenever we have rapid growth of a point the shoreline also advances seaward. This latter gain is only temporary; following the attainment of equilibrium at the inlet, the seaward face of the point is rapidly cut back.

Beach Protective Devices

An examination has been made of the entire Jersey coast, covering all structures now apparent that have been constructed for the purpose of beach protection. It will be noted that it appears, in general, that any structure which is sufficiently tight to intercept the littoral drift will result in accumulation of sand on the side from which the littoral drift comes. It appears that no particular shape of the structure in plan can be considered as more effective in arresting the drift than another, other things being equal. It does not appear from the information available that straight structures are not more effective in final results than curved structures, by reason of the fact that wash along the base of the straight structure is less than in case of the curved structure, which, by reason of its shape, concentrates the wash along its curved portion. Low groins, built usually at right angles to the general shore line, have been, as a rule, successful in holding the beach along the New Jersey coast. Where bulkheads have been built along unimproved beaches, well upon the beach above the high water line, they have usually been effective. It is noted that the principal instances of failure of beach protective works have been due, in general, to such causes as failure to maintain the structure, selection of unsuitable type of structure, or unfavorable location of structure.

The three principal approved kinds of beach protection as generally recommended by engineers are (a) sea walls, or bulkheads, parallel to the shore and situated about the high water line, or even farther seaward in the case of reclaiming beach land; (b) groynes, which are structures extending across the beach from high water usually to or beyond low water; (c) breakwaters, which may be located off shore and connected, if so desired, with the shore by spurs; (d) beach revetment, or paving between high and low water.

Sea Walls and Bulkheads

The function of sea walls, or bulkheads, is to protect the beach from the attack of waves and tides which would erode or inundate the beach. Such should ordinarily be located at or back of the ordinary high water line, otherwise it is liable to serious attack by breaking waves at high water. Where attempts have been made to reclaim beach by building bulkheads with groynes, bulkheads have generally been built too far out, and practically all of the failures in them have been from this cause, although in many cases they have been built in a very costly manner of concrete. Unless built in a very substantial and costly manner, more so than anything that has heretofore been attempted on the Jersey beach, they cannot withstand the effects of the ocean, and the general rule should be to build them for the purpose of maintaining beach rather than of regaining or making it. Along some of the northerly beaches, notably at the Highlands, this situation has been met and seems to be pretty thoroughly in hand, due to the regular and systematic use of groynes in connection with the bulkhead. Here the sea acts against a directly exposed bulkhead which has been constructed of wooden make-up, backed and reinforced by a heavy derrick stone embankment. When exposed to the wave action bulkheads, if of wood or concrete, must be very strongly built, conforming to two important principles—(a) they should be thoroughly protected at their lower outside faces against any possibility of scour or undermining. This has been a source of much trouble from improper foundation of piles or lack of apron in front. It can usually be avoided by a suitable pile protection or by a layer of riprap placed in front of the bulkhead. (b) They must be so designed that in some way the wash of the waves, if carried over the top in unusual storms, is not allowed to fall back upon the beach, creating scour at the toe of the structure, nor must it be permitted to penetrate into the structure or behind it, producing a destructive back wash and saturating the fill in the rear of the structure. This feature may be cured or helped in great measure by building the face on a curved section, upon which many admirable designs have been developed. This principle has been adapted to some ordinary vertical sheet pile bulkheads by bolting braces oceanward at the upper part to which deflecting boards have been attached.

Where property is of high value, and other considerations render absolute protection essential, a concrete or masonry sea wall should always be provided, as in the case of the Galveston sea wall.

Timber walls or bulkheads alone, or with riprap reinforcement, are used where a less expensive type and a more temporary construction is desired, because property values are not sufficiently great to warrant the more expensive structure. These types are more generally suitable for the Jersey coast.

GROYNES

The purpose of groynes is to build up a beach or to maintain it at a given level by catching and holding the littoral drift. Groynes are of three classes—(1) high, substantial groynes placed at short intervals, intended to build up a beach; (2) less expensive, low groynes, rising only a short distance above the beach and intended to preserve or maintain the beach, and (3) single, longer, permanent structures built as key works to accumulate material over considerable lengths of beach. The low groyne, built at right angles to the general shore line, appears to be the best type for general use.

Two principles mentioned above should be considered in the building of groynes. When it is expected simply to hold beach, they should be built low and at a fixed elevation. When it is expected that beach may be made, they may be built in the same manner except that provisions are made for raising them as the beach rises. Where, for some particular reason, groynes have been carried at right angles from the shore for a certain distance and then diverted in direction on a curve, it is questionable whether this form has been a success in that it has set up a scour in almost every instance. If an oblique direction is necessary to the jetty, for some specific reason, it appears that a straight jetty, directed from the shore line upon the required angle, is all that would be necessary.

When groynes have failed, or where the beach has broken through, it has usually been by reason of faulty construction, insufficient penetration of piles, or lack of repair. In some groynes this has been noticeable even where but a single break has been allowed to go without repair, and serious inroads have been made in the beach, in such cases, until checked by the next groyne or repairs made. This may be noted particularly in the groynes at Bay Head where the system, except for one break, appears to be doing admirable work.

The efficacy of groynes in systems or long stretches in maintaining the beach is noted at Sea Girt, where they have held up the beach on the same line for years. At the northerly end, where the beach for a long stretch is unprotected to the north, there has been a decided recession in the shore line westward, or inshore. Groynes for either beach holding or beach making should extend well inshore past the high water line into the bank or sand dunes where there is no bulkhead. Where there is a bulkhead particular care should be taken to tie them firmly into the bulkhead. Failure to do this has been the cause of many initial failures, since lack of proper connection permits wash and scour around and through the break between the groyne and the bulkhead.

Piles for groynes should have a penetration of not less than 22 feet below normal beach level—25 feet is better. They may be built, in general, by some form of the two-pile row alignment, piles being either opposite or staggered, and providing for proper wales to secure the head of sheet piles. The sheet piles should be of tight construction, preferably tongued and grooved, or splined, or in two contiguous rows, breaking joints with each other. Sheet piling should extend about 15 feet into the sand below the beach level. The top of the groyne, when built in permanent form for holding beach, should follow the general conformation of the average beach cross section from 3 to 4 feet above it, and should extend well out beyond the line of mean low water, say, into depths of from 2 to 3 feet below mean low water. In general, it will be found that the most rapid movement of sand along the beach is between low water line and the bar usually found just offshore from low water. This trough between the bar and low water is generally formed by what is commonly called the undertow, which moves up and down the beach carrying most of the sand in movement. If the groyne is sufficiently long to intercept this movement, it is likely to be most effective.

When groynes are exposed to prevailing storms they usually build up on that side, and unusual storms will often change this beach building to the opposite side. In normal times the scour along the beach is usually continual. Resulting from many conditions, during heavy storms the scour proceeds at a more rapid rate, often endangering the structures. This is principally due to wave action, either in advancing or receding, or both. Reaction of the waves against the smooth face of the groyne which presents no obstacle increases agitation, and scour is not in any way retarded. By the addition of riprap on each side of the groyne, the force of the wave action on both sides is broken up, its velocity retarded, breaking the wave up among the rocks as it progresses or recedes, thus relieving the bottom from scour.

It appears that the life of the timber used in the groynes might be materially increased, in many cases, by the use of creosoted timber.

BREAKWATERS

As the name implies, breakwaters are structures intended to break the force and impact of waves

before reaching the beach, thus rendering them harmless or nearly so. They are necessarily large and massive structures, so as to resist and break up the waves. The relatively quiet water between them and the shore does not have the eroding quality of the unobstructed ocean, and may reduce deposit. Breakwaters are generally constructed offshore at such distance as to provide the necessary expanse of water between it and the shore, generally lying parallel with the shore. On account of the great expense of such massive structures as are required they are not considered suitable for use on the Jersey coast.

BEACH REVETMENTS

Various classes of revetments have been used for beach protection, from timber mattresses to concrete paving. These, however effective they may have been found abroad, are deemed too expensive to attempt in this country.

SAND DUNES

Sand dunes are accumulations of beach sand which form along the shore as a result of the movement of sand shoreward by the winds. This accumulation may be started and maintained by any means that will catch and hold the wind-blown sand, such as beach vegetation, shrubbery, or artificial sand catches. These dunes frequently accumulate to great heights, and are subject to movement by the sand being blown up one face, over the top, and lodging on the other side, unless held and fixed in place by vegetation. The presence of sand dunes is always an indication of a stable beach at that point, it taking some time for them to form. A flat beach, back of high water mark, is an indication of a new or unstable beach, sand dunes not having had time to form. A beach recedes by reason of the sand washing away faster than it comes in in the general movement of sand along a beach. A flat beach will therefore recede faster than one where the sea is attacking the sand dunes, as the dunes will supply a relatively greater amount of sand per foot of beach eroded—that is, they may be considered as a reservoir of sand to supply a deficiency when the coast is attacked. Sand dunes are not permitted to accumulate on those portions of the beach where pleasure resorts are established, but do so on unimproved portions. Changes in the beach may therefore be expected to be more rapid on improved portions than on unimproved portions.

INLETS

The beach protection considered above has special reference to the frontal beach. Those bordering on inlets are subject to special and more violent disturbances due to the inlets, and require a somewhat more pronounced type of structure. Conditions usually encountered at the Jersey inlets are that there is a relatively rapid accumulation of sand on one side of the inlet, and an equally rapid erosion on the opposite side, accompanied by a bodily movement of the gorge in one direction or another. The tidal prism flowing into and out of the inlet remains practically constant, and the tidal velocities can change only within narrow limits, if at all, hence the cross sectional area of the gorge will always be nearly constant. If one side of the gorge grows, the other side must cut.

The cutting side, however, may be protected by a jetty, revetment, or otherwise, and held in place. When this occurs, the building side will continue to build out until the cross sectional area of the gorge is so contracted as to result in a sufficiently great increase of tidal velocity to bring about an increase in erosion which will stop any further increase of the growing side. When this condition of affairs is reached another protective jetty should be provided on that side, and the inlet may then be considered as fixed.

The type of jetty best adapted to accomplish this result is a stone structure built on either a brush mattress or a thick layer of spalls, and composed of large derrick stone, of from one to ten tons, and extending up to 3 to 4 feet above high water. One or more of these may be required on each side of an inlet. Structures of this character would have saved the lost portion of Longport. An excellent example of the effectiveness of such structures is found in Beaufort Harbor, N. C. The small groynes generally used for beach protection and heretofore relied upon will never prove satisfactory in face of the strong forces working at inlets.

MECHANICAL MEANS

BRASHER SYSTEM OF BREAKING WAVE MOTION BY BLOWING COMPRESSED AIR BUBBLES UNDER THE WAVES AT A DISTANCE OFF SHORE

Attention should here be drawn to a system of wave-breaking by means of compressed air. A few years ago Mr. Philip Brasher, an engineer, devised a system which is said to have been successfully used and is now in use as a protection for ships lying in areas exposed to heavy wave action, and it is claimed by the inventor that this system will be effective also in preventing the movement of the sand along the shore under the influence of a heavy sea.

In general, the Brasher system consists simply in the erection of a power plant on shore generating a large volume of low pressure air and blowing it through pipes to other pipes connected with the mains, these other pipes being perforated, through which the air bubbles upward and breaks the oscillation or synchronic action of wave motion.

APPENDIX "C"

Winds, Currents, and Littoral Drift

Erosion and accretion on the Atlantic coast of New Jersey are the resultant of the forces of winds, waves and currents varying in direction, strength and duration.

Northeasterly winds of high velocity and southeasterly winds of nearly equal strength, but not lasting so long, raise the sea level, bring its forces farther inland and produce waves which strike the beach diagonally, break there and excavate the beach material. The receding wave carries sand in suspension, part going to the current running along the shore and part beneath it to seaward, to be deposited at a place where the water moves less rapidly. Winds coming at right angles to the beach cause much less erosion. The destructive winds blow for a small portion of the year, but their action is rapid.

The work of rebuilding the beach is slower, but goes on for a longer time. Westerly winds lower the sea level, bring the water's edge farther out, and expose, or nearly expose, the sand bars lying off the coast in many places, which act as breakwaters. These winds retard the crests of incoming waves, causing material which was picked up farther out from shore and held in suspension to be deposited on the beach by the combined action of wave translation and the undercurrent. The erosion by cutting-out winds is thus made good in part, but the net result for the whole coast is in general a loss. This is due, partly at least, to the drift of beach material in persistent currents along the shore, running towards the estuaries of the Hudson and Delaware Rivers. At the extreme points, Sandy Hook and Cape May, the current is toward the estuary irrespective of tide and ordinary wind. The constant northerly current may be traced back as far south as Monmouth Beach and the constant southwesterly current a short distance northeast of Cape May Point. The velocity increases toward Sandy Hook and Cape May, and the direction is changed only by a high wind. The northeasterly storms cause temporary alongshore currents of great velocity southward while the storms last, reversing or greatly accelerating any prevailing currents which may exist. Westerly winds cause a landward undercurrent which builds up the beach. If the westerly winds follow a northeast storm large accretion follows.

Winds—Velocity and Direction

The weather bureau of the United States has furnished climatological data from which the following tables of high and average wind velocities have been made up.

The information at Sandy Hook is more in detail than that at Atlantic City and Cape May, as to average wind velocities.

In the vicinity of Sandy Hook it indicates that wind blows from the sea 43% and the destructive northeast and southeast winds for 22% of the time. Between 1914 and 1921 the northeast wind exceeded the hourly velocity of 59 miles per hour seven times, the maximum being 70 miles per hour.

During the same period the southeast wind exceeded 50 miles per hour three times, the maximum being 64 miles per hour; and the south wind nine times, with 73 miles per hour maximum.

At Atlantic City the results are stated by the Weather Bureau to be too low, owing to difficulty in obtaining a proper exposure of the anemometer. The average velocity as observed with proper exposure is little different from that at Sandy Hook. The maximum velocities at Sandy Hook appear higher.

Between 1902 and 1921 the hourly wind velocity at Atlantic City exceeded 39 miles per hour, 10 times for the northeast wind; maximum 49 miles per hour, 6 times for the southeast wind and 9 times for the south wind; maximum in both cases 60 miles per hour. At Cape May the hourly velocity of 39 miles per hour was exceeded by the northeast wind eleven times between 1902 and 1921, the maximum being 50 miles per hour; by the east wind 6 times, maximum 50 miles per hour; by the southeast wind seven times, maximum 52 miles per hour, and by the south wind 9 times, maximum 48 miles per hour.

RECORD OF HIGH WIND VELOCITIES

Direction of Wind	Times When Hourly Wind Velocity Exceeded 59 Miles Per Hour	Highest Hourly Wind Velocity Miles Per Hour
Sandy Hook, 1914–1921		
Winds from ocean—		
N. E.,	7	70
E.,	1	68
S. E.,	3	64
S.,	9	73
Winds from land—		
S. W.,	1	64
W.,	6	65
N. W.,	10	74
N.,	1	65
Atlantic City, 1902–1921	Exceeding 39 Miles per Hour	
Winds from ocean—		
N. E.,	10	49
E.,	1	43
S. E.,	6	60
S.,	9	60
Winds from land—		
S. W.,	1	52
W.,	0	..
N. W.,	2	55
N.,	1	43
Cape May, 1902–1921		
Winds from ocean—		
N. E.,	11	54
E.,	6	50
S. E.,	7	52
S.,	9	48
Winds from land—		
S. W.,	3	48
W.,	1	40
N. W.,	20	50
N.,	0	..

RECORD OF AVERAGE WIND VELOCITIES

Sandy Hook, 1920–1921

Direction of Wind	Length of Time per Year	
	Hours	Percentage of Year
Winds from ocean—		
N. E.,	1017	12
E.,	531	6
S. E.,	884	10
S.,	1346	15
		43
Winds from land—		
S. W.,	1651	19
W.,	1357	15
N. W.,	1283	15
N.,	551	6
		55
No wind recorded,	140	2
Total,	8760	100

Direction of Wind	Average Velocity Miles Per Hour	
	June to Oct., Inclusive.	Nov. to May, Inclusive
Winds from ocean—		
N. E.,	12.6	17.9
E.,	10.0	11.6
S. E.,	11.8	13.0
S.,	14.6	15.3
Winds from land—		
S. W.,	11.8	14.1
W.,	11.8	18.7
N. W.,	13.8	20.4
N.,	15.2	18.6

Direction of Prevailing Wind	Length of Time per Year		Average Hourly Wind Velocity Miles Per Hour
	Months (Inclusive)	Percentage	
Atlantic City, 20 years			
Northwesterly,	Oct. to April	58	11.1
Southwesterly,	May to Sept.	42	9.1
Cape May, 26 years—			
Northwesterly,	Oct. to April	58	12.8
Southerly,	May to Sept.	42	9.4

Influence of Winds on Wave Motion

Waves usually come in the direction of the wind. At Sea Bright and some points farther south exceptions were found, probably due to local conditions. Westerly winds cause waves to come broadside to the shore. Ground swells come in the same direction. The latter occasion a good deal of motion. In deep water a diver was unable to keep his footing on the bottom at a distance of a thousand feet from shore, although there was no wind.

Effect of Wind on Sea Level

Observation by coast guard station keepers indicates that at Sea Bright a northeast wind raises the water in Shrewsbury inlet three feet, while southerly wind has no effect. Westerly winds were observed to lower the water level. Near Brigantine Inlet a combination of strong northwest wind and moon in perigee caused the lowest tides, but did not prevent the tide from rising. With the same wind and the moon in apogee the tide stays out.

Effect of Wind on Erosion and Accretion

The unanimous testimony of persons interviewed was that the northeast wind causes the greatest erosion at all places on the New Jersey coast.

The southeast wind is equally effective while it lasts, on the northerly portion of the coast, but its duration is less. The coast changes its general direction below Barnegat Inlet, and the southeasterly winds striking it almost at right angles, have little erosive effect if they are moderate.

At the north point of an inlet, however, it was found that winds from the southeast, south and southwest cut away the shore where there is a large enough expanse of water behind the inlet for the formation of waves.

MOVEMENT OF DRY SAND BY THE WIND

At Coast Guard Station 116, 6 miles N. E. of Beach Haven, a considerable movement of dry sand to sea was observed, caused by westerly winds. Lost articles are found, exposed by this movement; coins, for instance, resting on small cones of sand raising them an inch above the surrounding surface.

This movement of sand by the winds builds up and destroys the dunes which act as a breakwater against storm waves running inland and a source of supply to a denuded beach. Their importance has been recognized in foreign countries.

In Belgium the planting of trees on the landward side and of shrubs on the seaward side of dunes has been carefully studied and practiced.

In France the southerly coast of the Bay of Biscay is guarded by dunes built and preserved by the planting of the maritime pine. In England the destruction of the dunes near Lowestoft, on the east coast, marked the beginning of a severe erosion.

In Holland the dikes are planted with the grass called *helm* or sea lyme. In Denmark, on the west coast of Jutland, a long barrier beach separating the North Sea from a bay is protected by jetties abutting on a dike of sand.

This bank in many places has been built up by fascine barriers, which the wind soon covered with a ridge of sand.

On the New Jersey coast, at Bay Head, losses during the storms are attributed by a resident to the removal of the dunes.

South of Sea Side Park they were found very unstable, it being possible to build them up by placing brush or seaweed on top. One was entirely removed by kicking around the sand on the upper part occasionally.

Two miles south of Barnegat the tides, which formerly ran through the glades between the dunes, were stopped by the planting of cross-ties by the railroad company, causing these openings to fill with sand.

Currents

TIDAL CURRENTS

The following information is supplied by the U. S. Coast and Geodetic Survey:

The velocity necessary to transport material by a current in knots per hour is at least 0.4 for sand, 1.0 for fine gravel, 2.5 for shingle about one inch in diameter, and 3.5 for angular stones about one and one-half inches in diameter.

These velocities are all greater than that of the swiftest tidal current observed off the New Jersey Coast, which runs about one-quarter knot per hour at time of strength.

At entrance to New York Bay. At Ambrose Channel Light vessel the tidal currents have a mean velocity of 0.2 knot at strength of the flood and ebb, the flood setting in a westerly and the ebb in an easterly direction.

Direct Tidal Current to beach. The current necessary to fill or empty the tidal prism was calculated and found to be almost imperceptible.

Influence of New York Bay and Delaware Bay. (U. S. Coast Pilot.) These bays affect the direction of the tidal current for the distance of about 20 miles from their entrances but the strength of the offshore current is not affected until within a few miles of the mouth.

TIDAL CURRENTS AT INLETS

An idea of the velocity of the only tidal currents which seriously affect the shores is given by a map which Col. E. I. Brown, U. S. District Engineer at Wilmington, had prepared to show the results of current observation made at Absecon Inlet.

Group float runs were made, from which several have been selected each extending over an average period of 6 hours and 40 minutes. The mean velocities, in miles per hour for that period were found to be

On flood tide, 0.48, 0.57, 0.61 and 0.64.
On ebb tide, 0.56, 0.61 and 0.64.

Single float runs in the deep southerly channel of the inlet gave

On the flood, one hour and ten minutes before high tide 1.71.
On the ebb, at half tide 2.16.

At Little Egg Inlet the tidal current was given by the coast guard as 10 miles an hour on storm or full moon tides. A boat capable of making that speed was barely able to hold against it.

At Barnegat Inlet slack water comes at half tide, the top and bottom currents running in opposite directions.

The tidal currents from this inlet are not felt at a distance of two miles south of it.

At Longport, just north of Great Egg Inlet, the current along the seashore was reported to vary with the tides, while the offshore current varies with the wind. At Ocean City, south of the same inlet, there is a tidal current attaining a velocity of two miles an hour between the bar and the beach. At Cape May City the inshore currents vary with the tide.

Currents caused by the general circulation of ocean waters. From information by the U. S. Coast and Geodetic Survey. It is generally accepted that along the coast of New Jersey from the 20 fathom curve outward almost to the gulf stream there is a southerly or southwesterly drift having a velocity of about one-quarter knot per hour. Observations at the Northeast Light vessel, although not extensive, bear out the fact of this southerly set, but the velocity there is nearer one-tenth knot per hour than one-quarter knot.

This southerly drift may be the net resultant of the currents brought about by winds. In the northern hemisphere the wind-current deviates about 20° to the right of the direction of the wind.

None of these currents appear to have velocity enough to cause movement of beach material except by accelerating other currents.

WIND CURRENTS

A statement from the U. S. Coast and Geodetic Survey is as follows:

"From general considerations it would appear that the wind currents are the most effective agent in the erosion of the New Jersey Coast, since the tidal currents alone are too weak to be effective. The velocity of a wind-driven current is about 1½ per cent of the velocity of the wind. Hence current of 0.4 knots and over would occur as the result of winds blowing with a velocity of 25 miles per hour or more. Observations made on the Northeast End Light vessel show that southwesterly currents with a velocity of 1.0 to 1.2 knots came as a result of northeasterly winds of 40 to 50 miles per hour."

ALONGSHORE CURRENTS

Information is from interviews with Coast Guards and shore residents. A current extending out about 200 to 300 feet from the beach is observed at nearly all points on the coast. At Sandy Hook and Cape May it flows constantly into the New York and Delaware Bays. From Sandy Hook to a point between Sea Bright and Long Branch it is constantly to the north, running about 2 miles per hour at Sea Bright except during high northerly or northeasterly winds.

At Long Branch it is generally to the north, changing to the south during calms and light winds from shore as well as during northerly winds.

At Asbury Park it changes with the wind.

At Avon, north of Shark River Inlet, the current runs south during northerly winds. There is no current from southerly winds.

At Belmar, south of the same inlet, the current runs north with southerly winds, but generally south.

At Bay Head it runs north in summer.

From this point to Cape May the alongshore currents vary with the wind. At Cape May Point there is a current constantly flowing into Delaware Bay, irrespective of tide and ordinary wind.

The temporary alongshore currents caused by northeast gales are reported by local observers to attain a velocity of four to six miles per hour.

OFFSHORE CURRENTS

At Sandy Hook there is a constant offshore current to the south. At Bay Head strong currents, running in either direction, and lasting three or four day, were observed. They were half a mile offshore and independent of tides and local winds. At Berkeley, near Sea Side Park, there are tidal currents three miles out. At Hereford Inlet tidal currents are felt half a mile offshore. At Cape May City offshore currents change with the tide.

To: Chief, Division of Charts, Member New Jersey Engineering Advisory Board.
Via: The Director, U. S. Coast and Geodetic Survey.
From: Chief, Division of Tides and Currents.
Subject: Erosion, Coast of New Jersey.

In reply to the questions in your letter dated September 14, 1922, relative to the above subject, the following statements have been prepared by Mr. H. A. Marmer of the Division of Tides and Currents.

Question 1. Does the tide, as a physical phenomenon, include or produce any agency effective in the erosion of the beaches along the New Jersey Coast?

Answer. The constituent of the tide which can be effective in the erosion of the beaches along the New Jersey coast is the tidal current. But it is to be observed that, in order to transport material, a current of at least 0.4 knot is required; for it is generally accepted that sand will be driven along the bottom if the velocity of the current is 0.4 knot, fine gravel, if about 1 knot, shingle about 1″ in diameter if 2½ knots, and angular stones about 1½″ in diameter if 3½ knots.

Question 2. What is the character, direction, velocity and extent of the tidal currents, if any, along this coast?

Answer. Tidal currents always accompany the rise and fall of the tide, so that tidal currents are to be expected along the coast of New Jersey. In general, however, offshore tidal currents are weak. Such observations as have been made off the coast of New Jersey indicate that, in general, the direction of the flood current is directed normally to the shore and the ebb current in the opposite direction away from the shore. However, the presence of inlets will affect the directions of the tidal currents in the regions immediately north and south of such inlets. The velocities of the tidal currents offshore, from such observations as have been made off the coast of New Jersey, are in all cases less than 0.4 knot. Observations on Northeast End Light Vessel covering a period of several months show the tidal current to have a velocity of about 0.25 knots at time of strength, flood setting N. 65° W. and ebb S. 65° E.

The velocity of the tidal current near the coast may be readily computed if we assume the current here to be hydraulic—that is, due to differences in level. Thus taking a section normal to the coast we may consider the current at any distance x as due to the inflow or outflow of the tidal prism between high and low water. If the width of this section is one unit, r the range of the tide and d the depth of the water, measured from mean low water, we have for the volume of the tidal prism at a distance x from the shore, $v = rx$. This volume of water must pass through a section whose average area is $d + \frac{r}{2}$; and since the time

elapsing between high and low water is on the average 6h 12½m or 6.21h, the average hourly velocity is $\frac{r\,x}{6.21\ (d+\frac{r}{2})}$.

The velocity of the tidal current is not uniform through the tidal cycle, but varies as the ordinate of a cosine curve in which the ratio of the maximum ordinate is to the average ordinate as $\frac{\pi}{2}$: 1. Hence the velocity of the current at strength is $\frac{r\,x}{2\times 6.21\ (d+\frac{r}{2})}=\frac{0.253rx}{d+\frac{r}{2}}$.

If the units in the above formula are feet, the velocity will be given in feet per hour; to reduce to knots divide by 6080.

It is to be observed that in the above formula no account is taken of friction, and wave motion is not considered, so that the results are only approximate. Should more accurate formulæ, based on wave motion, be desired, reference may be made to the "Manual of Tides," by R. A. Harris, Part V, pp. 319-20.

Question 3. Do available data indicate that the general circulation of the ocean waters has any bearing on this problem?

Answer. The general circulation of the ocean waters undoubtedly has a bearing on the problem, for it is evident that while the tidal current along the coast of New Jersey, by itself, may be too weak to be effective in the erosion of the coast, this current combined with the persistent nontidal current may bring about a velocity sufficiently strong to be effective. Furthermore, the existence of a littoral current, sufficiently strong to carry away material, will also make more effective the work of the wind waves.

It is generally accepted that along the coast of New Jersey, from the 20-fathom curve outward almost to the Gulf Stream, there is a southerly or southwesterly drift having a velocity of about ¼ knot. While the observations on Northeast End Light Vessel are not extensive enough to give conclusive data, they tend to bear out this accepted southerly set, though it appears that the velocity is nearer 0.1 knots than 0.25 knots.

In this connection it is to be observed that the general southerly drift may be merely the net resultant of the currents brought about by winds. From observations made on the Atlantic coast it appears that the velocity of the currents brought about by winds are about 1½ per cent. of the wind velocity. So that the current accompanying a southerly wind of 20-40 miles an hour would completely reverse the general southerly drift and bring about a northerly current. It must be noted too that the current produced by the wind is very largely a surface current, and that the direction of this wind-driven current is, in the Northern Hemisphere, to the right of the wind direction. On the Atlantic coast along the route marked out by the light vessels this deviation of the wind current from the direction of the wind has been found to be about 20° to the right.

Question 4. Is there evidence to indicate that wind currents, as distinguished from tidal, are an effective agent in the erosion of this coast?

Answer. From general considerations, it would appear that wind currents are the most effective agent in the erosion of the New Jersey coast, since the tidal currents alone are too weak to be effective. And as stated in answer to the previous question the velocity of a wind-driven current is about 1½ per cent. of the velocity of the wind. Hence, currents of 0.4 knots and over would occur as the result of winds blowing with a velocity of 25 miles per hour or more. Observations made on Northeast End Light Vessel show that southwesterly currents with a velocity of 1.0-1.2 knots came as a result of northeasterly winds of 40-50 miles per hour.

In this connection attention may perhaps be called to the paper on shore line changes in the vicinity of Cape Hatteras, which was presented by G. T. Rude before the Association of American Geographers, in December, 1921. In that paper a very good case was made out for wind-driven currents as the effective agents in the changes of shore line.

With regard to data on currents in the various inlets on the coast of New Jersey, it is to be stated that detailed data are available for the entrances to Delaware Bay and New York Lower Bay. For the other inlets no data appear to be available.

It is to be noted, however, that in so far as tidal currents are concerned they may, for all practical purposes, be determined from a series of observations extending not over two or three days. Should the New Jersey Engineering Advisory Board secure appropriations, whether State, municipal, congressional or other, for this purpose, the Coast and Geodetic Survey will gladly co-operate in the making of such observations and in their discussion.

Chief, Division of Tides and Currents.

Littoral Drift

ORIGIN OF BEACH MATERIAL

The Director of the United States Geological Survey expresses the following opinion: "The sands that compose the present beaches were probably derived chiefly from the shore of Monmouth County, where the waves appear to be cutting away the mainland. The materials thus derived are distributed southward along the coast, forming the barrier beaches and northward into Lower New York Bay, forming Sandy Hook."

DIRECTION OF DRIFT

From observations of the accumulation of beach material at piers and jetties, and the movements of wreckage, the direction appears to be southwardly south of Barnegat Inlet and northwardly north of Manasquan Inlet.

This movement has been attributed to tidal currents, but no current of sufficient strength has been found.

Another theory is that the wind currents from the northeast move sand southwardly along the shore, the winds from the southeast carry it north again, giving it a net movement due to the more effective of the two. A wind at right angles to the beach causes much less current alongshore than one oblique to the beach. South of Barnegat Inlet, southeasterly winds strike the shore nearly at right angles, northwesterly winds very obliquely; hence the drift from the north is the stronger. North of Barnegat both northeast and southeast winds strike obliquely. This would counteract the southerly drift to some extent, but as the record of wind directions and velocities at Sandy Hook shows, the northeast wind, throughout the year, is superior in duration and velocity. Hence the resultant would still be a southerly drift, though smaller than that at the lower end of the coast.

The most reasonable explanation seems to be that the northerly part of the New Jersey shore is sheltered by Long Island.

The ordinary waves from the Northeast, on account of the short distance in which they gather strength, have on the whole less effect in producing

inshore currents, lasting for long periods of time, than the ordinary waves from the southeast, which come from the open sea.

Hence in the lee of Long Island the northward drift prevails. Farther south, where the superior force of the northeast wind strikes the unprotected shore, the resultant of the drift is southward.

However, additional data is necessary for a definite conclusion on this point.

Loss of Beach Material at Inlets and Estuaries

It is generally understood that as beach material drifts past inlets and estuaries it is carried inward or outward by the tide, some of it passing across the opening. Generally the inlet is marked by erosion on the side from which the drift comes, accretion on the other side, and underwater deposits of sand extend seaward from the mouth and inward.

Movement of Sand Seaward

At Spring Lake the borough superintendent sent a diver to examine a sewer pipe one thousand feet from shore. In December, 1921, it was found lying uncovered on a hard bottom. In April, 1922, after a severe storm which washed away the beach, the pipe was found buried under five feet of sand.

Sand Bars

A bar about 75 to 150 feet offshore, with a slough between bar and beach, is found along the greater part of the coast. This slough probably defines the width of the maximum current.

APPENDIX "D"

Practices in Beach Protection at other Localities

A large amount of material in the way of abstracts of reports, scientific articles and photographs of plans has been obtained by the Board, and although it is impossible to reproduce much of it in this report, still the records are available should they be desired for any purpose.

Below, however, are given extracts of some of the reports which will be of value in indicating how beaches have been protected in other localities in this country and abroad.

One of the most interesting of the reports examined was that of the Royal Commission on Coast Erosion and Afforestation, Great Britain, Vol. 1, published in 1907; Vol. 3, published in 1911; which contains evidence covering all phases of the subject and opinions expressed by experts. Following are the conclusions:

"Our review of the engineering evidence leads us to the conclusion that before a decision is arrived at with respect to the character of the works to be adopted for the defence of any particular locality, it is of the utmost importance that a thorough and careful inquiry should be made with regard to the physical characteristics appertaining to the case. Although it is impracticable to lay down rules for the design of such works which will be generally applicable to all portions of the coast line, one or two deductions from the evidence given may be specially referred to from the point of view of our enquiry.

"With regard to sea walls and similar works of defence, for the reasons we have given, their construction should almost invariably be accompanied by suitably designed groynes, extending seaward continuously from the face of such works and carried out simultaneously therewith.

"With respect to groynes, speaking generally, our view is that to be of maximum efficiency they should be of a distance apart about equal to their length; that they should extend continuously from the shore or work to be protected to the vicinity of low water of spring tides, and that with regard to direction, they should point slightly to windward.

"With respect to their height, this must be governed almost entirely by local conditions and requirements."

The report states that agricultural land will not be worth the cost of defence work unless large areas of low lying lands are to be protected.

That a Central Authority is necessary to insure that no undue trapping of beach material is allowed.

That all information available from government records or from any other source with respect to submarine erosion and the changes in sand banks be given to the Central Authority.

Foreshore works in Holland and Belgium, on a low, flat foreshore entirely of sand would not be available in the United Kingdom, and their expense would not be justified. The skill and care applied to the construction and prompt repair of these works are commended.

Following are extracts from the report showing examples of Shore Protection Works on the East Coast of England:

"To the south of Yarmouth the coast line is fringed for many miles by the soft and incoherent deposits belonging to the Glacial Drift and Pliocene crag. These usually form a somewhat low cliff on this coast . . . interrupted by the alluvium of many small river valleys which reaches down to the beach. Lowestoft Ness, the most easterly point in England, is formed by a tract of blown sand and shingle."

"Since 1901, on the advice of Mr. W. T. Douglas, extensive sea defence works, consisting of concrete sea walls, protected by timber groynes and revetments, have been erected and they have proved very successful. These works are purely of a sea defence character and do not include any promenades or other works of a similar nature. The total cost, including the cost of groynes erected before 1901, of the defence works undertaken by the corporation since 1896 has amounted to £68,500."

N. B.—Mr. G. H. Hamby gives cost to 1912 as £75,000, not including unsuccessful works. This protects 2.84 miles at about $130,000 per mile.

"To the north of Lowestoft the harbor works have resulted in a considerable accretion of shingle between Lowestoft Ness and the harbor, about 6 acres having been gained from the sea during the twenty years before 1906.

"The rest of the sea frontage, however, within the borough of Lowestoft is subject to erosion.

"The erosion, especially in Suffolk, has not been continuous, but has occurred in periods followed by a series of years during which there was little or no encroachment.

"The heaviest seas are caused by gales from the northwest, especially when they are followed immediately by gales from the east or northeast. The loss of land during historical times has been greater than on any other part of the coast of the United Kingdom, with the exception, perhaps, of the coast of Holderness."

W. T. Douglas, in a paper before the Institution of Civil Engineers, February 21, 1911, says that:

The movement of the material deposited by tidal action on the foreshore can be determined with precision by ascertaining carefully the local contours of the coast, the depths of water, the set of the tide and the direction of prevailing winds.

The set of tides is obtainable from admiralty charts. Also soundings, contours, etc.

Direction of prevailing on-shore winds coincides usually with that of flood tide.

The strength of flood tide is superior to that of ebb tide. A combination of all the forces of wind and tide occurs about every 6 years in the North sea and strains sea defence works to their utmost.

In deep bays the shingle is usually deposited inside the bay—in estuaries, on the middle ground at its mouth.

If the foundation is rock, the elliptic section for the face of a sea wall is useful. On an erodible foundation, with varying beach level, the vertical section is just as good. Bastions built out from face of wall tend to minimize the effects of racing of waves along wall, but do not altogether overcome it.

On a low sand foreshore of small exposure, much may be accomplished for 5s per lineal foot, but on the Atlantic with a steep beach, the expenditure will be as much as 10 pounds per lineal foot.

Where foreshore is greatly exposed and lies parallel to longest line of "fetch," a system is recommended of high groynes, to or above high water mark for entire length, spaced 500 feet apart. The longer the groyne, the more material is collected, provided it is to be found in the neighborhood of the groyne. The intermediate shore to be protected by lower and shorter groynes.

The shore end is to be as high as shingle is thrown by the waves in the vicinity. The seaward end to be level with the foreshore. Between, the height should be a little above expected level of beach.

Planking up groynes as beach grows is not recommended in all cases, as groynes must be high enough to arrest beach material at the time of a sudden storm. Holes may be left at about neap tide high water mark, which may be opened or closed as necessary under variable conditions.

The distance apart depends on the angle at which waves impinge, being greatest for a direction at right angles to beach.

At Yarmouth and Lowestoft, beach levels have been raised on lee side of long piers.

Groyne No 1, built 1883, collected eastbound shingle. Groyne No. 2, built in 1894, 500 yards west of No. 1, caused erosion between 1 and 2, while protecting cliff assisted by Case groynes. Sea walls were built, but foundation was undermined. Groynes 3 and 4 constructed in 1905, raised beach at sea wall 11 feet. Cliffs are of glacial material, shingle size of an egg, no sand.

Cromer—Similar works at Cromer protect 3,750 feet of shore.

Hornsea—Cliffs are composed of glacial drift—boulder clay intermixed with gravel and sand beds. Foreshore is of sand and shingle, overlying peat beds in many places. Exposure from NNE to SE with heavy erosion by Northwest gales. In 1906 all beach material was carried away and cliffs washed down.

Lowestoft—Erosion by heavy gales occurred November, 1897, and March, 1901—North Denes are eroded by NW and NE winds. South Beach by SE winds. Harbor piers caused scour and banking up. Works were built in 1901-3, consisting of a concrete wall one mile long at North Denes, four main groynes 1,500 feet apart, three 290 feet long, one 340 feet long with shore end four feet above high water, seaward end 3 feet below high water, 16 intermediate groynes 110 feet long follow accreted beach level and begin 50 feet seaward of wall. Plan shows increased height of 5 feet 3 inches average.

To stop erosion at Kirkley Cliffs, which had destroyed several houses, a massive wooden groyne was built on the south side of the South Pier and another of same length at Pakefield with revetment. Low water mark in front of Royal Hotel was by this driven back 150 yards; at Pakefield, 43 yards, the beach was raised 5 feet. No further erosion of cliffs occurred.

In the Royal Commission's Report, there appears the following:

Evidence of Wm. Tregarthen Douglas, M. Inst. C. E. Resident Engineer to Corporation of Trinity House and Engineer to Royal Life Boat Institution.

Had charge of sea defence at Cromer, Sheringham, Hornsea, Pakefield and Lowestoft.

Littoral drift is with flood tide in England, Ireland and Wales. Sand comes largely from bed of sea, shingle from cliff erosion. Drift travels between half tide and high water mark in a band along the coast. In crossing a bay or estuary, would be carried off into deep water and lost.

High groynes were used. Low groynes would not do. In heavy weather a bucket of water from the beach would be found to contain 30 or 40 per cent of sand and shingle. With a heavy sea this would all be driven over a groyne 1 or 2 feet high. Low groynes are successful only in large embayments with a low sandy foreshore. To prevent undue trapping of shingle, the low groynes might do if extended 500 or 600 yards from shore.

The Crown Hotel groyne, Sheringham, is of medium height and has the planking arranged to be taken down for the travel of shingle during northeast gales. The movable part is toward the head of the groyne. The life of the groyne is from 5 to 40 years.

Erosion of unprotected beaches adjoining protected frontages will eventually outflank the protected frontages and leave them peninsulas.

Protection of the whole coast line is possible but at very great expense.

A paper by G. H. Hamby, Borough Engineer of Lowestoft, at a meeting of Institution of Municipal and County Engineers at Lowestoft on the Saturday previous to June 28, 1912, states:

Erosion going on for many years partially stopped some years previous to 1912, in that year stopped altogether. Sand banks which formerly protected shore, have disappeared. First jetties, 1832, gave some relief. Erosion recommenced in 1871 after construction of groynes at Corton, stopping supply of sand from north. In 1894-1897 sand-hills covered with marrum grass were damaged and their protection against high tides lost.

In 1897, 12 groynes of 4-foot plank protected beach until water swept around them for want of a bulkhead.

In 1890, contract was made for 60 groynes with Case Syndicate, at £5,000. Contract terminated in 1900 as 200 feet of beach washed away and several groynes washed out.

Existing works commenced by Wm. Tregarthen Douglas in 1902-1903.

The principal features were a sea wall, 4 main groynes, 16 intermediate groynes, 2 spur groynes, 240 feet long. In addition, 4 groynes in 1902; 6 small spurs were added as scours appeared.

Total cost since 1896, £79,000. Protects 4,997 yards of sea front.

Evidence before Royal Commission, of G. H. Hamby, Borough Engineer of Lowestoft:

Erosion became acute in 1860. Harbor jetties built in 1832, and groynes at Corton in 1871. Sand hills covered with marrum grass protecting the coast have been lost, 1894-1897. 12 groynes built in 1897 did not succeed. Erosion on north beach, 20 feet 6 inches per year for twenty years, on south beach, 7 feet per annum for twenty years.

Spur groyne on south side of pier stopped erosion due to pier, beach has become 12 feet deeper in corner.

Case groynes were washed out. Contract for 60 of them never finished, due to slight construction. Beach gradient is sharp and beach scours 3 or 4 feet in a tide. Present defense works were built by W. T. Douglas, 1901—date (1907) frontage, 4,997 yards—groynes holding beach but not yet filled up.

Range of tide is 5 feet 6 inches to 6 feet ordinary tides. Cost of works £65,000, about £22,000 per mile, includes groynes, sea wall and timber revetment; repairs, £340 per year; material, pitch pine. Groynes are at right angles, 3 of them fitted with spur groynes which saved whole system. They would have done better if at right angles. Pakefield to the south is much eroded.

Notes on Papers from the Transactions of Institute of Civil Engineers, at the Engineering Conference, June 17, 18, 19, 1903, on the subject of the Lowestoft Coast Protection.

W. T. Douglas recommended that:

Channels parallel to beach, and cross channels, are to be located.

Groynes must be arranged to arrest beach on their flood-tide side, as beach travels with flood-tide. Gales cause scour on lee side, which is filled up by opposite winds.

Groynes should be calculated to stand up when scoured on lee side by continuance of gales in one direction.

Sea walls are necessary when shore above high water mark is friable.

The groyne at its junction with the wall should be no higher than spring-tide high water mark. The

level of the beach never gets above this when making.

Spur groynes on the leeward side of a breakwater or pier will accumulate sand by causing an eddy and by driving the tide off the foreshore.

The longer the groyne the more useful it will be. They should go as far as possible beyond low water mark. Groynes to low water mark either form channels in front of the groynes or drag the beach into deep water.

The best angle to the shore is 85° on the side facing the flood tide.

Following is from the evidence of Wm. Henry Wheeler, Member, Inst. C. E.:

Has studied coast erosion in England, France, Belgium and Holland and written a book on the subject. He believes that:

Low groynes or Case groynes are valuable on a sand beach, but not useful to hold shingle. They are also useful when a creek is cut parallel to the shore at about high water line. For collecting shingle a groyne should be six feet above high water. Such groynes were built by the government at Spurn Point. Higher groynes spoil the beach.

Cost of such groynes for shingle beach is about £3,000 per mile. The life of a groyne is about 30 years.

	Per mile of shore.
High groyne, Cromer, ...	£8,356
Low wooden groynes, Worthing, Felixstowe,	1,231
Case groynes, ...	1,407
Long distance groynes, 6 miles apart, ...	1,670

There should be a warden for a certain length of coast. The coast guard should report to him whatever needs repair, so that it may be attended to.

Most of sand and shingle remains from the glacial period. (Contrary evidence by Wm. Shield.)

Fishermen have objected to groynes as dangerous to boats running on to the sand.

Groynes in general give best results at right angles to shore. There are some exceptions.

From the evidence of L. F. Vernon-Harcourt, M. Inst. C. E.:

At Blankenberghe the long groynes go to low water, the small ones are placed between them to catch sand toward the top of the beach, and the spur groynes break up waves and prevent undermining of the principal groynes. The groynes are at right angles to the shore, the wind being about the same in both directions. Groynes are inclined away from the direction of the travel of sand or shingle.

Dr. J. S. Owens, Associate Member, Inst. C. E., Member Research Department, Royal Geographical Society, Consulting Engineer, in his evidence before the Royal Commission said in effect:

High groynes are bad, as they arrest shingle completely. The difficulty cannot be overcome by "scuttling" to allow shingle to pass over the top. Low groynes trap only part of the drift. Sea walls cause erosion if toe is exposed. An apron will not protect the wall unless it is more resisting than the foreshore. Recommends stepped wall or wall directing back wash tangentially to beach. . . .

None but an empirical rule for distance apart of groynes can be given. If too close together the water is unduly disturbed. Present opinion of witness is that the distance apart should be somewhat less than the length of the groynes. The gradient should follow roughly the gradient of the foreshore. The tops of the groynes should be 2 or 2½ feet above the beach. They should not be high at the shore end except to save an accumulation already present. . . .

The groynes will be most effective at right angles to shore. Any deflection only shortens the groynes and diminishes their effect to that extent. The oblique position is a survival from the high groyne.

Groynes do not merely save beach material by holding it at the place where they are located, but prevent loss that would occur on a groyneless shore at the mouths of rivers, &c., and the loss of shingle by attrition.

Alexander Beazeley, in his "Handbook," quotes from Transactions of Institute of Civil Engineers of Ireland.

A groyne at Ardmore, Ireland, "was built of timber, 3 feet above beach and extended 33 feet seaward. It was built in a zigzag, the engineer thinking that form best calculated on account of the undertow, to catch the accumulation which consisted chiefly of sand. It was constructed . . . of rough piles driven in pairs and 3-inch sheeting dropped between them and spiked through with half-inch spikes, clenched, stayed in some cases on the weather side. The groyne filled rapidly up to the level of the top of the paved toe (of the sea wall) and since it was completed, in May, 1880, no damage has (up to February, 1884) occurred to the wall, although there have been unusually heavy gales and great

damage done to the coast in other places. The cutting out gales have often almost emptied the groyne, yet the foundation of the wall (which it was built to protect) has never been laid bare. It was subsequently doubled in length, the last bay being only 1 foot above the beach." The cost was 6 shillings per running foot.

Mr. L. Duffin, County Supervisor, M. Inst. C.E.I., discussing timber groynes in Dungarvan Bay, says in effect:

The groynes were placed at an angle of 80 degrees to the line of the tidal stream. The upper end was generally filled. It was necessary to put rubber pieces on the lee side (with reference to the tidal stream), that side being exposed to cutting out winds. The weather side was untouched.

In discussing the groynes at Tramore, Ireland, he says that:

Groynes to protect a road at Tramore, Ireland, were built 45 feet in length, their shore ends 50 feet from a low sea wall. They soon had to be extended to the wall to stop the travel of shingle. The height at the land end was 4 to 5 feet, at the sea end 2 feet 6 inches above the beach. The middle groynes failed to fill well, so their direction was altered from 90 degrees to 80, and they were soon filled.

He further says that:

When a length of coast is to be protected groyning should begin at the farthest point to leeward and be carried on slowly against the stream, which will allow the leeward groyne to fill before it is robbed by its weather neighbor. This will give the correct distance between them, which should be such that the shingle should be thrown well back on the next groyne. They should not be made to the full height or length at first, but should be added to as the beach rises, and this also should proceed from the leeward. In a bay like Dungarvan, where two tidal streams meet, the work should begin near the point of meeting and proceed in both directions.

Long groynes should be of three sections, light at shore end, heavier in the middle to retain gravel and strongest at the sea end. to withstand wave action and wear of shingle. Scour is avoided by making the sea end low.

Engineering News Record, July 22, 1916, contains the following:

"COAST EROSION AND SEA DEFENSE

"Speaking before the Institution of Municipal and County Engineers, John S. Brodie, Borough Engineer of Blackpool (England), presented a summary of his experiences in coast erosion and sea defense. About 10 years ago erosion on the east coast of England resulted in a demand for State assistance in the protection of shores. The agitation culminated in the appointment of a Royal Commission in 1907, and after four years spent in taking evidence and inspecting the coast lines of practically the whole of Great Britain and Ireland, the commission finally reported in 1911 that, within a period of 35 years, while 6,640 acres of land had been lost to the United Kingdom by erosion, on the other hand 48,000 acres had by accretion and reclamation been gained. The commission made recommendations to Parliament, but up to the present time no legislation has been enacted.

"Expert opinions on sea defense works, according to Mr. Brodie, are divided between the use of sea walls and groynes. As usual, the truth of the matter is that neither is of universal application, but that each foreshore must be considered in relation to its own particular circumstances and conditions.

"A sea wall may be the best protection for one particular foreshore, while groynes may be the best for another, and a combination of both sea wall and groynes may be the only protection adequate for still another. But apart altogether from the adequate protection of the coast line, it must be obvious that groynes are very unsightly and inconvenient on a wide sandy foreshore used for recreation purposes, and should be avoided where possible on these grounds alone. It must be further kept in mind that experience has amply shown that there are no engineering difficulties in building a sea wall which will not depend on groynes to prevent it from being undermined by the sea.

"The financial considerations are really the determining factors in sea defense works."

Evidence of P. H. Palmer, Member Inst. C.E., former President of the Association of Water Engineers, member of Sanitary Institute and of Council of Incorporated Association of Municipal and County Engineers. Has worked at Hastings and St. Leonards.

Witness believes that shingle travels in deep water. The most efficient groynes on the south coast, those at Hastings and Brighton, are 3 feet above high water mark of spring tides; any less would be useless with a sea wall and the range of tides there. It is necessary to accumulate beach on the western side of the groynes for storing boats, bathing machines, etc., which would have to be removed to the Esplanade otherwise.

They are 3 feet wide on top, not reinforced, battered one in 10, carried to rock, 6 feet thick at bottom, made of blocks weighing 2 cwts. each, faced

with Rhenish basalt. At the first they are 4 feet above the beach, then they are raised as the beach rises. There is not much difference between the filling on the two sides at St. Leonards. There is a difference at Hastings.

The length is 200 to 250 feet; the cost is from £600 to £800 according to depth of foundation. Sometimes they have scuttled the groynes or cut holes for shingle to pass.

Oak groynes were put in 20 years before at Brighton. They are in fair repair and partly buried.

Repairs must be effected promptly. If a plank comes off and is not replaced by the next tide with one sufficient to cover 3 or 4 piles, there will probably be serious damage in rough weather, as well as the loss of considerable shingle. If this is done, there will be no trouble for five or six years, and then bolts, walings and land ties have to be secured from getting loose.

The storm slope is 1:5 or 1:6 on the upper part of beach and 1:10 or 1:12 on the lower part. The groynes incline slightly to windward.

One end of the beach has been damaged by the construction of part of a harbor pier. Taking material from beach damaged it; that is now stopped.

The shingle travels in deep water (10 fathoms).

Groynes should extend to low water mark, below that they will do little good. Long groynes bring up sand, but shingle keeps to within a couple of hundred feet of high water mark.

The life of a common Swedish timber groyne is 15 years, oak groyne 25 years, Australian jarrah wood 30 or 35 years.

Alfred Weller, Borough Engineer of Brighton, states in effect:

The sea frontage of Brighton is 2¼ miles. It has always been subject to erosion.

All groynes are of massive concrete, wooden ones have been abandoned. The first one was built in 1867, 17 are built now. They are 255 to 465 feet in length, distance apart 710 feet, average. Tidal range is 19.75 feet. The highest part of groyne is 12 feet above ordinary spring-tide high water mark, 16 to 20 feet above beach, 24 feet above chalk. The outer ends are 5 feet above chalk.

Cost eastern shore, £10 14c. 2d. per lineal foot of groyne.

Cost western shore, £8 10s. 5d. per lineal foot of groyne.

The sea wall cost £9 3s. per lineal foot. It is intended to raise groynes when the beach accumulates. Some groynes have openings to let shingle through when necessary. Since 1858 they have reclaimed a beach 110 feet wide, covering 30 acres. Some of this has been used for buildings. The accumulation was checked by the extension of Shoreham Harbor. Taking shingle from the beach for bulding, etc., was stopped in 1893.

The average cost of new groynes each year is £2,907 and of repairs £566 (20%). This included repairs to parapet, etc., of promenade on one groyne. It is intended to trim the face of the cliffs to provide shingle for the groynes east of Brighton. Wooden groynes were formerly used. They were made of oak or greenheart; their life was 20 years with constant renewals of planking.

Timber groynes would not go so far seaward, and would have to be heavy on account of the height. The timber groynes cost from £3 to £5 per lineal foot of groyne.

A. T. Walmisley, Member of Inst. C.E., has stated that:

The height of groynes should be 2 feet above the beach, to be increased as beach accumulates. Groynes should be carried out well into low water and up to the height of full tide. Strutting groyne to prevent overturning is recommended.

The south coast of England is rougher than the east coast and more beaten by waves.

A groyne should last 30 years if well constructed, or 15 years without repairs.

From £1 to 30s. or more per foot of length would be the cost.

The angle of groyne should be a little to windward of right angles to shore.

A. Poulsen, in describing the protection on the west coast of Jutland, Denmark, declares:

The first attempts at protection were by groynes in imitation of those used on the coast of Holland. They were found unsuitable, owing to the difference in local conditions.

The work was commenced in 1875. Granite blocks were used, but as these became difficult to obtain, concrete blocks were substituted. Each block is a cube containing 62 cubic feet, and weighing 4 tons. The height of the groyne at the shore end is 14¾ feet above mean water level, the outer end at mean water level. The mixture used is one part of cement to 2½ parts of sand and 5½ parts of stone.

The slope of the top is one in 20 at the shore end, one in 80 at the sea end. The groynes are at right angles to the shore, 620 feet long, 1,230 feet apart.

The dikes are of sand, 16½ feet high when built. The height is increased by drifting sand and some portions have been built up entirely by regulating the drift of sand, using fascine shelters 3¼ feet high. The dikes are in some instances 164 to 328 feet behind the groynes, and connected with them by lateral dikes.

In a paper by Kerner, Hafenbaudirector, on Coast Protection works on the Baltic, the following appears:

The object of these works is to protect the coast of Mecklenburg, in the neighborhood of the town of Rostock, and keep open the entrance of Warnemunde, by trapping the sand borne along the coast by the prevailing current, and thus creating a beach. Groynes have been built along 2.48 miles of coast, carried out to 8.2 feet depth, spaced not more than 1.5 times their length apart. To retain the very fine sand, piles 7.88 inches in diameter were driven 3.28 feet between rows, 2.46 feet apart, and weighted fascines were packed between the rows, secured by transverse timbers and longitudinal walings.

The head of each groyne is weighted with stones, and the piles are sunk 5 feet to 6 feet 6 inches in the ground.

With hand-driving, the cost was 46.8 marks per metre (42s. 10d. per yard), 28.5 marks being for labor of driving. Afterwards, with twin electric pile driver, the cost was 6.2 marks for driving.

As a result, a sand beach has been formed 164 feet wide, averaging 6½ feet thick. Some of the groynes had stood for 11 years and resisted the ice of severe winters.

The Report of the Royal Commission gives the following information regarding foreign sea defenses:

France.—At Pointe de Grave, Gironde—Groynes were tried but not found useful.

At Port du Collet—on boundary of Loire-Inferieure and La Vendee—a timber groyne, 100 metres long was found successful.

At Angoulins, south of La Rochelle, Charente—a combined groyne and pier shelters fishing boats and protects the cliff against erosion. It is about 60 metres long, is rounded at its end, is joined to the cliffs and points southeastwardly. It is 1 metre wide at the top and is as high as the highest tide. It is made by piling up the largest stones eroded from the cliff (66 to 88 lbs.) and bonding them together carefully. The government has repaired it several times.

Arrondissement du Centre, Calvados—Groynes were used but not found satisfactory.

Arrondissement de L'Ouest, Calvados—Groynes were used, results were variable.

Good results have been obtained in preservation of dunes by planting the maritime pine.

Belgium.—The shore is sandy, with a gradual slope and there is a line of dunes above high water mark. Wenduyne, Blankenberghe and Heyst have been protected from time immemorial, Breedene, Ostend and Middlekerke in more recent years.

The works are: Jetties across the entire shore, and groynes across the upper part. They are made of brick, of fascines or of riprap.

Revetments on the seaward slope of the dunes —of brick, rubble or concrete.

The beaches are public land, and all protection work is done by the State. The dunes are partly owned by the State, partly by private individuals, the owner in each case building the revetment. The State furnishes the plans.

The coast is not adapted to the growth of trees, but the dunes are fixed by planting dwarf willows and other suitable plants.

The government has plantations of pine, balsam, maple, osier, alders, ash and birches covering 321 acres on the landward side of the dunes.

Prussia.—Works are carried on to prevent river mouths from shifting among sand banks, and to secure works on land. They generally consist in the construction of dunes where the coast has been little eroded; of dunes, dikes and works, usually stone walls, parallel to the coast where the land has been encroached upon. The dunes are omitted where the coast is of loam, clay or marl. The results have been satisfactory.

The coast protection is generally left to the owners of the lands, and other persons interested except when there is question of the silting up of river mouths and ports, the destruction of spits and islands protecting them, or damage to State property.

Oldenburg.—In the estuary of the Weser works of fascines founded on piles and built up in layers with stone are used. They are 184 feet long and 738 feet apart. The foreshore is protected by stone paving, sloping 1 in 3½, 43 feet wide. They are expensive to build and maintain. More recently a slope 8.2 feet wide protected by groynes 33 feet long and 164 feet apart has been placed 33 feet seaward of the larger work. Brick slopes are coming into use extensively. One of these, 1⅜ miles long, has stood for 30 years without any repairs.

The work has been carried on by dike associations under State control.

Mecklenburg-Schwerin.—The coast consists of flat sand banks, with occasional bluffs of clay.

Pile jetties and rows of piles parallel to the shore have been used and have proved expensive to maintain. Their construction has been discontinued and reliance is now placed on the building of dunes by means of hedges and the planting of sand grasses.

Large artificial sand dikes have been built to prevent the breaking through of sand spits. These works were in the domains of the Grand Duke.

Groynes of piles and fascines have been used with success by the municipality at Rostock.

Hamburg.—Coast constructions at the mouth of the Elbe are of riprap or concrete blocks weighing from ¼ to ½ ton, on a gravel foundation.

Layers of fascines and stones were previously used. Nearly all the work is on State land, and built by the State.

Bremen.—Works at the mouth of the Weser are not strictly coast works but preserve the position of the channel among the sand banks. They are fascine constructions in the form of dikes at right angles to the bank and are weighted with quarry stone.

Training walls of the same materials maintain the channel. The results have been satisfactory. The costs are covered by navigation taxes levied by virtue of an agreement between Prussia, Bremen and Oldenburg.

Lubeck.—The coast lies in a bay and the use of slopes paved with brick on concrete foundations has been found satisfactory.

Hobart D. Shaw, City Engineer of Gulfport, La., in an article before the Louisiana Engineering Society, said in effect:

This system provides for a curved-face sea wall and groynes 120 feet long, 120 feet apart, with the top at a 5 per cent gradient. The designer stated that no filling of the beach by accretion could be expected in that locality, so he would artificially fill the beach to the tops of the groynes with sand, and depend on the groynes to preserve it.

Drainage from the back is also provided for by lateral drains from a roadway along the top of the wall, with outlets about 103 feet from shore.

Average tide variation is about 2 feet.

Storm tide with gale of over 90 miles per hour reaches 10 feet above mean low tide.

A contour map was made of upland, to the 18 feet contour, U. S. datum, with stadia sections of beach every 500 feet, to determine the gradient of the beach. It was from 0.4% to 1%. Ground water 100 feet back from beach was found to be 6.3 feet above datum and did not fluctuate with normal tides.

Charles H. Higgins, in an article in Engineering News, says:

"The terrific damage done to many beach resorts on the coast of New Jersey, Delaware and Long Island, by the two ocean storms at the end of December and the beginning of January (December 25-26, 1913, and January 3-4, 1914), direct attention to the beach protection of Asbury Park, which suffered comparatively little damage on those occasions. The method in vogue there is to allow a free sweep for the surf, but to reduce the energy in the waves by means of carefully designed and well-built system of timber groynes (sometimes termed jetties).

"An examination of a map of the New Jersey coast shows a sandy beach extending from Barnegat to Sandy Hook, with Asbury Park occupying a central position. The typical shore consists of a sand beach, beyond which there is usually a sand bar, just covered at low water. Between the beach and the bar there is normally a strip of deeper water, in which the prevailing current is parallel with the beach, and usually in a northerly direction. During a storm from the northeast or southeast this current frequently becomes so rapid that a strong swimmer cannot make progress against it. It is this prevailing northerly current, between the beach and the bar, which tends always to move the sand toward Sandy Hook. The latter was probably built by this action.

"It is the northeaster which erodes the beach. It strikes it, not at right angles, but on a diagonal line. The waves break in a progressive line along the beach and the water runs back with a whirling motion, which carries the sand into the current described above. This current is below the surface of the water and the waves pass over it as they strike the beach. It is therefore sometimes referred to as an undertow.

"The theory of the groyne system is to prevent this diagonal swirling action which carries the grains of sand down to the current, and also to force the current farther out shore, by obstructing its course. The groynes then are not designed to resist the waves as they hurl themselves upon the beach, but to resist the secondary movements of the water, which follow the breaking of the waves, by making the returning water run back on a line at right angles to the general direction of the beach. This results in a lower velocity and a consequent reduction of

carrying power. The groyne also resists directly the movement of the undertow, parallel to and along the beach, thus forcing it farther out and broadening the beach. This still further breaks the force of the waves.

"The groyne system, then, is more than a defense. By progressive extension it can be made to build the beach out from an existing shore line. Sand is deposited between the groynes when westerly winds prevail.

"In the autumn of 1907 the Public Grounds Commission of Asbury Park asked for bids, the contractors to submit plans and specifications with their proposals; the writer prepared the plans and specifications submitted by the successful bidder, which provided for a system of timber groynes, and later he supervised the construction.

"The design was based on the practice and accumulated experience from observations of the successes and failures resulting from groyne building along that coast.

"A feature believed to be novel was the distinct recognition in the design of the relation between the length of the groynes and the distance between them. This ratio is based on the diagonal movement of the waves and can be understood from an examination of the diagram. Roughly, the distance between groynes should not, under conditions obtaining here, be much greater than their effective length. Another "first principle" recognized was that the groynes should slope outward, at an angle about equal to that of the beach to be maintained, with their outer ends well down, at least to the average sea level.

"The second requirement essential for the most successful groyne system is based on the theory of offering the least possible resistance to the sea and that the groyne accumulate sand during times of westerly wind. The most successful groyne is that which is completely buried by the sand. The sand accumulated acts as protection during the fierce northeasters, while the action of the groyne is to resist the displacement of this protecting sand.

"The yellow pine timber and piles used in this construction were first treated with creosote—12 lb. absorption to the cubic foot. The bolts were heavily galvanized.

"The piles (14 inches or more in diameter at the butt and about 25 feet long) were jetted to a penetration of about 20 feet by means of hydraulic jets of 1¼-inch pipe 20 feet long, fastened to hose at the upper end. The sand beach of Asbury Park bears on a stratum of blue clay about 20 feet below the surface, and the piles were jetted to this stratum. The jets were manipulated by two men, and two jets were sufficient to rapidly penetrate to the clay stratum. Then with one jet in operation, a pile was hoisted by means of a block and fall attached to shear legs, and set in the hole, the sand quickly filling in around it.

"The wales or stringers are spiked in place on the first row of piles and the sheathing jetted down in the same manner as the piles; although in this case a single jet will soon push the sheathing in place. Upon the sheathing wales are spiked and the second row of piles jetted in place; after which all are bolted together.

"Low jetties, i. e., service jetties with their tops at about mean tide level are very difficult to construct, as the men can work only during low water. It is practically impossible to carry on the work in the summer, as very low tides are so infrequent then; while in the winter storms often delay the work for several days. The work can be done in the winter, but the spring and fall are better times. At these seasons, when off-shore winds hold down the tide and smooth the sea, the work can be pushed most of the day. But always, it is a case of watching the wind and tide and grasping the opportunities afforded by low water. The work at Asbury Park was carried on during the winter, spring and autumn months.

"That the groyne system has proved effective here is evidenced by the fact that certain structures which were dangerously exposed in 1908 were not affected by the heavy storms of December 25-26 and January 3-4. The system is in excellent condition after its service of six years; neither teredo nor decay have developed. Shortness of funds prevented the construction of as complete a system as perfection of design might demand; but it has demonstrated its value and is amply worth the $30,000 it cost. On January 24 the Public Grounds Commission expressed its satisfaction over the performance of the groyne system.

"The conclusions to be drawn from the behavior of the jetty system of Asbury Park, under trying service conditions, are several. First, it has shown that a sand beach can be not only protected but actually extended, and at a most reasonable cost. Second, the entire New Jersey coast could be adequately protected at far less cost than that represented by the damage resulting from a single great storm, like the one early in January, 1914. Third, for such protection, continuity in the groyne system is essential. Asbury Park, with a mile of shore front, under single control, is in an exceptionally advantageous position."

Mandes Golder, in an article on "Beach Erosion and Shore Protection, Atlantic City, N. J." says:

"The coast of Atlantic City is formed of a sand deposit which is easily moved by the waves, from the action of which the shore line is constantly

changing. Inasmuch as a permanent, smooth beach is one of the requirements of a successful seaside resort, the separate interests which control the beach at Atlantic City have made it their practice to build shore protection structures all along the frequented part of the beach, which is the entire city ocean front. Unfortunately, this construction has not been under the charge of any central authority, so that various methods have been used to prevent the beach from eroding. Some of these have been successful while others have not served the purpose for which they were designed.

"At Atlantic City, the prevailing type of protection is the timber groyne and timber wall, although in a few cases, stone groynes have been built. The best wall which is now in service has been built by the Hotel Chalfonte owners to protect the beach in front of that hotel. It consists of a row of piles about 4-ft. c. to c. penetrating from 10 to 15 feet and projecting about 5 feet above the sand. Near the top of the piles, a 6x6-in. timber is fastened. Two rows of 2-in. sheathing are then driven in front of the 6x6-in. stick and fastened to it, and in front of the sheathing a riprap protection is dumped.

"Another wall is built very nearly according to the same design as the one just mentioned, but the stone protection has been left off in front and instead there has been placed a banking of sand to the rear of the sheet piles.

"A groyne built above Young's Pier consists of 6x8-in. treated timbers, spaced 8-ft. center and 4-in. apart. Between these timbers, are placed 4x12 in. treated plank, fastened to the timbers by galvanized iron bolts. It is important in building this form of groyne to get the plank about 3 feet below the beach level so that there will not be any chance for water to wash under them. The plank between the centers are put in as the beach rises. The groyne is built from the mean high-water line to the mean low-water line.

"Another groyne which has been used rather extensively consists of two rows of piles driven 2 to 3 ft. centers and about 4 ft. apart. Near the top, the piles are connected by a timber beam and the two rows are connected with bolts. In the space between the rows of piles, bundles of brush are placed and on top of that several layers of stone are laid.

"All the walls are built under the boardwalk, which runs along the beach front, so that they may be concealed from view.

"In planning a system for protecting a shore and maintaining a beach in the State of New Jersey, there are three sources of information: (1) Surveys of the State and Federal departments; (2) information from residents in the vicinity or from the life-saving crews; (3) examination of defences built as near the proposed work as possible. On the Jersey coast, the first source of information very often is quite valuable as surveys have been made in many places. Information from the second source shows the actual action of the waves during severe storms. From the third source, the effectiveness and weaknesses of a system already employed can be learned.

"It is important to note that groynes when well built and properly located, will raise the beach level but will not protect the shore line against storms. Shore protection, such as sea walls, if well built, will protect the shore line but will at the same time cause a greater scouring action and thereby tend to lower the beach. Both forms of construction must, therefore, be combined in designing a beach-protection system."

A paper by Prof. Henry Robinson, on foreshore erosion and reclamation from the Transactions of Surveyor's Institution, states that:

At Peterhead Breakwater, where rise of spring tides does not exceed 11 feet, 40 ton blocks were displaced 37 feet below water of spring tides.

At Land's End, lobster creels in 30 fathoms of water, were found filled with sand and stones, some weighing a pound, after a heavy gale.

This was disputed by R. F. Grantham, who cited testimony of Captain Maxwell, R. N., before Royal Commission.

At Dover, the highest waves are 15 to 18 feet. At the mouth of the Tyne and Peterhead, waves 35 to 40 feet high have been recorded.

Drain pipes and channels carried only to high water mark, cause erosion—they should be carried to low water mark. Concrete blocks placed irregularly before a sea wall, have prevented erosion, by breaking up the waves.

Mr. W. R. Whitaker, F. R. S., gave instances of a landslip which ended sharply at ground which had been drained. Inferred that drainage might protect.

Low groynes of the Case type are preferred to high groynes.

Chain cable groynes devised by Mr. Allanson-Winn, are useful for arresting beach material in deep water below low water line. They are made by attaching bushes, trees, crates and other material to old chain cables or wire rope from ship's rigging. They may be laid as easily in deep water as in shallow water.

Reduction in level of beach by the taking away of material allows the tides to pass over the area excavated and injure the adjoining foreshores.

W. F. Ingram gave instance at Newhaven and Seaford (Sussex). Owing to a breakwater on the

west side of the harbor, beach material moved from east to west, contrary to the direction previously taken, and threatened to block Newhaven Harbor.

The Harbor Company and private owners built a sea defense wall 2¾ miles long at the cost of £70,000. The work was in charge of Mr. Ingram.

Mr. F. Stileman has made efficient groynes by using jute sheets, each large enough to take one day's work—say 30 cubic yards of concrete. The sheet was laid down and the concrete thrown in. At the end of the day the whole was turned over, forming a bag of concrete with rounded side to the tide. The work was very cheap and efficient.

J. S. Owen made experiments showing that sea sand began to move in a current of 0.85 feet per second, forming ripples. These ripples were swept away when the current exceeded 2.5 feet per second.

While the ripples persisted, they trapped stones and coarse material in their troughs, although the current might be sufficient to move them over a smooth bed.

E. J. Dent, in an article on Preservation of Sandy Beaches in Vicinity of New York—from transactions of American Society of Civil Engineers, states in effect:

Tidal currents are said to be of little effect except near inlets.

Analysis is made of wave motion and oscillation of beach material, which is said to be eventually carried to sea or washed above ordinary high water line

Origin of beach material is stated to be on the upland, not in the sea. Berms are formed at last breaking point of waves. Temporary berms are built up during storms and undermined during quiet weather.

Littoral drift carries sand along shore, inlets, jetties and groynes are said to interfere with this movement and divert material to deep water.

Bulkheads, when not too far seaward, are said to protect upland without extensive erosion at base. If too far seaward, loss of beach is caused.

The accretion at some points is claimed to be due to "sand waves", the crest being a projection from the shore line and the trough a bay. These waves travel along the coast at a very slow rate. The covering of groynes out of sight is attributed to this movement, as the groynes have no effect when buried.

Discussion: Prof. Haupt cited instances where groynes built up beach. Mr. Higgins, designer of Asbury Park groyne system also cited these.

Allan Hoar described beach at Pasadena destroyed by a bulkhead too far seaward.

Mr. Buel gave instances of good results from Case groynes in England, with curved extension devised by Allanson-Winn.

Mr. Cresson showed that low groynes slow the movement of beach material, causing it to deposit on both sides of groynes.

At Revere Beach, near Boston, Mass., there has been built for the protection of the coast a flight of reinforced concrete steps, 30 feet wide and rising a distance of 8 feet. This work was done by the Metropolitan Park Commission, and extends for about 1500 feet, and on last reports it has succeeded in saving the rapidly eroding beach.

In San Francisco, outside of the Golden Gate, on the oceanfront, there has been built a reinforced concrete wall with a curved face with steps. No groynes have been built.

An inspection of this in 1919 showed that a number of the steps had been covered by sand, and the beach had been apparently protected.

Dr. Corthell, an eminent authority on coast protection, in an article on "The War Against the Waves" in referring to Holland says:

"The whole Netherlands coast of the North Sea was protected by nature by a continuous line of sand dunes placed there by the onshore winds, which, at low tide pick up the sand and deposit it along this cordon away from the high tide limits. About 600 years ago, in successive storms, perhaps accompanied by tidal waves, the sea breached these natural dikes. At places far behind them the people built mounds (one of which the writer saw not far from the great artificial dike of Westkapelle on the Island of Walcheren) 40 or 50 feet high, as a refuge for the inhabitants of the 'polders' and their cattle and movables when at times the sea rushed through these great breaches half a mile to a mile wide in the chain of sand dunes.

"In these breaches the engineers of these later times have built great dikes of clay and sand and have permanently protected their shores down to below low water and have, by means of spur dikes or groynes built of piles, willow and stones, forced the sea to recede—and stay receded."

Mr. Carl Wesemann suggested a novel type of construction to Dr. Corthell in a letter which read as follows:

"Open work sea walls with elastic air cushion resistance against wave stroke."—A great many sea walls fail on account of the foundation being undermined, especially if the sub soil consists of material that is easily eroded like sand and clay. Every sea wall cuts down the beach like an excavator. The stroke between wave and wall is a non-elastic one. The sea wall therefore sets up first a downward force that loosens and excavates the beach material at the foot; second, an upward force that throws upward a mass of water that in falling down carries away the loosened material. The excavating action is followed by a transporting one.

"Material that is easily eroded cannot stand those destructive vertical forces that are set up by the full faced sea wall on account of the non elastic stroke between water and wall. The open work sea wall converts the non elastic stroke into an elastic one by interpolating an elastic medium (air cushion) between water and wall face (like a buffer with railways).

"The excavating downward force will be greatly diminished; so will the upward force. The destructive forces that are set up by the otherwise close faced sea wall will be less effective and the beach will be better protected against scouring and depletion.

"Features of the 'open work' sea wall.—Pipes (ferro-concrete, earthenware or cast iron) are imbedded into the body of the structure. The pipes are arranged gently upward sloping and are provided with a solid bottom at the back; the pipes are usually above water level. The onrushing water shuts up the air in the pipes and compresses the air that cannot escape (elastic stroke between water and wall). If you attach to the bottom of the pipe a small pipe that communicates with the outside air, the wave stroke is compelled to force out the air through a comparatively small orifice. That means loss in energy. The reverse water will draw in air again and thus will lose in energy once more. The whole of the movement of the wave (onward and outward) will be a smoother one.

"By means of compressing the air in the pipes, the wave stroke can be converted into useful energy. Compressed air is a ready medium for the purpose of storing up and transmitting energy.

R. G. Allanson-Winn, M. Inst. C.E., now Lord Headley, in a paper on "Foreshore Protection" delivered before the Royal Institute of Public Health at Eastbourne in 1901, states among other things the following:

"Given a free hand and sufficient funds, it is always possible for engineers to keep the sea out by means of a wall of adequate strength if the foundations are taken well down below the low water. The author places groynes first in the list of protective devices, because they help to utilize, or should utilize if properly constructed, the current and wave forces of the sea, and at the same time may lead to an enormous saving in expense.

"There is probably no branch of civil engineering where disappointment so frequently follows the expenditure of money as it does in that connected with sea defense work. Of all methods of protecting foreshores, that advanced by the late Mr. Edward Case appears to be the most scientific and successful. Mr. Case's main idea was to utilize the destructive forces of the sea in such a way that they should be induced to carry materials to and deposit them in situations where their presence is needed. To bring about this result he devised a simple form of groyne, the construction of which has been so frequently described, that, for the purpose of this paper, it is sufficient to say that it is of timber, is easily constructed by unskilled workmen and that it is economical both as regards construction and maintenance.

"These long low groynes are slender structures which create no scour, run down from mean sea level to low water mark, and arrest and divert shorewards the material bearing currents travelling along the shore. They present but little surface to the force of the waves or currents, and are therefore not liable to destruction during stormy weather.

"Half and half measures should be avoided; tinkering with short lengths is likely to do more harm than good, and such works should not be undertaken unless a shore can be treated as a whole, or, at any rate, a reasonable length such as half a mile or more dealt with at a time.

"According to the Case theory, the perfect section of any shore should be an ellipse, the eccentricity of which depends upon the horizontal distance between high and low water marks and the range of tides. The light step wall * * * is so designed that on any particular shore it shall form a portion of the calculated ellipse. It thus causes no scour and has a great additional advantage of being economical in cost.

"The authorities at most seaside places are quite content to go on spending money in the happy belief that what was good enough for their predecessors is good enough for them. They have a particular aversion to anything new, and the saving of cost and scientific nature of a discovery seem in themselves to be elements and factors to be regarded with suspicion and disfavor.

"An examination into the cause of breaches in sea walls has convinced the authorities that the

mischief is very frequently traceable to the existence of some high groyne in the vicinity of the beach."

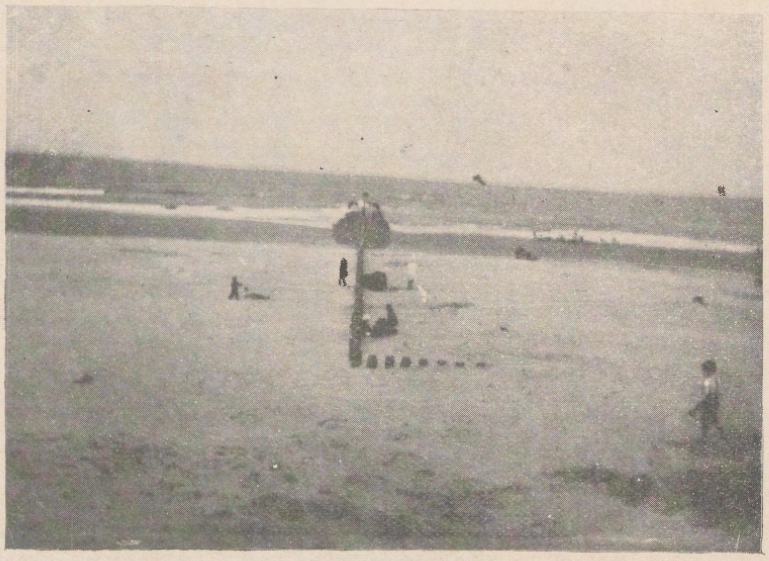
In a letter by Allanson-Winn suggesting the means of scientifically watching coast lines, the following appears:

"Among the duties of the suggested department, the following may be enumerated:

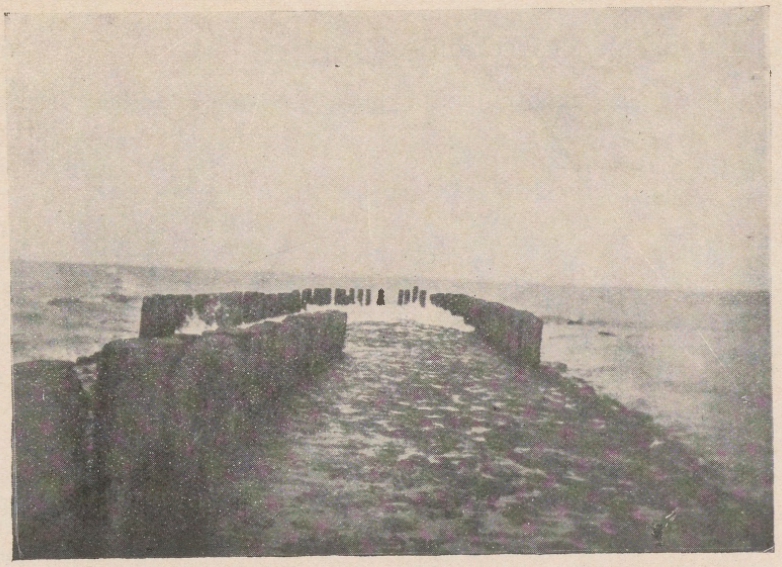
1. The systematic and repeated taking of sections (over the same lines) on all shores, as well as contours at high water, low water and mean sea level lines; this latter is very important as much damage is done during storms taking place at half tide.
2. The taking of soundings.
3. Calculations based on observations respecting the varying rates and directions of currents, at high water and low water and mean sea level.
4. Observations as to the velocity and vis viva of waves.
5. Observations on travel of beach sand, and other material, especially around headlands, piers, breakwaters and across bays and the estuaries of rivers.

"The so-called Case groynes invented and patented by Mr. Case are so well known that they need but little description. It is sufficient to say that they are low structures, built generally a foot or two above the sand with provisions for adding to their height as the sand rises and extending from a tight bulkhead out at least as far as low water."

An examination was made in the summer of 1922 of certain coast protective works in England, Holland and Denmark. The situation in Holland is more nearly comparable to that in New Jersey than is England except that the coast of Holland is subject to more severe attack by the North Sea during storms than is the coast of New Jersey. This is so by reason of the greater tidal variation, being twenty feet and more between the plane of low water and the plane of high water, and in consequence the effect of storms in producing waves and causing scouring currents is very severe. The beaches in Holland are very attractive and are much used for bathing and recreational purposes. The sand is fine and slope of the beach is very gradual, more nearly approaching the slope of our South Jersey beaches. But it is necessary to protect the lowlands of Holland from inundation by the construction of very substantial dykes along the entire oceanfront. These dykes in such places as Scheveningen are perhaps fifty feet high and their face is paved with masonry. In addition to these dykes there is a masonry wall with a curved face, and in addition to that there are splendidly constructed groynes extending from well above ordinary high water to well below ordinary low water. The groynes are constructed by first driving three parallel rows of vertical piles close together and about eight feet between each row. The piles on the outside rows are cut off about at the level of the beach and the piles in the center row are allowed to project four or five feet above the level of the beach, and from the center row of piles to the side rows of piles very carefully placed stone paving with a rough top is laid. This constitutes substantially a masonry groyne, and the effect of these groynes, as the beach existed in 1922, was that there had been no piling up on one side or the other but that it was a level continuous beach. On the outshore end of these groynes the center row of piles is cut off down to the level of the masonry paving and the two side rows are allowed to extend four or five feet above



Jetty at Scheveningen, Holland, on the North Sea.



End of Jetty at Scheveningen, Holland.



Jetty with Opening, Brighton, England, on English Channel.



Masonry Jetty, Brighton, England, English Channel.

the paving, curving them around the end of the groyne to constitute what is apparently intended to be a wave screen.

On the English Channel, notably at Brighton and vicinity, there have been serious encroachments, but here the character of the beach is entirely different from that on the Holland coast or on the coast of New Jersey. The material composing the beach is known as shingle, and is composed of pebbles of an average least dimension of perhaps one inch. These are evidently broken down from the chalk cliffs where the silica laden waters have deposited flint globules in the chalk. There is no fine sand anywhere on these beaches. The methods of protection employed are masonry groynes well built, and their effect has been to pile up the shingle on one side practically to the level of the top of the groyne, and to erode the beach on the opposite side to a varying depth, perhaps as much as six feet.

In order to relieve this situation and to supply shingle to the beach on the eroded side of the groynes, holes have been left in these groynes through which the shingle has passed and the photographs accompanying this report will indicate the effect of a hole in one of the groynes upon the beach on either side of the groyne.

In addition to the above there are many maps, charts and additional references to methods of coast protection and their defects and results.

APPENDIX "E"

Ownership of Riparian Lands as Affected by Erosion

This question arises in connection with the building of devices along the Atlantic Coast to prevent or check further encroachments by the ocean, pursuant to the provisions of Chapter 318 of the Laws of 1920, page 570.

Riparian lands, within the boundaries of the State of New Jersey, passed to the State at the time of the Revolution.

Arnold v. *Mundy, 6 N. J. L., page* 1.

The interest of the State is proprietary in character.

Stevens v. *Paterson &Newark R. R. Co.,* 5 *Vr.* 532.

The State may make disposition of these lands and such regulations concerning them as it may think fit, this disposition and regulation to be exercised in its sovereign capacity through the Legislature, and in the exercise of this power may lawfully erect ports, harbors, basins, docks and wharves on the coasts of the sea and in the arms thereof and in the navigable rivers, and may bank off these waters and reclaim the land upon the shores; that it may build dams, locks and bridges for the improvement of the navigation and for the ease of passage; that it may clear and improve fishing places to increase the product of the fishery; that it may create and enlarge and improve oyster beds therein; in order to procure a more ample supply; that it may do these things at the public expense or may authorize them to be done by others at their own labor and expense, giving them reasonable tolls, rents, profits, or exclusive or temporary enjoyment.

Arnold v. *Mundy, supra, at page* 78.

Under existing statutes these riparian lands may be granted or leased, but subject to a right of priority given to the owner of the upland abutting thereto. This right of priority can be cut off upon notice to the upland owner by following a procedure set forth in the statutes.

There are a number of statutes in force relating to these lands, but the Act of 1869 (page 1017, P. L. 1869) is the main statute on the subject.

Prior to the passage of the Act of 1869, there was no general statute providing for the granting or leasing of the State's riparian lands.

From the Revolutionary period until the year 1851, the upland owners assumed the right to improve and occupy riparian lands adjoining their upland, and the courts have recognized some claims based on such occupation as good.

By the act of 1851, known as the Wharf Act (P. L. 1851, page 335), an upland owner was given the right to build upon and improve these riparian lands in front of his upland out to the low water mark, and when so built upon and improved, to appropriate the same to his own exclusive use.

It was further provided by that Act that such upland owner could extend docks, wharves and piers beyond the low water line by obtaining a license from the Board of Freeholders so to do, pursuant to the procedure set forth in the Act.

The Wharf Act was repealed by the Act of 1869, referred to, as to the tide waters of the Hudson River and Kill von Kull, and totally repealed by the Act of 1891 (P. L. 1891, page 216).

By the Act of 1894 (P. L. 1894, page 123), the riparian lands then owned by the State were irrevocably appropriated for the support of free schools in this State.

Riparian lands have been granted from time to time by special act of the Legislature, and may still be so granted, but since the Act of 1869 there has been a duly constituted State agency, first the Riparian Commission, and now the Board of Commerce and Navigation, authorized to make grants of the same. While these lands are still subject to the control of the Legislature, it may not now grant any interest therein directly or through a duly constituted agent except upon payment of the value of the lands granted by virtue of the Act of 1894 referred to and Article IV, Section 7, Paragraph 6 of the Constitution—as by that paragraph of the Constitution property appropriated to the support of free schools may not be borrowed, appropriated or used for any other purpose.

The proprietor of lands having a boundary on tide water is obliged to accept the alteration of his boundary by the changes to which the shore is subject. He is subject to loss by the same means that may add to his territory; and, as he is without remedy for his loss, so he is entitled to the gain which may arise from alluvial formations. This rule is vindicated on the principle of natural justice; that he who sustains the burden of losses imposed by the contiguity of waters, ought to receive whatever

benefits they may bring by accretion, but to entitle the proprietor to the right of accretion he must be the riparian owner and his land must adjoin the land lying at ordinary high tide, so that if a strip of land, however small, intervened between the premises conveyed and the water at ordinary high tide, the owner will not be entitled to the accretion, and as between vendor and vendee this right depends upon the condition of the land at the time of the transfer of the legal title. If there is an erosion resulting in the washing away of an intervening strip by which lands obtain a boundary upon the shore, and thereafter there be an accretion by which the lands are restored, the owner of the back land is restored to his original boundary and the owner of the intervening strip is restored to his possession as a riparian owner.

Ocean City Assn. v. *Shriver,* 64 *N. J. L.* 550.

In conclusion:

1. Structures and devices for the improvement or protection of riparian lands may be built by the State or authorized to be built by private interests.

2. State lands may be occupied with such structures without compensation to the School Fund by reason of the necessity to protect and preserve.

3. Private lands may not be so occupied without the consent of the owner unless compensation be made.

4. The boundary line of riparian lands is the natural high water line, as it shall exist at the time the work is done.

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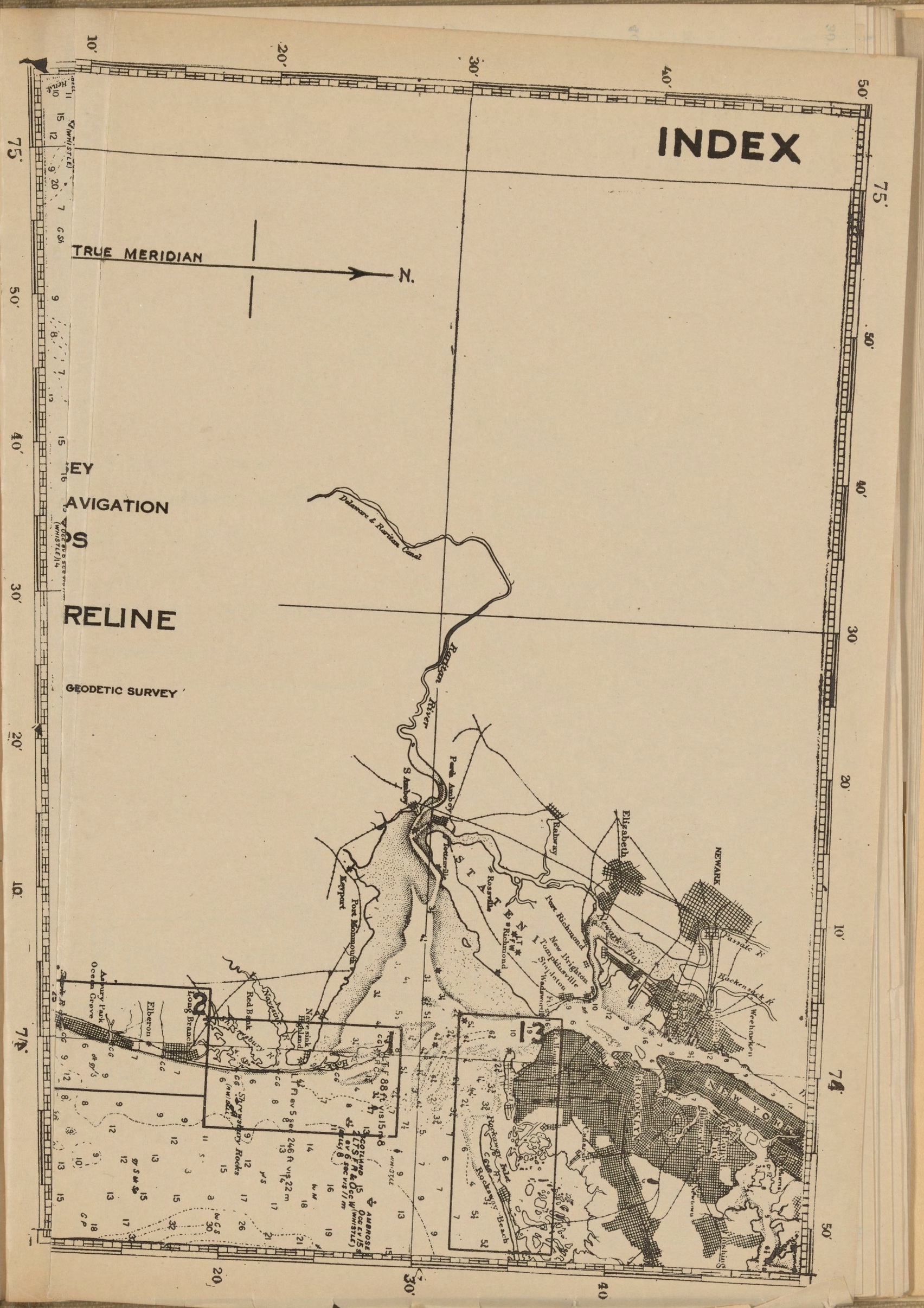
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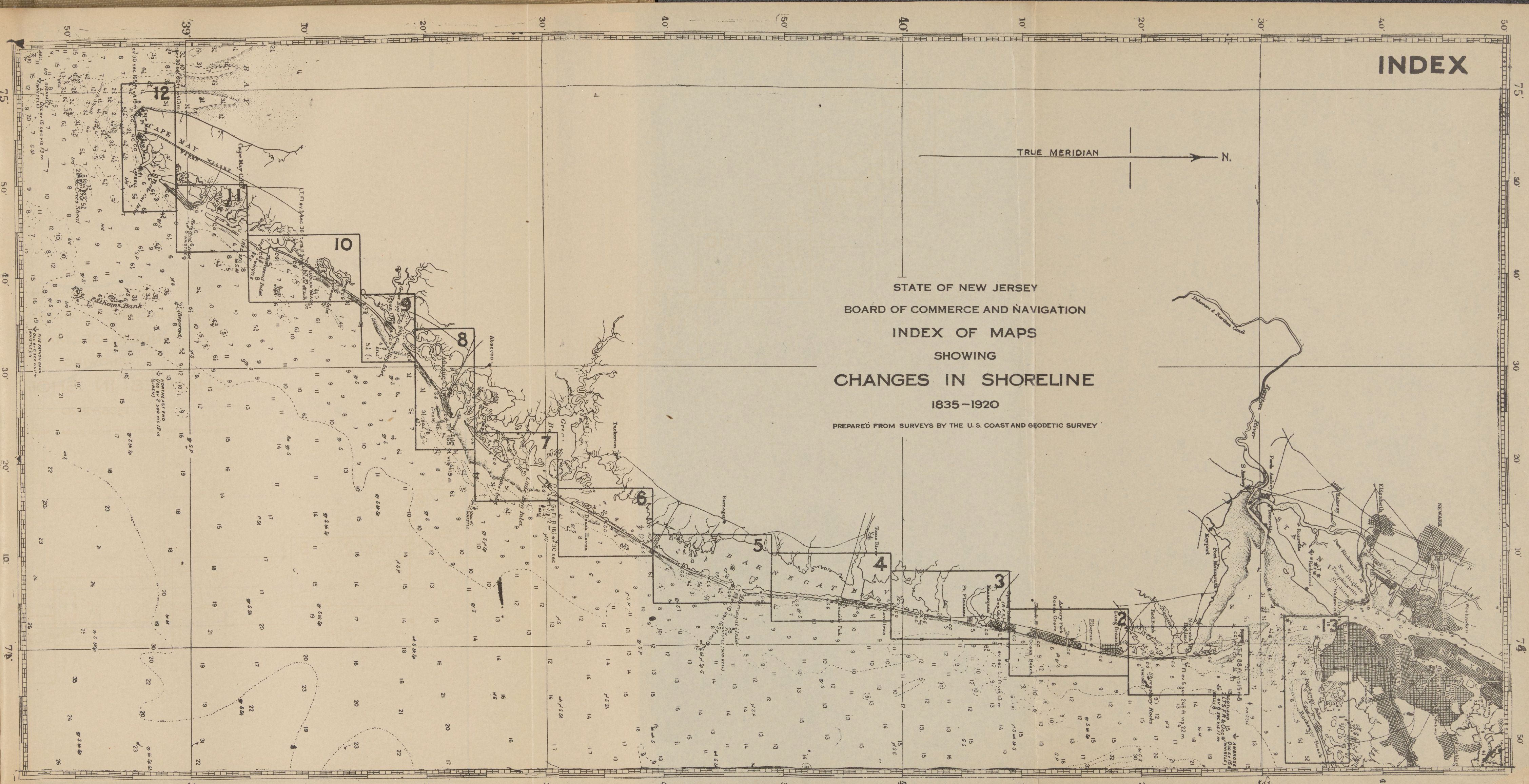
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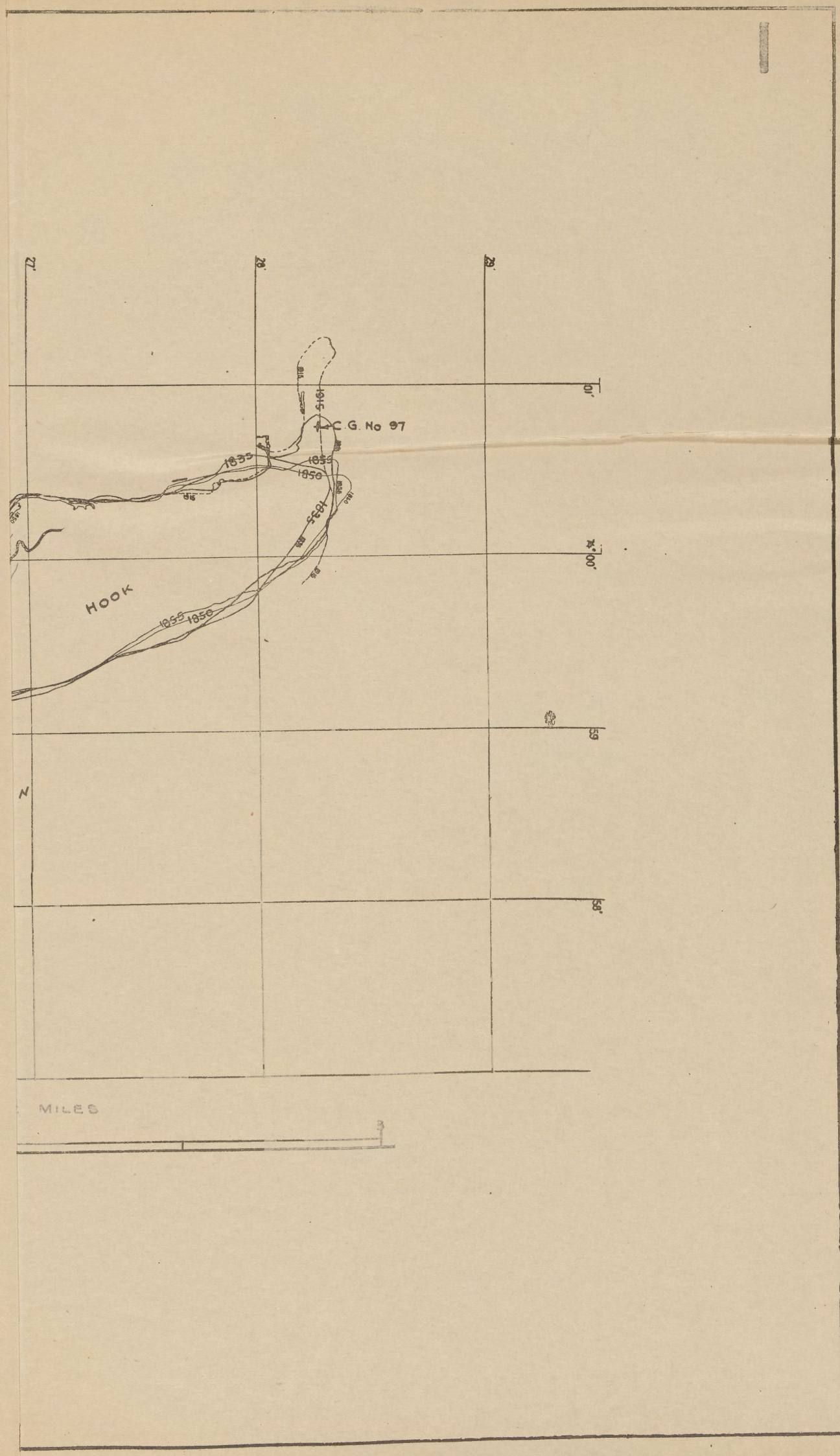
Southwest Spit
Sandy Hook Point
Sandy Hook Proper
Spermaceti Cove
Horseshoe Cove
Gravesend Bay
Coney Island
Rockaway Beach
Rockaway Inlet
Jamaica Bay
Barren Island
Canarsie
Flatbush
Brooklyn
Long Island
Fort Hamilton
Fort Wadsworth
Staten Island Sound
Prince Bay
Tottenville
Great Kills
Princes Bay
Lighthouse Point
Seguine Point
Old Orchard Shoal



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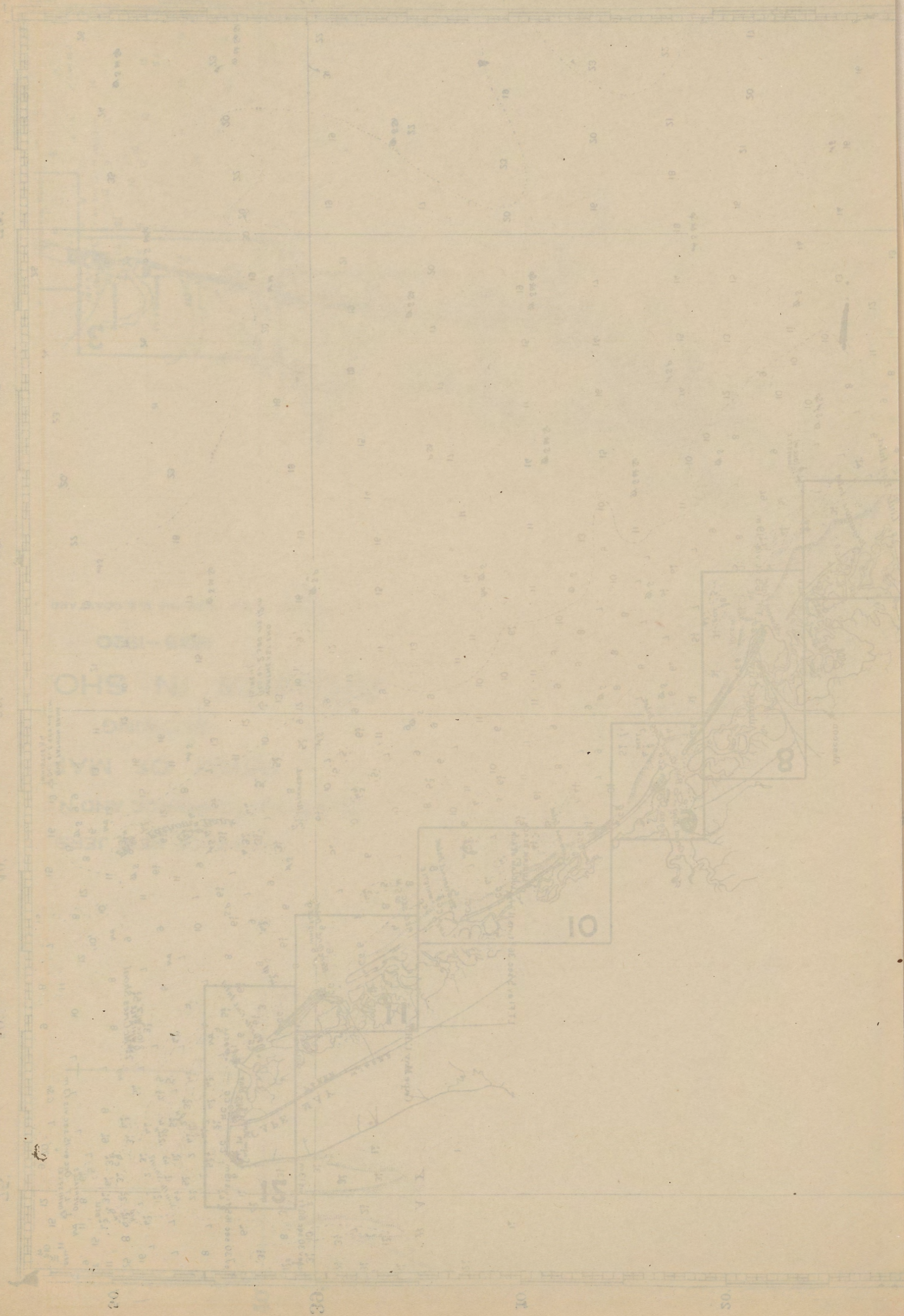
MILES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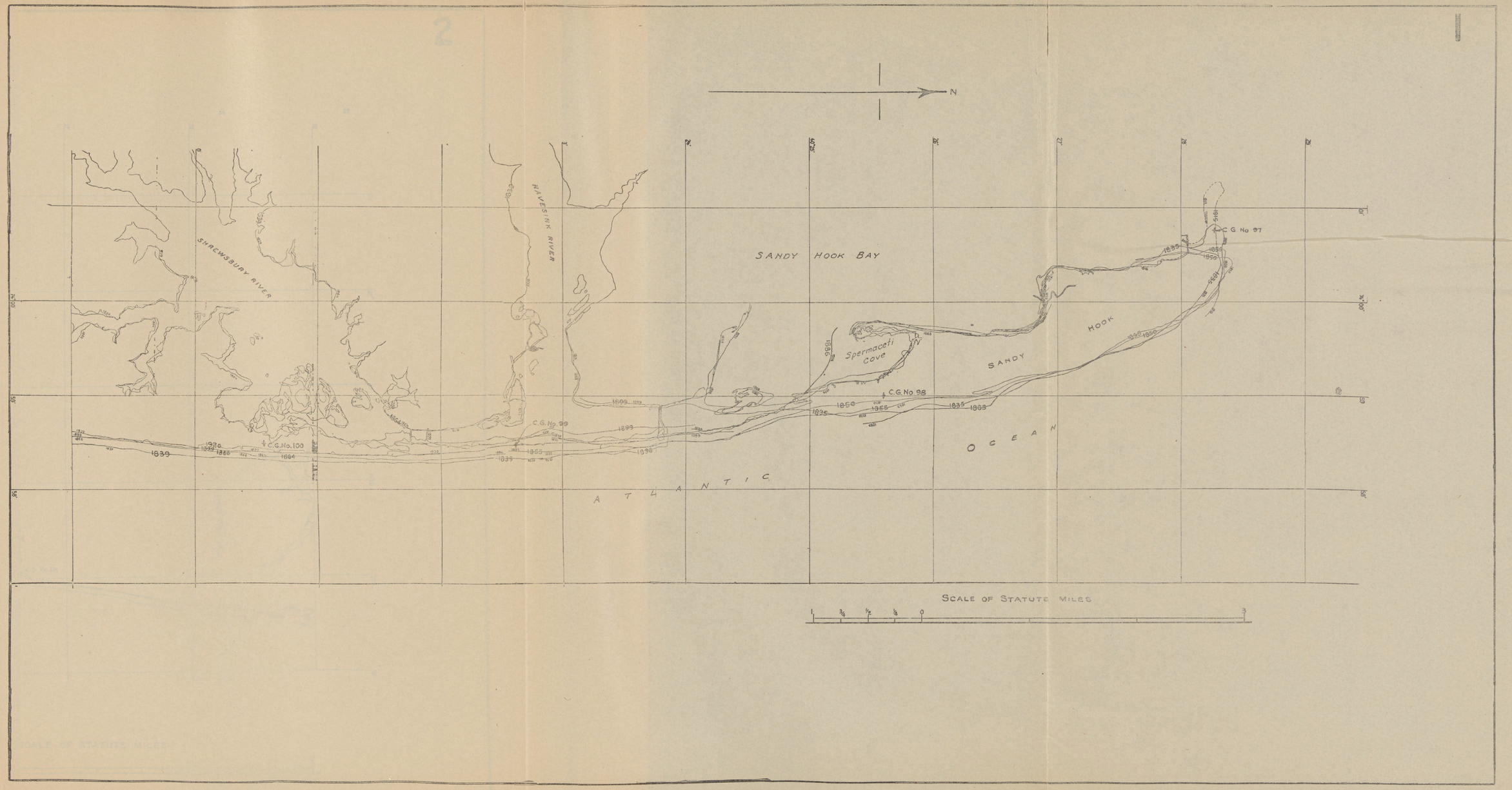
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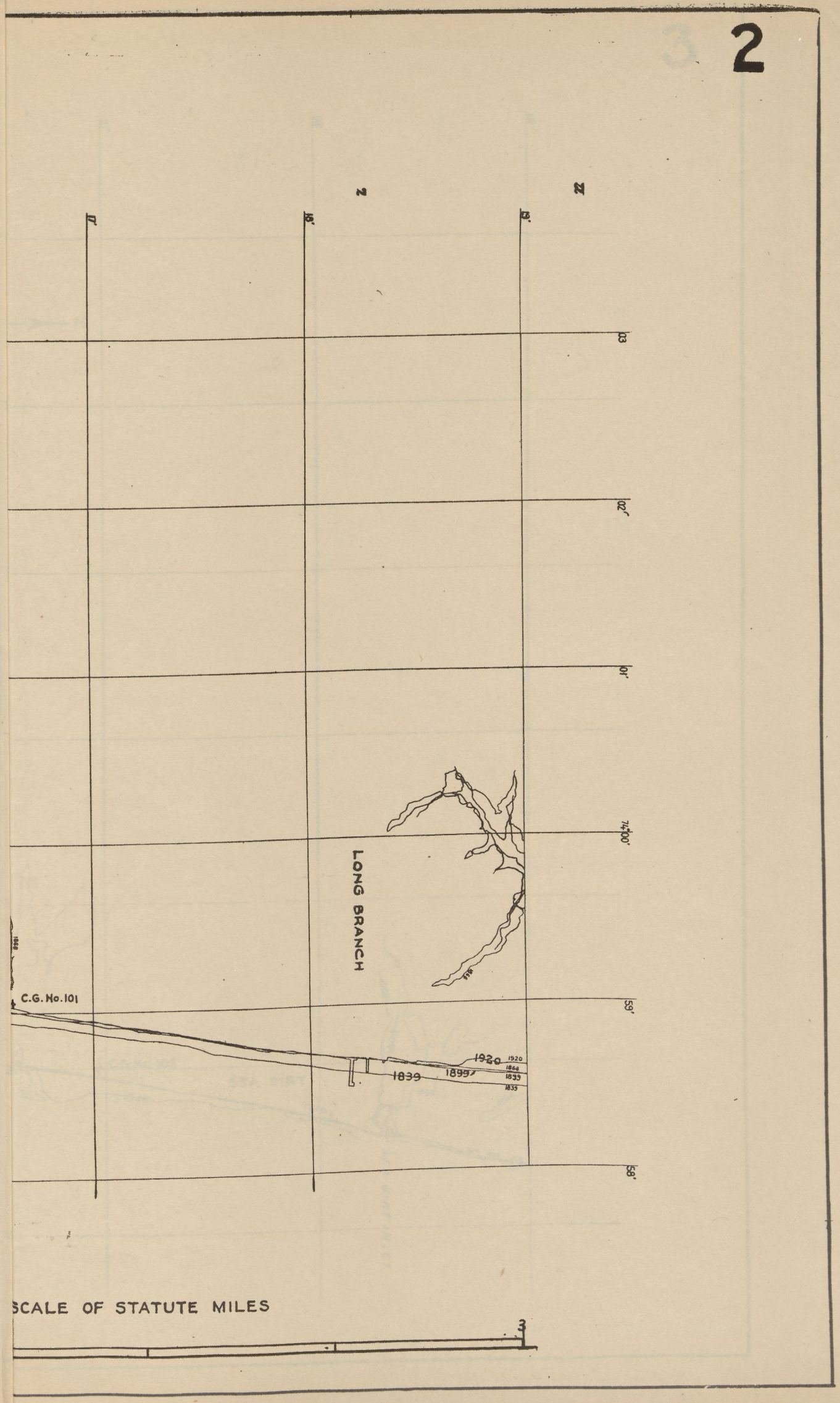
SHREWSBURY RIVER
HAVESINK RIVER
SANDY HOOK BAY
Spermaceti Cove
SANDY HOOK
OCEAN
ATLANTIC
C.G. No. 97
C.G. No. 98
C.G. No. 99
C.G. No. 100
SCALE OF STATUTE MILES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SCALE OF STATUTE MILES
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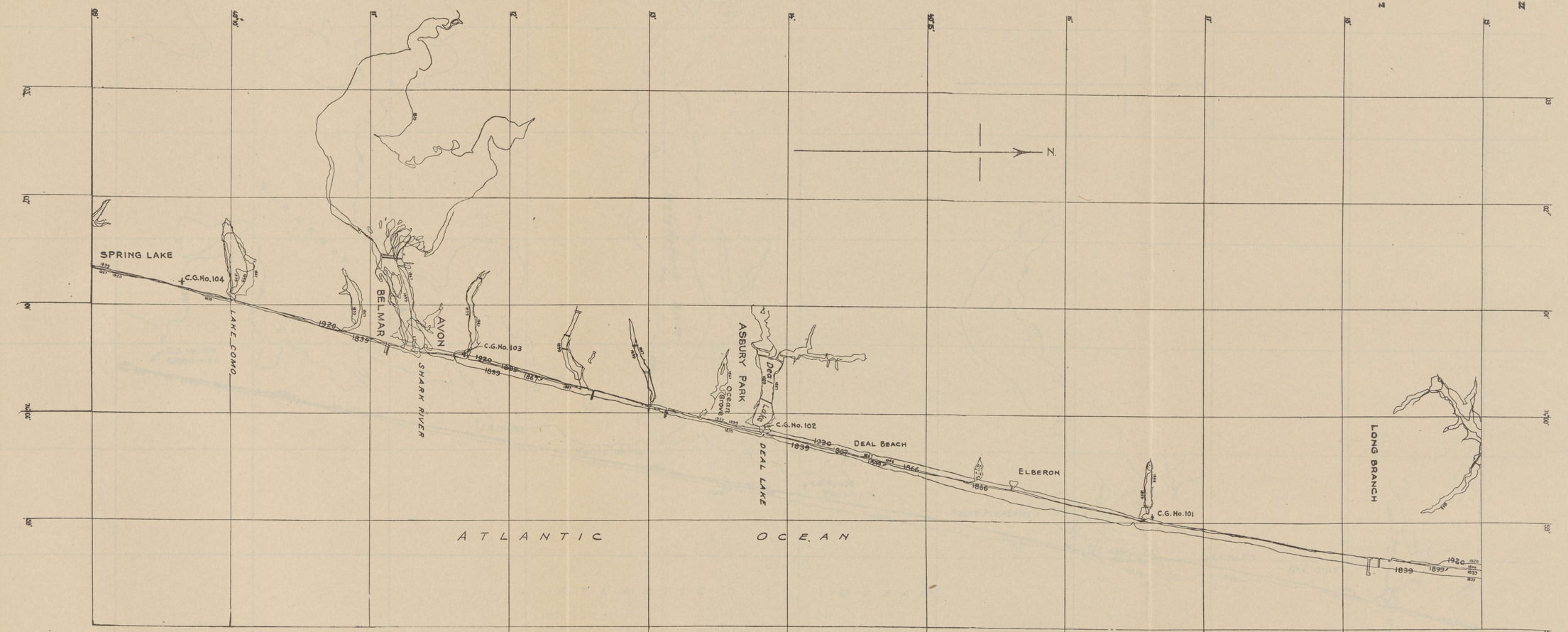
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AVON
C.G. No. 103
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Ocean Grove
DEAL LAKE
C.G. No. 102
DEAL BEACH
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C.G. No. 101
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SCALE OF STATUTE MILES
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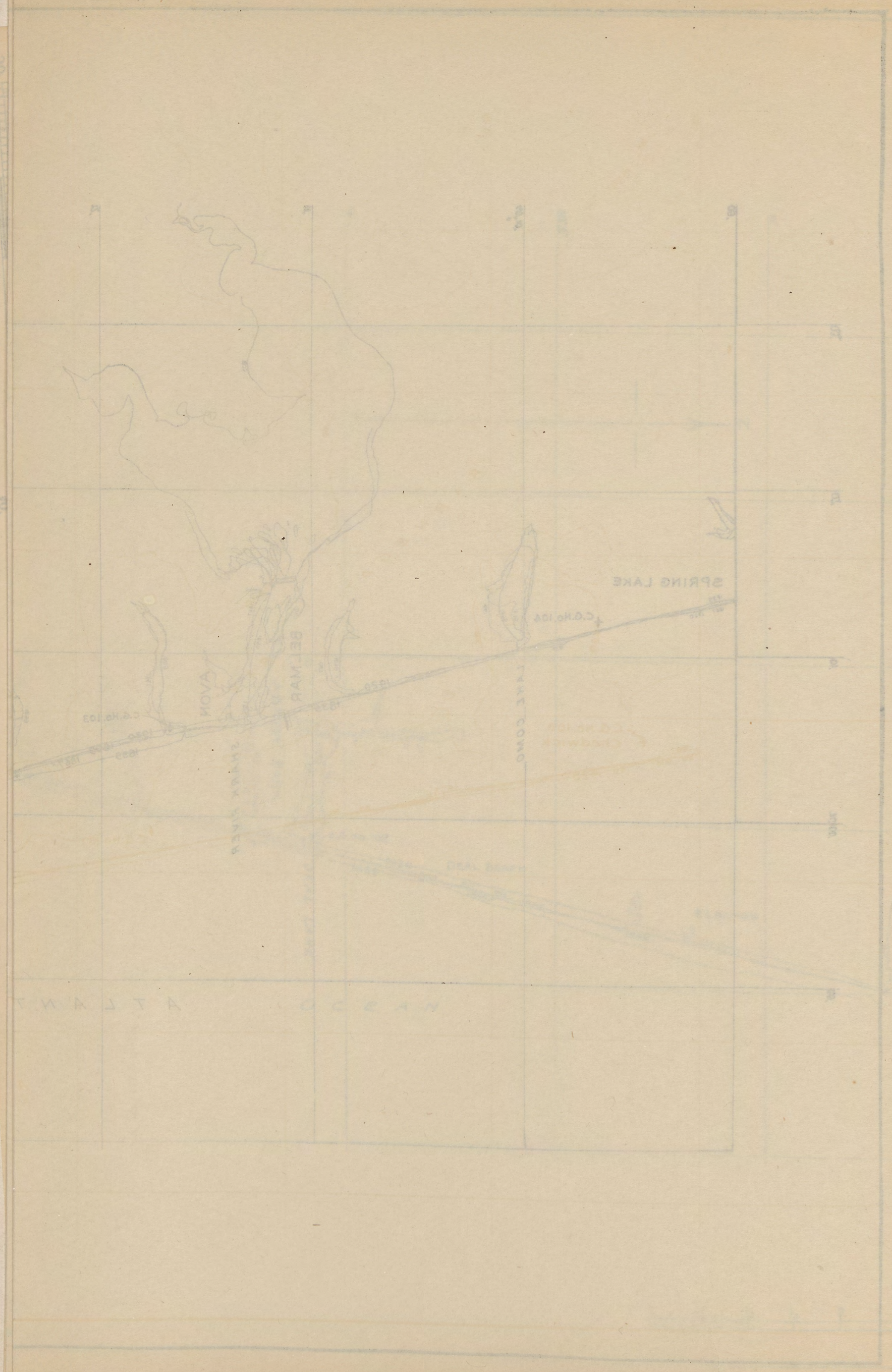

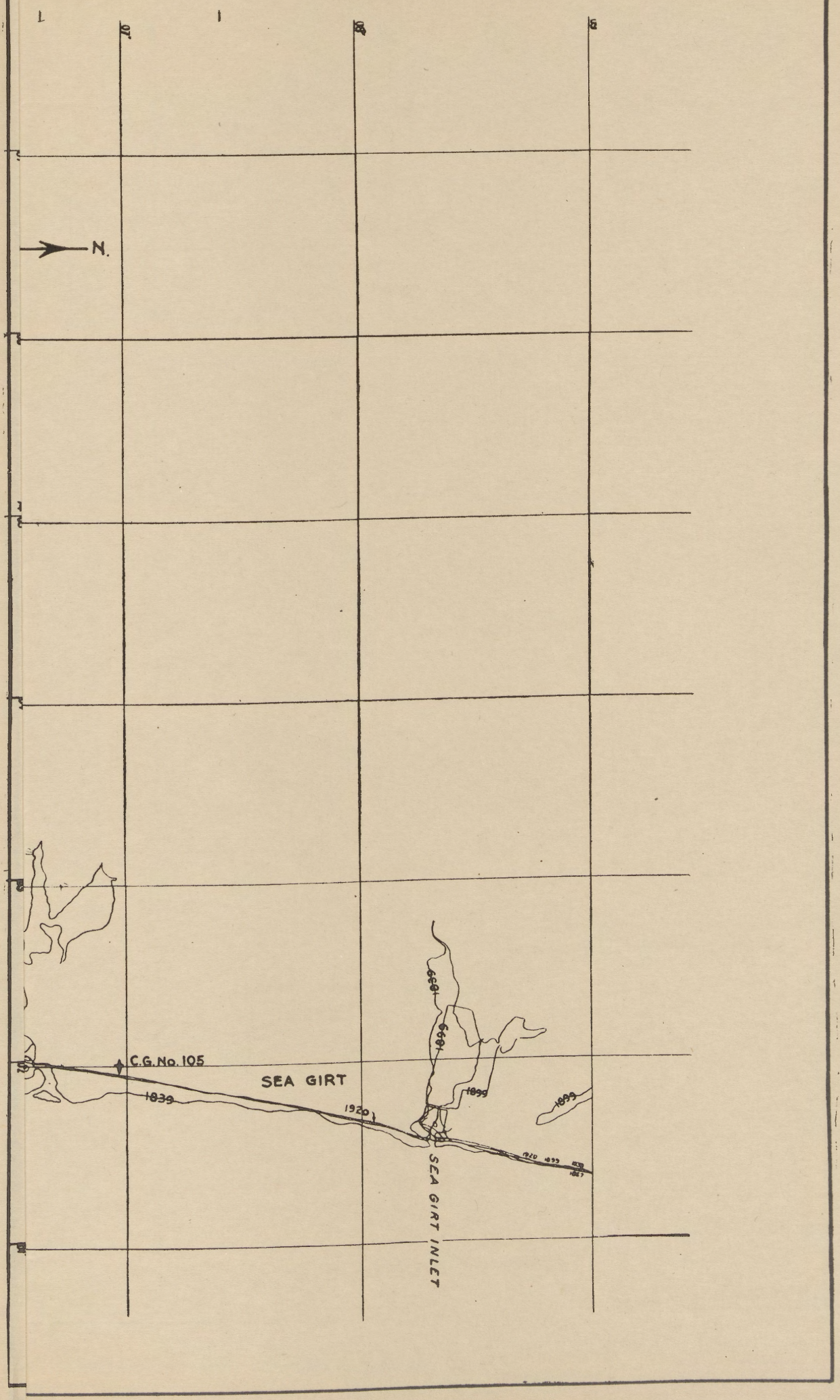
N.
C.G. No. 105
SEA GIRT
1839
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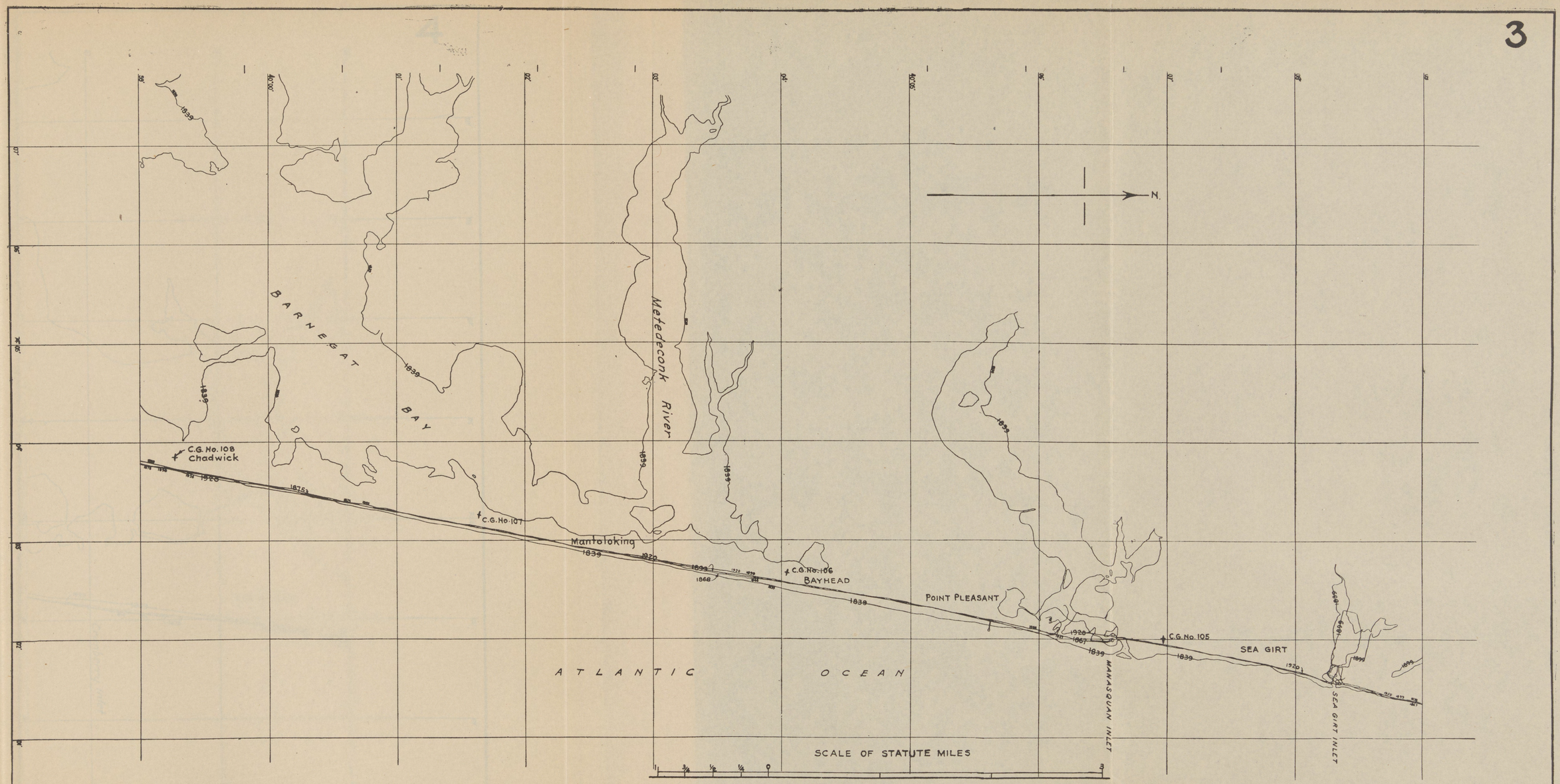
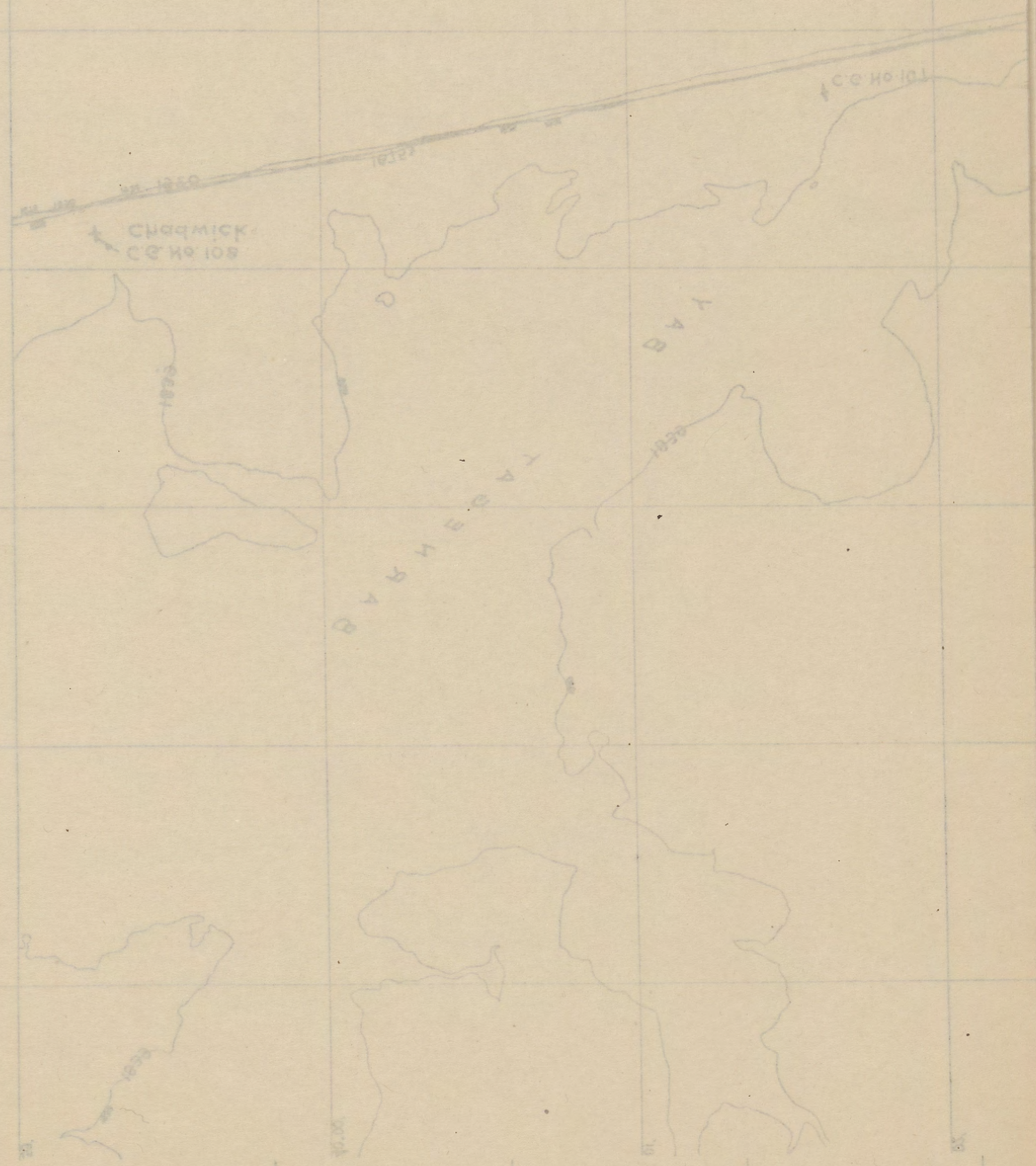
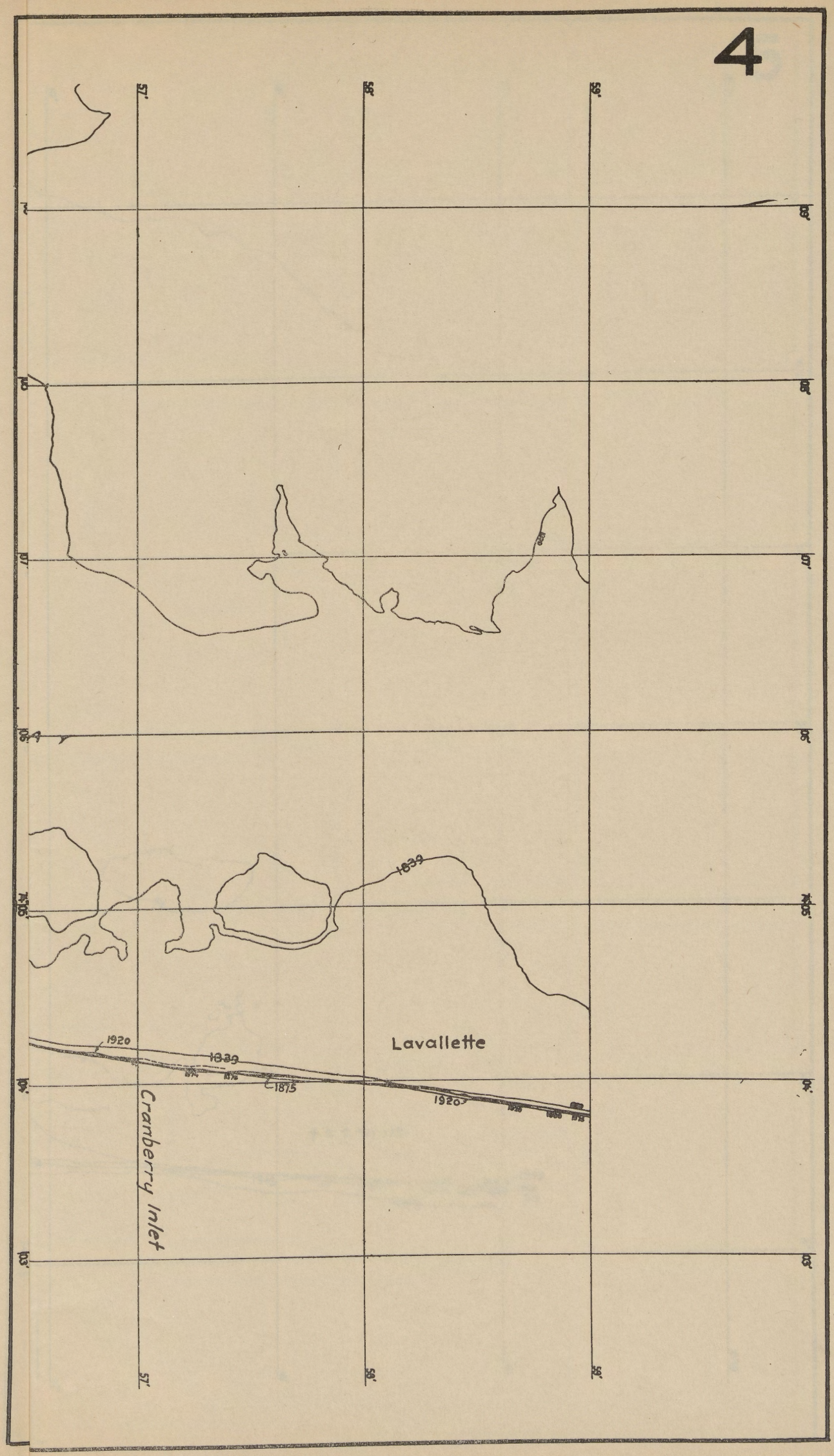
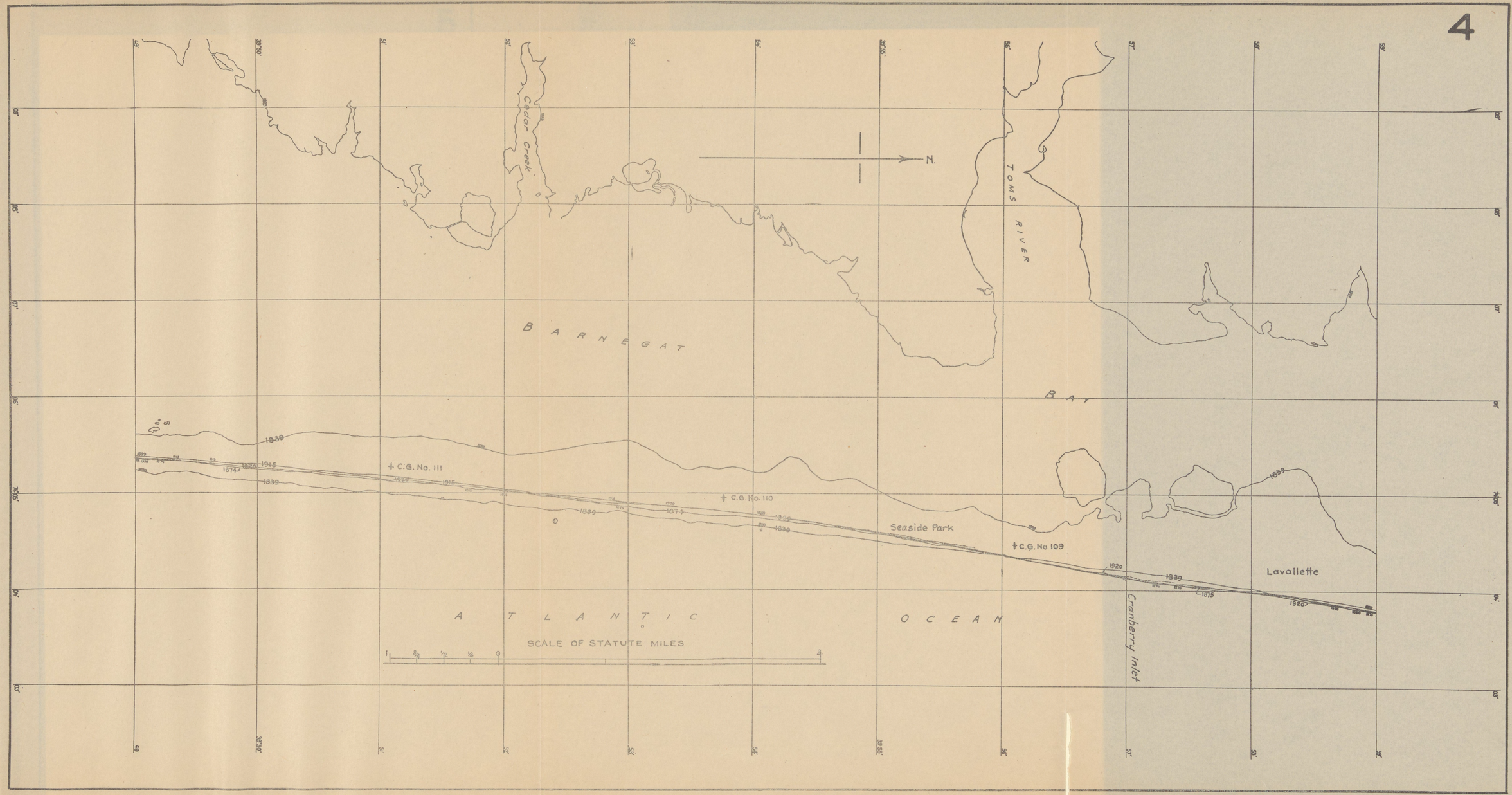
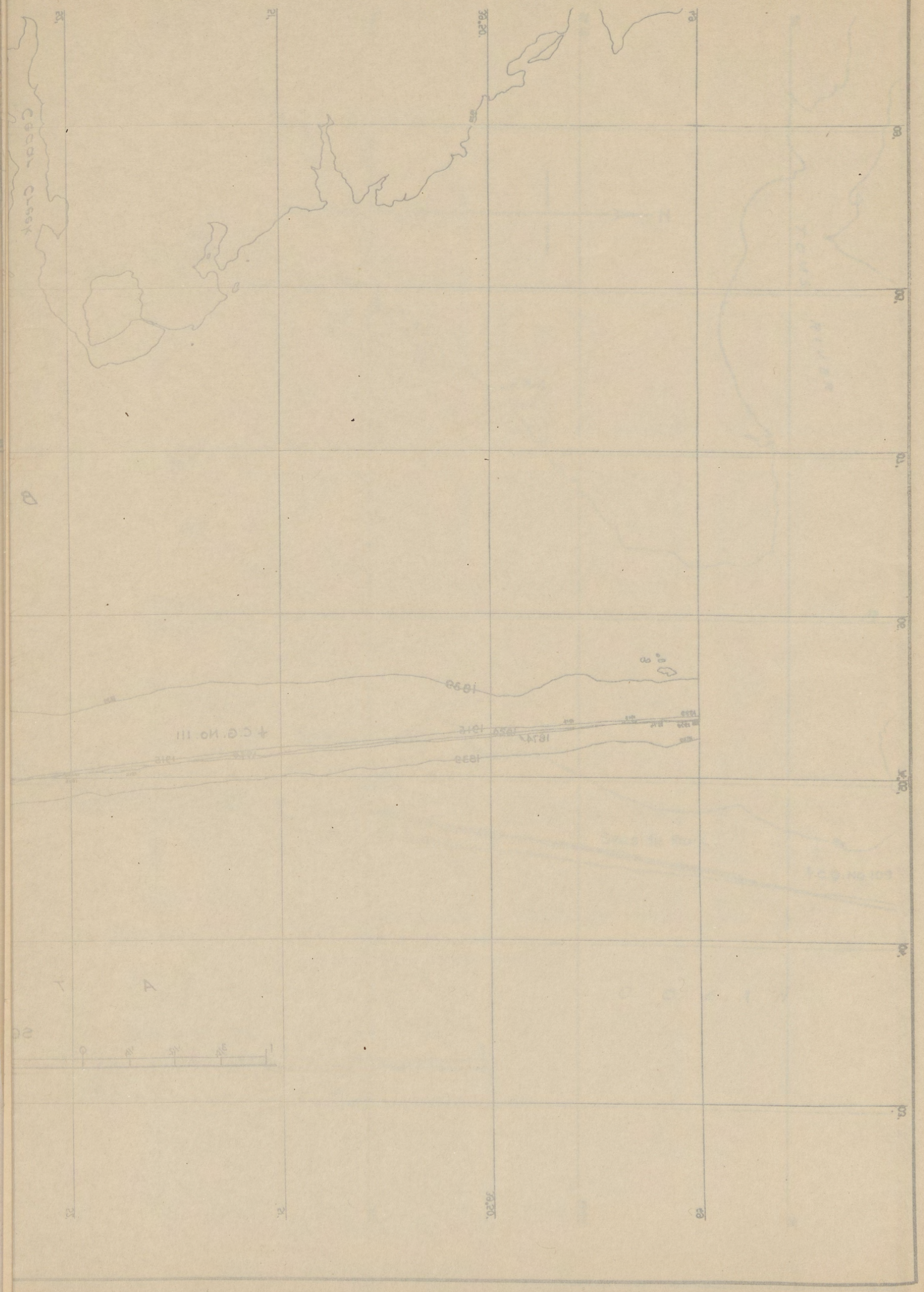
SEA GIRT INLET

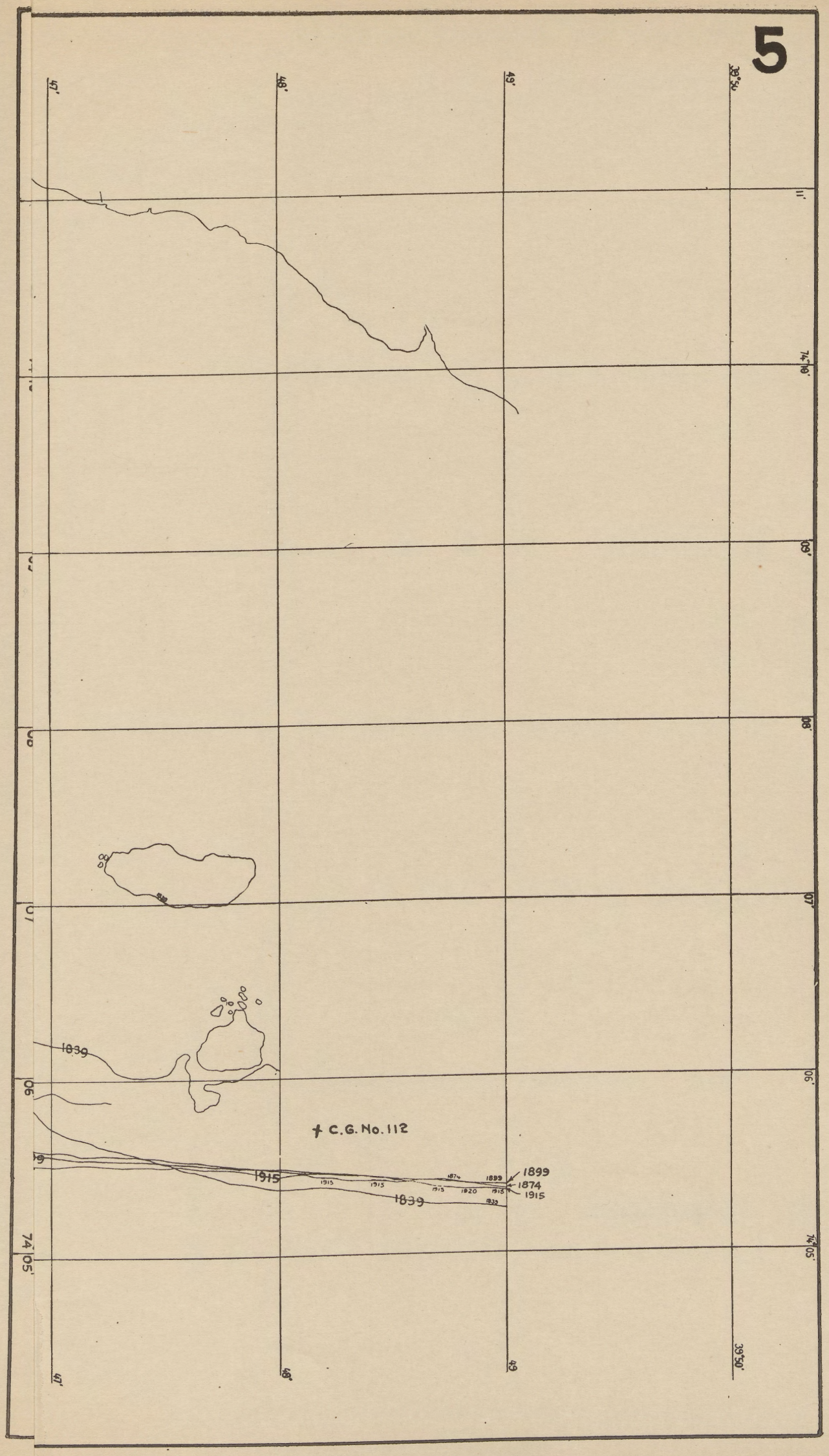

BARNEGAT BAY
Metedeconk River
ATLANTIC OCEAN
C.G. No. 108
Chadwick
C.G. No. 107
Manoloking
C.G. No. 106
BAYHEAD
POINT PLEASANT
C.G. No. 105
SEA GIRT
MANASQUAN INLET
SEA GIRT INLET
N.
SCALE OF STATUTE MILES

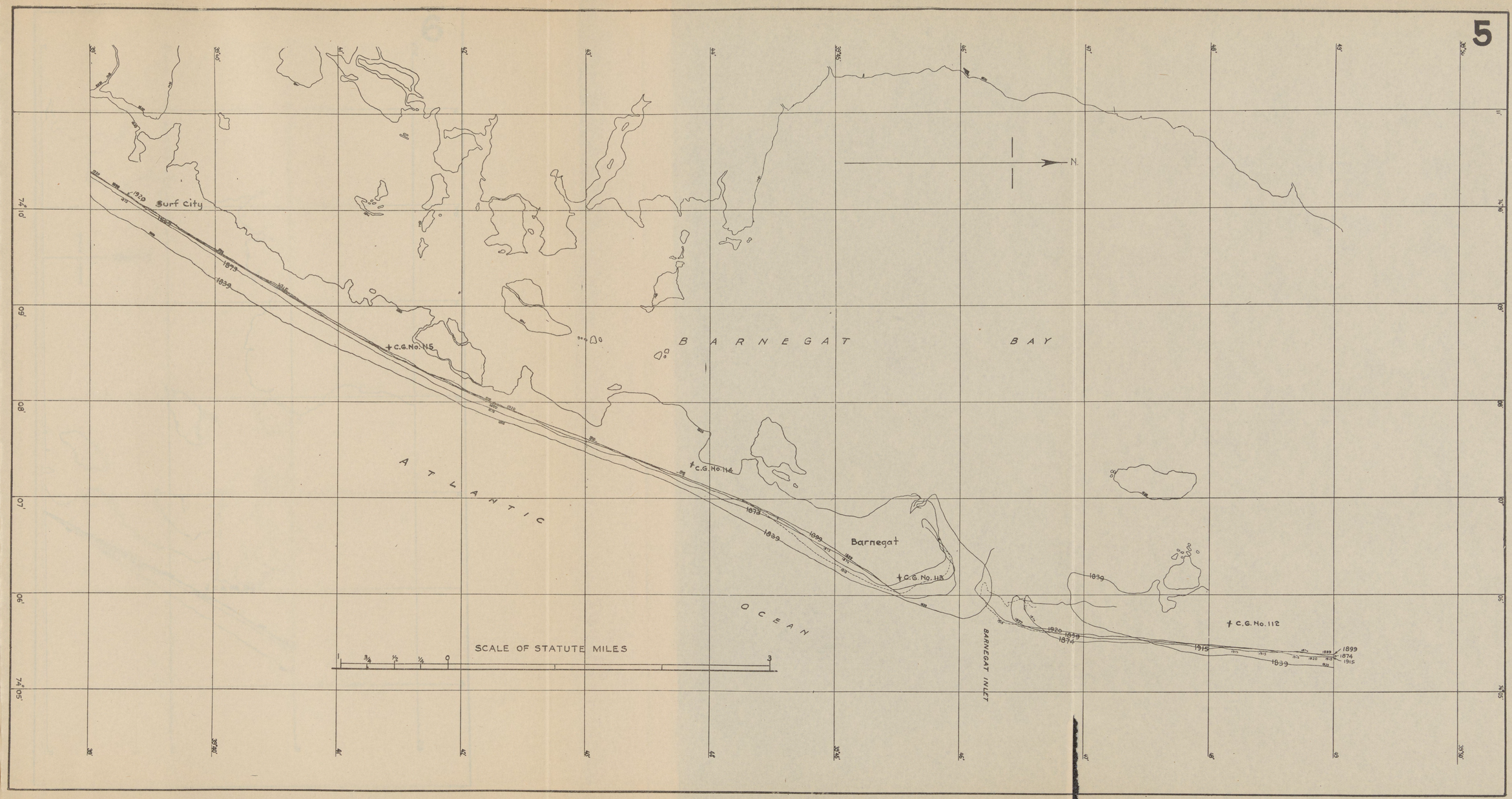


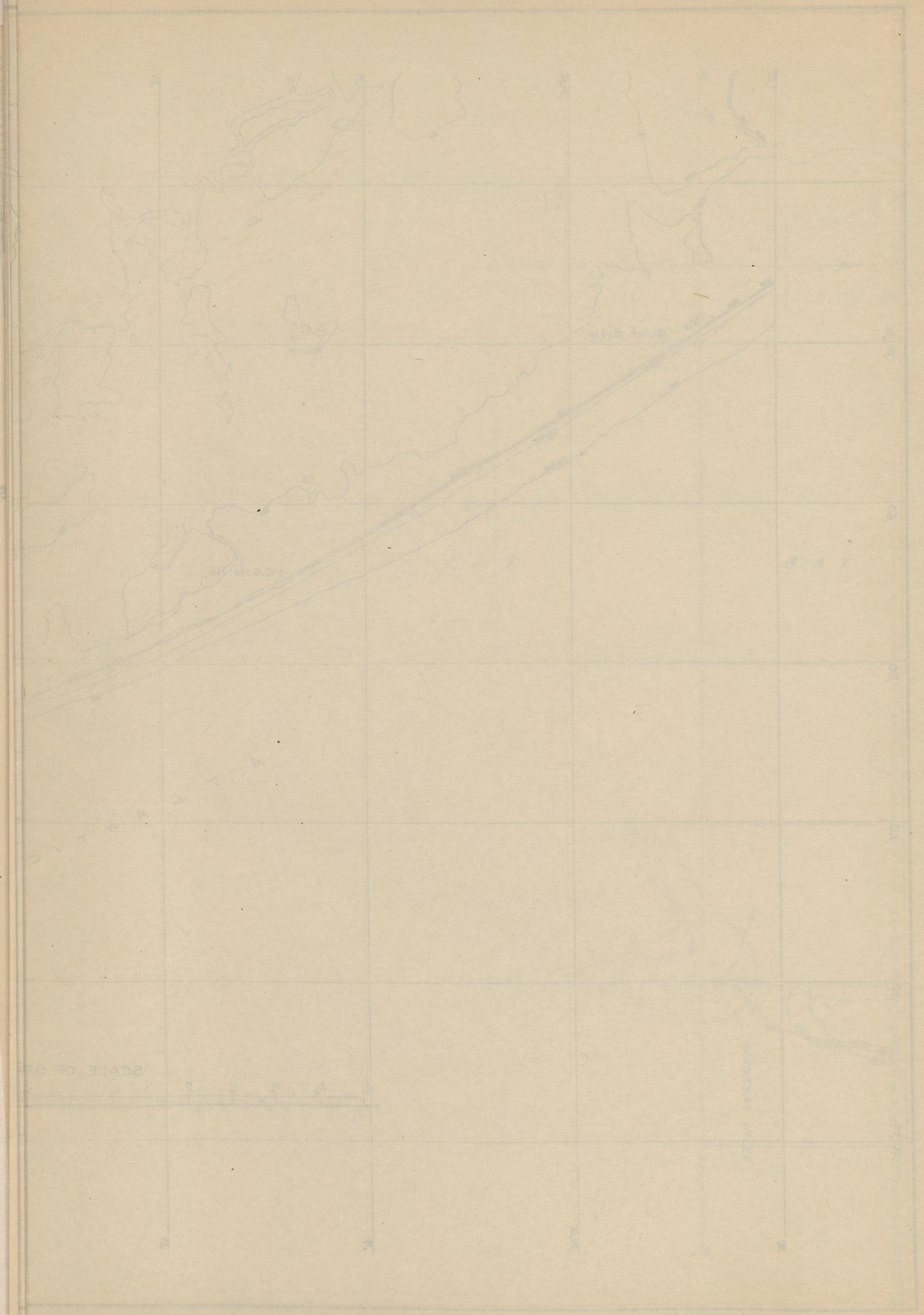

4
57'
58'
59'
1839
1920
1839
1875
1920
Lavallette
Cranberry Inlet

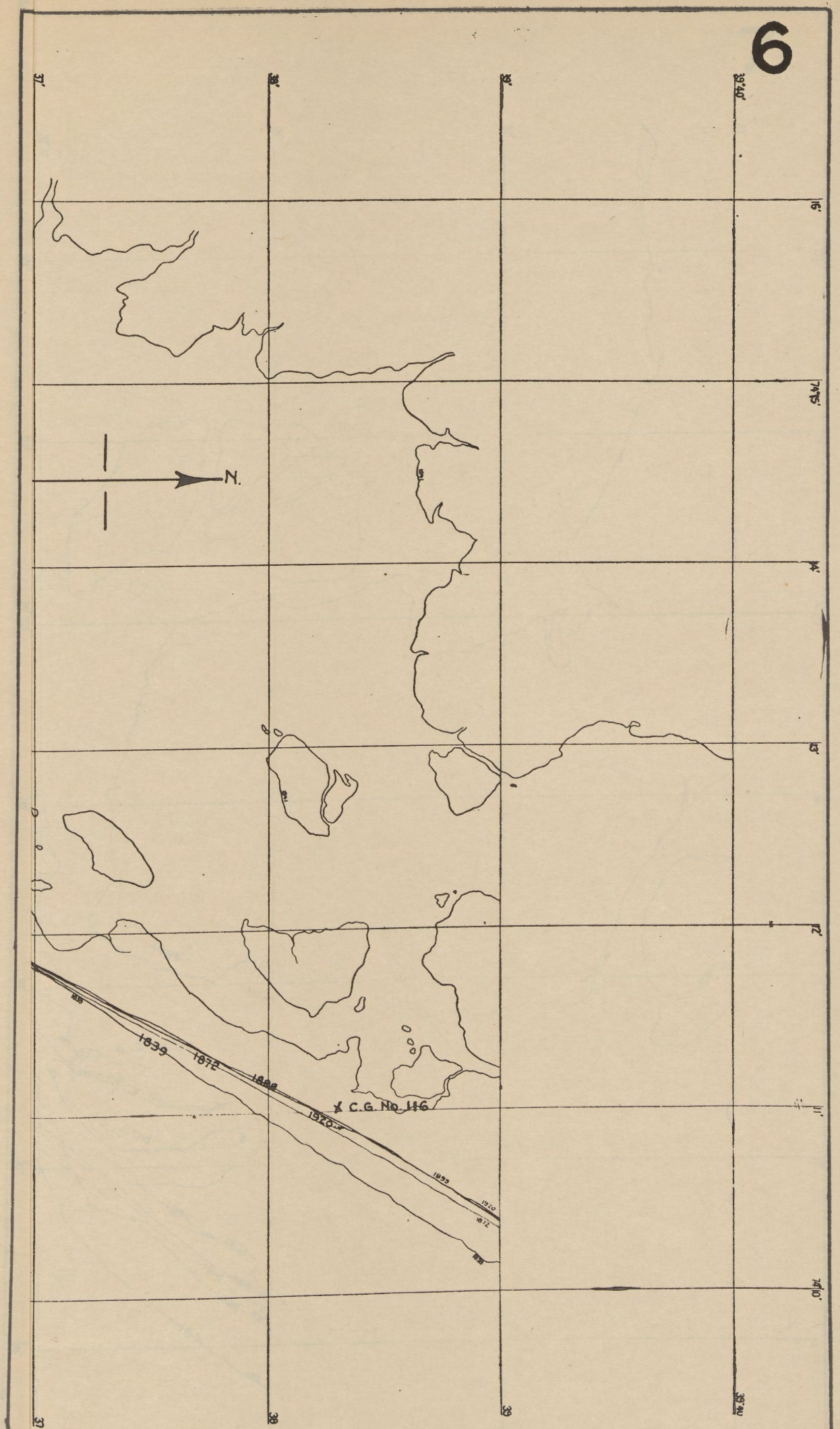

Cedar Creek
N.
TOMS RIVER
BARNEGAT
BAY
C.G. No. 111
C.G. No. 110
C.G. No. 109
Seaside Park
Lavallette
Cranberry Inlet
ATLANTIC
OCEAN
SCALE OF STATUTE MILES

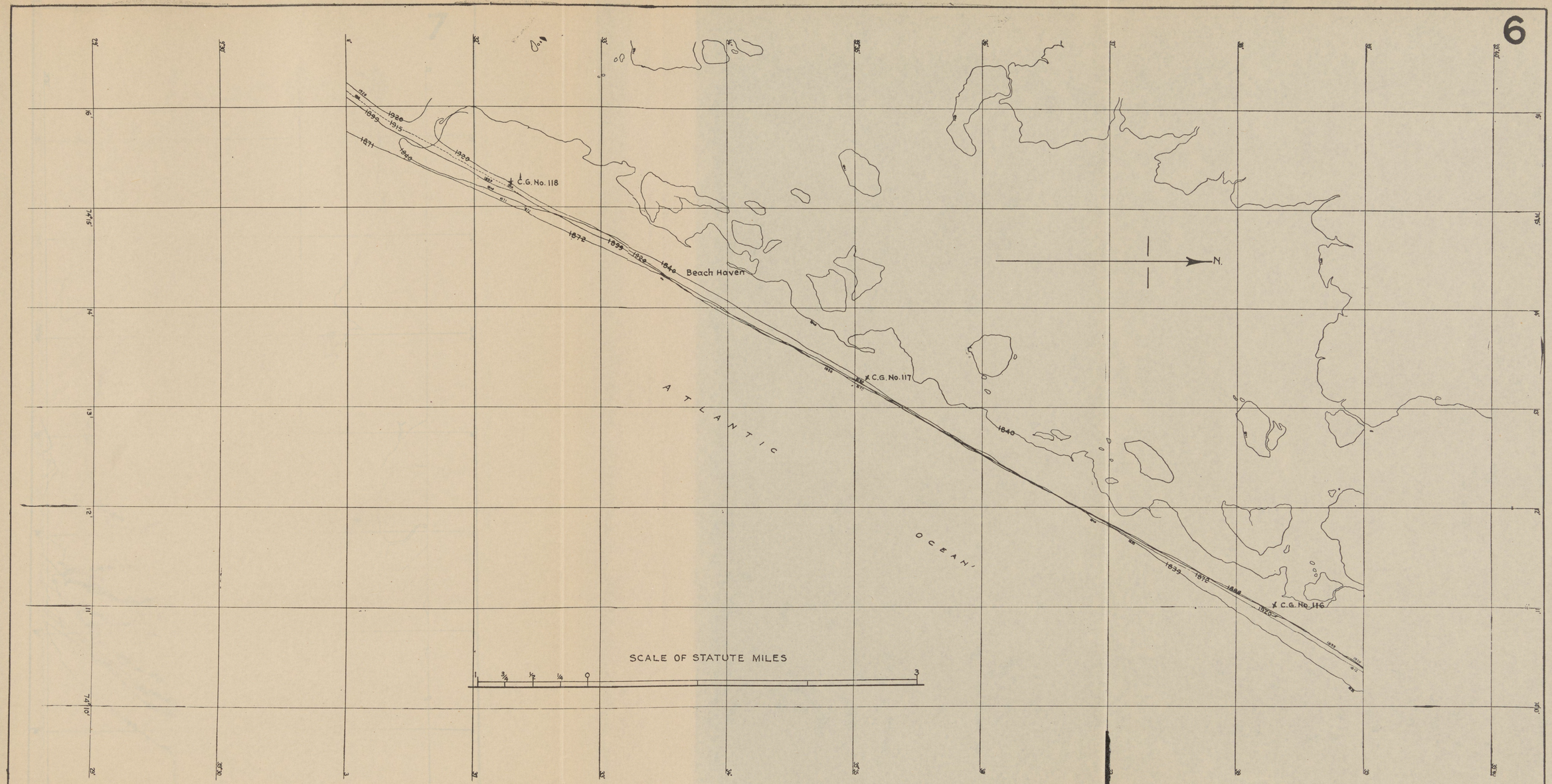

CEDAR CREEK

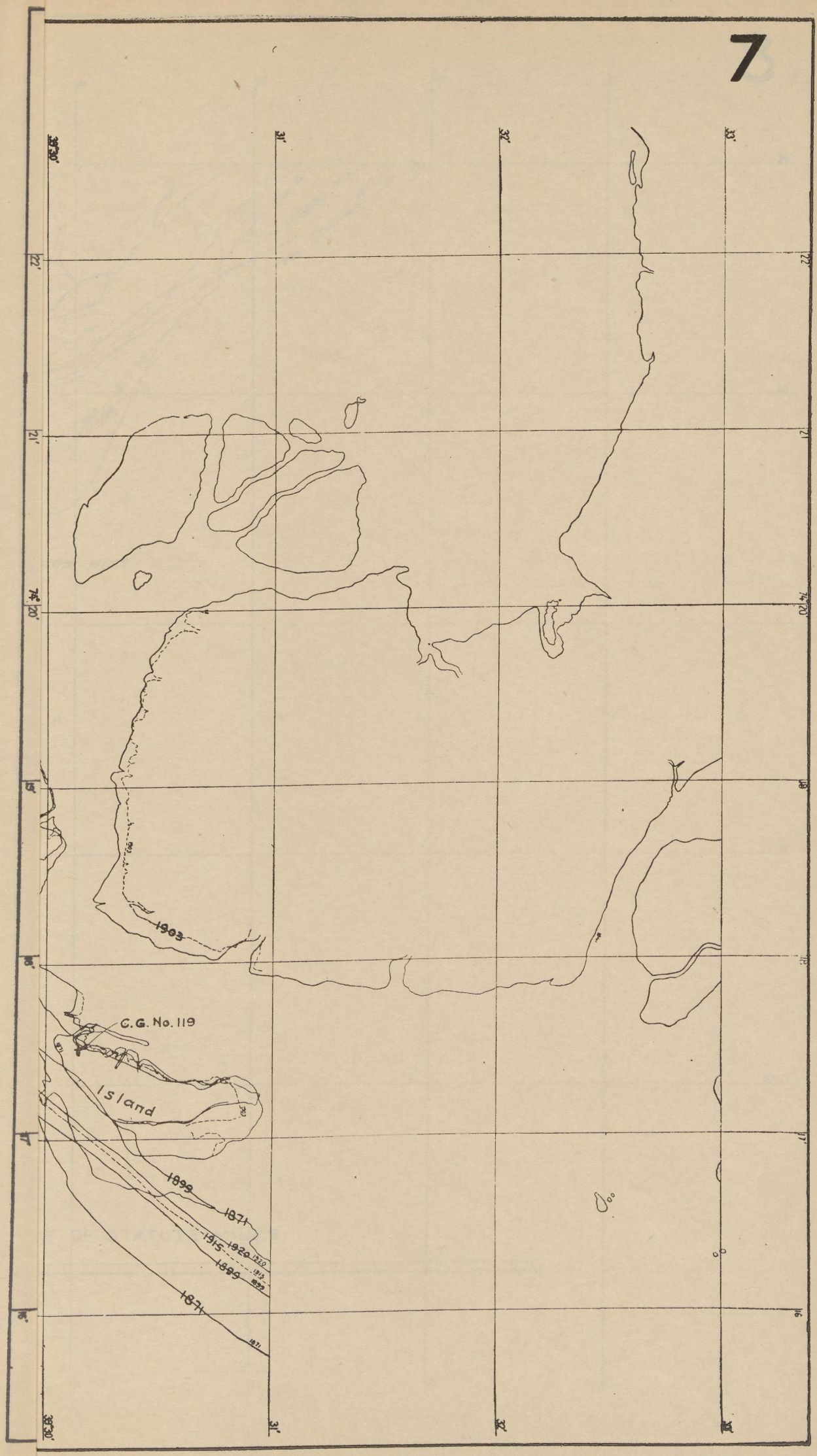

5
47'
48'
49'
39°50'
11'
74°10'
09'
08'
07'
06'
74°05'
1839
1915
1899
1874
1915
1839
C.G. No. 112


5
N.
Surf City
1920
1873
1839
C.G. No. 115
BARNEGAT BAY
C.G. No. 114
ATLANTIC
OCEAN
Barnegat
C.G. No. 113
1899
1874
1915
C.G. No. 112
BARNEGAT INLET
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3



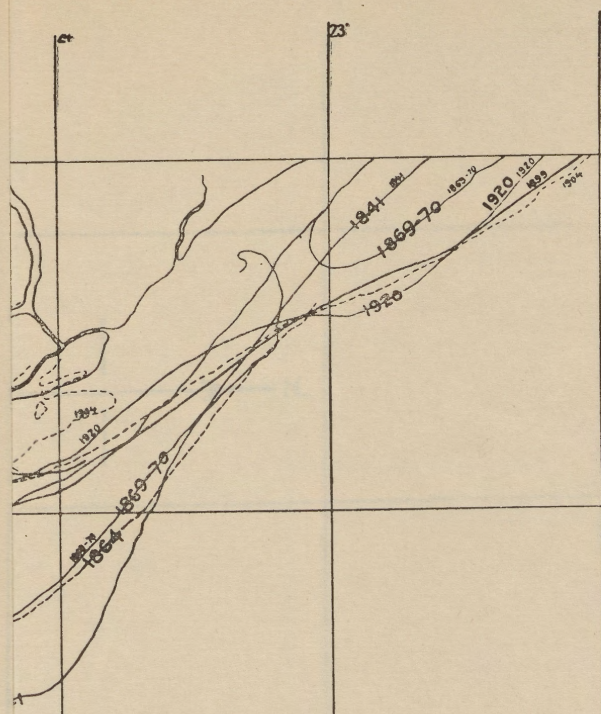

6
N.
C.G. No. 116
1839
1872
1888
1920
1899
1920
1872
37'
38'
39'
39°40'
16'
74°15'
14'
13'
12'
11'
74°10'


6
C.G. No. 118
C.G. No. 117
C.G. No. 116
Beach Haven
ATLANTIC
OCEAN
N.
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3
1920
1915
1899
1871
1840
1872
1839


7
C.G. No. 119
Island
1903
1899
1871
1915
1920
1899
1871

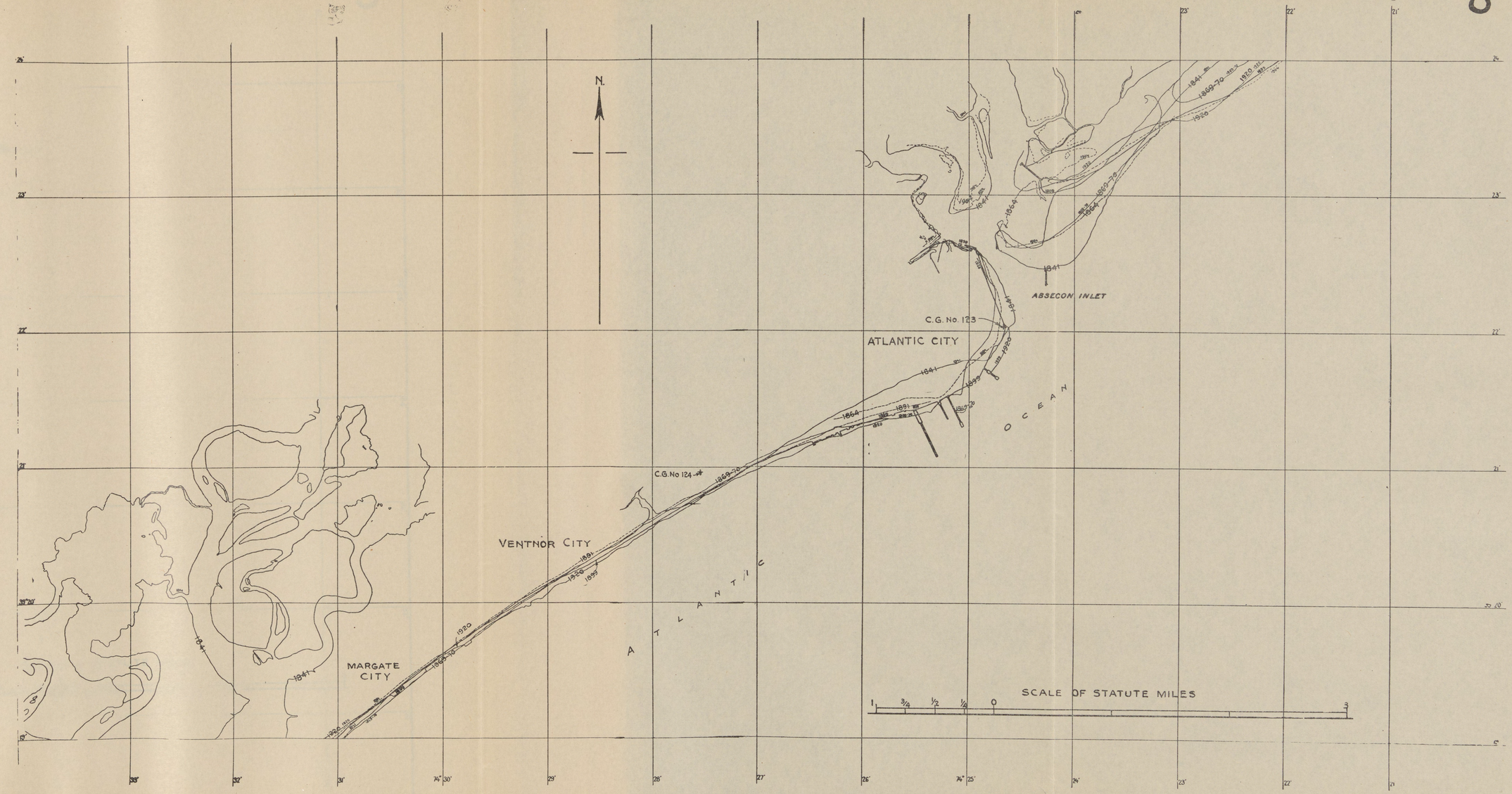

C.G. No 128
Brigantine
C.G. No 121
C.G. No. 120
C.G. No. 119
Tucker Island
BRIGANTINE INLET
LITTLE EGG INLET
ATLANTIC OCEAN
N.
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3

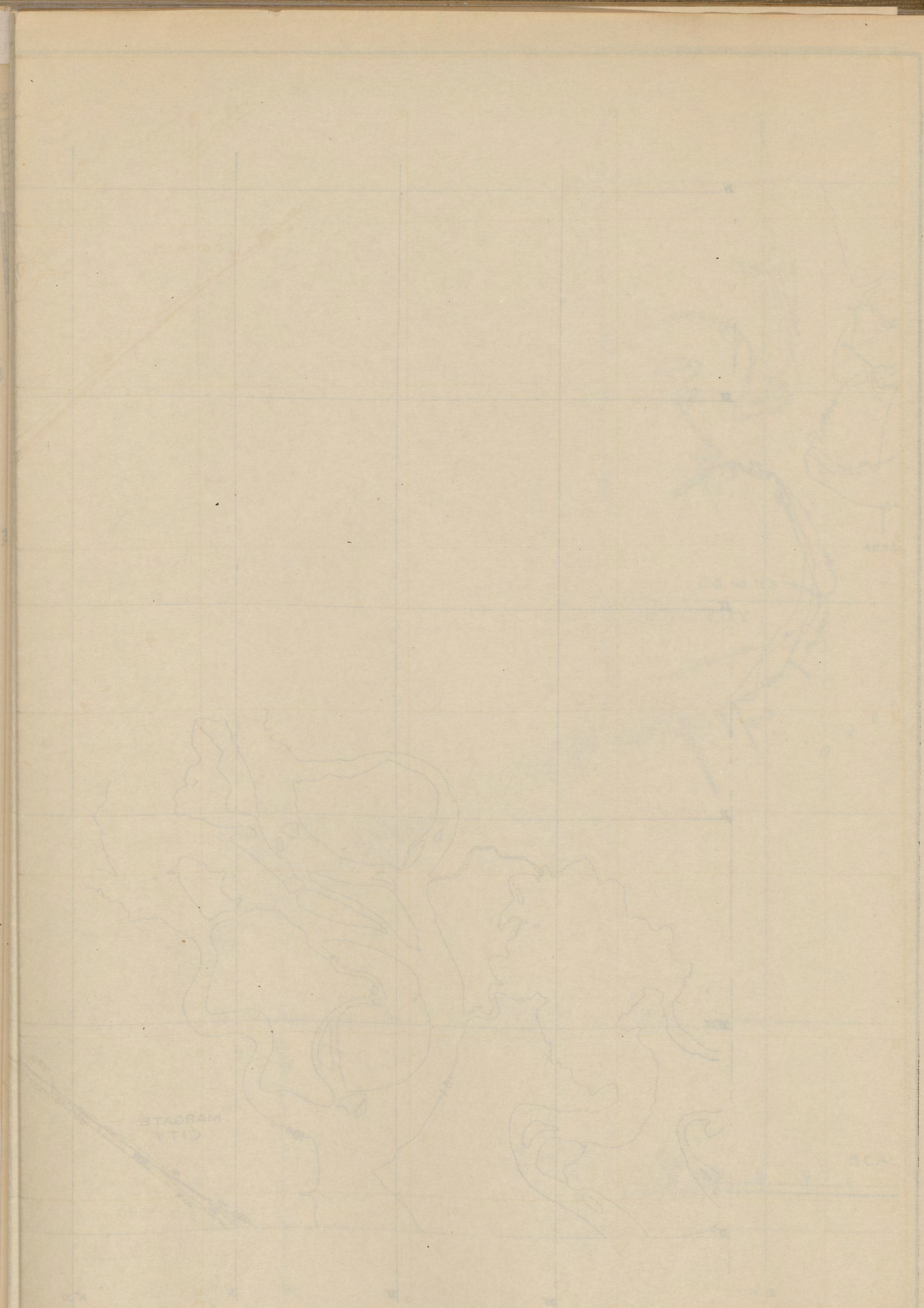
8



CON INLET

E OF STATUTE MILES


N.
ABSECON INLET
C.G. No. 123
ATLANTIC CITY
C.G. No 124
VENTNOR CITY
MARGATE CITY
ATLANTIC OCEAN
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3

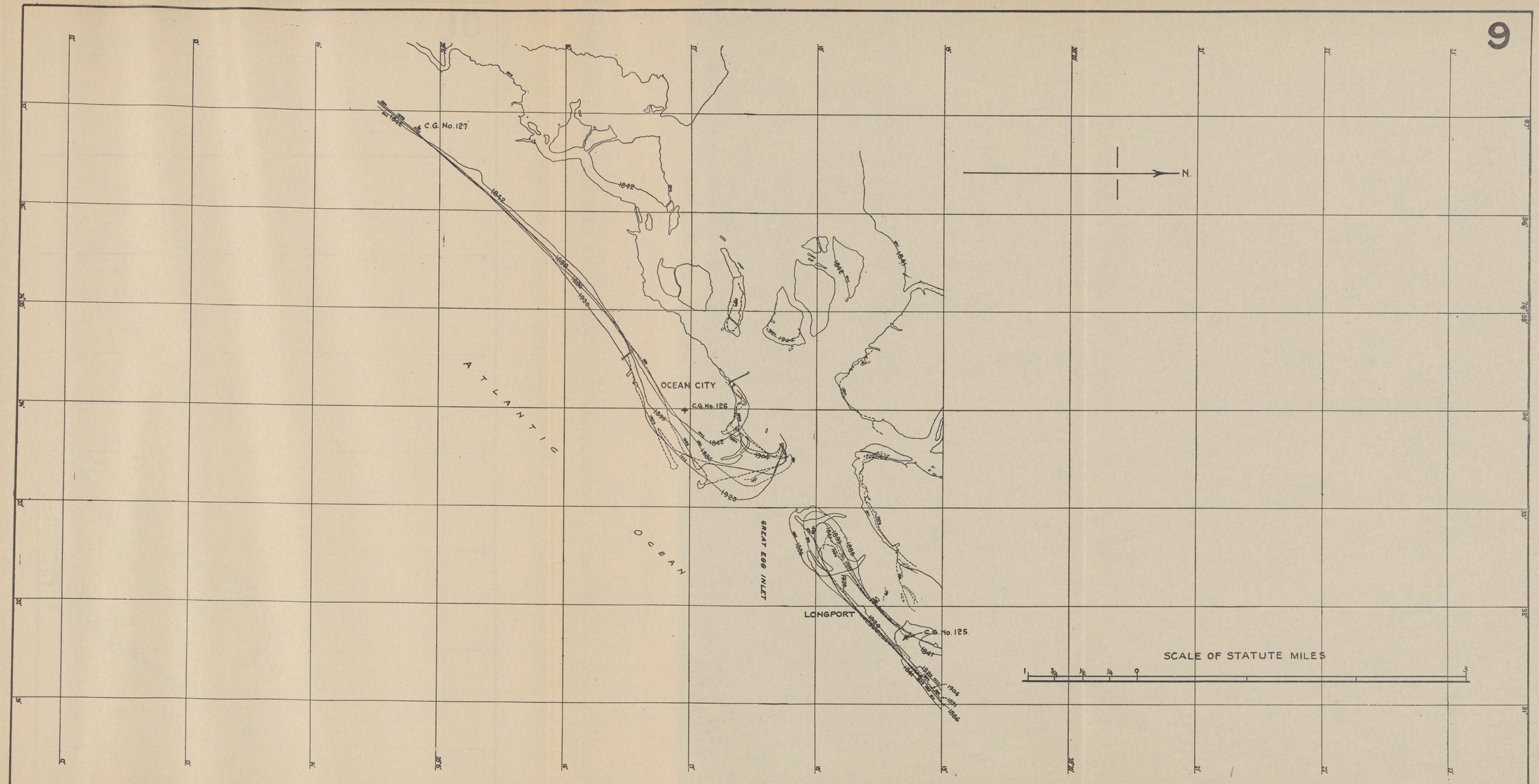


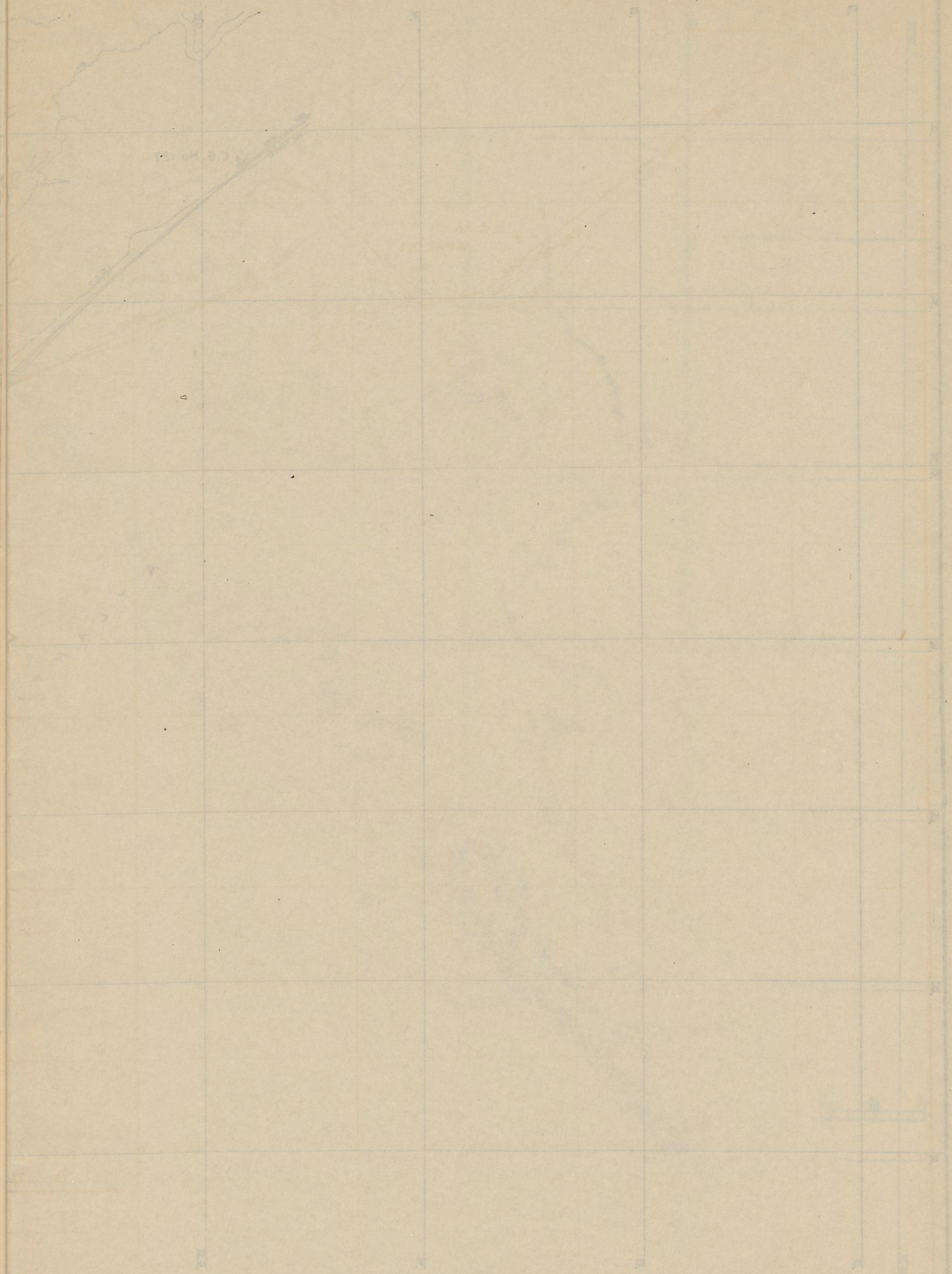
9

N.

SCALE OF STATUTE MILES

1/4 0 3


9
N.
C.G. No. 127
OCEAN CITY
C.G. No. 126
ATLANTIC
OCEAN
GREAT EGG INLET
LONGPORT
C.G. No. 125
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3



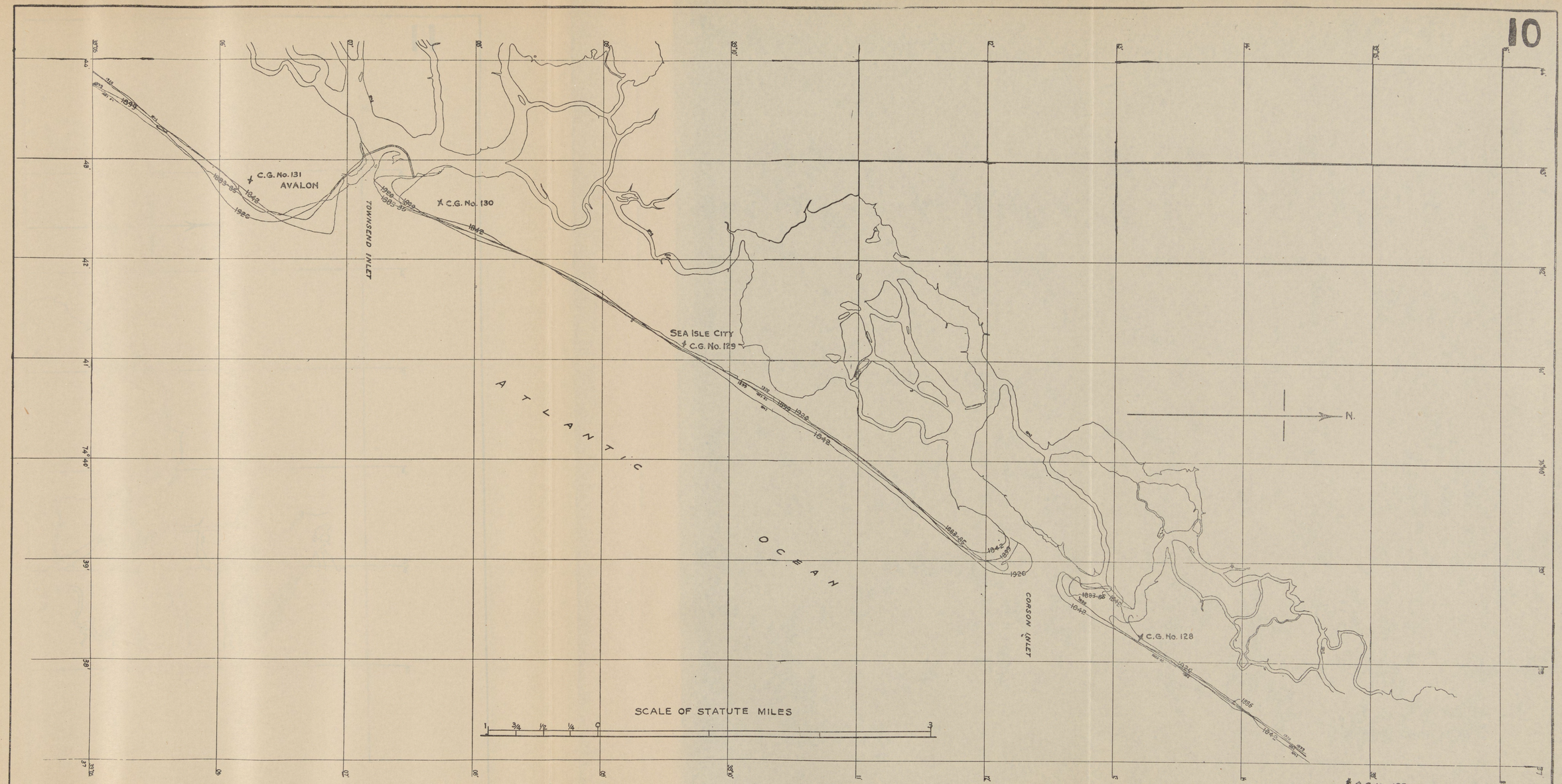
10

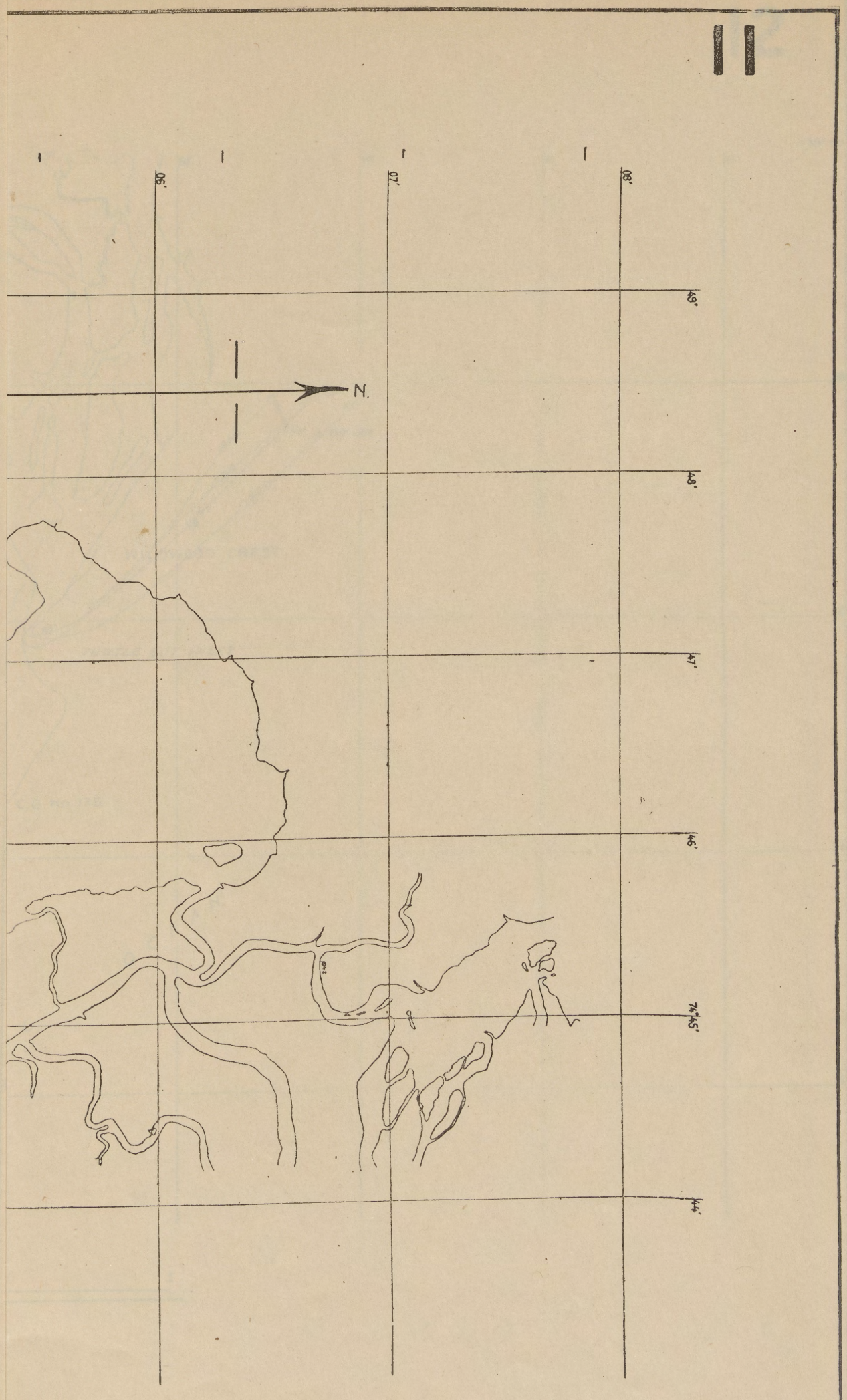
N.

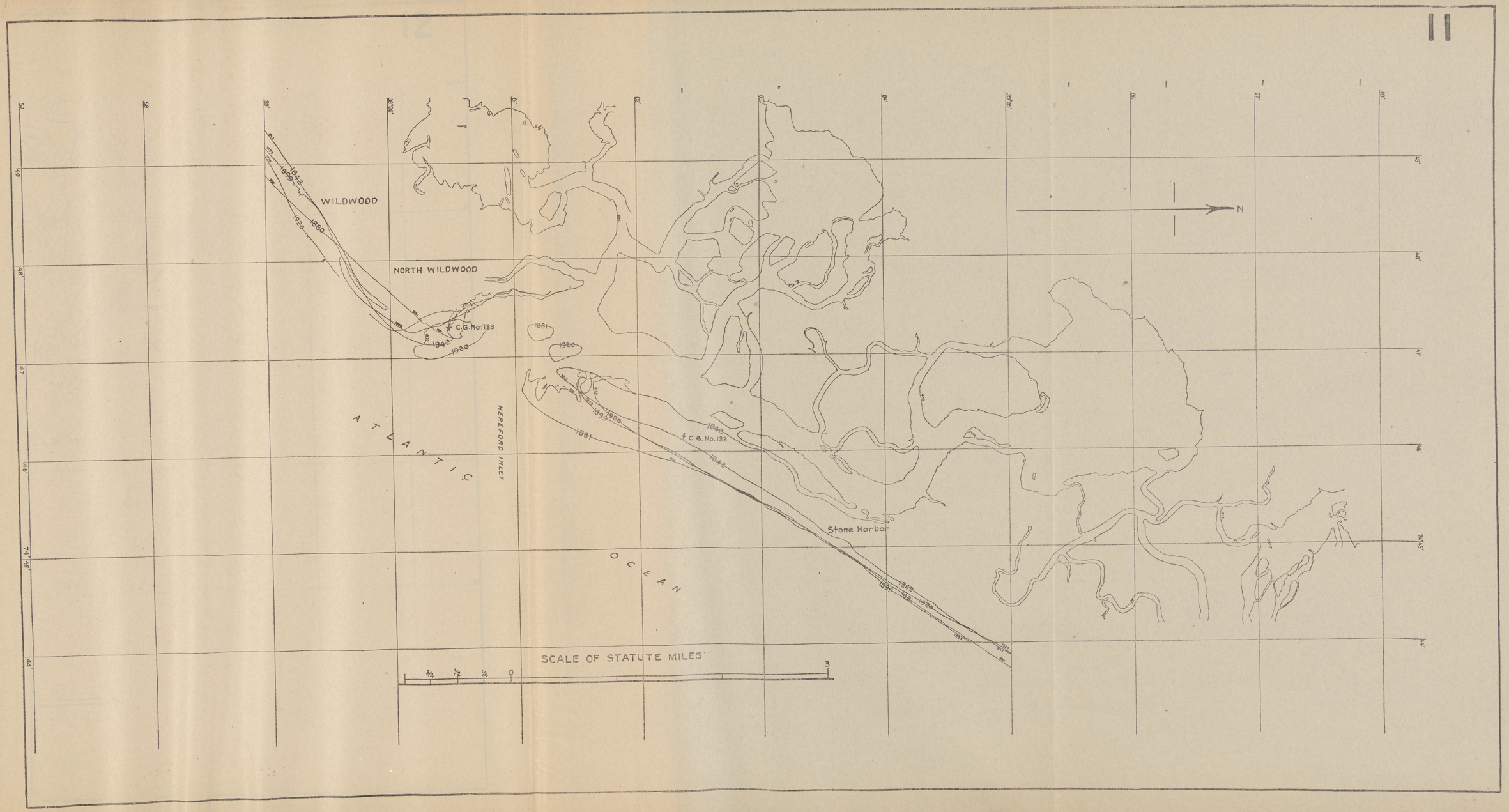
C.G. No. 128

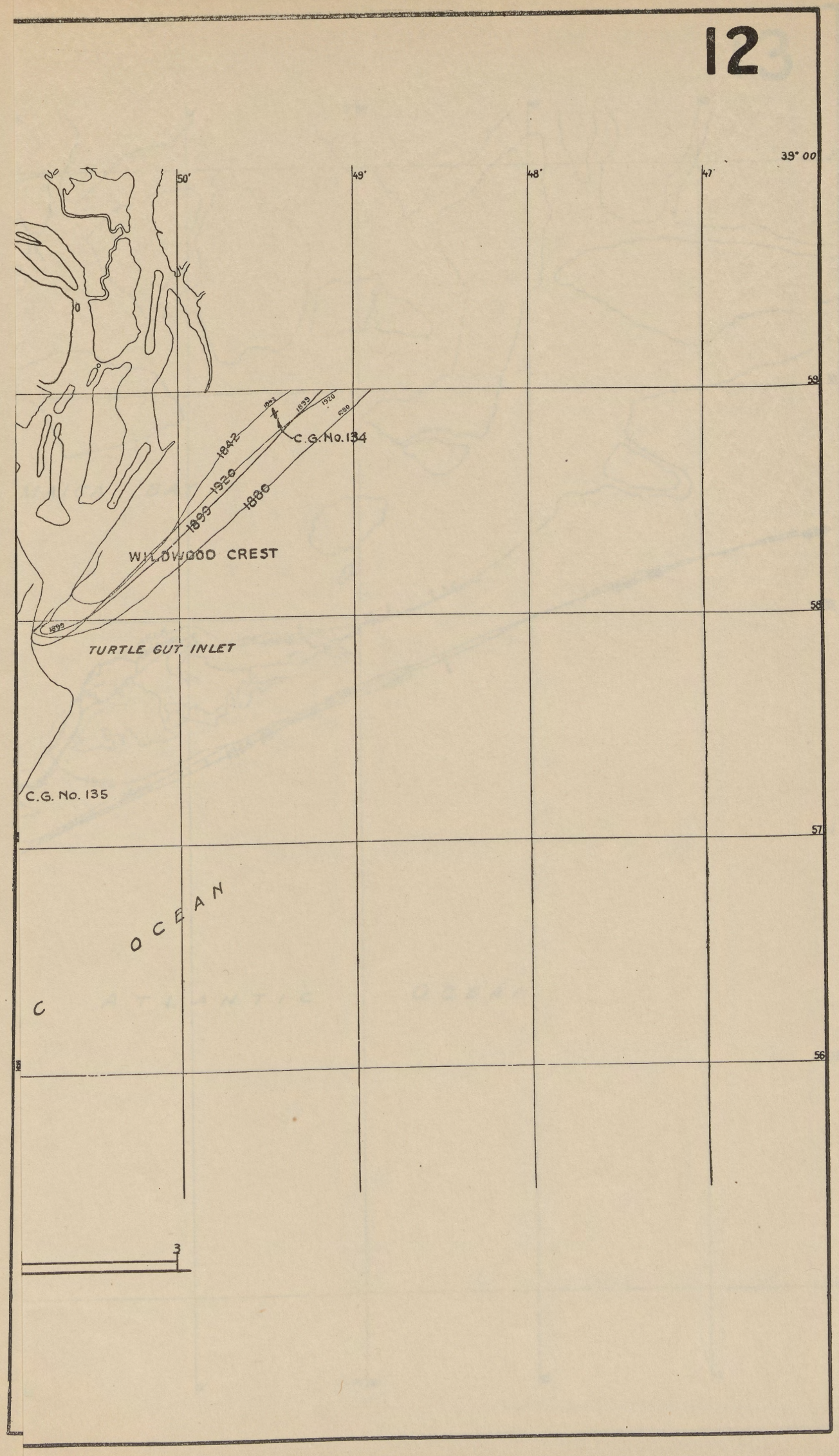
1886

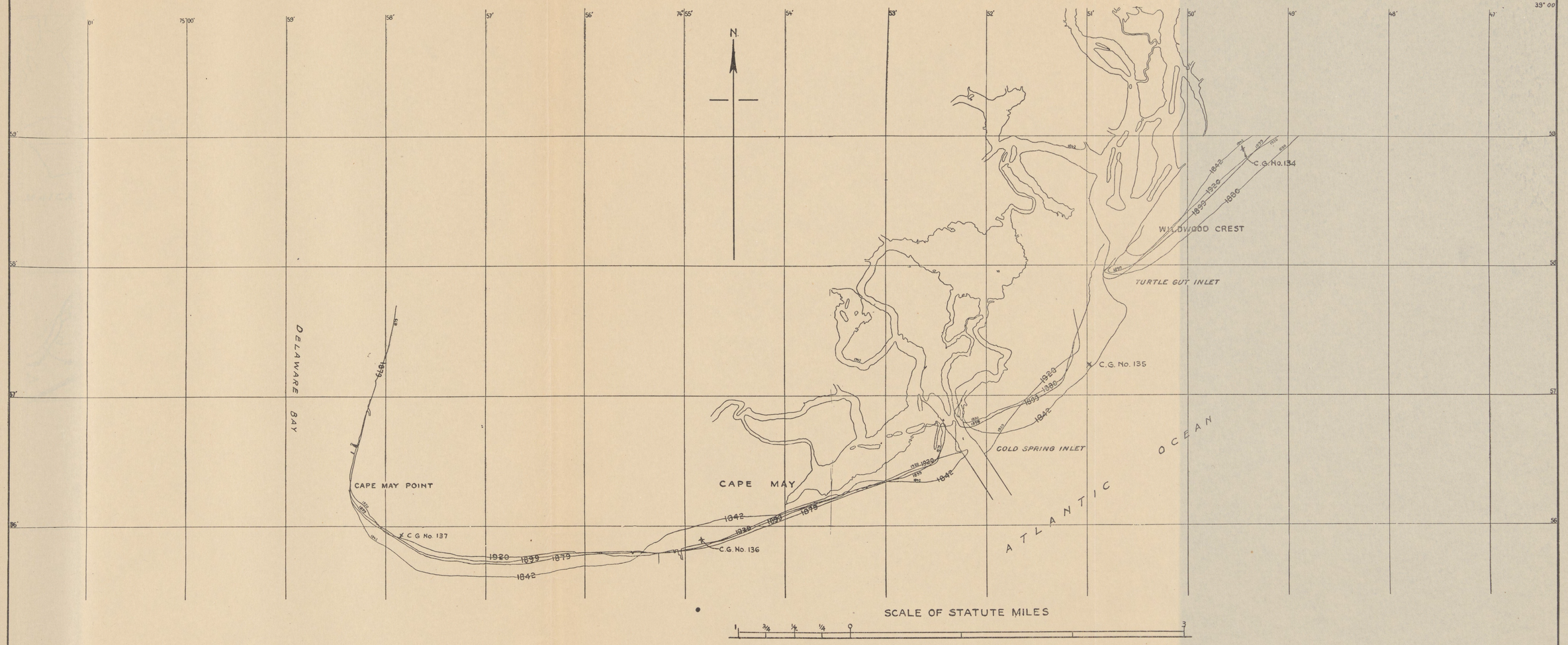
C.G. No 127

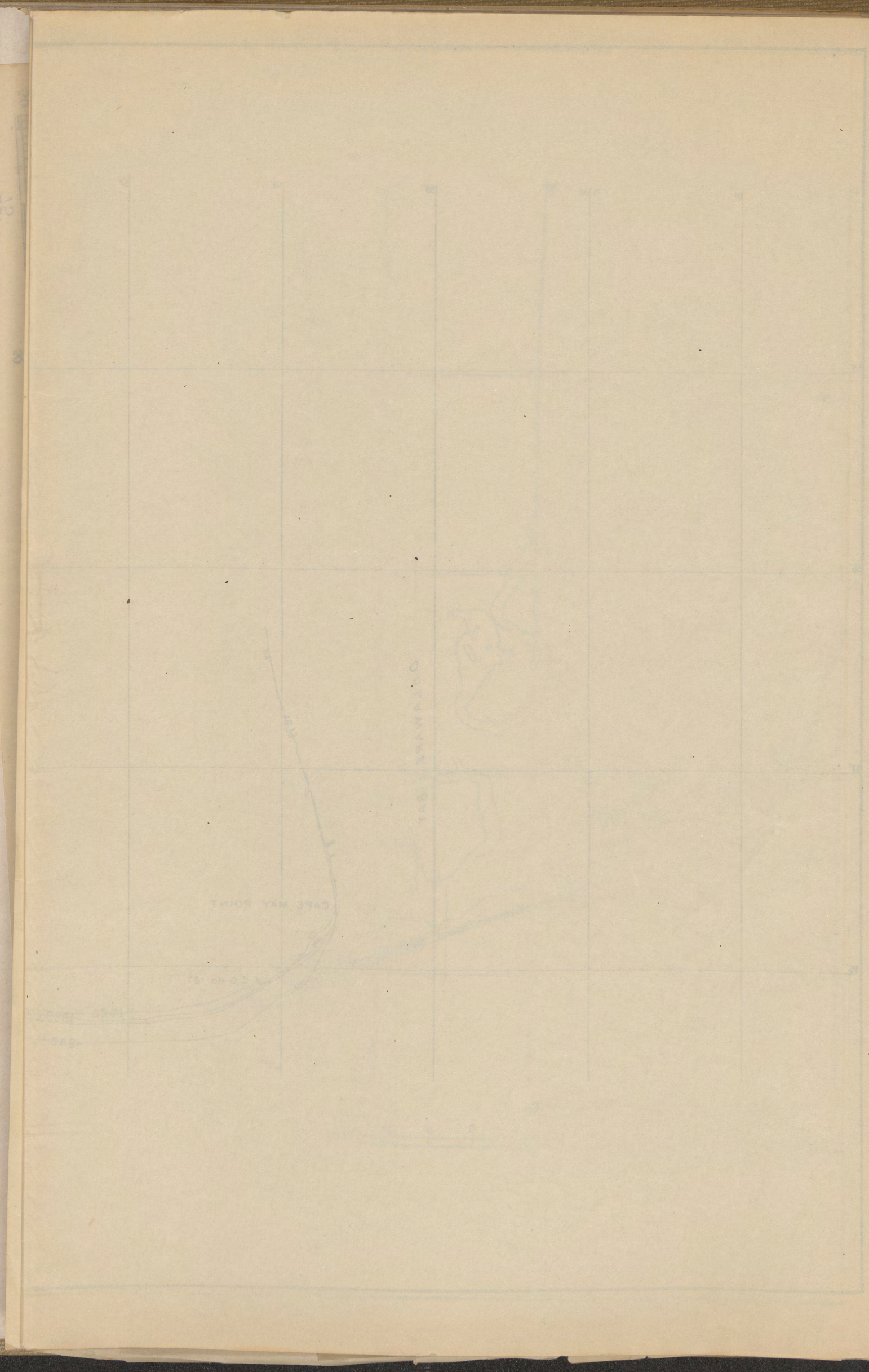

C.G. No. 131
AVALON
C.G. No. 130
SEA ISLE CITY
C.G. No. 129
C.G. No. 128
C.G. No 127
TOWNSEND INLET
CORSON INLET
ATLANTIC
OCEAN
N.
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3

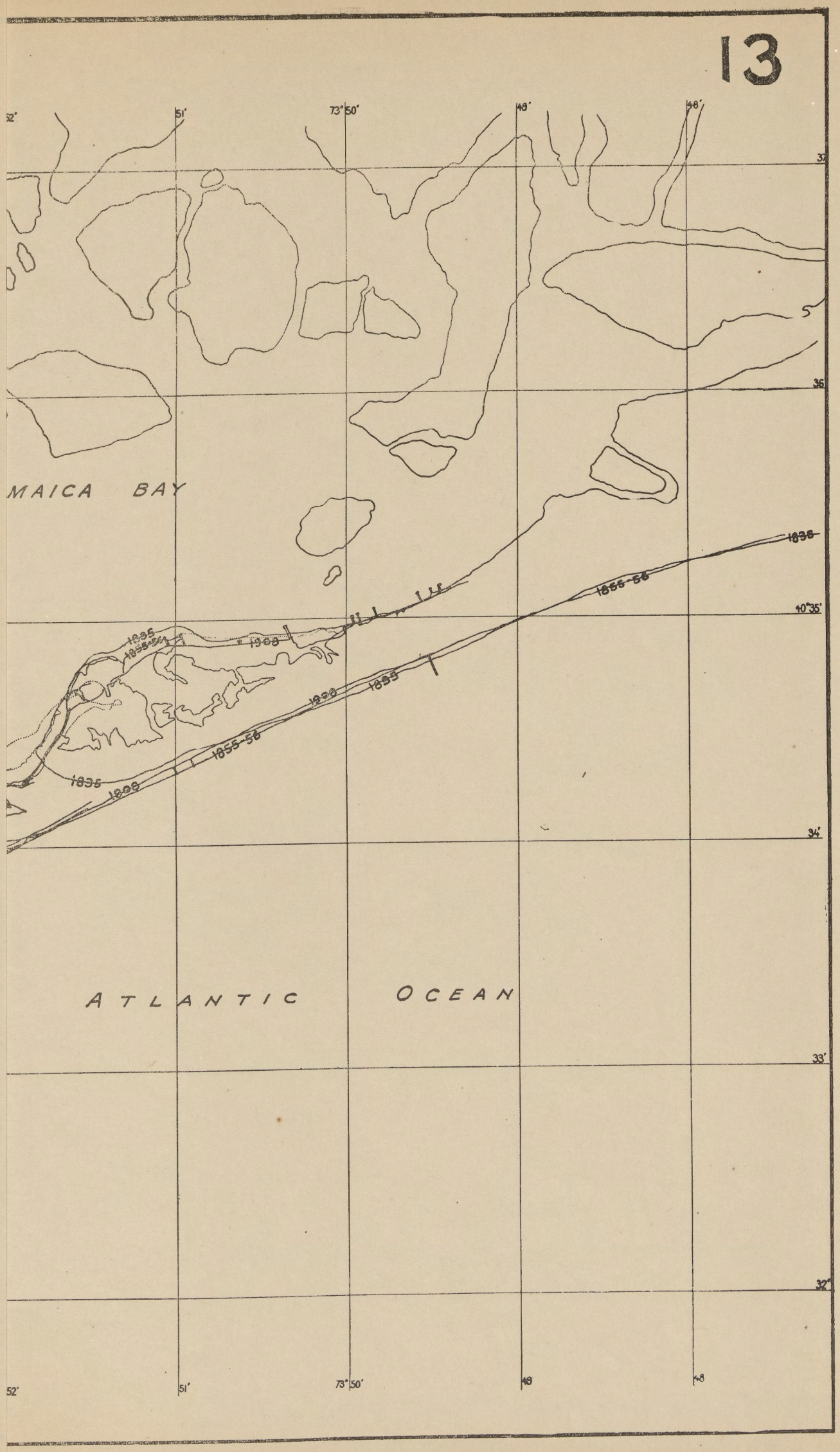

96'
97'
98'
49'
48'
47'
46'
74°45'
44'
N.

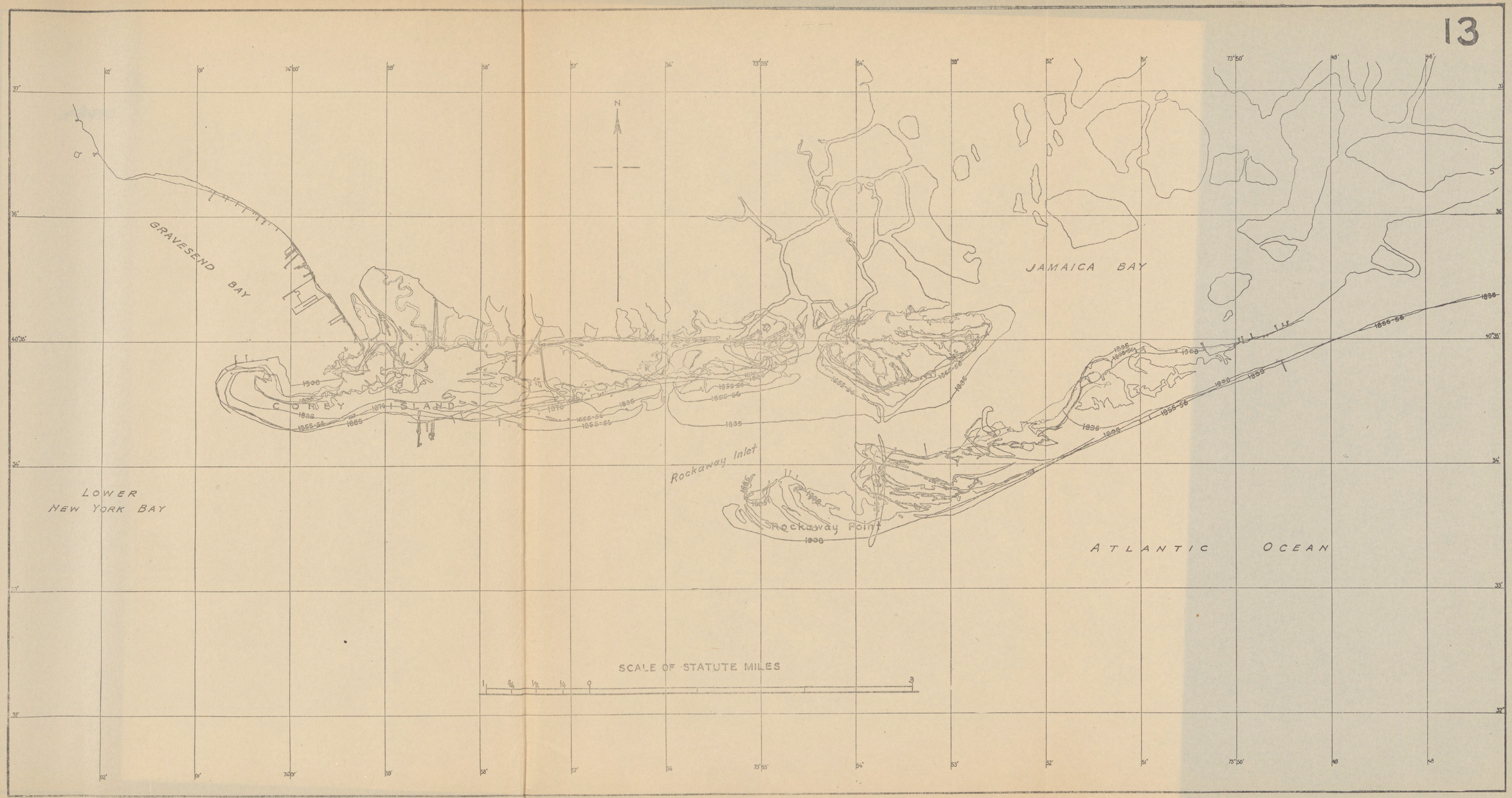

11
WILDWOOD
NORTH WILDWOOD
C.G. No. 133
C.G. No. 132
Stone Harbor
HEREFORD INLET
ATLANTIC
OCEAN
N.
SCALE OF STATUTE MILES
3/4
1/2
1/4
0
3
1842
1899
1880
1920
1881

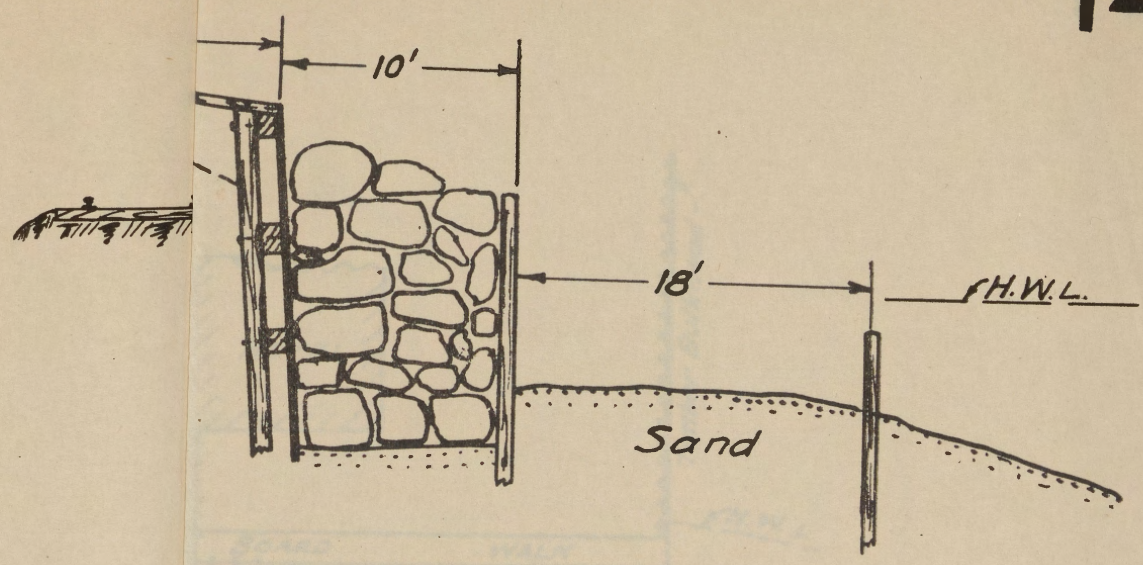

12
39° 00
50'
49'
48'
47'
59
58
57
56
1842
1899
1920
1880
C.G. No. 134
WILDWOOD CREST
TURTLE GUT INLET
C.G. No. 135
OCEAN
C
3


N.
74° 55'
01'
75° 00'
59'
58'
57'
56'
54'
53'
52'
51'
50'
49'
48'
47'
39° 00
59'
58'
57'
56'
DELAWARE BAY
CAPE MAY POINT
CAPE MAY
C.G. No. 137
C.G. No. 136
C.G. No. 135
C.G. No. 134
COLD SPRING INLET
TURTLE GUT INLET
WILDWOOD CREST
ATLANTIC OCEAN
1842
1879
1899
1920
1836
SCALE OF STATUTE MILES
1
3/4
1/2
1/4
0
3




13
52'
51'
73°50'
49'
48'
37'
36'
40°35'
34'
33'
32'
MAICA BAY
ATLANTIC OCEAN
1835
1855-56
1908
1838
1855-56
1908
1835
1855-56
1835
1908
52'
51'
73°50'
49'
48'

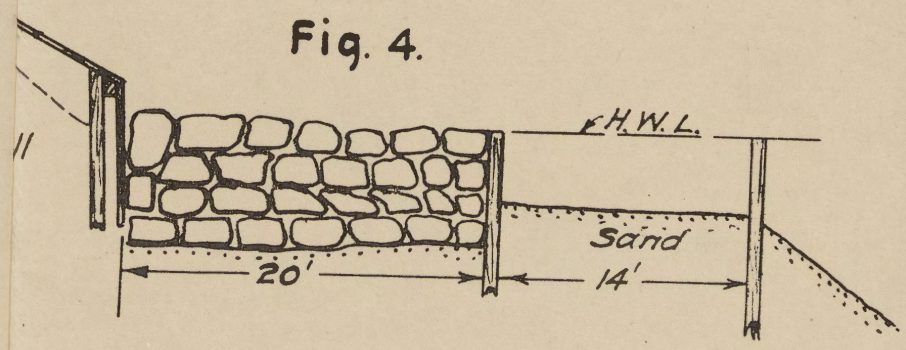

GRAVESEND BAY
JAMAICA BAY
CONEY ISLAND
Rockaway Inlet
Rockaway Point
LOWER NEW YORK BAY
ATLANTIC OCEAN
SCALE OF STATUTE MILES
1 3/4 1/2 1/4 0 3
N



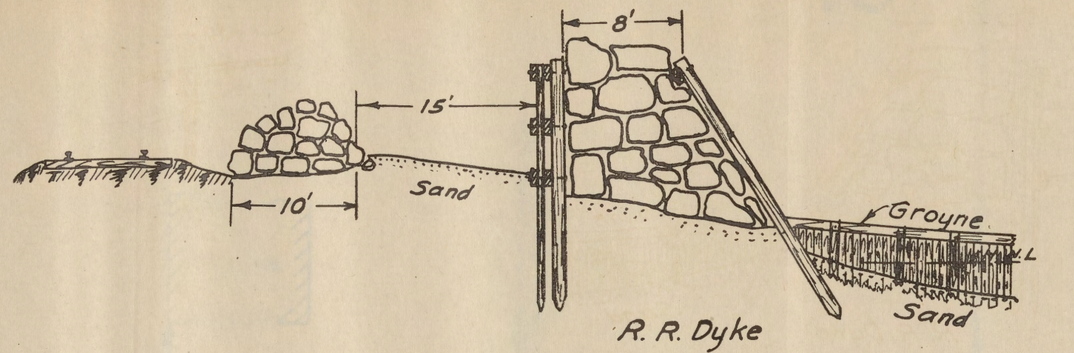
SEA BRIGHT (BULKHEAD TYPE)

Fig. 3.

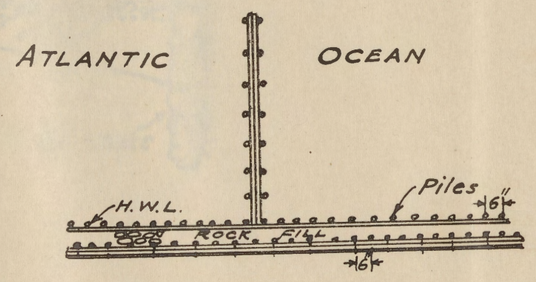
Fig. 4.



SEA BRIGHT
(BULKHEAD TYPE)



R. R. Dyke



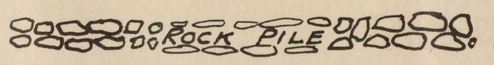
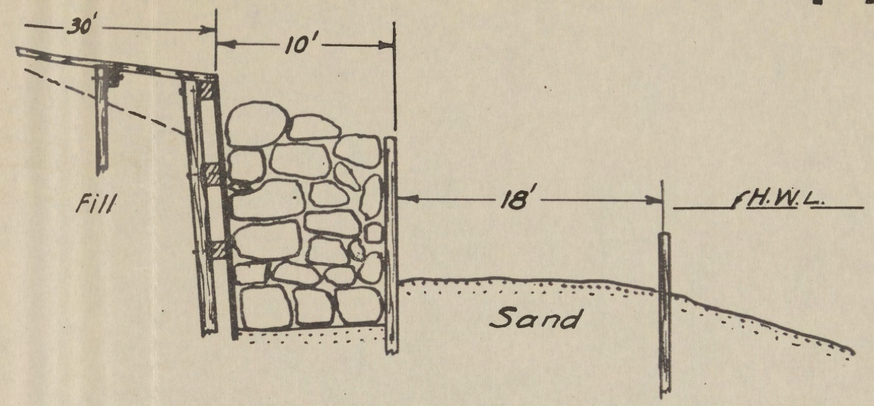


Fig. 1.

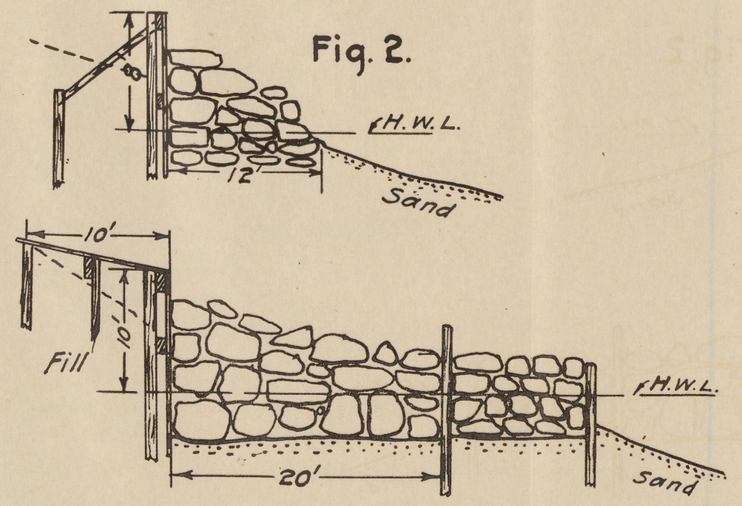
HIGHLAND BEACH



SEA BRIGHT (BULKHEAD TYPE)

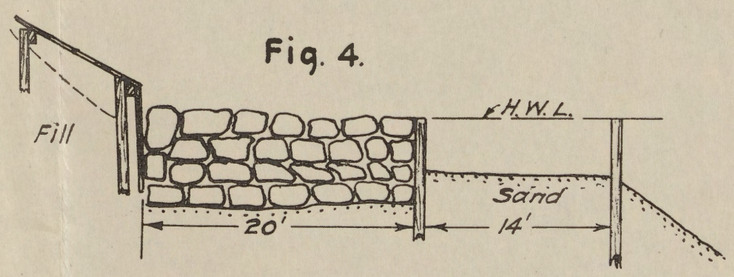
Fig. 3.

Fig. 2.



SEA BRIGHT (BULKHEAD TYPES)

Fig. 4.



SEA BRIGHT
(BULKHEAD TYPE)

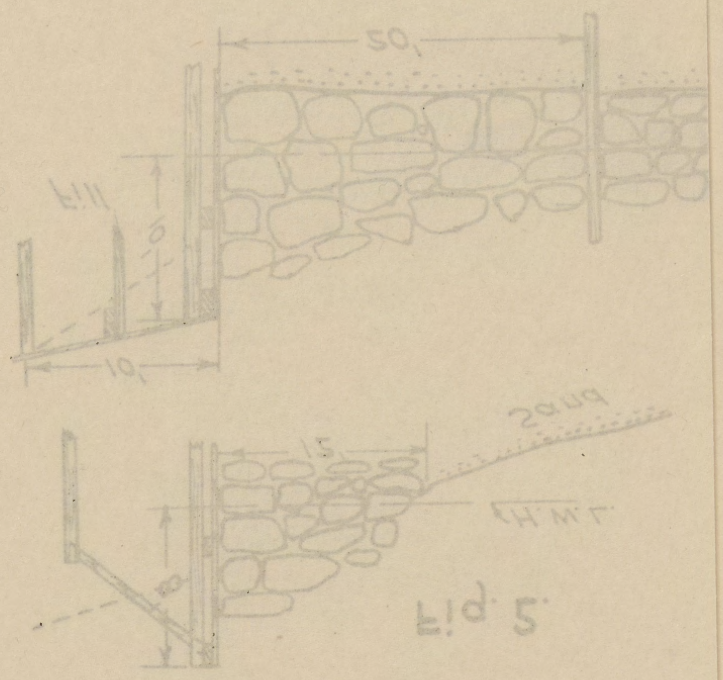
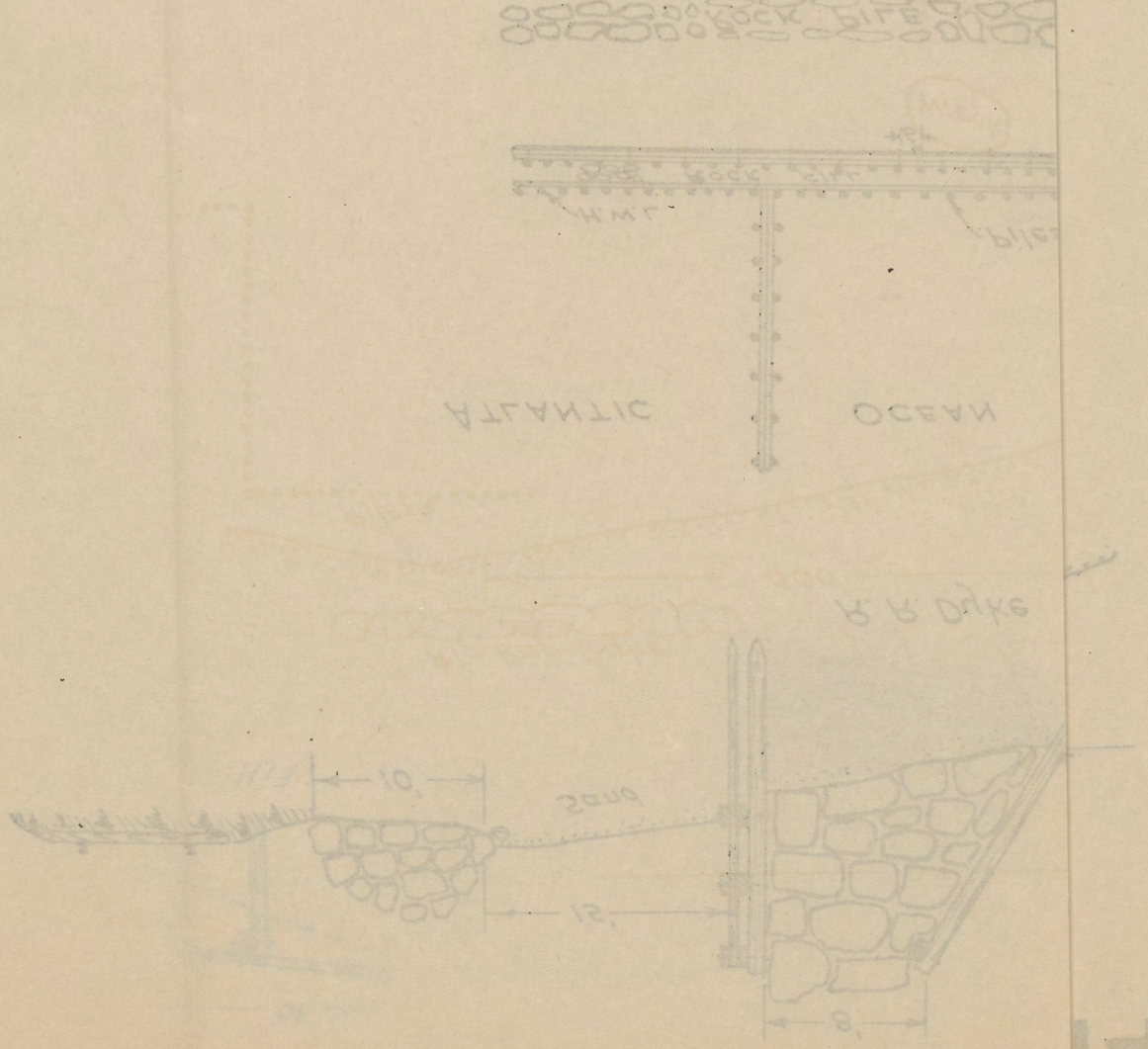
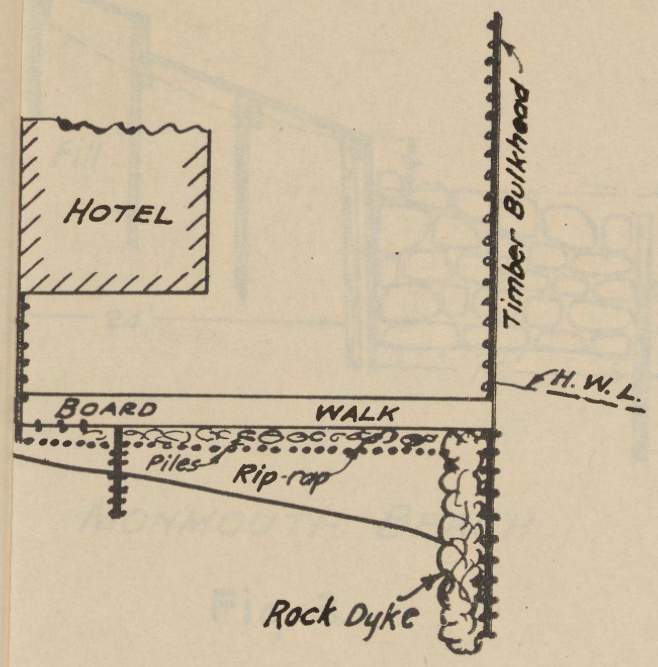
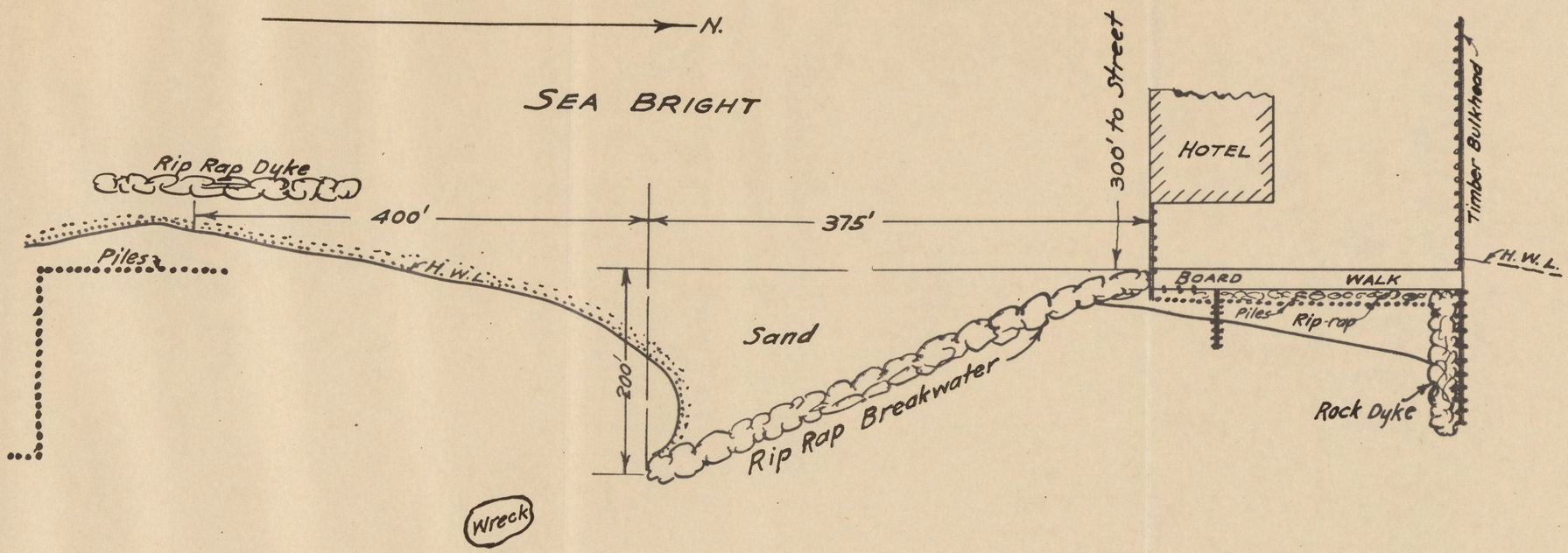


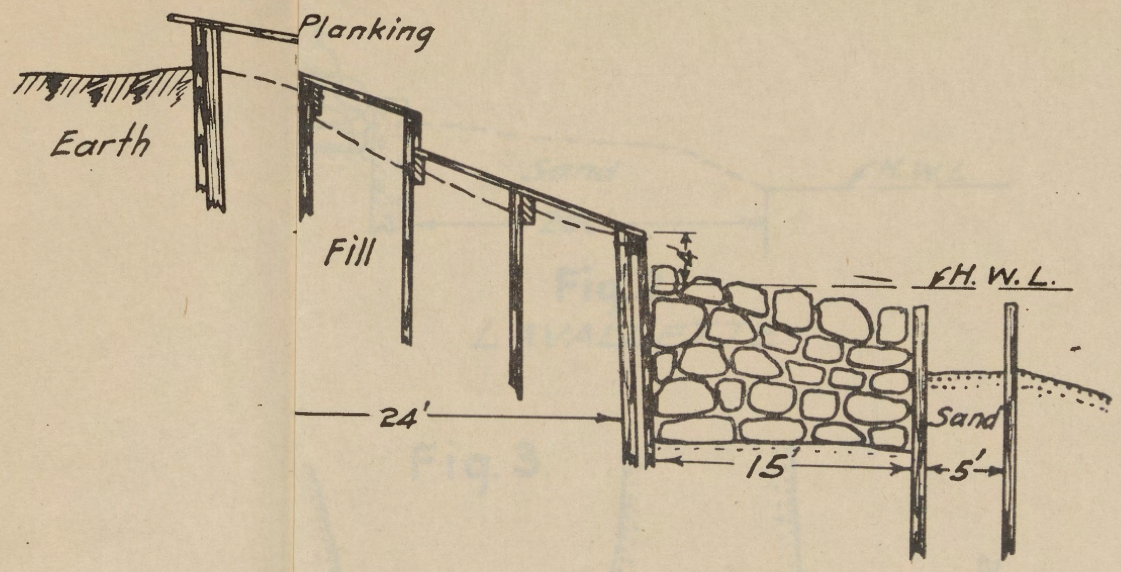
Fig. 5.




HOTEL
Timber Bulkhead
H. W. L.
BOARD WALK
Piles
Rip-rap
Rock Dyke


N.
SEA BRIGHT
Rip Rap Dyke
400'
375'
300' to Street
HOTEL
Timber Bulkhead
Piles
H.W.L.
BOARD WALK
Piles
Rip-rap
H.W.L.
Sand
200'
Rip Rap Breakwater
Rock Dyke
Wreck
ATLANTIC OCEAN

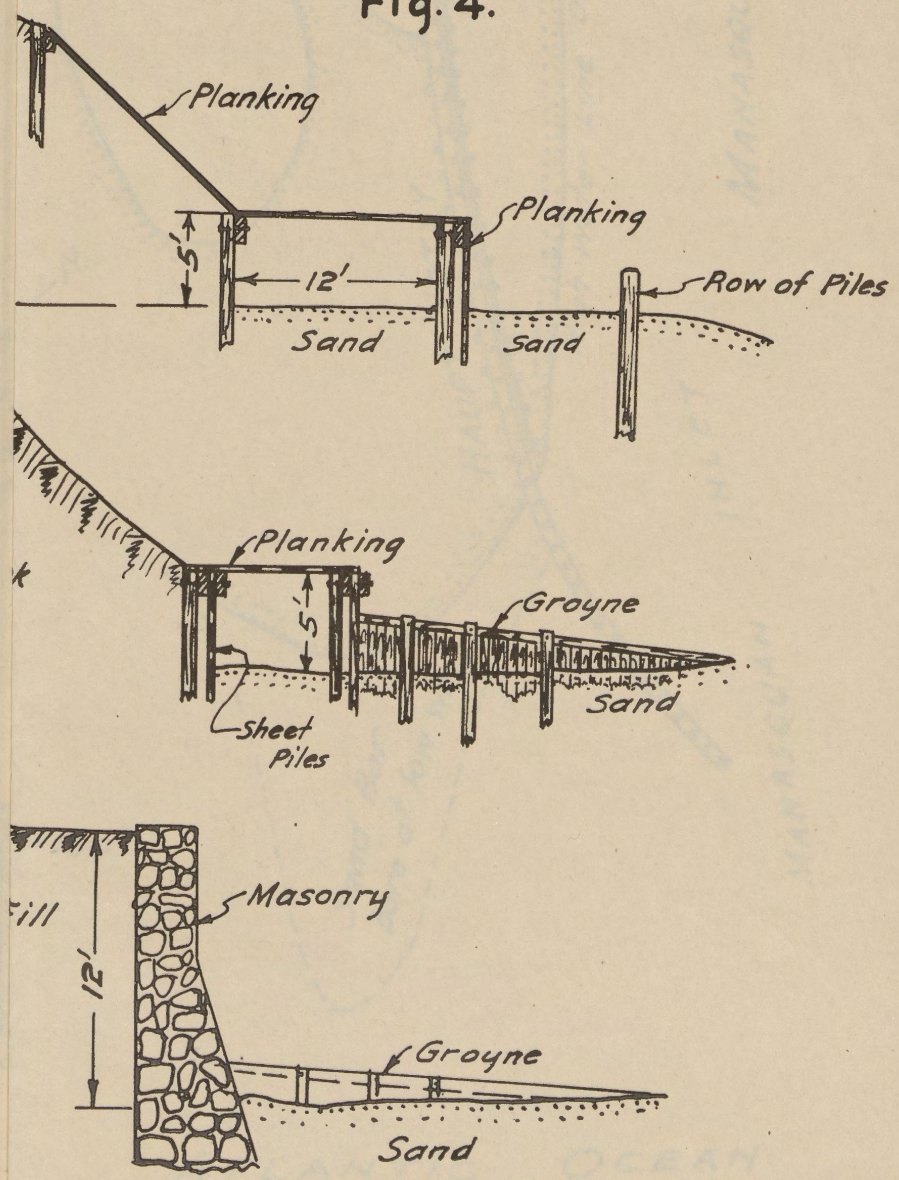




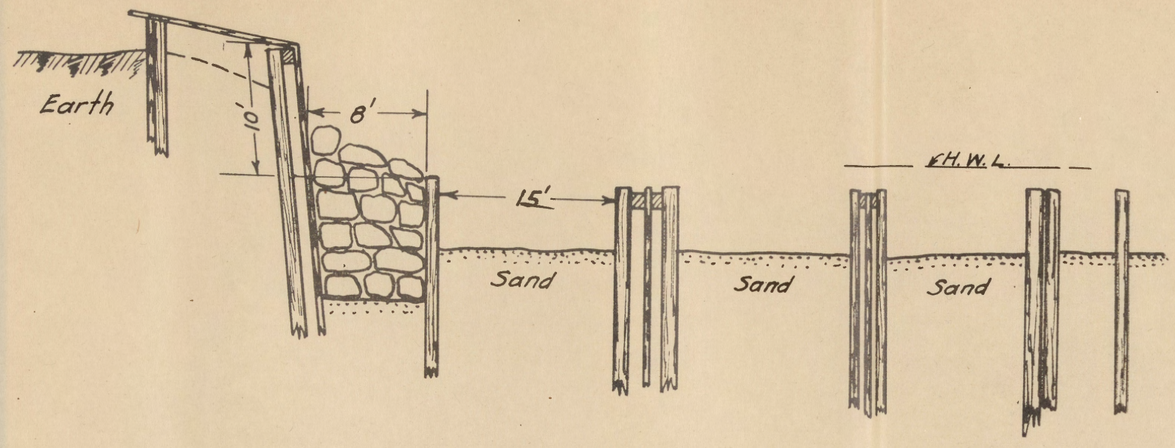
MONMOUTH BEACH

Fig. 3.

Fig. 4.



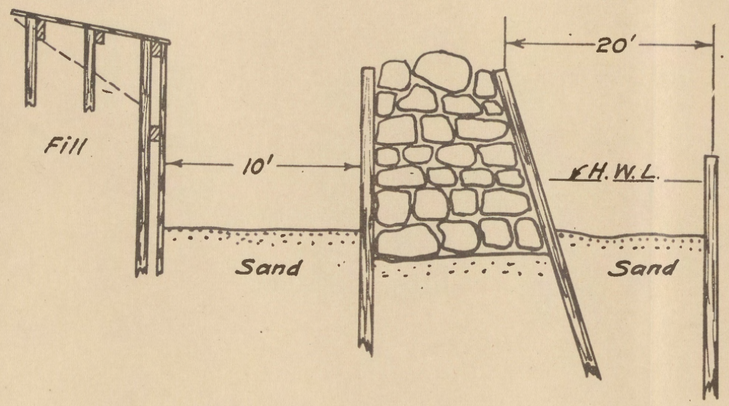
ELBERON (BULKHEAD TYPES)



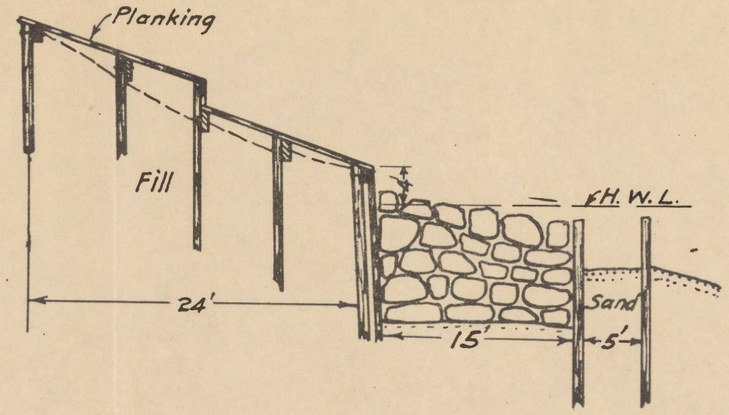
SEA BRIGHT

Fig. 1.

Fig. 2.



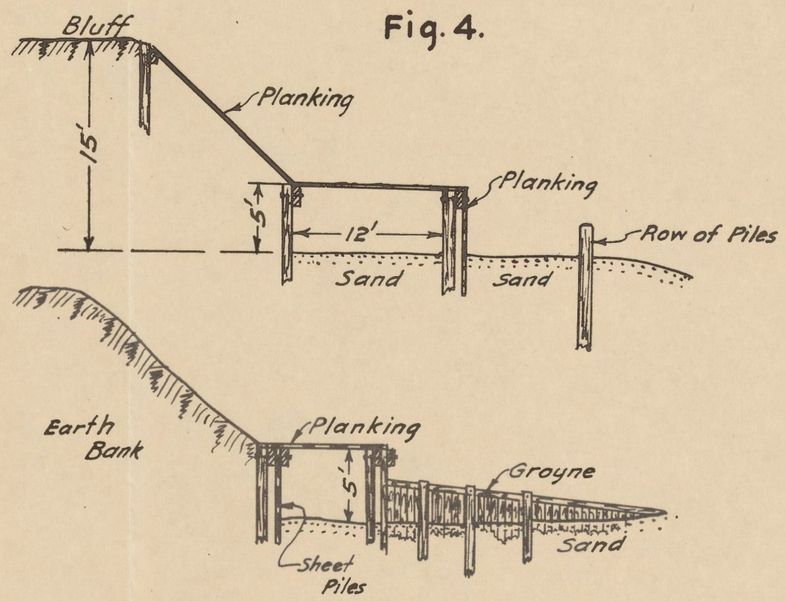
SEA BRIGHT



MONMOUTH BEACH

Fig. 3.

Fig. 4.



ELBERON (BULKHEAD TYPES)

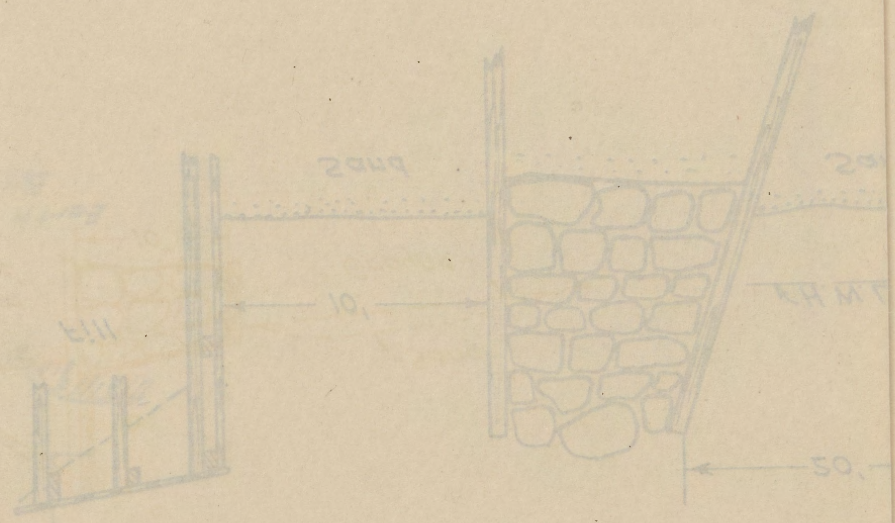


Fig. 5.

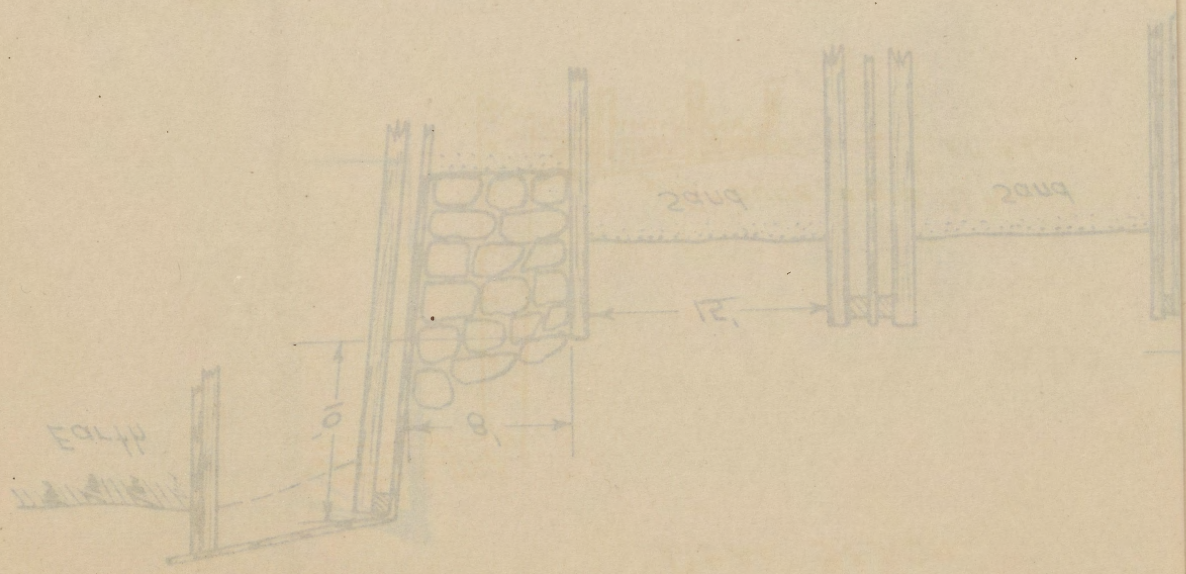


Fig. 1.

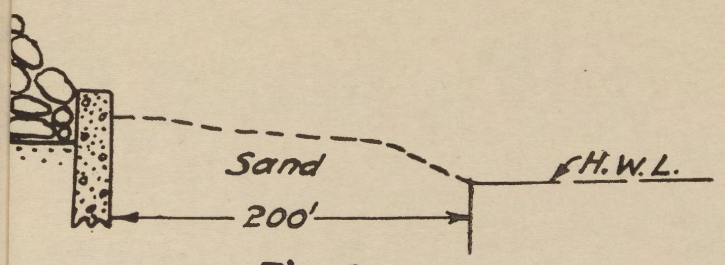
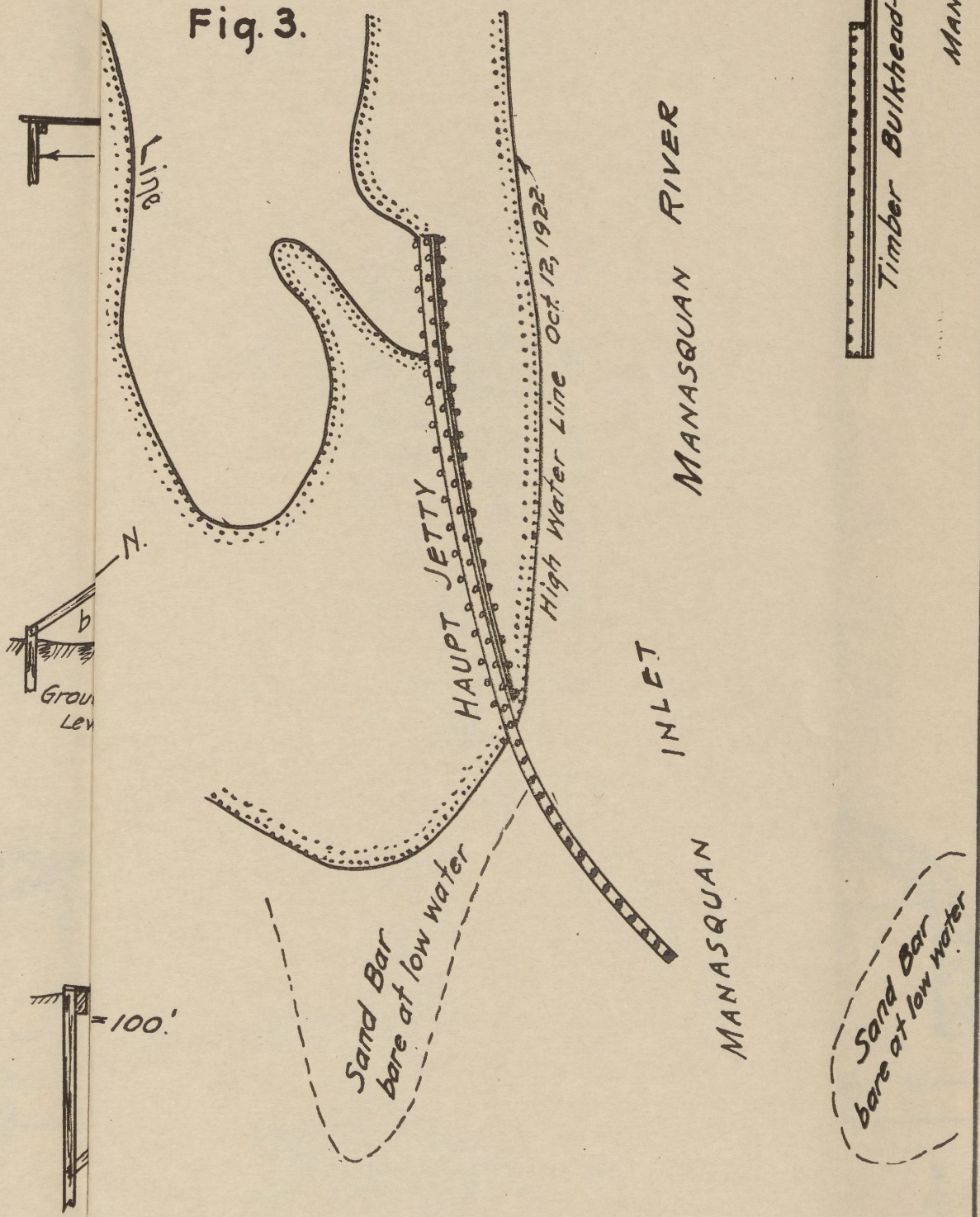


Fig. 2.

LAVALLETTE

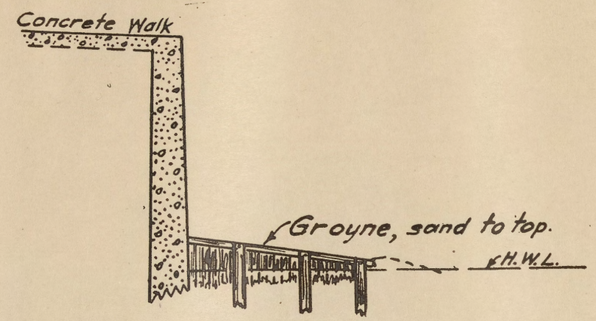
Fig. 3.

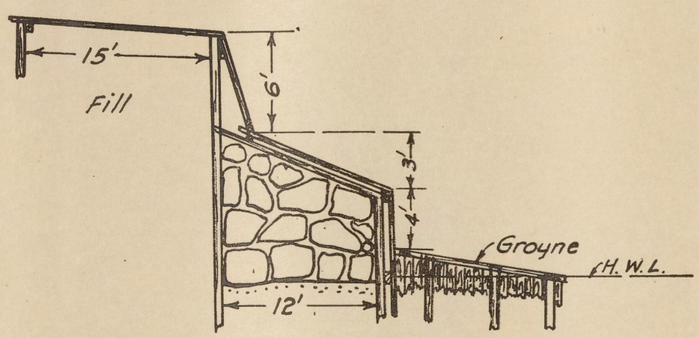


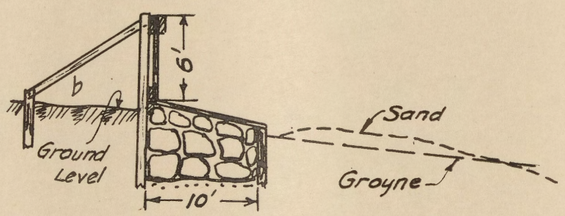
PLEASANT AND MANASQUAN.

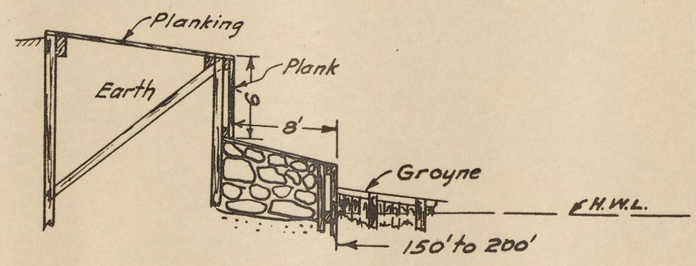
Fig. 1.

DEAL BEACH









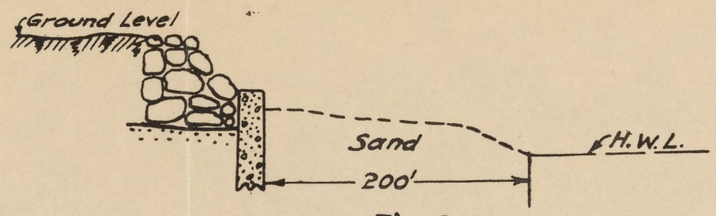
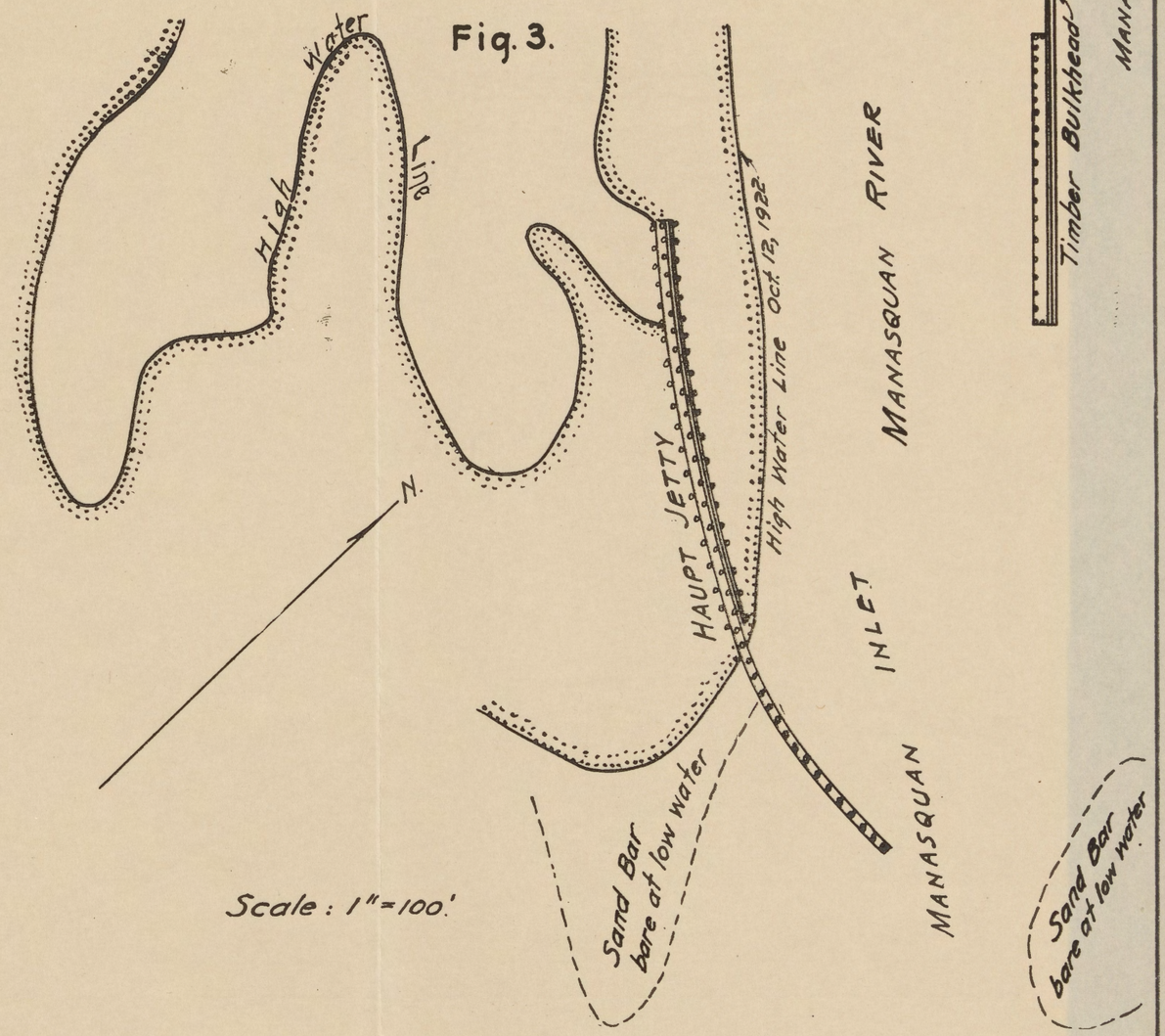


Fig. 2.

LAVALLETTE

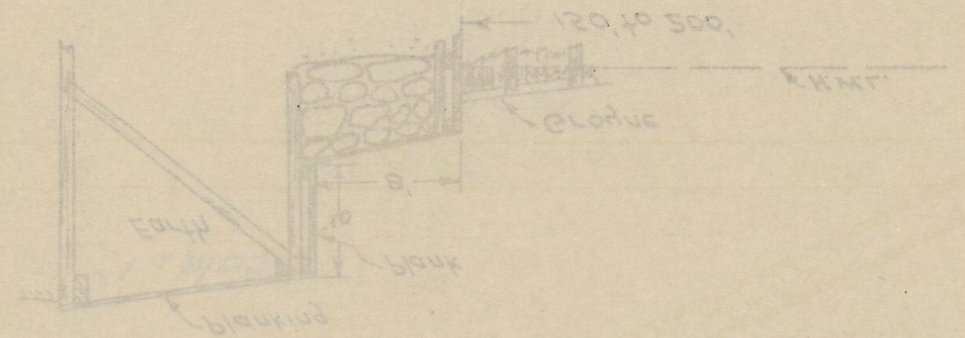
Fig. 3.

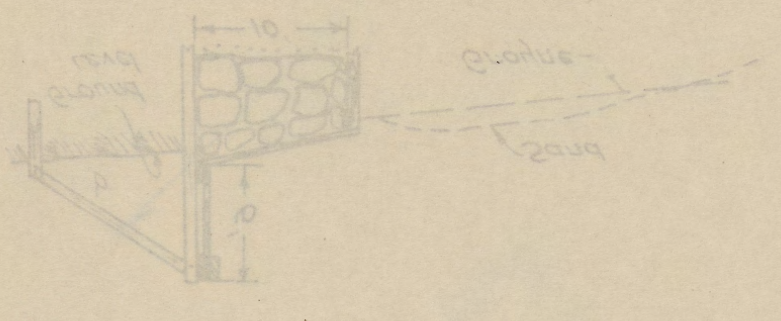


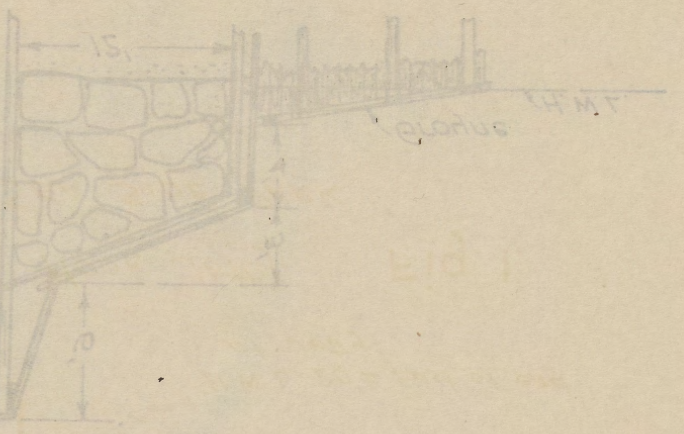
Scale: 1" = 100'

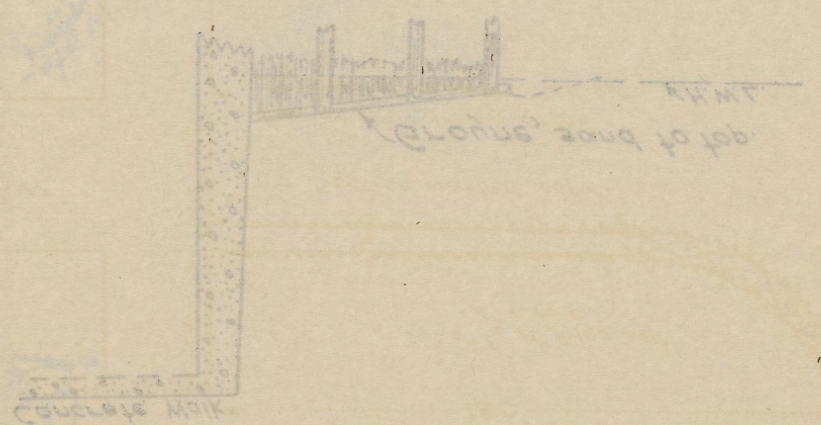
ATLANTIC OCEAN

POINT PLEASANT AND MANASQUAN.









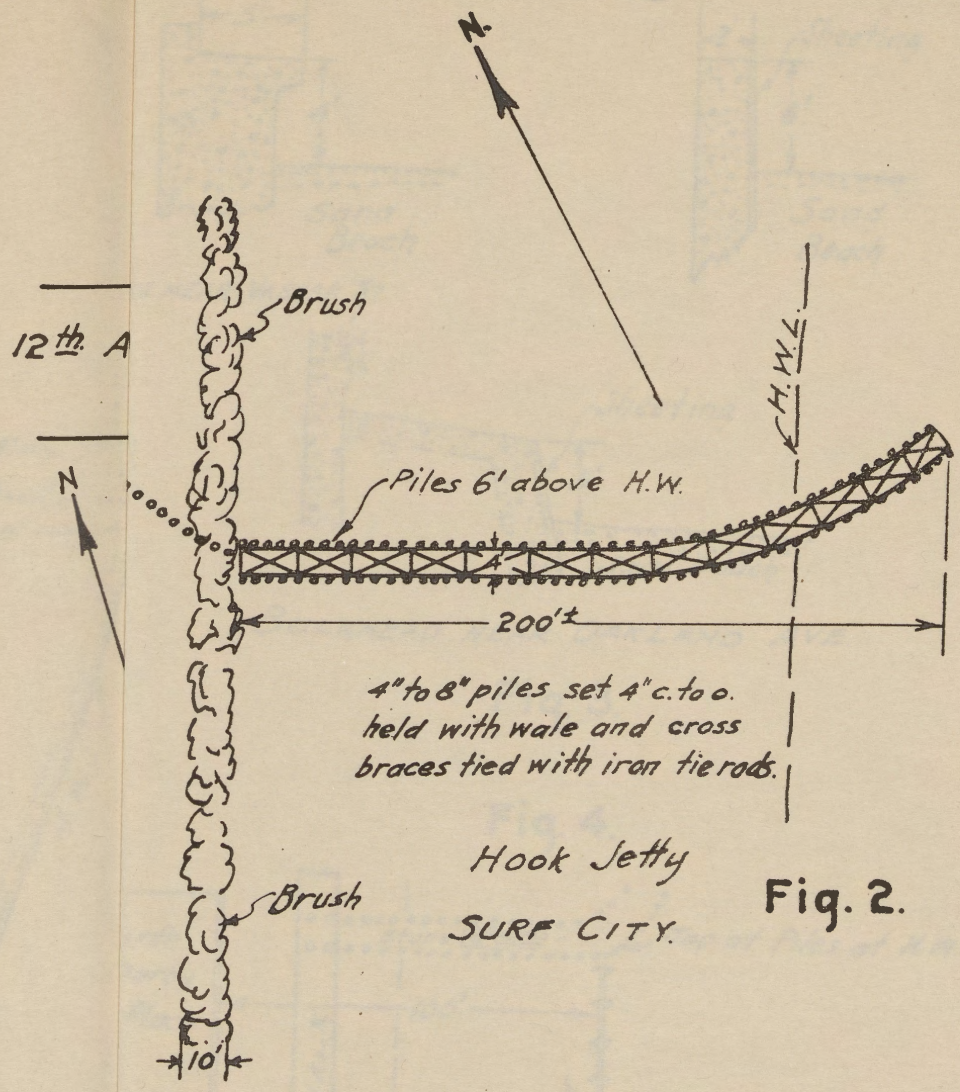
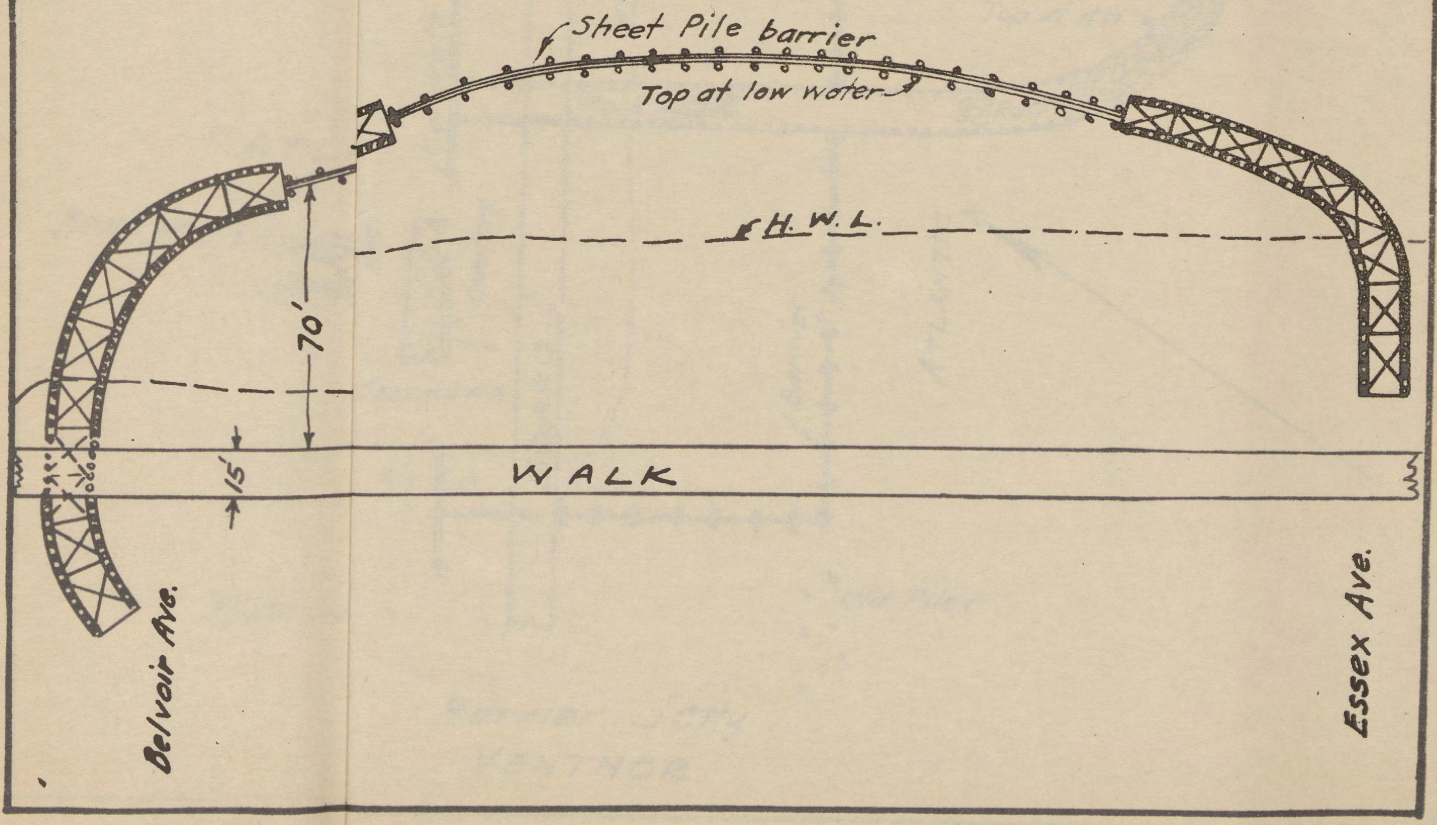
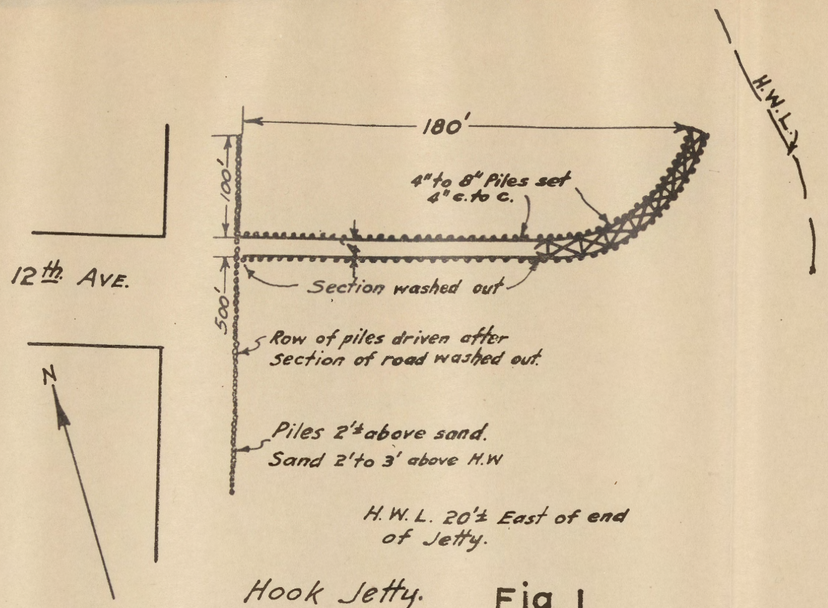

N.
12th. A
Brush
H.W.L.
Piles 6' above H.W.
200'±
4" to 8" piles set 4" c. to c.
held with wale and cross
braces tied with iron tie rods.
Hook Jetty
SURF CITY.
Brush
10'

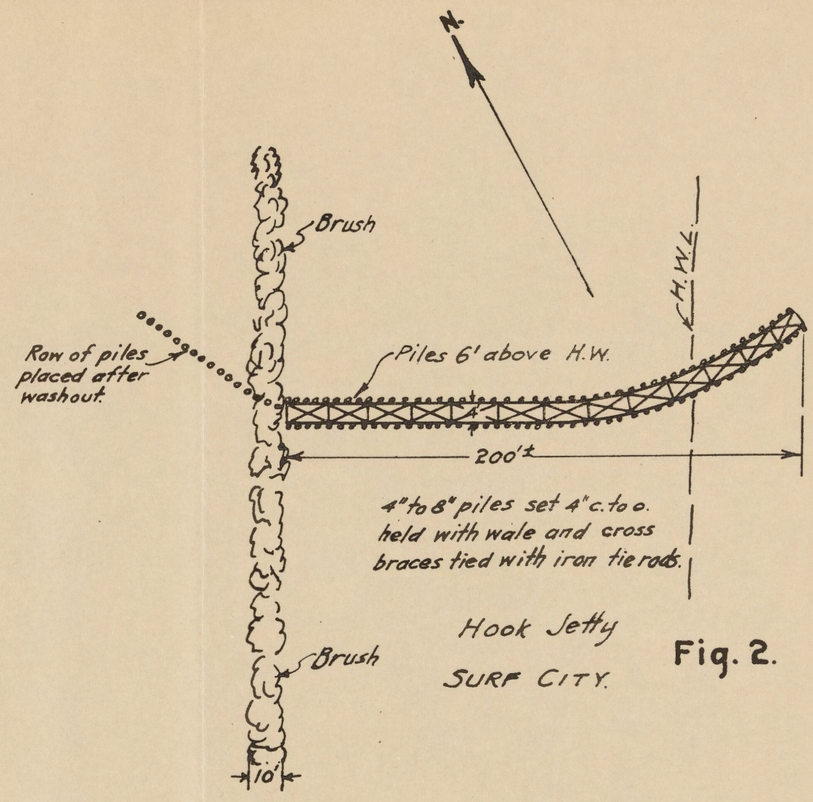
Fig. 2.


Sheet Pile barrier
Top at low water
H.W.L.
70'
15'
WALK
Delvoir Ave.
Essex Ave.



Hook Jetty. Fig. 1.

SEA SIDE PARK

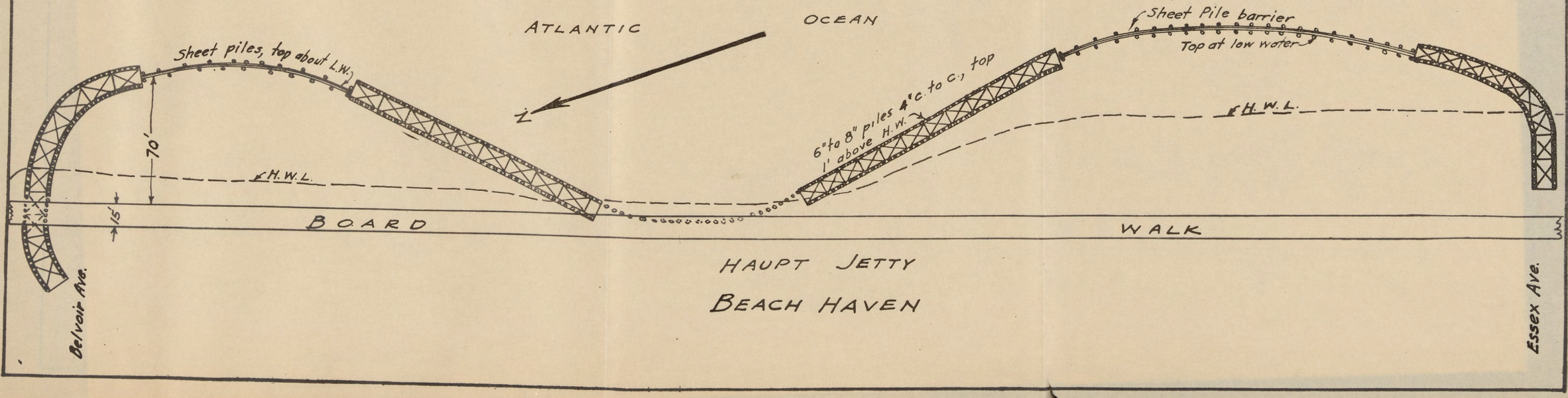


Hook Jetty

SURF CITY.

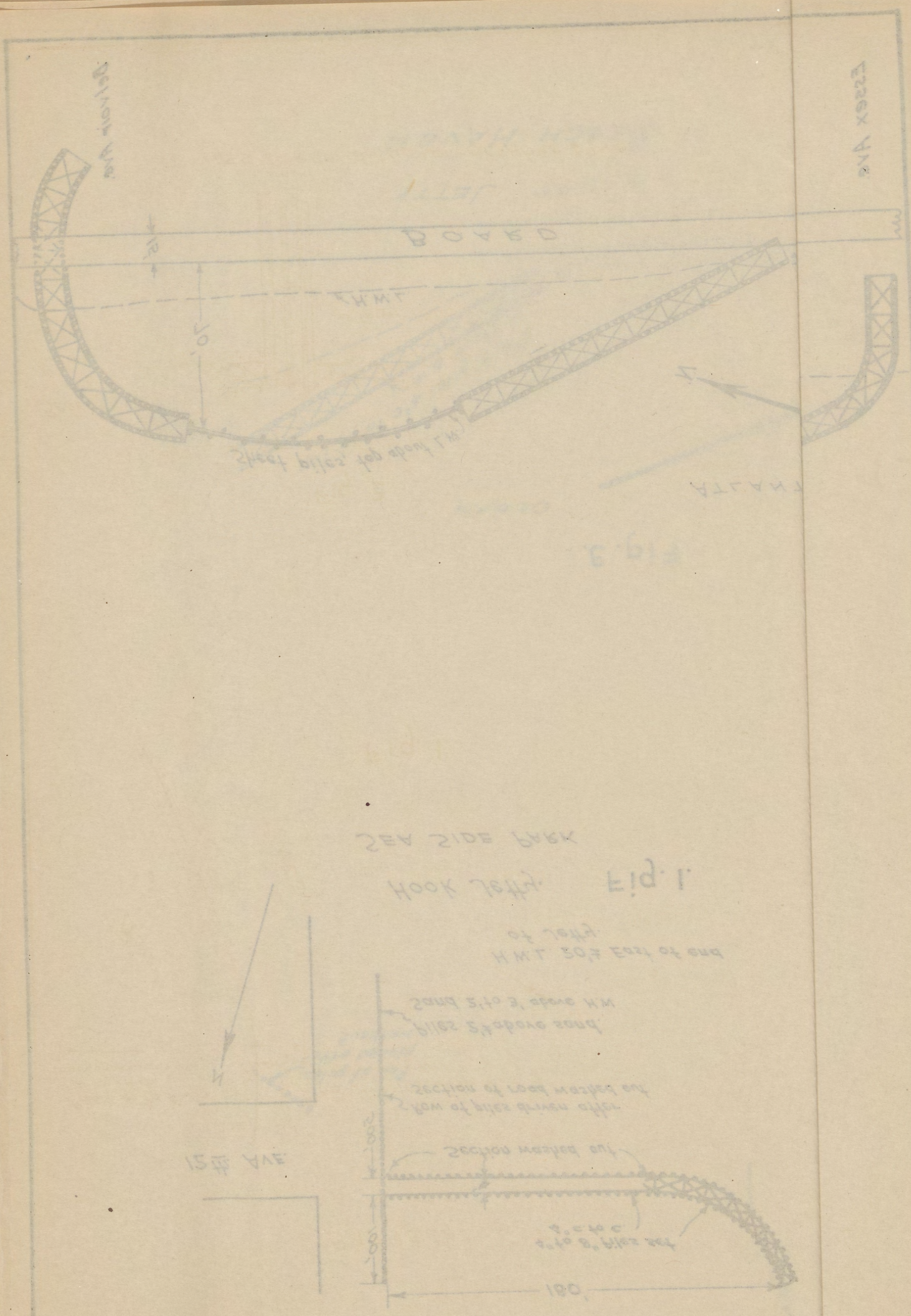
Fig. 2.

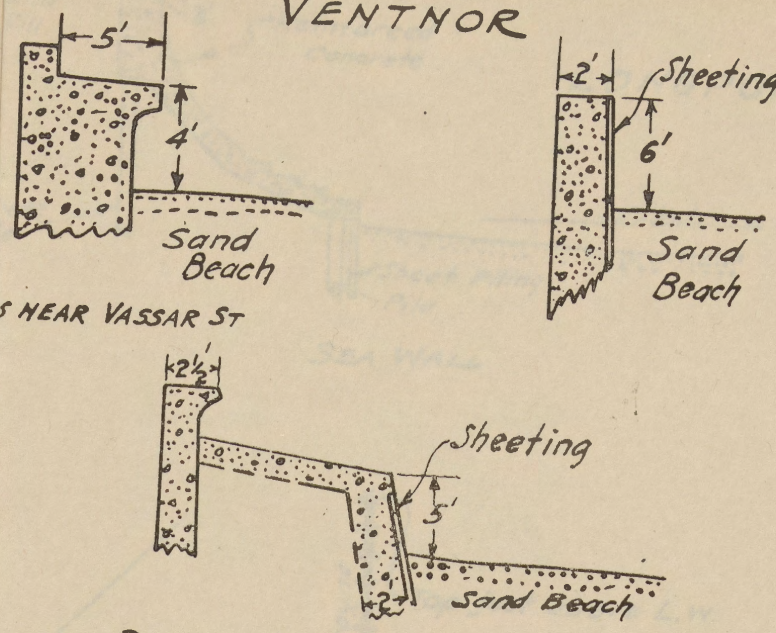
Fig. 3.



HAUPT JETTY

BEACH HAVEN





BULKHEAD NEAR OAKLAND AVE.

Fig. 3.

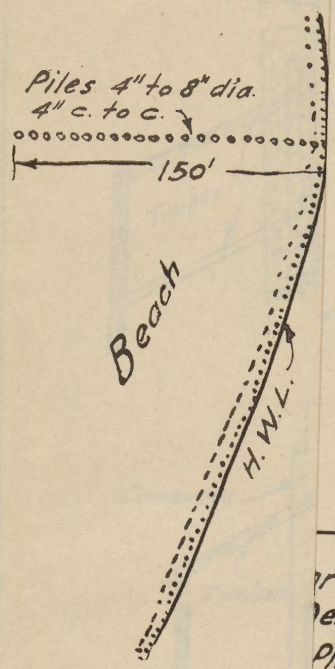
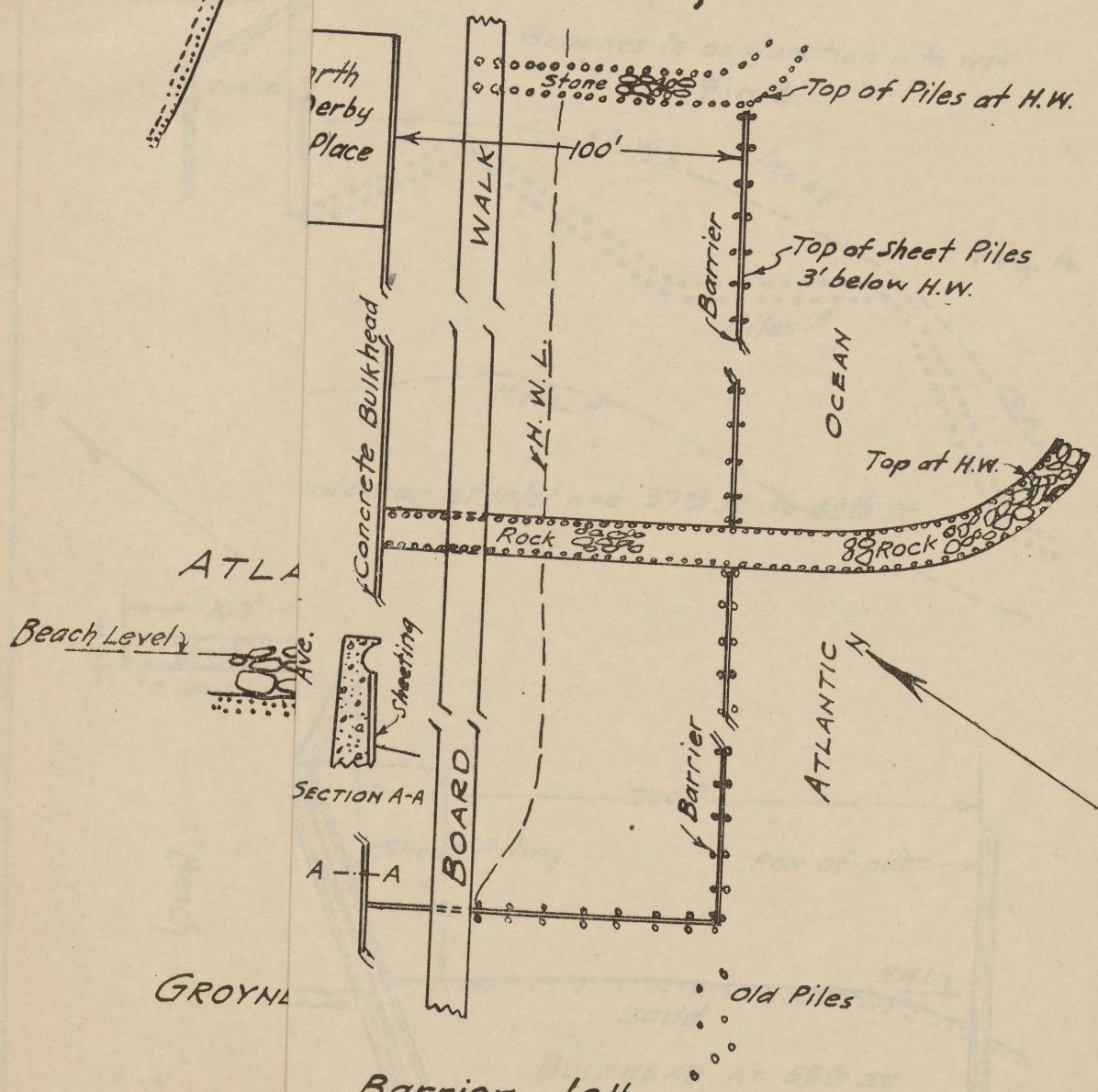


Fig. 4.



Barrier Jetty
VENTNOR.

BARNEGAT CITY

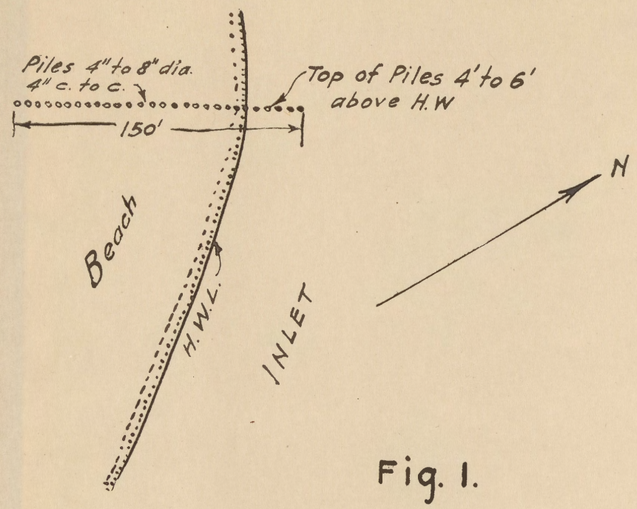
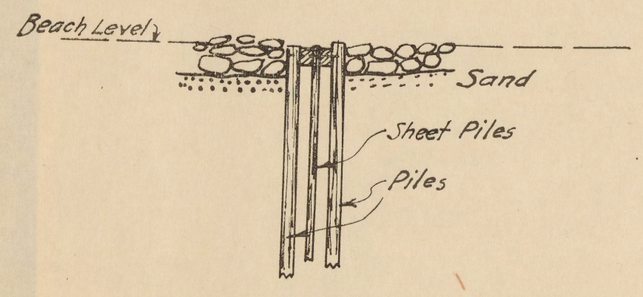


Fig. 1.

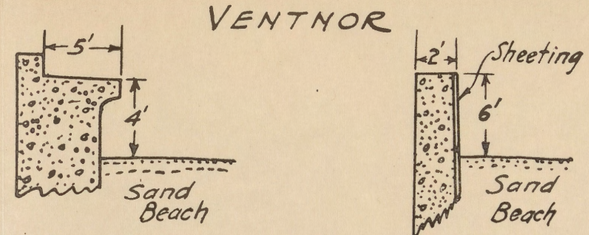
Fig. 2.

ATLANTIC CITY

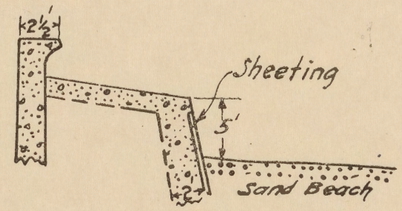


GROYNES, PERPENDICULAR TO SHORE LINE

VENTNOR



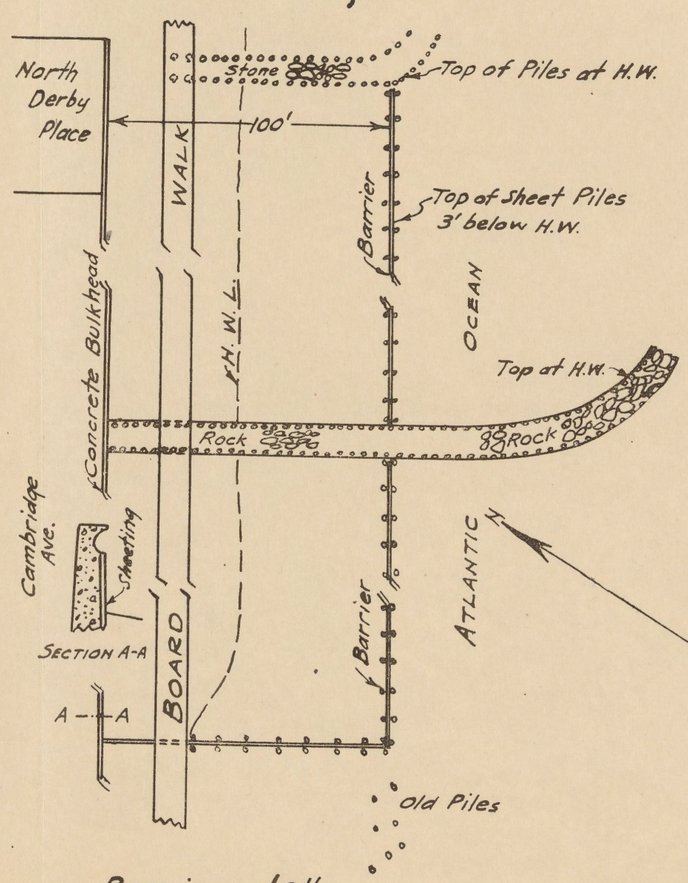
BULKHEADS NEAR VASSAR ST



BULKHEAD NEAR OAKLAND AVE.

Fig. 3.

Fig. 4.



Barrier Jetty
VENTNOR.

BARNEGAT CITY

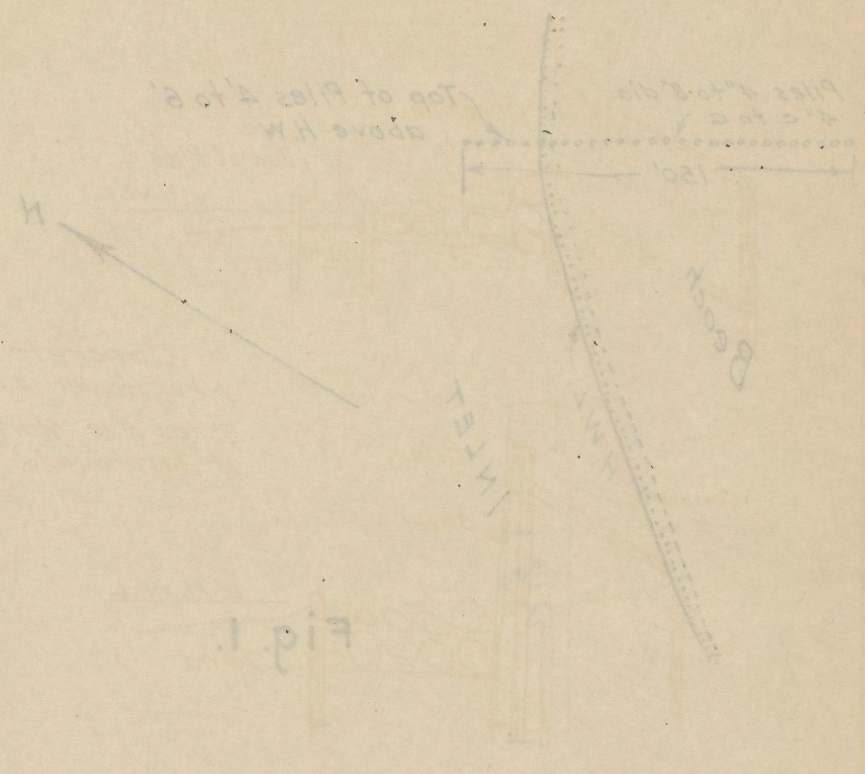
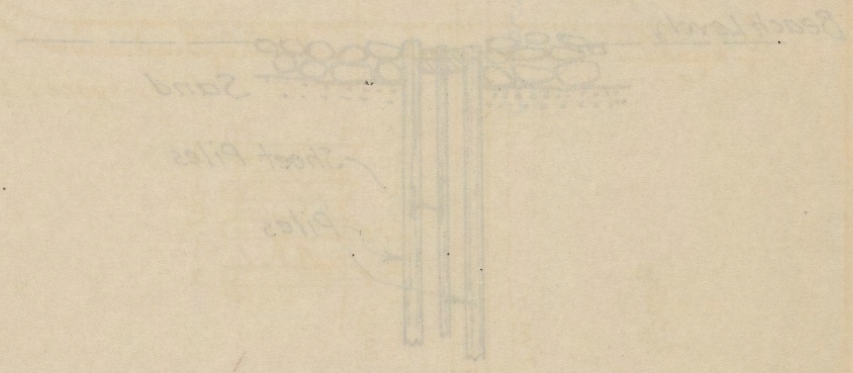


Fig. 1.

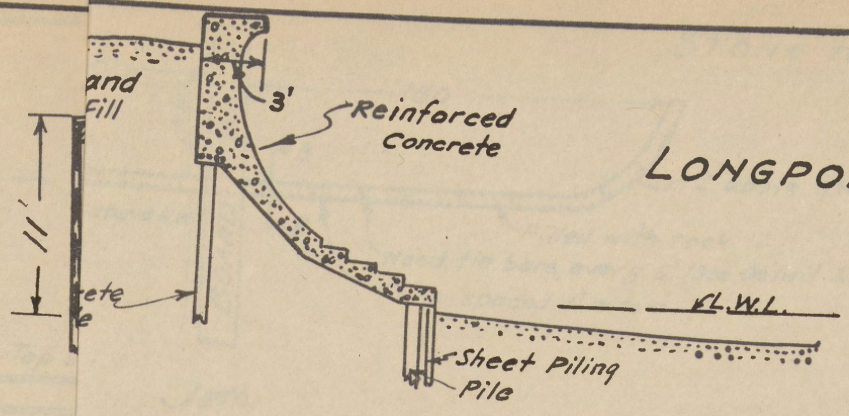
Fig. 2.

ATLANTIC CITY

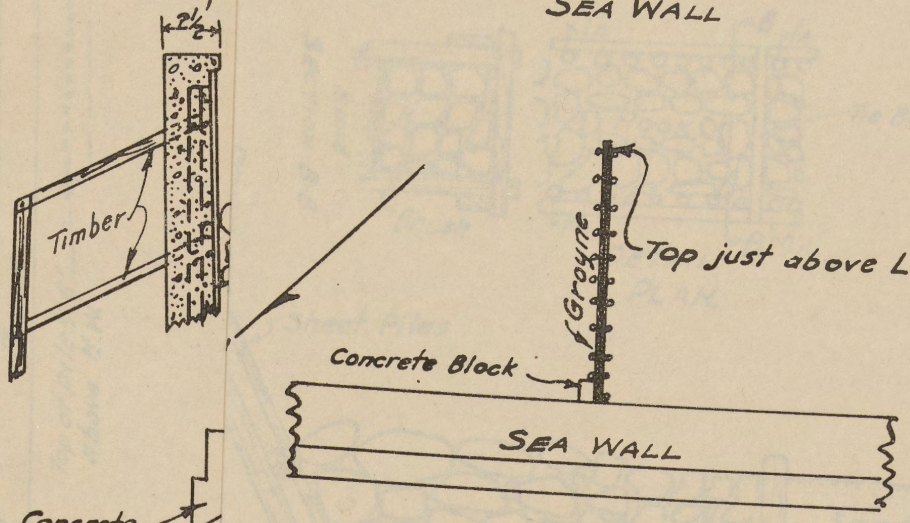


GROYNES, PERPENDICULAR TO SHORE LINE

LONGPORT



SEA WALL



Groynes in conjunction with wall

Fig. 3.

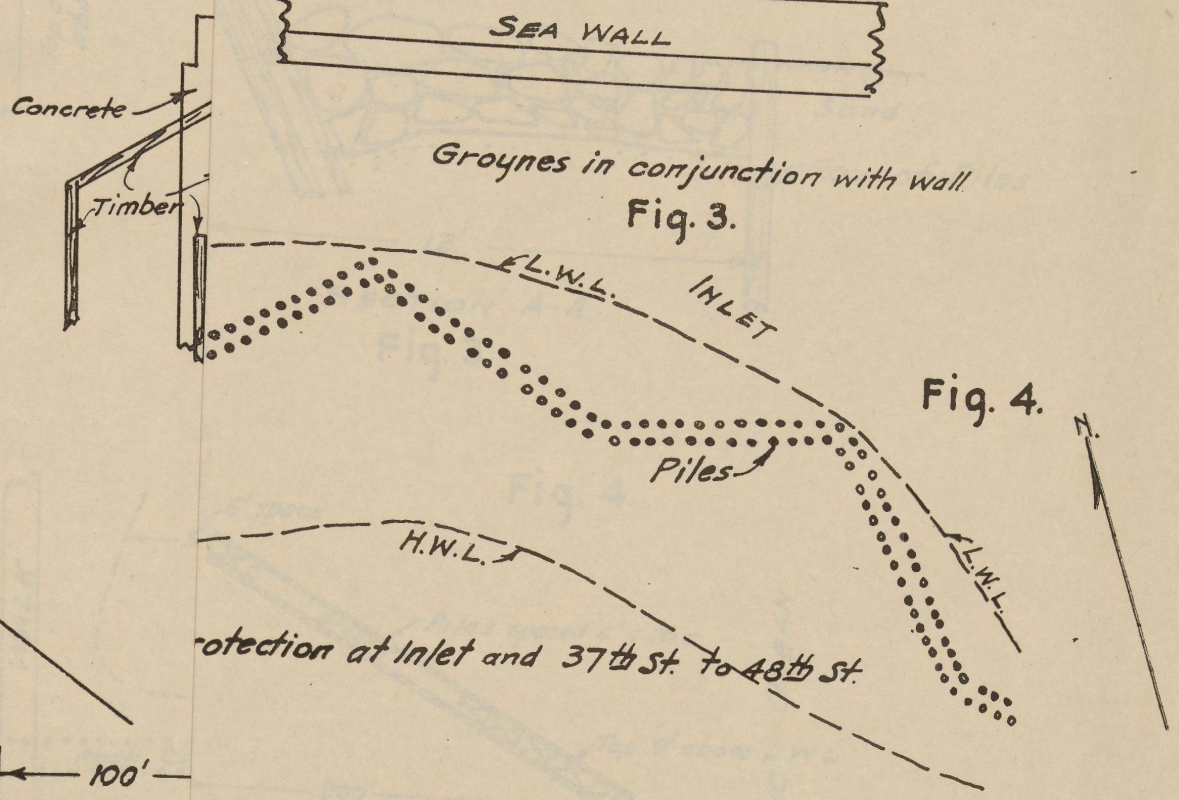
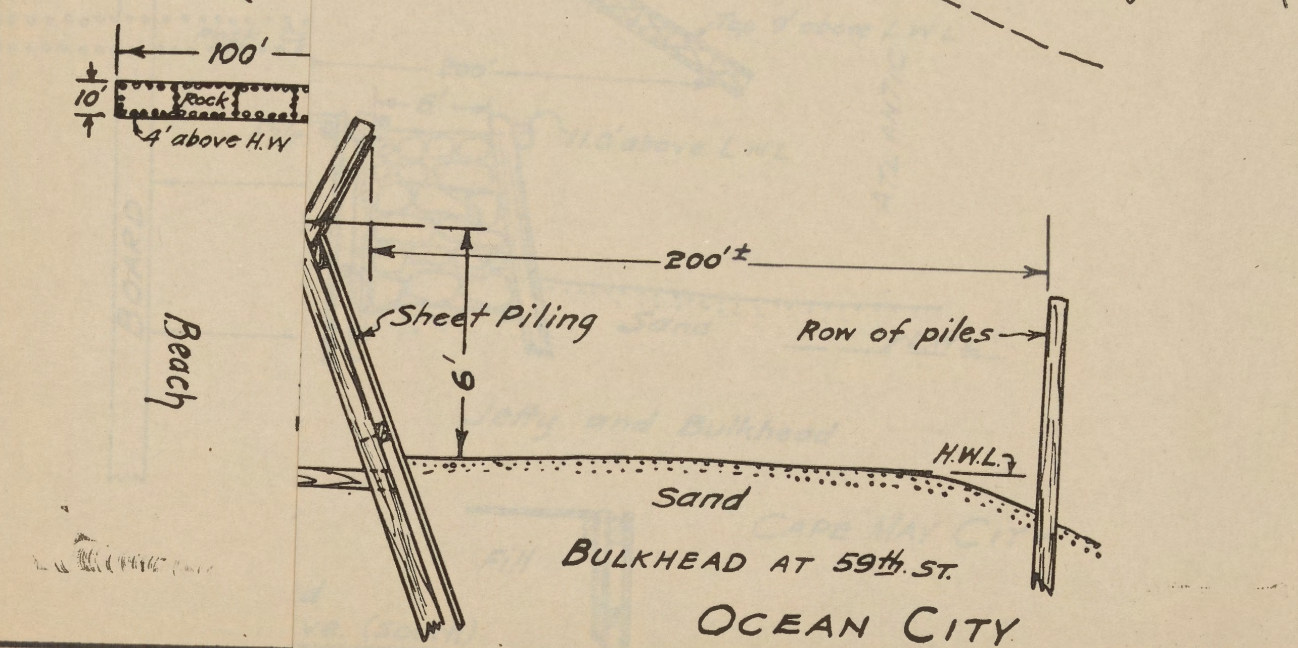
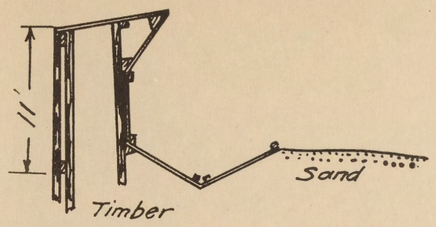


Fig. 4.

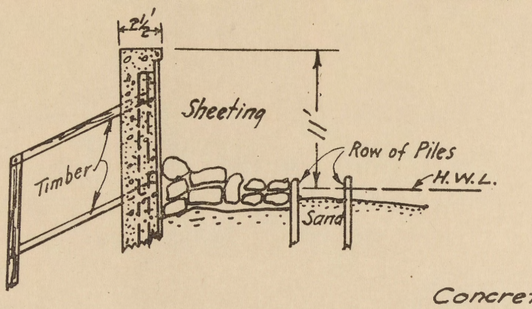


BULKHEAD AT 59th ST.

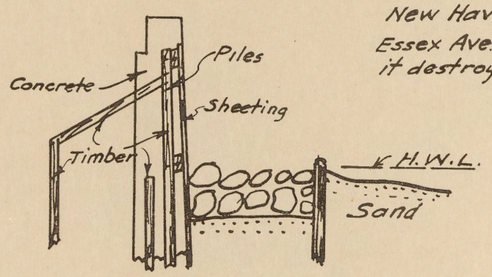
OCEAN CITY



Near Princeton Ave.



Concrete wall from New Haven Ave., Ventnor to Essex Ave. Margate. Most of it destroyed.



VENTNOR
BULKHEAD TYPES
Fig. 1.

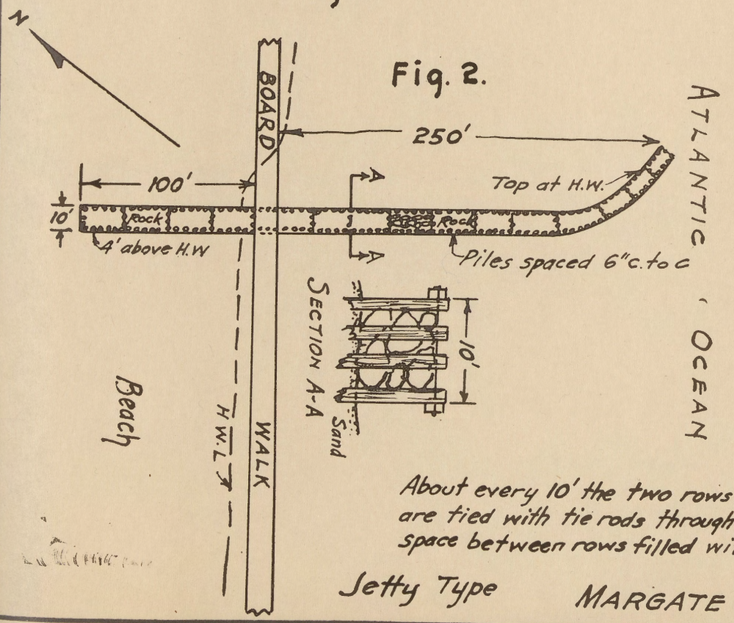
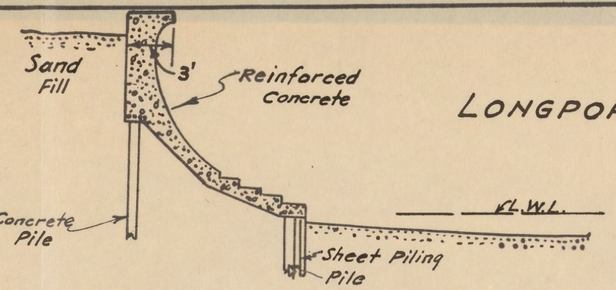


Fig. 2.

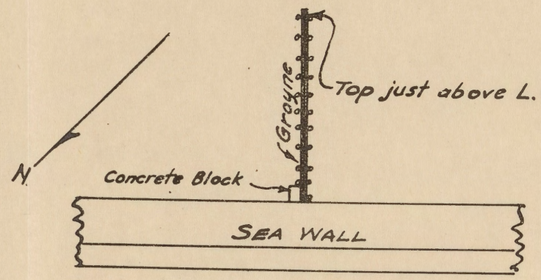
About every 10' the two rows of piles are tied with tie rods through two piles, space between rows filled with rocks.

Jetty Type MARGATE CITY



LONGPORT

SEA WALL



Groynes in conjunction with wall
Fig. 3.

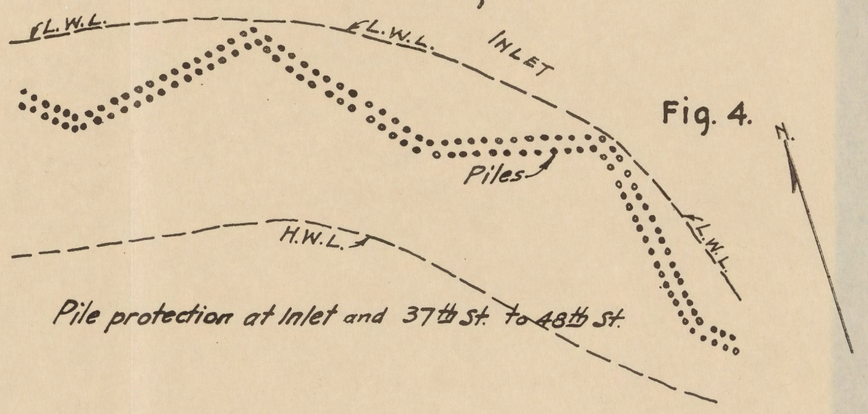
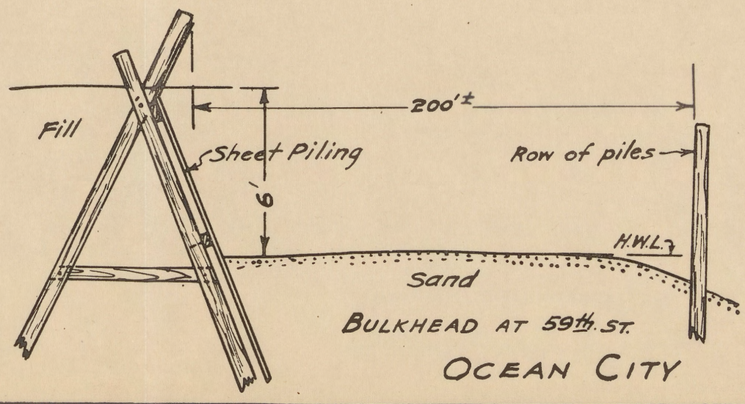


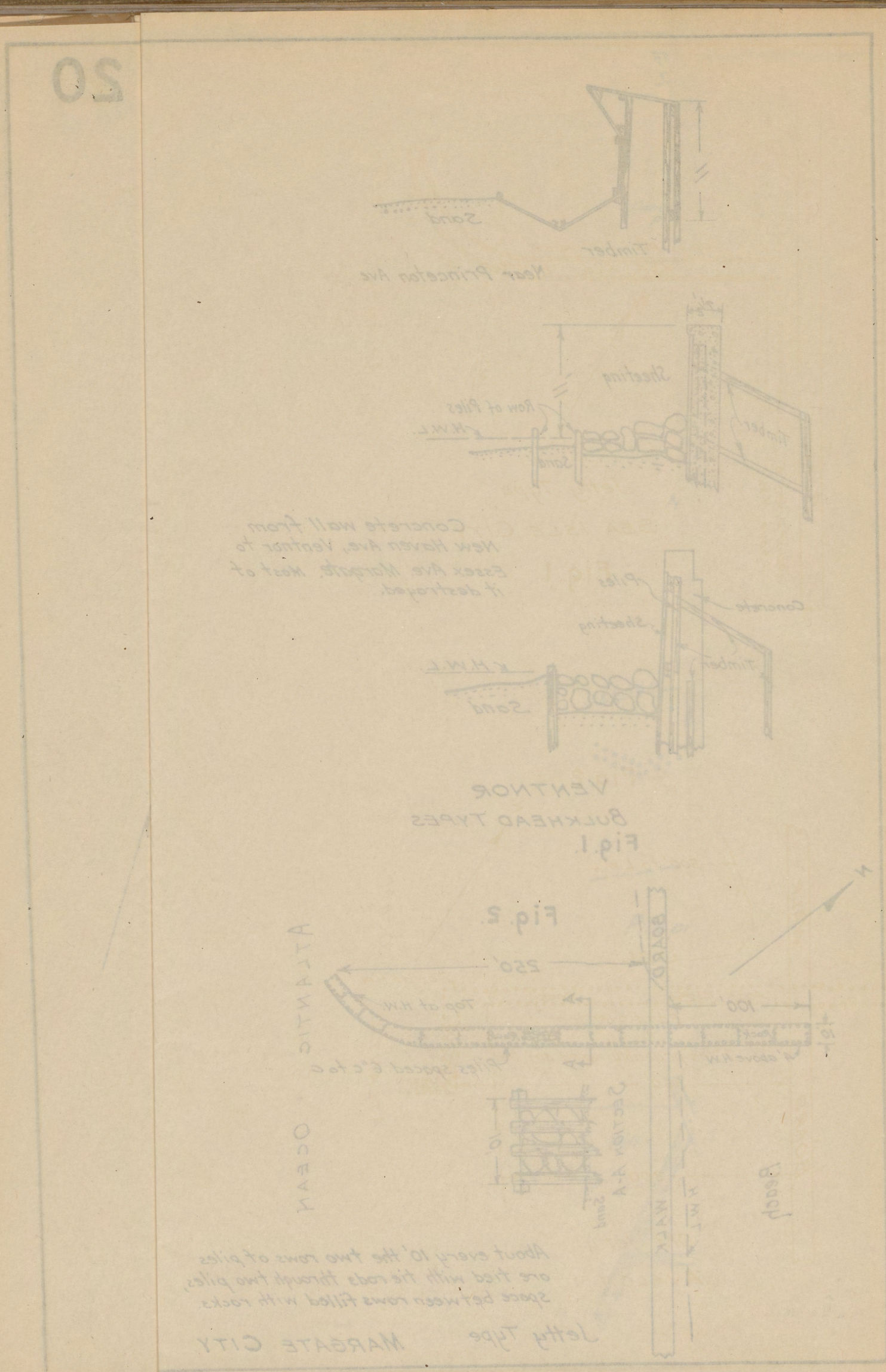
Fig. 4.

Pile protection at Inlet and 37th St. to 48th St.



BULKHEAD AT 59th ST.

OCEAN CITY



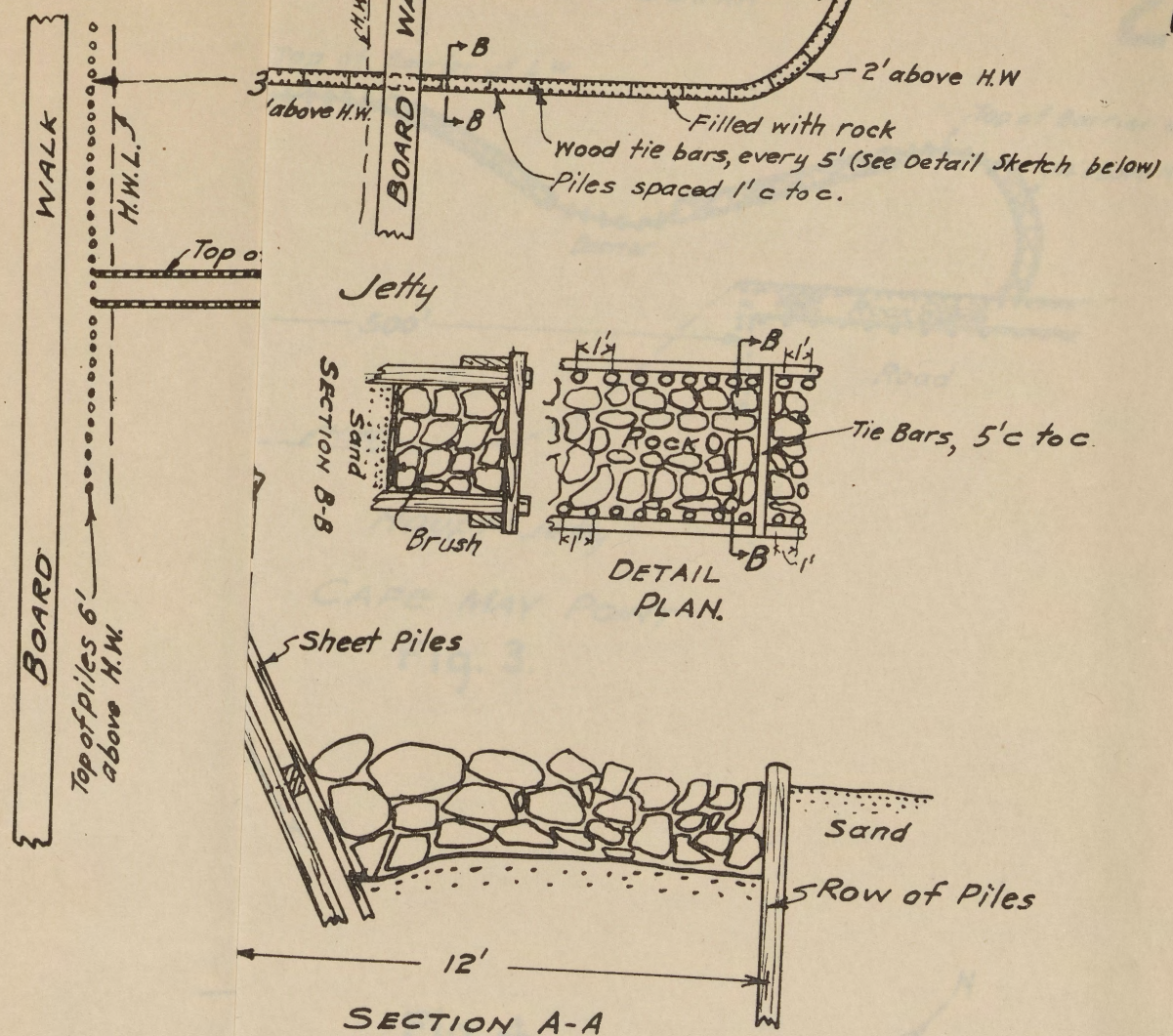
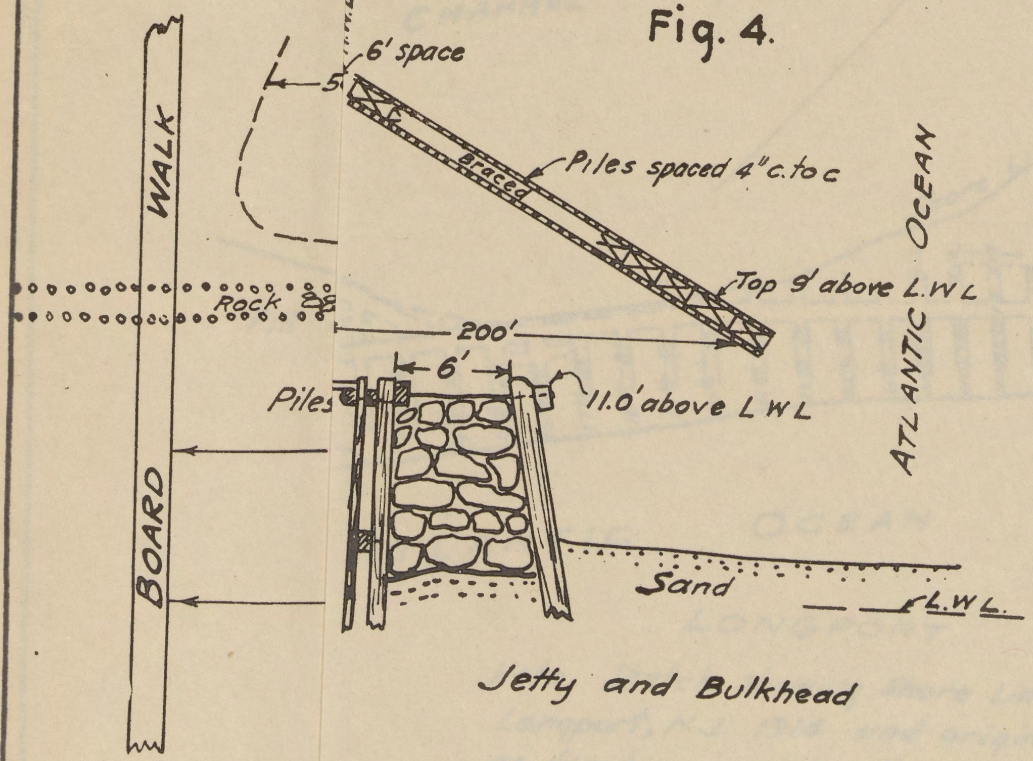
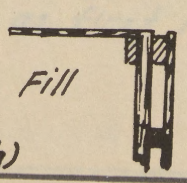


Fig. 3.

Fig. 4.

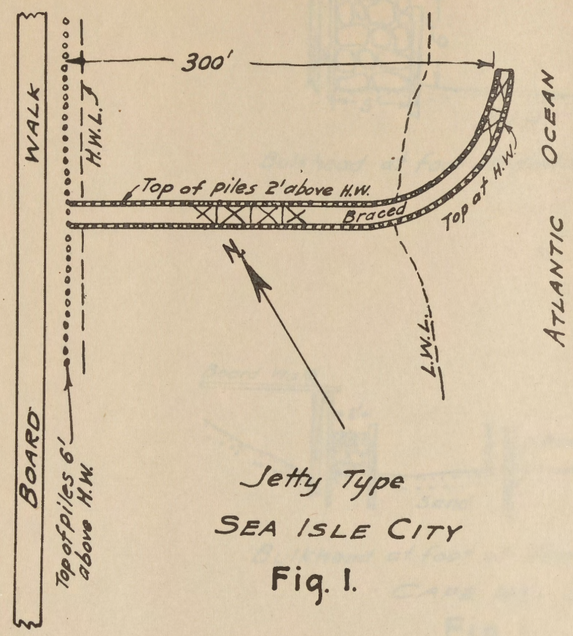


Jetty and Bulkhead



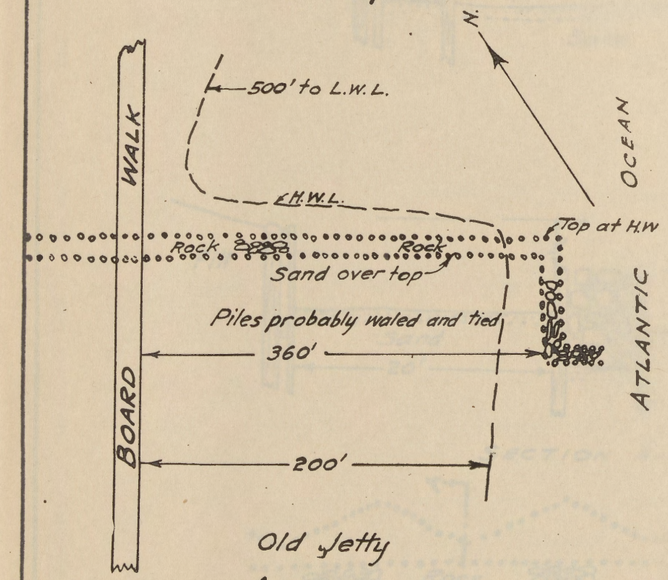
CAPE MAY CITY

ve. (South)



Jetty Type
SEA ISLE CITY
Fig. 1.

Fig. 2.



Old Jetty
AVALON

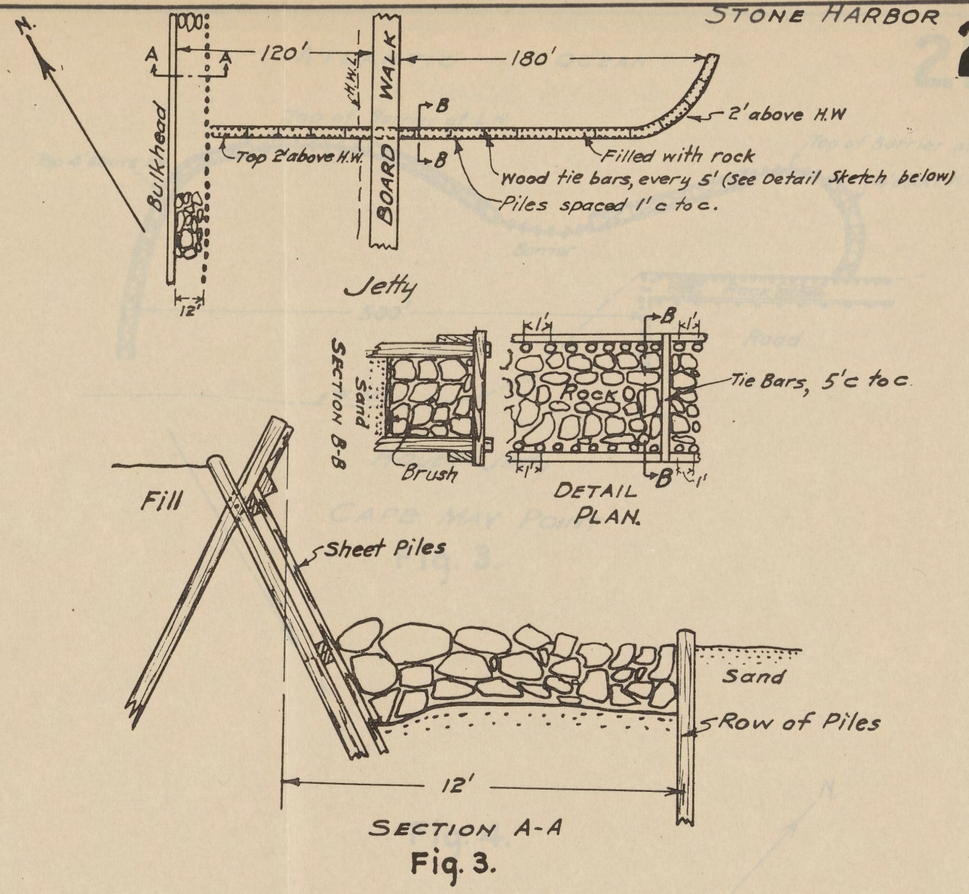
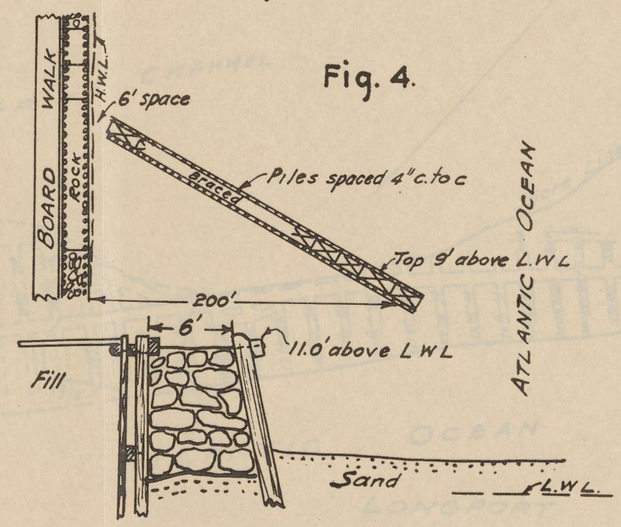
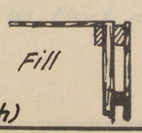


Fig. 3.

Fig. 4.

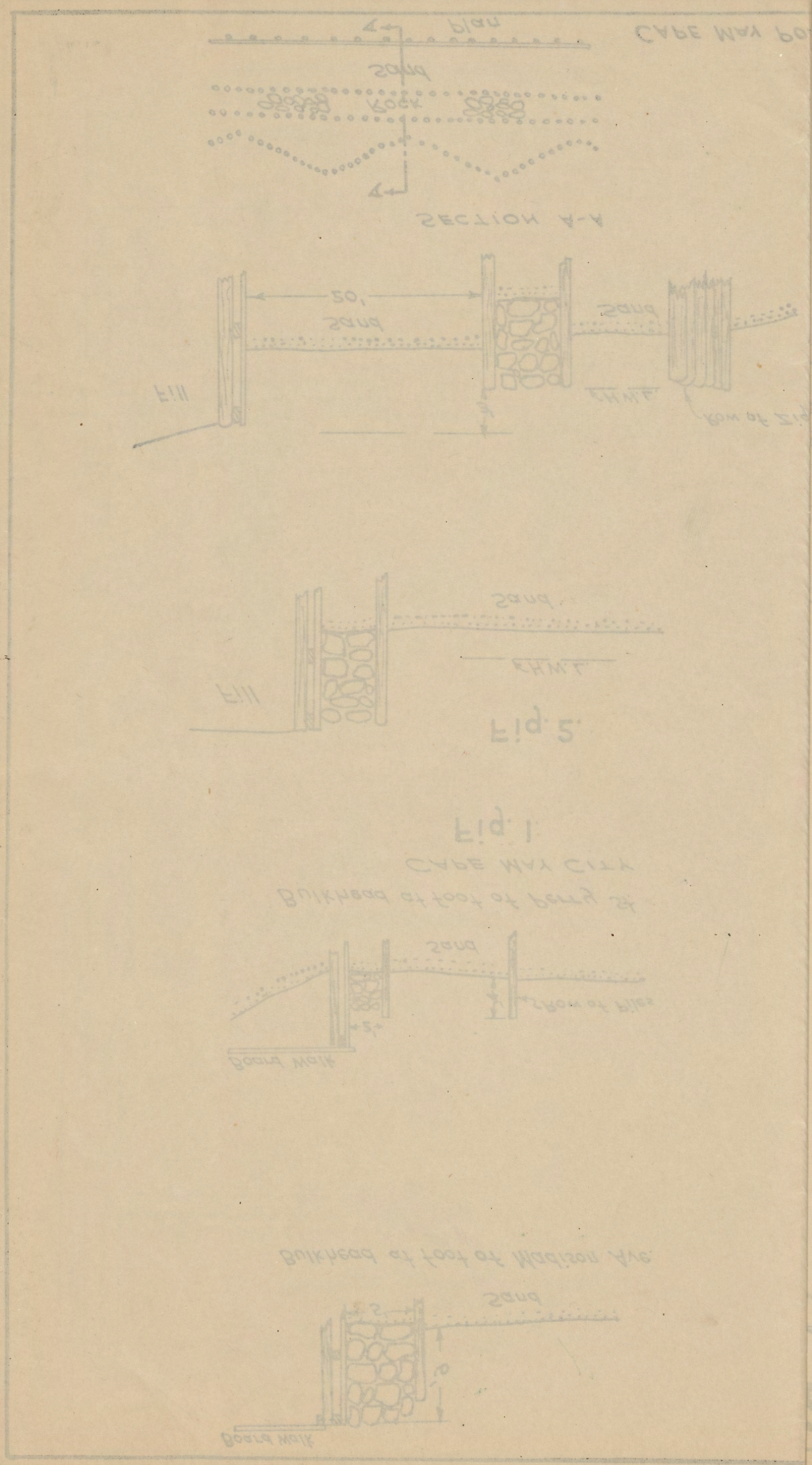


Jetty and Bulkhead



Bulkhead
Madison Ave. (south)

CAPE MAY CITY



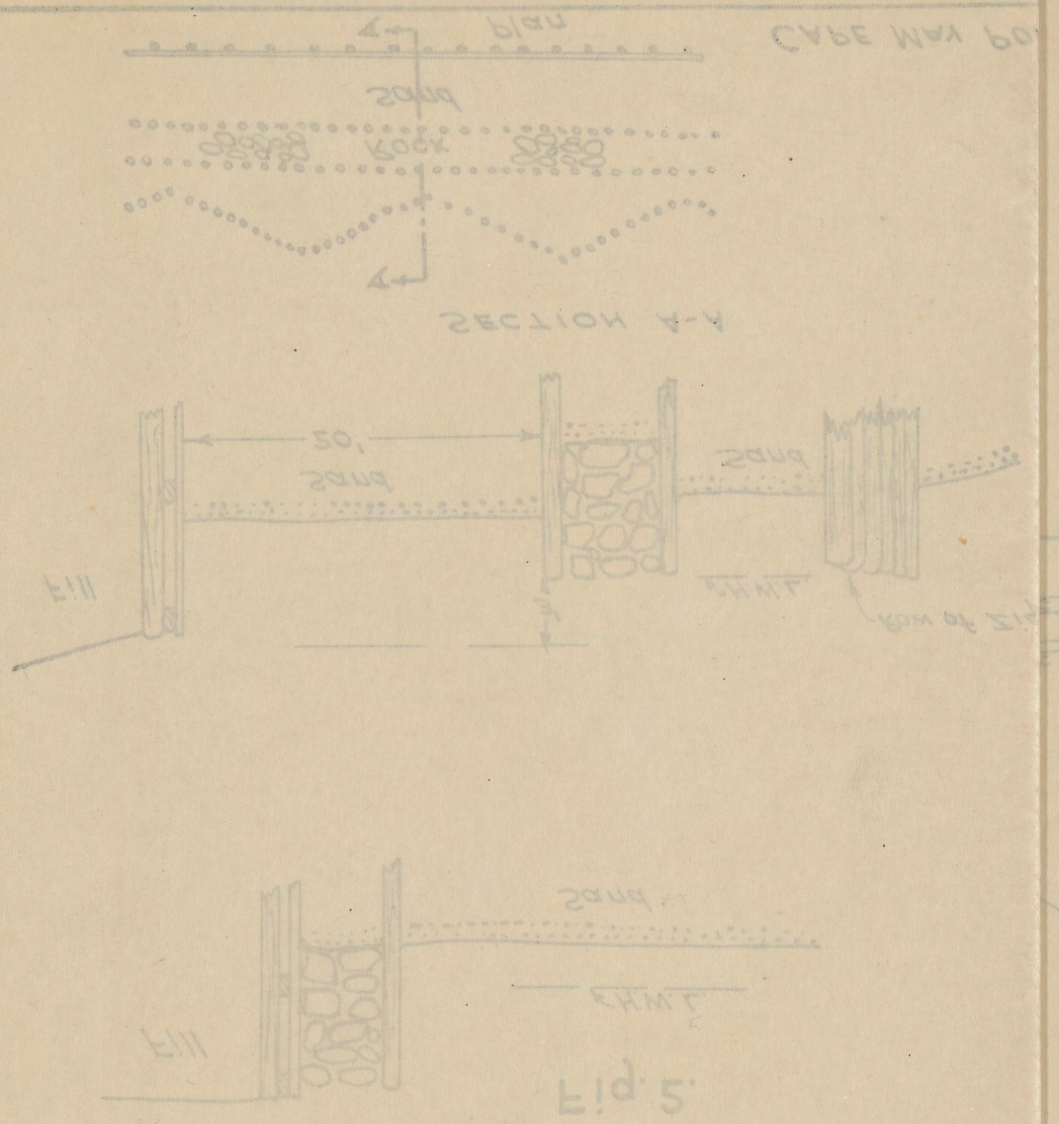


Fig. 5.

Cape May City

Bulkhead at foot of Decatur Ave.

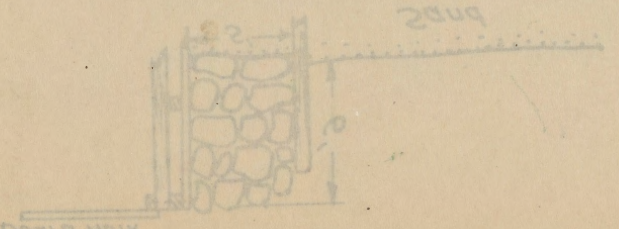
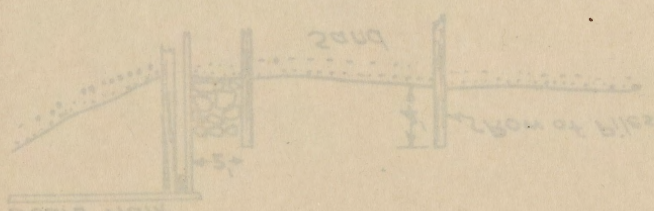


Fig. 1.

Cape May City

Bulkhead at foot of Perry St.



Bulkhead at foot of Madison Ave.