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Report to the Towns of Brookhaven and Islip, N. Y., on the Hydrography of Great South Bay and Moriches Bay

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Director

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I. INTRODUCTION

During the summer of 1950, The Woods Hole Oceanographic Institution conducted a study of the waters of Great South Bay for the Town of Islip, New York, with a view to seeking the cause of the decline of the oyster industry, which has deteriorated steadily during the past twenty years. The report of these studies was submitted in January 1951, (7). The survey revealed two conditions which in combination appeared to be unfavorable to the oyster industry.

One unfavorable condition was the local change in circulation occasioned by the opening of Moriches Inlet in 1931, which had increased the salinity of Bellport Bay, creating a condition which might well be detrimental to the production of seed oysters. Aside from this, it was concluded that little change had taken place in the salinity and tidal exchange of the central and western part of the bay during the past twenty years.

The second unfavorable condition was the pollution of Great South Bay by wastes from the duck farms located along the Carmans River and the tributaries of Moriches Bay. Chemical studies indicated that the bay water is unusually rich in the products of decomposing organic matter. These materials appeared to arise from the mouth of the Carmans River and the tributaries of Moriches Bay, from which they are carried westward across Great South Bay. They provide nutriment for the growth of an unusually dense population of microscopic plants. Evidence existed that oysters do not feed properly on water containing such large concentrations of plant cells, and available statistics showed a clear correlation over a period of years between the condition of bay oysters and the numbers of plant cells in the water. Finally, the decline in oyster production has been closely paralleled by the growth of the duck industry, which increased fourfold during the period.

In the report on the survey of 1950, it was pointed out that a number of questions had been revealed which were not anticipated when the field work was in progress and that these questions merited additional study. One of these related to the behavior of uric acid, the peculiar form in which birds secrete nitrogenous wastes, which promised to provide unambiguous evidence on whether the duck farms are the source of pollution. Another was the more detailed study of the circulation of Moriches Bay and its connection with Great South Bay through Narrow Bay, since this appeared to be the principal avenue of the pollution of Great South Bay. Finally, more detailed information was desired concerning the actual quantities of pollutants arising from the duck farms and of the alterations of its components by biological and other action upon introduction into the bay water.

Before these additional studies could be undertaken, the problem acquired a new aspect because of the spontaneous closure of Moriches Inlet which occurred on May 15, 1951. While this terminated any possibility of increasing knowledge of the circulation between the bays as it previously existed, it afforded an opportunity to observe the effect of the opening on the condition of the bay waters. This information was of prime importance in view of the proposal to reopen and stabilize Moriches Inlet.

Field parties visited the region on three occasions during the summer. On July 12-14, 1951, a survey was made of the entire system of bays lying between the western extremity of Great South Bay and the Shinnecock Canal. Between July 27 and August 5, studies were made of the chemical conditions in Moriches Bay and its approaches, and a detailed examination was carried out on the immediate conditions associated with the duck farms along the Terrell River. On September 24-29, an attempt was made to measure the exchange of water and associated pollutants between Moriches Bay and Great South Bay, and through the Quantuck Canal. On this occasion continuous observations were made at Smith Point and Beach Lane Bridge for a period of fifty hours, including four complete tidal cycles.

II. REPORT ON THE INVESTIGATIONS

1. The Hydrography of Moriches Bay and Approaches

Moriches Bay has a mean depth of four feet, an area of 450 million square feet, and a volume of 1800 million cubic feet. Since the closure of Moriches Inlet on May 15, 1951, it has been drained by two passages; the opening between Narrow Bay and Great South Bay at Smith Point and the Quantuck Canal. See Figure 1.

The renewal of water in Moriches Bay is effected by tidal action and by the flow of fresh water from the watershed, which requires that more water leave the bay on the ebb than returns on the flood.

The tides of Moriches Bay result from a tidal wave which enters Fire Island Inlet and reaches Smith Point about four and one-half hours later. Two hours are required for the crest to reach the eastern end of Moriches Bay. The range of tide is reduced in Narrow Bay, resulting in a mean range of tide of less than 0.3 feet throughout Moriches Bay.

The tidal current in the Quantuck and Quogue Canals results from differences in level in Moriches and Shinnecock Bays. These differences are due to the greater tidal range and earlier time of high water in the latter bay. The reported difference in mean sea level should result in a net eastward flow through the canals. The difference in level is small and may be expected to be affected greatly by strong winds.

Measurements during four complete tidal cycles on September 24-26, 1951, showed an average movement into and out of Moriches Bay of 112 million cubic feet per tide. The flow past Smith Point accounts for 85 per cent of this movement.

At Smith Point the average ebb flow out of Moriches Bay exceeded the flood by about eight per cent. Long-term averages of the flow at Smith Point indicate that the excess westward flow may be twice as great as this figure indicates (4).

In the Quantuck Canal the eastward flow exceeded the westward flow. Consequently there was no net movement of water across Moriches Bay from Shinnecock Bay into Great South Bay.

The net loss of water from Moriches Bay is balanced by accessions of rain water entering the bay from the watershed. The mean rainfall on the watershed is 24.6 million cubic feet per day of which 85 per cent or 21 million cubic feet probably enter the bay as runoff and seepage. During dry periods this quantity may be reduced. It follows that on the average a particle of water or attendant pollutant may remain in the bay about eighty-three days.

Salt was being lost through both passages indicating that Moriches Bay is still freshening after the closure of the inlet. The daily loss was about 0.8 per cent of the total salt content of the bay.

The net loss of fresh water and of salt was divided between Smith Point and the Quantuck Canal in the same proportions as the total flow; namely, in a ratio of about 85:15. Strong local winds may check the normal flow of water through the passages with the result that the current does not reverse, to flow against the wind, at the expected time. When such failure to reverse occurs on several successive days, a very large part of the water of Moriches Bay must be exchanged with Bellport Bay.

The average salinity of Moriches Bay decreased in the course of the summer and was 19.7 ‰ in late September. The salinity is lower along the north side of the bay, especially in the western end, indicating that the water freshened by river flow and seepage is moving rather directly into Narrow Bay and thence past Smith Point into Bellport Bay.

2. The Effect of Moriches Inlet on the Hydrography

The closure of Moriches Inlet has led to a reduction in the range of tide and a decrease in the volume of water exchanged at each tidal cycle.

The principal access of sea water to Moriches Bay since the inlet closed is past Smith Point where the tidal flow has increased by perhaps fifty per cent since 1950.

As a means of removing pollutants from Moriches Bay, the circulation past Smith Point may be expected to be less effective than the former exchange through the inlet.

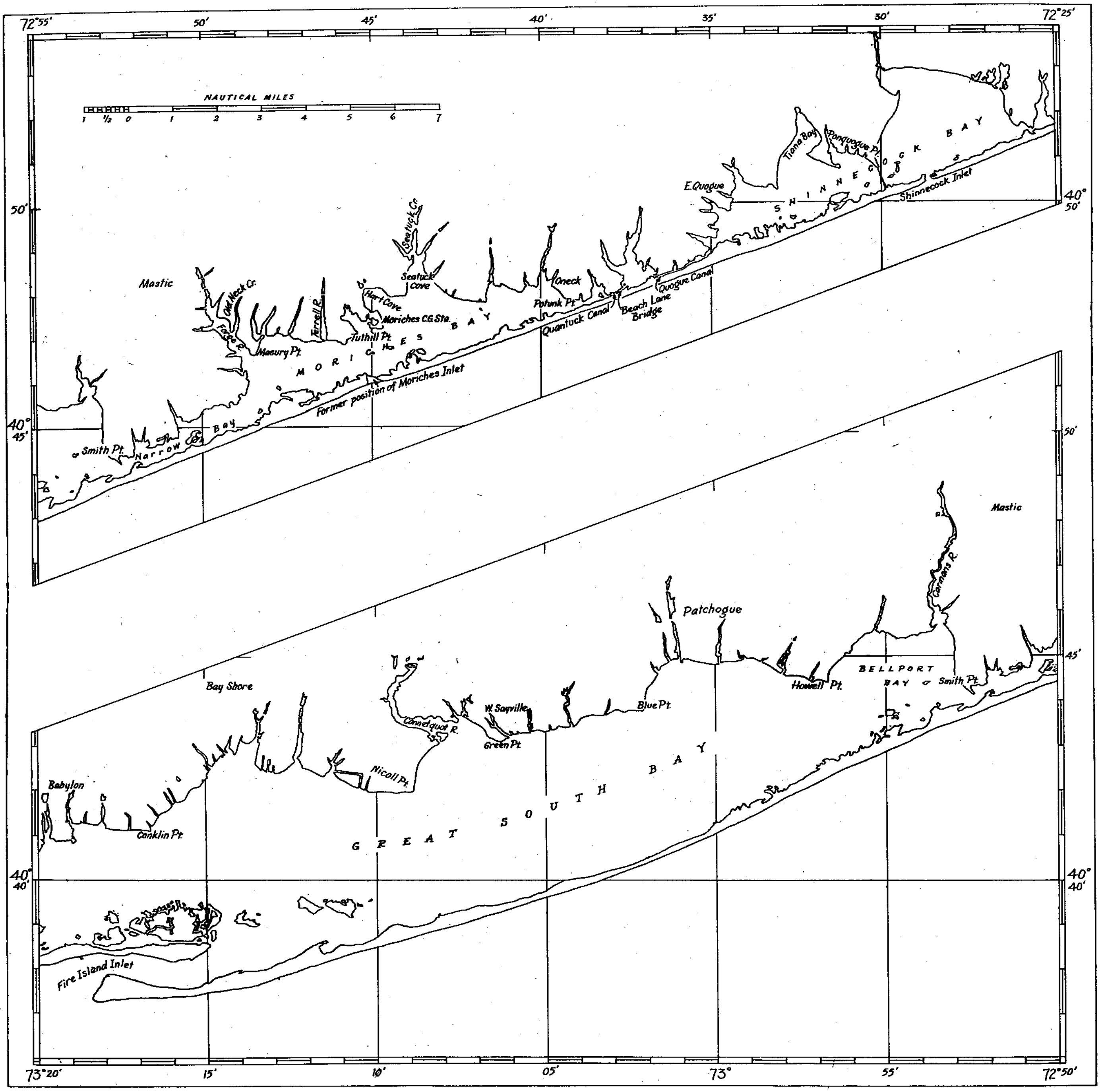

Figure 1 Map of Great South Bay and Moriches Bay.

This is because its flow is smaller than was that through the inlet, and also because the water escaping accumulates in Bellport Bay and much of it returns to Moriches Bay on the subsequent flood tide.

During the summer of 1951 the salinity of Moriches Bay was decreasing at a rate of 0.033 o/oo per day and by the end of September had become 8 o/oo lower than it was in 1950. There is evidence that the progressive freshening of the bay is interrupted by the flow of salt water across the beach and by abnormal tidal exchange, both resulting from occasional periods of high wind. The effect of these events is to renew the Moriches Bay water with more saline water from external sources, and thus delay the freshening. The effect of such disturbances will be to accelerate the removal of accumulated pollutants from Moriches Bay.

The influence of the closure of Moriches Inlet in freshening the water extends into Bellport Bay, where the salinity has fallen 4 o/oo, but is not observable in Great South Bay west of Patchogue.

If the inlet remains closed the salinity of Moriches Bay will continue to decrease, but should not reach a final value quite as low as 10 o/oo, the condition existing before Moriches Inlet opened.

In summary, the effect of closure of Moriches Inlet on the circulation of water has been such as to greatly retard the escape of pollutants from Moriches Bay. It is possible that at any one time the bay might retain a quantity of pollutant equal to the eight or ten weeks' contamination.

3. Pollution by Duck Farms

The duck farms on tributaries of Moriches Bay and on the Carmans River produce four million ducks annually. After allowing for the fraction of food utilized by the growing ducks, it is estimated that 2.7 million pounds of nitrogen and 0.82 million pounds of phosphorous are available annually in the wastes from these farms. The duck pens are so laid out that much of this waste finds its way directly into the tributaries of the bays. See Figure 2.

In a study of the Terrell River, on which 400,000 of the ducks are grown, it was found that the principal

Figure 2 Duck farms on Terrell River. Photo by Joseph Adams, Brookhaven, N. Y.

nitrogenous constituent of the waste, uric acid, is converted rapidly by bacterial action into soluable forms readily assimilated by plants and bacteria, and are so assimilated before reaching the bay. Inorganic phosphates are also assimilated within the tributaries, but considerable excesses of dissolved phosphate finds its way into the bay water.

Measurements of the exchange at the mouth of the Terrell River indicate that between one-third and two-thirds of the wastes produced daily find their way into Moriches Bay. It is estimated that the accumulation of the wastes present in Moriches Bay on August first could be produced in four to six weeks by the tributary farms.

The only way in which chemical constituents of the wastes have been recognized in bay water is by the abnormal concentrations of nitrogen and phosphorous. In Moriches Bay these elements are present in eight or ten times the quantity to be expected in uncontaminated water. The nitrogen and phosphorous are present chiefly in the living cells of microscopic plants, animals, and bacteria, and in soluable products of decomposition. Much phosphorous is also present as inorganic phosphate.

The quantitative distribution of nitrogen and phosphorous in the bays indicates that these materials originate in the tributary rivers of Moriches Bay and from the Carmans River. The concentrations decrease progressively as the contaminants are dispersed from there eastward through the Quantuck Canal and westward into Great South Bay and to Fire Island Inlet.

The occurrence of abnormal concentrations of nitrogen and phosphorous is seasonal. Concentrations rose rapidly in Forge River in May and at Smith Point and Green Point in June. After October first they decline rapidly and level off at low values in November.

Measurements at the end of September indicated that nitrogen and phosphorous were moving into Great South Bay past Smith Point. After making allowance for the contribution from Carmans River, it was estimated that the abnormal accumulation of these elements present in Great South Bay could be accounted for by three to six months additions from these sources.

The total phosphorous and nitrogen present in Moriches and Great South Bays at the end of September was equivalent to about thirty per cent of the wastes available from the seasons crop of ducks raised on the tributary streams.

In summary, these observations, measurements, and estimations leave no doubt that the abnormal quantities of nitrogen and phosphorous arise from the tributaries on which the duck farms are located and that the wastes from the farms are quantitatively adequate to produce the observed contamination of the waters of Moriches and Great South Bays.

4. The Effect of Pollution on the Biology of the Bays

No attempt has been made to survey the animal life of the bays. The facts concerning commercial species are well known to fishermen and the conservation authorities. Our study is limited to plant life and the chemical conditions which may influence the qualities of the bay water as an environment for animal life.

During the summer the bay water becomes filled with an exceptionally dense bloom of an unicellular algae related to the genus Chlorella--locally known as the "small form". This population extends from Babylon in Great South Bay to Ponquogue Point in Shinnecock Bay. The center of abundance lies between Smith Point and the Forge River. The numbers decline gradually across Great South Bay and drop suddenly at the eastern end of Quogue Canal.

The distribution of the small forms geographically and their period of abundance corresponds closely to the enrichment of the bay waters with nitrogen and phosphorous. Practically all of the nitrogen and a large part of the phosphorous are in fact present in the cells of these and other organisms.

The growth of the small form population is limited by the quantity of nitrogen in the water. Inorganic forms of nitrogen produced by bacterial action, or by the introduction of pollutants, are practically absent and evidently are consumed as rapidly as they become available. Phosphate, in contrast, is present in excess of the requirements of the plants.

The reason for this is that the duck wastes contain nitrogen and phosphorous in a ratio which is small compared to the requirement of the plant cells. In the duck food and in the effluent of the Terrell River, which is heavily contaminated, the ratio of nitrogen to phosphorous is about 3.3:1. The plants require these elements in a ratio of about 15 to 1. Consequently, the growing plants use up the nitrogen first and leave the excess phosphorous, as phosphate, in the water.

The fact that nitrogen and not phsophorous is the limiting factor in the growth of algae in the bay should be considered in any attempt to reduce the pollution. Partial removal of phosphorous from the wastes may have no effect whereas any reduction in nitrogen will be directly effective.

The oxygen supply in Great South Bay appears to be adequate, the water being at least eighty per cent saturated at all depths. In Moriches Bay the water contains generally less than seventy-five per cent of the saturation value. Along the northern shore near the tributaries on which the duck farms are located, the water is less than fifty per cent saturated. In this region much lower values occur near the bottom. In the Forge River and in the pond at the head of Hart Cove, the oxygen was greatly depleted in some samples. There is no doubt that in many of the tributaries anaerobic conditions develop as the result of excessive organic content. In one instance, it is reported that a freshly painted cottage was blackened by the hydrogen sulfide released from the water during hot calm weather.

The heavy growth of plants limits the visibility of submerged objects to 1.5 to 2.5 feet. Measurements show that ninety per cent of the light is absorbed before reaching the bottom in five feet off West Sayville. In Narrow Bay ninety-nine per cent was absorved in ten feet. A similar result was obtained in 3.3 feet in the Forge River.

Experiments showed that off West Sayville, plant cells could produce more oxygen by photosynthesis than was used up by respiration, even at the bottom. In Narrow Bay in contrast this did not take place below 5.5 feet. It is evident that where the growth of plant cells is sufficiently dense, as it is in Moriches Bay, oxygen will tend to disappear from the deeper water unless it is renewed by mixing with water from above. This is evidently what is happening in the northern part of Moriches Bay.

The organisms in a sample of water from Great South Bay consumed only 0.45 ml oxygen per liter in twenty-four hours but those in a sample from Narrow Bay used 1.7 ml per liter in that time. At this rate they could consume all the oxygen in saturated water in three days. All of the samples of water collected in Bellport Bay and Moriches Bay had similar high rates of oxygen utilization.

It is concluded that while serious oxygen deficiency occurs only in a limited area near the source of pollution, the margin of safety is so small throughout Moriches Bay that an unfavorable combination of circumstances might easily lead to severe oxygen lack with attendant undesirable results.

5. The Effect of Moriches Inlet on the Pollution of the Bays

A comparison of the conditions existing in mid-summer in Moriches Bay before and after the closure of Moriches Inlet, on May 15, 1951, indicates that the resulting change in circulation has markedly increased all those factors which are associated with pollution.

In 1950 the bay water was relatively clear and colorless, thus contrasting strongly with the condition in Great South Bay. Submerged objects and the bottom were clearly visible at depths of 3.5 to 5 feet. In 1951 Moriches Bay water had a dull yellow-green color due to great numbers of plant cells. Submerged objects were invisible at depths of only 1.5 to 2.5 feet. The condition was similar to that in Great South Bay as observed both in 1950 and 1951, except that the turbidity was more marked.

Measurements of the range in concentration of total phosphorous, total nitrogen, and particulate phosphorous all indicate that the bay water was much more heavily contaminated after the closure of the inlet. The concentrations of total nitrogen and phosphorous was about doubled. The particulate phosphorous was increased fourfold, indicating that the polluted water remained in Moriches Bay long enough for the contaminants to be absorbed into the cells of living organisms.

The oxygen content of Moriches Bay water was definitely lower in 1951 than in the year before, as might be expected from its increased organic content.

These changes are also reflected in the water in the eastern part of Bellport Bay. Throughout the remainder of Great South Bay, however, the conditions observed in 1951 did not differ from those existing before the inlet closed.

Estimates of the total nitrogen and phosphorous present in the bays on about the first of August have been made from the data obtained during the surveys in 1950 and 1951. In Moriches Bay the total quantities of these pollutants was about double in the latter year. In Great South Bay the quantities were nearly the same in the two years. The total quantities present in both bays was also about the same, being 990,000 pounds of nitrogen and 171,000 pounds of phosphorous in 1950 as compared to 950,000 pounds of nitrogen and 237,000 pounds of phosphorous in 1951. It is concluded from this that when the inlet was open a relatively small part of the pollutants escaped through it to the sea. The greater part evidently found its way into Great South Bay even then.

In summary, it is clear that the nitrogen and phosphorous derived from the wastes from the duck farms accumulate and are held much longer within the open waters of Moriches Bay than was the case before Moriches Inlet closed. As a result Moriches Bay contains a much more dense population of microorganisms. Except for some increase in the pollution of Bellport Bay, the conditions in Great South Bay have not been changed by the closure of the inlet.

The data upon which the foregoing conclusions are based are presented and discussed in the Appendix.

III. COMMENTS ON PROPOSED IMPROVEMENTS

Three different measures have been proposed for improving the state of the waters in Moriches and Great South Bays; reducing pollution by duck farm wates, reopening and stabilizing Moriches Inlet, and restricting the flow between Moriches and Bellport Bays. These measures are discussed in the light of the surveys made in 1950 and 1951.

Reducing pollution

The studies made in 1951 have strengthened our belief that the pollution by duck farm wastes are the primary cause of deterioration of the biological and recreational values of Great South Bay. They have shown, in addition, that the conditions in Moriches Bay have become critical since the closure of the inlet. It seems evident that the surest way to improve conditions is to reduce the pollution substantially below its present level. Recent action of the New York State Pollution Board promises to lead to a fundamental betterment of conditions.

Our studies indicate that only a portion of the duck wastes, estimated at perhaps a third, reach the bays directly. This is probably the material carried into the bays by the troughs draining the farms or deposited by the ducks in pens extending into the water. First attention should be given to reducing these sources of contamination.

The present conditions in the bays arise from the excessive plant growth which results from the large quantity of nitrogen and phosphorous available. These elements are absorbed by plants in the form of simple inorganic molecules (ammonia, nitrates, and phosphates) after they have been made available by the bacterial decomposition of organic matter. It will be desirable not only to reduce the introduction of organic wastes into the bay, but also to avoid the direct discharge of the products of decomposition of such material. The effluents from settling tanks, filter beds, etc., may still be harmful by stimulating the growth of microscopic plants. However, if the entrance of such effluents can be delayed and distributed more evenly through the year, substantial benefit should result. At present the contamination is concentrated in the four warm summer months. In winter it would be much less harmful.

If methods of reducing the contamination by compounds of nitrogen or phosphorous are considered, it should be recalled that at present the availability of nitrogen limits plant growth. A considerable reduction of phosphates might have little effect on the plant population.

Probably 500 tons of nitrogen and 100 tons of phosphorous are lost to the bay waters annually. Their recovery for use as fertilizer deserves consideration.

Reopening Moriches Inlet

The reopening and stabilization of the inlet would have obvious advantages in providing an outlet to the sea for boating and access to the bay for fish. Its effect on the state of the bay water, if not accompanied by a reduction in pollution, may be judged by the conditions existing prior to 1951. There is no question that the state of Moriches Bay water would be improved--to a degree depending on the width and depth of channel which is maintained. The objectionable conditions of the tributaries themselves would not be greatly improved. The effect on the conditions in Great South Bay could not be expected to be substantial, except that Bellport Bay would become more saline.

If pollution by the duck farms is reduced and the inlet is kept open, the state of Moriches Bay water may be expected to improve in proportion to the success of these endeavors. In Great South Bay the reduction in pollution would probably be very advantageous but it would be relatively unimportant whether the inlet was kept open or not.

If the reduction in pollution led to conditions in which oysters would grow once more in Great South Bay, the opening of the inlet might prove disadvantageous. Bellport Bay was once a valuable source of seed oysters, whose production is thought to be favored by relatively fresh water. Opening of the inlet would lead to a substantial increase in the salinity of Bellport Bay and might be unfavorable to the redevelopment of this resource.

Restricting the flow at Smith Point

In our 1950 report, the possibility of reducing the exchange of water between Moriches and Great South Bays by means of an embankment at Smith Point was discussed.

At that time Moriches Inlet was open and the possibility of reducing pollution at its source seemed remote. It was pointed out that such a construction, designed to reduce the pollution of Great South Bay by Moriches Bay water would be advantageous only if the inlet remained open. If pollution were satisfactorily controlled it would serve no useful purpose, except to reduce somewhat the salinity of Bellport Bay. In view of the present interests in correcting the polluted condition of Moriches Bay and the possibility that an opening at the inlet may not be maintained permanently, this proposal does not warrant further consideration at the present time.

In our judgment, the proposals to reduce the access of wastes from the duck farms to Moriches Bay and to reopen the inlet should both lead to a substantial improvement in conditions. Of the two, the reduction of pollution would appear to be very much the most beneficial. It would improve conditions in Great South Bay as well as Moriches Bay, and would eliminate the cause of the present undesirable conditions.

IV. ACKNOWLEDGMENTS

The work conducted in 1951 was supported jointly by the appropriations made by the Towns of Brookhaven and Islip at the initiative of the Long Island Fishermen's Association.

Mr. Harry T. Tuthill and Mr. Samuel B. Cross of the Suffolk County Department of Highways supplied invaluable data on the tides of the bays.

Mr. Alfred Tucker placed the facilities of the New York State Conservation Department at our disposal.

The Bluepoints Company, Inc., through Mr. Joseph B. Glancy, and George Van der Borgh and Son, provided laboratory space and boats for the field studies.

The School Department of the Town of Islip allowed us to use the chemical laboratory of the Sayville High School for our chemical studies.

Mr. Marshall F. Spear of the Long Island Duck Growers Marketing Cooperative and many of the duck growers have been most cooperative in supplying information relative to the practices of the duck farms.

The field parties from the Woods Hole Oceanographic Institution were led by Mr. Dean F. Bumpus, hydrographer, and Dr. Francis A. Richards, chemist, and included Dr. Mary A. Plunkett, Assistant Professor of Chemistry at Vassar College and Dr. Daniel R. Norton, Assistant Professor of Chemistry at George Washington University, Dr. Bostwick H. Ketchum and Mr. Ralph F. Vaccaro, microbiologists, Mr. Nathaniel Corwin, Miss D. Jean Keen, chemists, and Mr. John P. Barlow, zoologist. Their work in the field was assisted by Mr. Nicholas Griek of the Long Island Fishermen's Association, Mr. Edward Bevelander, and Mr. George Thilberg of the State Conservation Department, Mr. George Van der Borgh, Jr., and Mr. Stuart Cowan. Dr. James B. Lackey has been helpful in providing advice and information on the microscopic plants which are found in the bay waters.

V. APPENDIX

1. The Hydrography of Moriches Bay and Approaches

General Geography

Moriches Bay is one of a series of shallow bays lying between the south shore of the Long Island upland and the barrier beaches. See Figure 1. It is bounded on the west by Smith Point, where it joins Great South Bay. On the east it terminates at Potunk Point where it is connected with Shinnecock Bay through the Quantuck and Quogue Canals. The total length between these points is eleven nautical miles.

The bay is divided into two basins by Tuthill Point where it narrows to three-quarters of a mile and this division is accentuated by extensive shoals in this region which bare at low tide. These shoals appear to consist of sand washed in through Moriches Inlet, which formerly cut the barrier beach at this point. The maximum width of the basins is about two miles.

The bay narrows at the western end to form a passage three miles in length and one-half mile or less in breadth, known as Narrow Bay. This passage narrows to 1,000 feet at Smith Point where connection is made with Great South Bay.

The wider basins of Moriches Bay have level bottoms with depths of five to six feet. On the south, these basins shoal gradually toward the beach. The mean depth of the bay as a whole is about four feet. The channel of Narrow Bay is seven or eight feet in depth along most of its length with maximum depths up to twelve feet at Smith Point.

The northern side of the bay is indented with the drowned valleys of numerous small streams. The largest of these, the Forge River, situated at the junction of Narrow Bay and the western basin, is the principal fresh water tributary. Seatuck Creek, the second stream in size, opens at the widest part of the eastern basin. The greater part of the duck-growing industry is situated along the shores of these tributaries.

The bottom of the deeper basins is of soft black mud which is replaced by deposits of soft sludge, sometimes many feet deep in the channels of the tributaries. The shoal areas along the beach are sandy.

The total area of the surface of Moriches Bay, between Smith Point and Potunk Point is about 450 million square feet. Assuming a mean depth of four feet, its volume is 1800 million cubic feet. The passage into Great South Bay at Smith Point has a width of 1070 feet and a cross section of 6748 square feet. The Quantuck Canal, leading into Shinnecock Bay, is constricted at the Beach Lane Bridge to a width of 87 feet and a cross section of 809 square feet.

Hydrology

The mean annual rainfall for the region is 43.94 inches per year. The months preceding and during the survey were abnormally dry, as shown by the following data obtained at Patchogue (4):

	Normal	Observed 1951
June	4.29 inches	2.07 inches
July	3.56	2.80
August	4.78	3.16
September	3.54	1.51
4 months total	16.17	9.54
Rate per year	48.51	28.62
Mean rate per month	4.04	2.39

Applying these values to the area of the watershed, we obtain for the precipitation on the watershed:

	Area	Total Precipitation	
	square miles	million cubic feet per day	
		Normal	June-Sept. 1951
Drainage basin	80	24.6	14.6
Moriches Bay	20	6.15	3.64
Total	100	30.75	18.24

In the case of Great South Bay, it was estimated that the precipitation on the watershed became distributed as follows (7):

Rainfall on watershed	100 per cent
Evaporation from watershed	14.5
Ground water seepage	67.1
River flow	18.4

Applying these proportions to Moriches Bay, we obtain:

	Million cubic feet per day	
	Normal	June-Sept. 1951
Rainfall on watershed	24.6	14.6
Evaporation from watershed	3.57	2.12
Ground water seepage	16.5	9.79
River flow	4.53	2.69
Total accession to bay	21.03	12.48

The total accession of water to the bay, which should equal the loss by tidal exchange, is given by the sum of ground water seepage and river flow. On the basis of this calculation, it appears to be about 20 million cubic feet per day in normal seasons. During the survey period it may have been as little as 12.5 million cubic feet per day.

It is assumed that the rainfall on the bay itself equals the evaporation from the sea surface and may be left out of account (7).

According to the above estimates river flow accounts for a relatively small part of the total accession of water to the bay. Very little data is available for the flow of the rivers tributary to Moriches Bay. A series of gaugings of the east and west branches of the Forge River at Montauk Highway and of the west branch of Seatuck Creek at Pepperidge Lake Hatchery during five days between December 20, 1947 and April 17, 1948 gave the following values for the mean daily discharge (5):

Forge River	0.764 million cubic feet per day
Seatuck Creek	0.194 " " " " "

The combined total, 0.958 million cubic feet per day, of these two principal tributaries amounts to only one-twentieth of the estimated rainfall on the Moriches watershed. As in the case of Great South Bay, the greater part of the rainfall on the Moriches watershed finds its way into the bay by seepage

Tides

Since the closure of Moriches Inlet the tide has access to Moriches Bay only from Fire Island Inlet via Great South Bay and Shinnecock Inlet via the Quogue and Quantuck Canals. The available tidal data for the bays and passages between these inlets is given in Table I.* High water occurs progressively later in passing eastward from Fire Island Inlet across Great South and Moriches Bays. The delay is about 0.2 hours per nautical mile. High water at the eastern end of Moriches Bay, at Oneck, occurs seven hours after high water in the open ocean. The range of tide diminished on entering Fire Island Inlet. Throughout Great South Bay it is fairly uniform, averaging 0.6 - 0.8 feet. At the entrance to Narrow Bay at Smith Point, there is a further reduction in range. In the basins of Moriches Bay, the average range varies from 0.2 to 0.3 feet.

Physically, the tide is due to a progressive wave advancing steadily, but reduced in amplitude as it passes through the restrictions of Fire Island Inlet and at Smith Point.

In passing westward from Shinnecock Inlet, the tide undergoes a similar delay and reduction in amplitude. High water occurs in the western end of Shinnecock Bay, at East Quogue, 4 hours after high water in the open ocean. Its range there is reduced to about 0.5 feet.

Along both approaches to the Quogue and Quantuck Canals, the form of the tidal wave is distorted in the manner characteristic of tides in shallow water. The tide rises more abruptly than it falls; 5.5 to 6 hours being occupied by the flood, 7.0 to 6.5 hours by the ebb. This characteristic is imposed on the tidal wave at the inlets and is increased only slightly in the course along the bays.

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* The data between Smith Point and Oneck, supplied by the Highway Department, was obtained since the closure of the inlet; that for points in Great South Bay and for Shinnecock Inlet (ocean) is taken from the 1950 Tides Tables (8) but is based on measurements prior to 1949. These latter values should not be effected greatly by the closure of the inlet.

TABLE I

Tidal Data for Shinnecock, Moriches, and Great South Bays

	Longitude west	Mean Range feet	Mean Time of High Water[a] h	m	Duration[c] Flood hours	Duration[c] Ebb hours	Mean[c] Level above M.S.L. feet
Fire Island Breakwater	73°18'	4.1[b]	-0	45[b]			
Democrat Point	73°18'	2.6[b]	-0	35[b]			
Fire Island Light	73°17'	0.7[b]	1	05[b]			
Lone Hill, Fire Island	73°04'	0.6[b]	3	25[b]			
Sayville	73°04'	0.6[b]	3	40[b]			
Patchogue	73°01'	0.7[b]	3	35[b]	5.9	6.5	
Bellport Bay	72°56'	0.77[c]	4	00[b]			
Smith Point	72°52'	0.55[c]			5.5	6.9	0.30
Mastic Beach	72°50'	0.26[c]	4	15[c]	5.6	6.8	0.36
East Moriches C. G. Sta.	72°45'	0.20[c]	--				0.36
Oneck	72°40'	0.27[c]	6	20[c]	5.8	6.6	0.40
East Quogue	72°35'	0.49[c]	3	05[c]	5.4	7.0	0.24
Shinnecock Bay	72°30'	0.54[c]	1	20[c]	5.6	6.8	0.31
Shinnecock Inlet (Bay)	72°29'	0.76[c]	0	10[c]	5.7	6.7	0.21
(Ocean)	72°29'	2.3[b]	-0	50[b]			

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a Time is referred to high water at Sandy Hook
b Source of data Coast and Geodetic Survey (8)
c Source of data Suffolk County Highway Department (5)

The character of the tide at Smith Point conforms to the usual behavior of a progressive wave in passing up a long channel. Maximum strength of flood and ebb occurs at about the local time of high and low water, respectively. Slack water occurs at half tide. Measurements made at Smith Point on September 26, 1951, during a period of light winds, gave the following intervals for the principal tidal characteristics:

High water	4.00	hours after H.W. at Sandy Hook
Low water	3.9	" " L.W. " " "
Maximum Flood	3.4	" " H.W. " " "
Maximum Ebb	2.4	" " L.W. " " "
Maximum Velocity	Flood	0.64 knots (eastward)
	Ebb	0.51 " (westward)

Measurements made by the Highway Department over a period of five months give the following values for the average time of slack water at Smith Point (4):

Slack Flood begins	(eastward)	0.6	hours after H.W. at Sandy Hook
Slack Ebb "	(westward)	0.3	" " L.W. " "

It should be noted that these relations are greatly altered by wind conditions and that with strong winds the tide may fail to reverse at Smith Point during the tidal cycle. The average conditions will apply only during calm weather. Figure 3 shows in a diagrammatic way what these average relations appear to be.

The maximum velocity of current at flood and ebb past Smith Point is about one-half knot under calm conditions. The average maximum velocity during six months is 0.5 knots eastward and 0.55 knots westward (3). During strong winds, currents in excess of one knot have been observed and during storms even greater velocities are to be expected.

The character of the tidal motion in the Quogue and Quantuck Canals conforms to simple hydraulic motion; that is to say, the water flows back and forth depending on the relative elevations of the surface in Moriches and Shinnecock Bays. Table I shows that high tide occurs at East Quogue in the western part of Shinnecock Bay about 3-1/3 hours earlier than at Oneck and that the mean range of tide is nearly twice as great at the latter station.

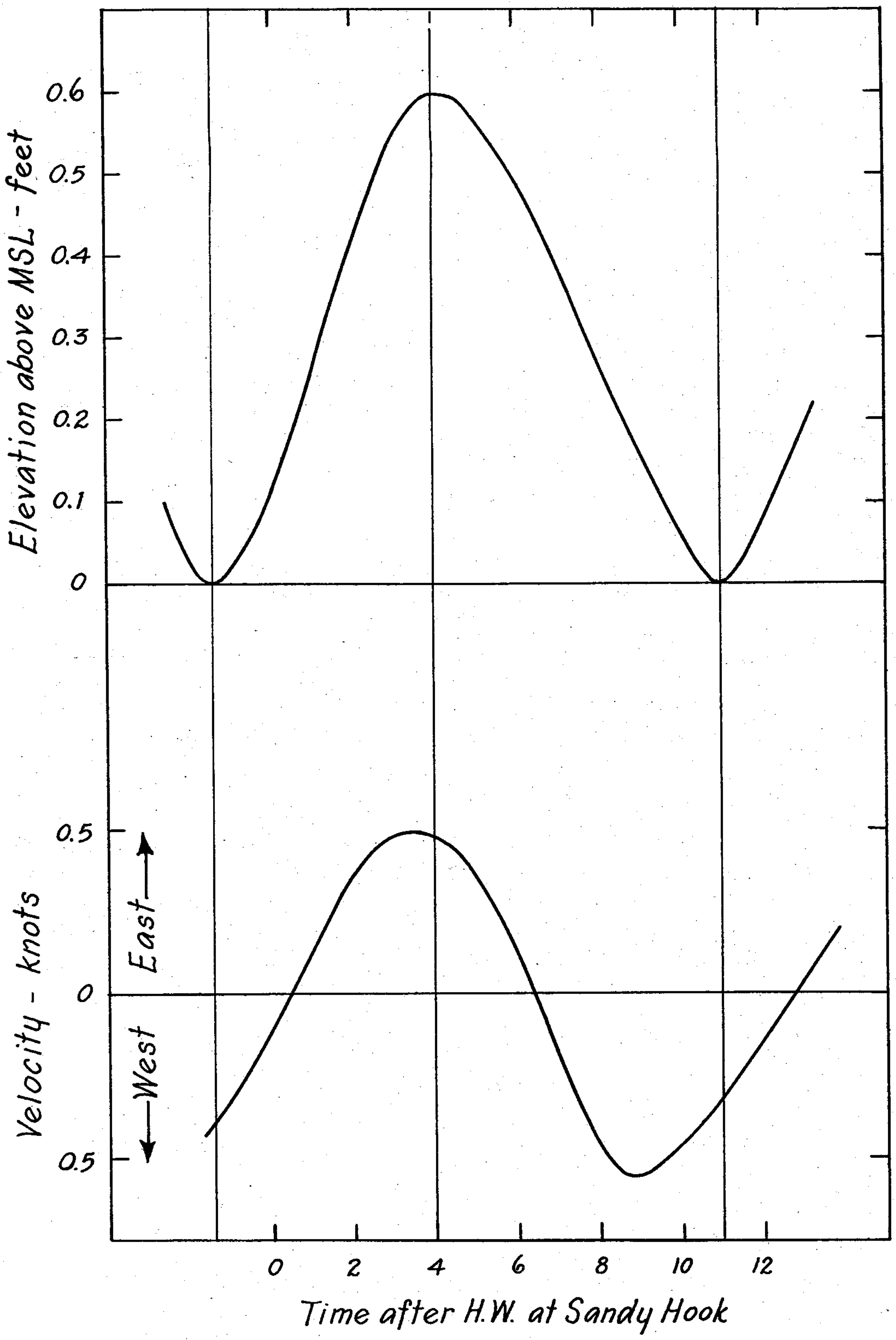

Figure 3 Average tidal relations at Smith Point.

These inequalities appear to control the flow in the canals. By reconstructing tide curves with the given characteristics, it may be shown that if mean sea level is the same in Moriches and Shinnecock Bays the current should turn east about one hour before high water at Oneck (4-1/3 hours after high water at East Quogue) and should turn west at corresponding periods relative to low water. However, the tidal data (Table I) indicate that mean sea level is about 0.15 foot less at East Quogue than at Oneck. Under this condition it may be expected that the hydrostatic head, and consequently the volume of flow, will be greater while the current is flowing eastward and it will flow eastward somewhat longer than in the opposite direction. If the mean sea level at the eastern end of the Quogue Canal were to exceed that at Oneck by 0.2 feet, as might easily result from easterly winds, these relations would be reversed and the current would flow westerly in the canals almost continuously.

It is evident that, because the range in tide is small in these bays, small fluctuations in the levels, such as are produced by strong winds, will cause the tidal flow in the canals to be very irregular. This conclusion is borne out by measurements made continuously during four complete tidal cycles on September 25 - 27, 1951. See Figure 4. During the first half of this period, water levels were distrubed by strong westerly winds which caused the tide to rise at high water 0.55 feet above mean sea level in Moriches Bay. During this period the current in the Quantuck Canal flowed eastward almost continuously. During the last half of the period, the tidal exchange appeared to be more normal and the westward flow in the canal was longer and greater than the eastward flow in the intervening periods.

Total water transport at Smith Point and the Quantuck Canal

In order to determine the volume of water flowing into and out of Moriches Bay as the result of tidal action, the currents at Smith Point and at the Beach Lane Bridge across the Quantuck Canal were measured at hourly intervals during a period of fifty hours (four complete tidal cycles), beginning at 7:00 a.m. E.S.T. on September 25, 1951. At each passage, current measurements were made at three positions across the channel. The total volume of flow per hour was obtained by suitably combining these measurements with the estimated cross section of the passage and multiplying the result by the factor 0.75 customarily employed to allow for the retardation of flow by friction along the bottom.

During the early part of the period, the flow was greatly disturbed by strong westerly winds which arose about 10:00 a.m. of the first day and continued for twelve hours. These winds were accompanied by an exceptionally strong eastward flow at Smith Point and an unusually high tide in Moriches Bay. Following this, the water flowed westward at Smith Point for nineteen hours, slackening at the time of high water in Bellport Bay but notactually flooding into Moriches Bay. During the last two tidal cycles, light easterly winds prevailed and the tides and currents became regular.

The estimated hourly flow and its direction at the two passages is shown in Figure 4. By adding up the hourly movement of water into and out of the bay at both passages, Figure 5 has been constructed showing the total change in the volume of water in Moriches Bay during the period. The resulting change in mean water level is also obtained from this figure by dividing the change in volume by the area of the bay (450 million square feet). The change in mean level is shown by the scale on the right side of Figure 5. As a check on the accuracy of the procedure, the change in level recorded by a tide gauge at the East Moriches Coast Guard Station, near the mid-point of the bay, is also entered in the figure.

The water transport through the two passages between successive periods of slack water are summarized in Tables II and III and the combined transport into and out of Moriches is shown in Table IV.

At Smith Point, the water flowed eastward for twenty hours and westward for thirty hours. The total flow eastward was 371.4 million cubic feet; westward 402.4 million cubic feet, producing a net movement out of the bay (westward) of 31.0 million cubic feet. In the Quantuck Canal, the water flowed eastward for twenty-four hours and ten minutes and westward for twenty-five hours and fifty minutes, a slight excess to the west. The total flow eastward was 64.9 million cubic feet; westward 59.4 million cubic feet, producing a net movement out of the bay (eastward) of 5.5 million cubic feet. The flow through the Quantuck Canal in either direction is relatively small, amounting to only about fifteen per cent of the total movement into and out of the bay (Table IV).

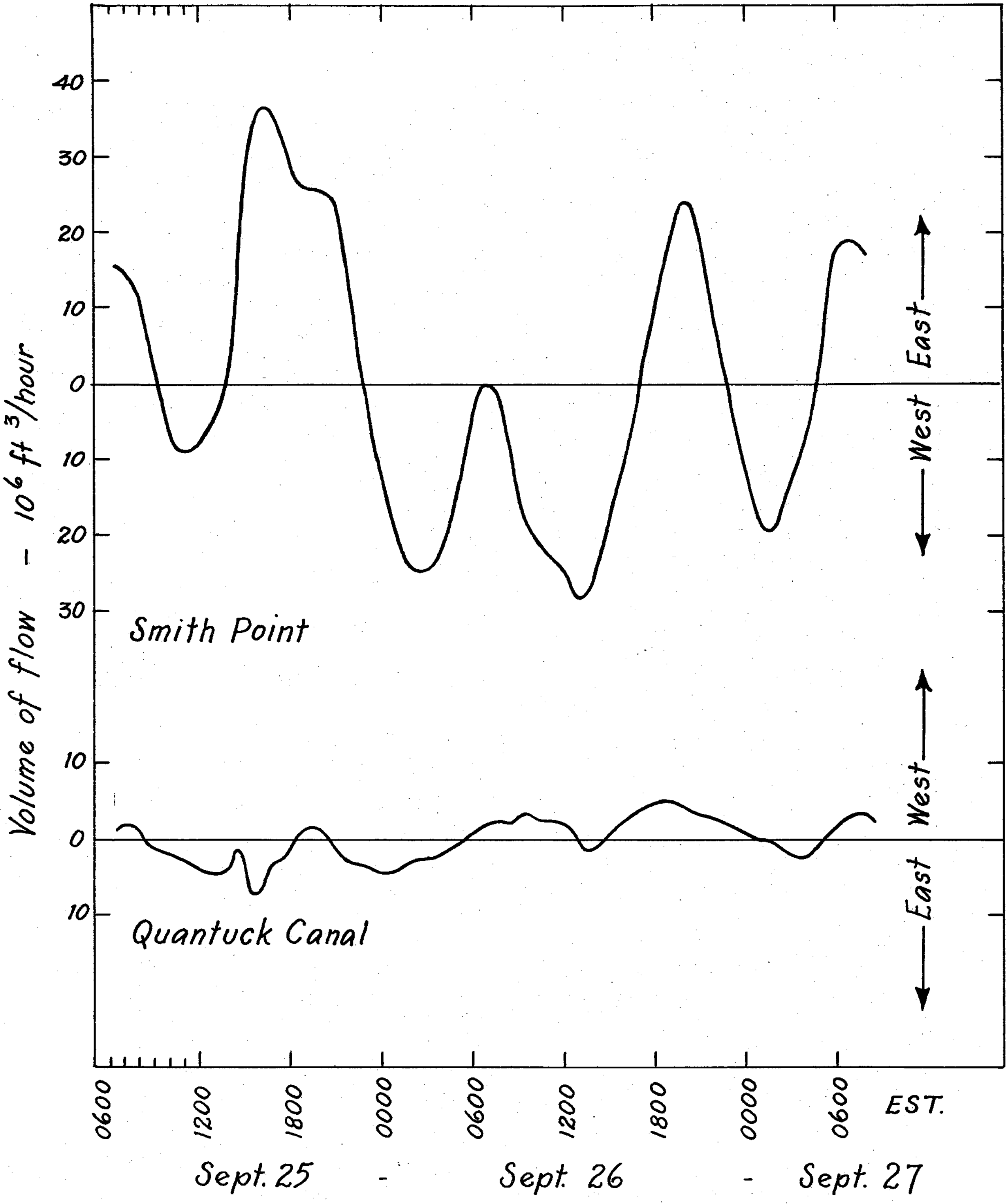

Figure 4 Tidal flow at Smith Point and Quantuck Canal September 25 - 27, 1951.

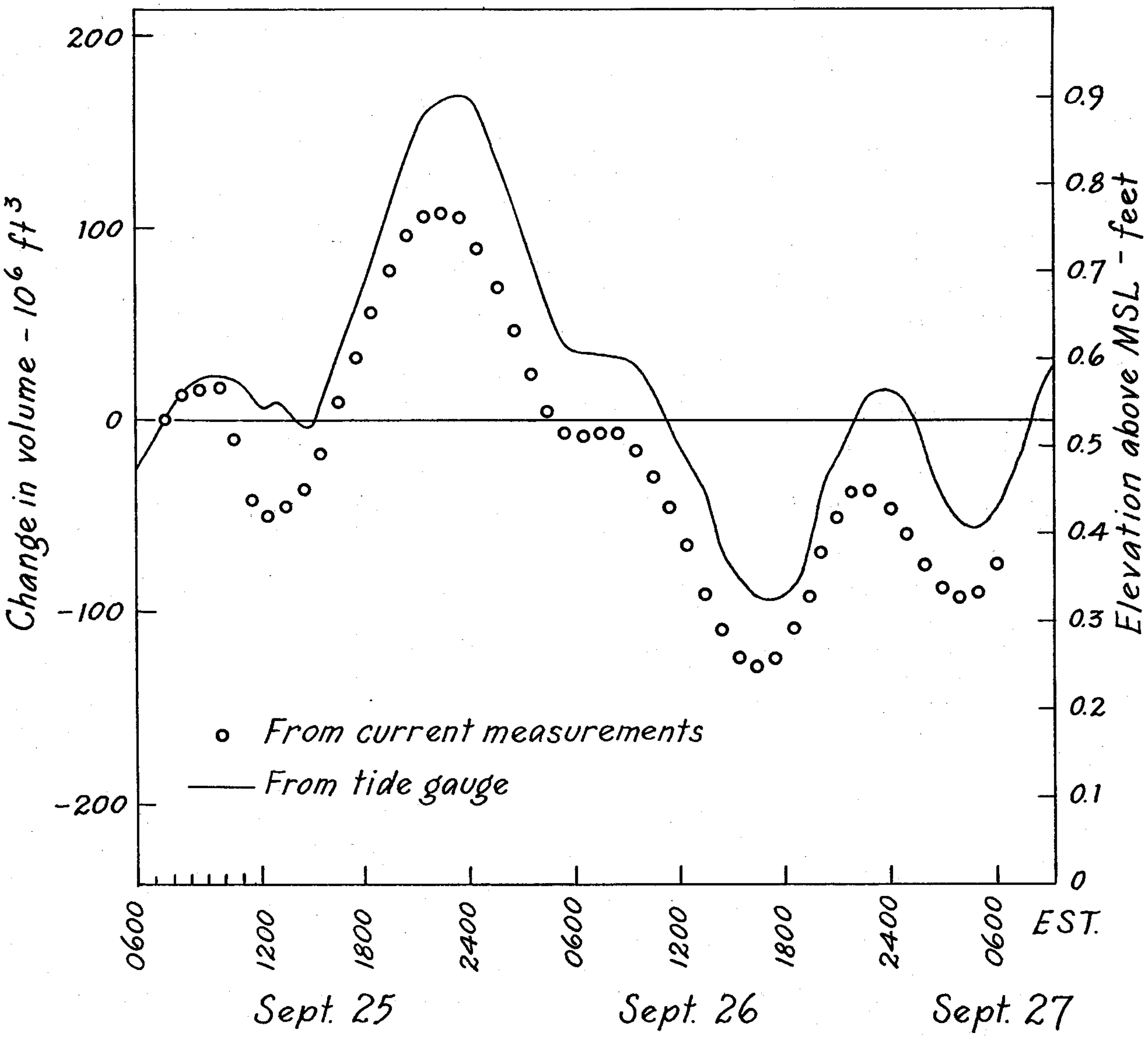

Figure 5 Change in volume and level of Moriches Bay, September 25 - 27, 1951.

TABLE II

Water transport past Smith Point during four complete tidal cycles

Date 1951	Time - EST	Flow East		Flow West	
		Duration h:m	Volume 10^6ft^3	Duration h:m	Volume 10^6ft^3
9/25	0700 - 0930*	2:30	20.9		
	0930 - 1340			4:10	27.0
	1340 - 2250	9:10	215.0		
	2250 - 0730			8:40	136.3
9/26	0730 - 1750			10:20	168.7
	1750 - 2220	4:30	76.8		
	2220 - 0510			6:50	70.4
9/27	0510 - 0900*	3:50	58.7		
Total flow East		20:00	371.4		
" " West				30:00	402.4

Ratio flow East:West		
	Duration	1:1.47
	Volume	1:1.08

Mean flow per 1/2 cycle	96.6 million cubic feet
Net flow West per cycle	7.8 " " "

* Incomplete cycle

During the fifty-hour period, 430.8 million cubic feet flowed into Moriches Bay through both passages and 467.4 million cubic feet flowed out. This represents an average movement, in or out, of 112 million cubic feet per tide. There was, however, a net loss to the bay through both passages of 36.6 million cubic feet during the period or 9.1 million cubic feet per tidal cycle.

It is proper to question whether these measurements, made during a short period in part of which strong winds prevailed, are representative of the long-term average behavior of the tidal exchange of Moriches Bay. Fortunately, the Suffolk County Highway Department has maintained a current meter at Smith Point since July 1951 (4). Table V compares the average flow as recorded by this instrument during six months with the result of the

TABLE III

Water transport through Quantuck Canal during four complete tidal cycles

Date 1951	Time - EST	Flow East		Flow West	
		Duration h:m	Volume 10^6ft^3	Duration h:m	Volume 10^6ft^3
9/25	0700 - 0820*			1:20	1.98
	0820 - 1830	10:10	33.21		
	1830 - 2100			2:30	1.68
	2100 - 0530	8:30	25.14		
9/26	0530 - 1300			7:30	16.02
	1300 - 1430	1:30	1.66		
	1430 - 0100			10:30	29.88
9/27	0100 - 0500	4:00	4.95		
	0500 - 0900*			4:00	9.86
Total flow East		24:10	64.96		
" " West				25:50	59.42

Ratio flow East:West — Duration 1:1.08
Volume 1:0.91

Mean flow per 1/2 cycle 15.5 million cubic feet

Net flow East per cycle 1.36 " " "

* Incomplete cycle

fifty-hour observations made in September. The average flows east and west agree reasonably well. Both measurements show a greater flow out of Moriches Bay when the tide ebbs to the westward. However, the westerly winds evidently reduced this movement during the fifty-hour observations, since the net flow westward out of Moriches Bay is more than twice as great in the five month average than during the shorter period.

As a further check on these measurements, it is possible to determine the range of tide to be expected from the observed tidal flows. The area of Moriches Bay is about 450 million square feet. Taking the average movement of water into and out of the bay through both passages as 112 million cubic feet per tide, it follows that the change in level would be 0.25 feet. This agrees

TABLE IV

Comparison of contribution of flow at Smith Point and Quantuck Canal to flushing Moriches Bay

million cubic feet
during 4 tidal cycles

	Smith Point	Quantuck Canal	Total 50 hours	Average per Tide
Into Moriches Bay	371.4	59.42	430.8	107.5
Out of " "	402.4	64.96	467.4	116.8
Total Flow	773.8	124.38	898.2	112.5
Per Cent Flow	86%	14%	100%	
Net Loss	31.0	5.54	36.6	9.16
Per Cent Loss	85%	15%	100%	

with the average of tidal ranges recorded in Table I for the stations in Moriches Bay.

Fresh water transport at Smith Point and the Quantuck Canal

From considerations of the rainfall on the watershed, we may expect Moriches Bay to receive accessions of fresh water from runoff and seepage estimated to average 21.03 million cubic feet per day for periods of normal rainfall. Since this is the only apparent source of water, other than the tidal exchange, and since the volume of the bay does not change appreciably over the years, this value should balance the net loss of water through tidal flow. During short periods the mean level of the bay may change, as the result of the rise and fall of the tide and of changes in mean sea level, and it is consequently necessary to take into account the change in volume of water in the bay in striking the balance. The tide gauge records from East Moriches Coast Guard Station have been used to estimate the mean level of the bay. Since the tide does not rise and fall simultaneously in all parts of the bay, the estimates are only approximate.

TABLE V

Comparison of average tidal flow at Smith Point as recorded by Suffolk County Highway Department between July 7 and Dec. 9 with measurements of September 25-27, 1951 - million cubic feet

	5 month average	50 hour average
Average flow per tide East	81.8 x $10^6 ft^3$	92.8 x $10^6 ft^3$
" " " " West	101.8	100.6
" " " " Mean	91.7	96.6
Net flow per tide West	19.8	7.8
Average duration per tide,		
Eastward	5.5	5.0
Westward	6.9	7.4

Table VI presents a balance sheet of the volume changes in Moriches Bay estimated from the fifty-hour period of observation. The total accession of water estimated from the net tidal outflow and the rise in tide level in the bay is 22.9 million cubic feet per day which compares closely with the accession of fresh water calculated from the normal mean daily rainfall. During the period of four months immediately proceeding the study, rainfall was deficient. Using rainfall measured during this period, the agreement is not as good. Since seepage of ground water is the major path by which rain water reaches the bay, and it is now known how fast seepage takes place, there is no way of knowing whether this discrepancy is serious.

In spite of this uncertainty the agreement indicates that the net loss of water from the bay by tidal exchange may be accounted for by the accessions of water from seepage and runoff and may be taken as an indication of the magnitude of such fresh water sources.

Considering that the volume of Moriches Bay is 1800 million cubic feet and that about 22 million cubic feet of fresh water enters the bay daily to escape through the passages, it follows that 1.2 per cent of the bay water is replaced daily. The average time a particle of

TABLE VI

Balance sheet of volume changes in water of Moriches Bay

	Million Cubic Feet Observed change in 50 hours	Million Cubic Feet Average change per day
Tidal Exchange		
Volume entering Bay	430.8	
Volume leaving Bay	467.4	
Net Loss	36.6	
Change in Volume*	11.2	
Total Accession of Water	47.8	22.9
Seepage and River Flow		
Based on normal rainfall		21.0
Based on rainfall June-Sept.		12.5

* Estimated from net change in water level at East Moriches C.G. Station (+ 0.025 feet) between the beginning and end of period of observations, multiplied by the area of bay ($450 \times 10^6 ft^2$).

water or any associated pollutant may remain in the bay is consequently about eighty-three days.

Salt transport at Smith Point and the Quantuck Canal

Analyses of the salinity of the water flowing past Smith Point and through the Quantuck Canal were made hourly during the four tidal cycles in which the current was measured. The average salinity of the inflow and outflow were as follows:

Average Salinity	Smith Point	Quantuck Canal
Inflowing water	18.05 °/oo	21.80 °/oo
Outflowing water	17.88 °/oo	21.60 °/oo
Per cent change	0.94	0.92

The outflowing water contains about 0.9 per cent less salt than the inflow in both passages, indicating that it has been diluted by fresh water.

By combining the data on the quantity of water flowing through the passages, Table IV, with its average salt content, the estimates shown in Table VII on the exchange of salt have been secured. In spite of the fact that the outflowing water contains less salt than the inflow, its volume is enough greater so that there is a net loss of salt through both passages. This shows that the bay was still freshening following the closure of Moriches Inlet. The total salt removed from the bay was 17.2 million kilograms in four tidal cycles or 8.3 kilograms per day.

Of the total salt lost, eighty-three per cent moved out past Smith Point and seventeen per cent through the Quantuck Canal. These proportions are almost the same as those found for the net loss of water which were 85:15 (Table IV). The two passages are effective in proportion to their flows in removing salt from Moriches Bay.

The total salt content of the bay at this time estimated from the average salinity at positions distributed along its length and from its volume is about 10,400 million kilograms. The fraction of salt lost was consequently 0.0172 during the fifty-hour period, or about 0.83 per cent per day.

The best available estimates of the numerical characteristics of Moriches Bay, and the exchanges through the passages are summarized in Table VIII.

The effect of winds

It is well established that strong winds have a great effect on the tidal movement and water level in shallow enclosed coastal bays. During the fifty-hour period of observation, southwesterly winds of not over twenty-four miles per hour checked the normal ebb at Smith Point and resulted in a rise in the level of Moriches Bay of 0.3 feet above the high tide level reached by the following normal tides. See Figure 4.

TABLE VII

Exchange of salt at Smith Point and through Quantuck Canal, September 25-27, 1951

	Million Kilograms in 4 tidal cycles		Total
	Smith Point	Quantuck Canal	
Into Moriches Bay	189.5	36.8	224.2
Out of " "	203.8	39.7	243.5
Net Loss	14.3	2.9	17.2
Per Cent Loss	83	17	100%

TABLE VIII

Numerical Data on Moriches Bay

Area	$450 \times 10^6 ft^2$
Volume	$1800 \times 10^6 ft^3$
Depth, Mean	4 ft
Mean level above M.S.L.	0.37 ft
Mean range of tide	0.24 ft
Normal seepage and river flow into the bay	$21.0 \times 10^6 ft^3$ per day
Mean flow at Smith Point	$112.5 \times 10^6 ft^3$ " tide
" " " Quantuck Canal	$15.5 \times$ " " " "
Net flow at Smith Point, westward	$7.8 \times$ " " " "
" " " Quantuck Canal, eastward	$1.36 \times$ " " " "
Net flow out of bay	$9.16 \times$ " " " "
Net loss of salt from bay	2.15×10^6 kilograms per tide
Fraction of bay water moving in and out with tide	6 per cent per tide
Fraction of bay water replaced by fresh water	1.2 " " " day
Fraction of salt being lost	0.8 " " " "
Fraction of exchange due to	
Flow at Smith Point	85 per cent
" " Quantuck Canal	15 " "

Current records for Smith Point made by the Suffolk County Highway Department show that between July 7 and December 9, 1952 the current did not reverse on sixteen occasions during the ebb and on six occasions during the flood in the course of about 240 tidal cycles (4).

Our observations in September indicated that when the wind causes the current to fail to reverse once during a single day, the effect is rapidly compensated for by increased flows in the opposite direction. While this is usually the case, the Highway Department records show that in winter the current may fail to reverse on several succeeding days so that cumulative effects are to be expected. Thus, in the period of November 3-6, the current failed to reverse four times on four successive days. The current flowed westward for eighty-two hours and eastward for only twenty-five hours. The net transport of water out of Moriches Bay at Smith Point was 1260 million cubic feet, or sufficient to lower the level of the bay by 2.86 feet and move two-thirds of its water into Great South Bay. The effect can have been compensated only in small part by flow through the Quantuck Canal and by accessions of rain water. Obviously, such an event will have a tremendous effect in renewing the water in Moriches Bay. However, protracted storms are rare in the summer when the effects of pollution develop and are most important. During this period the estimates arrived at in the preceding section probably describe the behavior of the water adequately.

It is natural to connect temporary changes in the height of tide and flow of water with the local wind. It should be considered that the general pattern of wind over the ocean, which varies with the passing of storms, may cause substantial changes in the daily mean sea level and thus influence the tidal circulation in the bays. A rise in sea level in the coastal water would be reflected rapidly in the level of Great South Bay since it would reduce the normal ebb at Fire Island Inlet. A rise in mean level of Bellport Bay of three inches from such cause would be sufficient to prevent the expected ebb at Smith Point and the flood current would not reverse.

The expected effects of the local and general winds at Smith Point are somewhat opposed. Westerly winds are expected to increase the easterly flow of water at Smith Point by raising the water level in Bellport Bay. Westerly winds offshore may be expected to lower the mean daily sea level along the coast and would tend to lower the level in Great South Bay and thus counteract the action of the local wind. This is a matter which deserves further study which might profitably be applied to the long-term records being made by the Highway Department.

Salinity distribution

The distribution of salinity within the bays is the result of such exchanges as have been discussed above. It not only permits a check on the exchange studies but shows in greater geographical detail the actual way in which the water is mixing in the bay as the result of tidal motion.

The distribution of salinity at mid-depth*, as observed on July 12-14, 1951, between Shinnecock Bay and the western end of Great South Bay, is shown in Figure 6. Starting at Shinnecock Inlet, the salinity decreases westward across Shinnecock Bay and the Quogue and Quantuck Canals into Moriches Bay. This is concordant with a net movement of fresh water out of Moriches Bay through the canals by tidal mixing but is probably augmented by seepage and runoff along the north side of Shinnecock Bay. The lowest salinities were observed at the mouths of the Carmans and Forge Rivers, and the lowest salinities along the channel (20 - 21 °/oo) extend from Forge River to beyond Howell Point. The most concentrated source of fresh water is evidently in this region. From there, the salinity increases westward to Fire Island Inlet. West of Fire Island Inlet, the salinity continues to increase. This effect confirms the observations made in 1950 which indicated that there was a net movement of salt water eastward from South Oyster Bay into this region.

The distribution of salinity in Moriches Bay is of interest in showing something of the details of the water exchange. The freshening of the water at the mouth of the Forge River extends westward into Narrow Bay, but does not extend eastward beyond Tuthill Point. The eastern half of Moriches Bay is about 3 °/oo more saline than is Narrow Bay. It appears that the escape of fresh water from the Forge River and the neighboring tributaries is primarily to the westward past Smith Point, as was indicated by the water exchange studies.

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* Except near the mouths of rivers, the salinity distribution in depth is nearly uniform. The mid-depth gives a good average.

The eastern part of Moriches Bay appears to be a dead end so far as the tidal movement is concerned and this is confirmed by its higher salinity which is maintained by the limited circulation through the canals.

Consideration of the time relations of tidal movement appears to explain why the fresh water of the Forge River is carried westward into Narrow Bay instead of eastward. The fresh water which accumulated in the estuaries of the Forge River and other tributaries is not discharged continuously. As the tide rises the fresh water is dammed back by salt water entering from the bay. As the tide falls, it escapes. It is obvious that in the main the tidal currents are flowing westward across Moriches Bay with the falling tide, when the fresh water escapes. Thus, it is that the fresh water tends to move westward along the shore from the river mouth. This effect is also indicated at the mouth of the Carmans River. See Figure 6.

The distribution of salinity in Moriches and Great South Bays was resurveyed on July 27 - August 2 and again on September 24-28, 1951. There was a continuous decrease in salinity in Bellport and Moriches Bays but the general patterns of distribution remained unchanged.

2. The Effect of Moriches Inlet on the Hydrography of the Bays

Any judgment of the benefits to be obtained by reopening Moriches Inlet should take into consideration the effects on the circulation of water and the rate at which fresh water accessions and pollutants are removed from the bay. There are available for comparison the observations made in 1950 when the inlet was open and the present (1951) studies when the inlet had been closed for three to six months. In addition, some information is available from the report of Whipple (6) on conditions existing in 1907 when both Moriches and Shinnecock Inlets had been closed for twenty years. This information is of particular interest because the full effects of closure of the inlet had not had time to develop when the studies were made last summer, and it gives an idea of the limiting conditions which may be expected to develop with time.

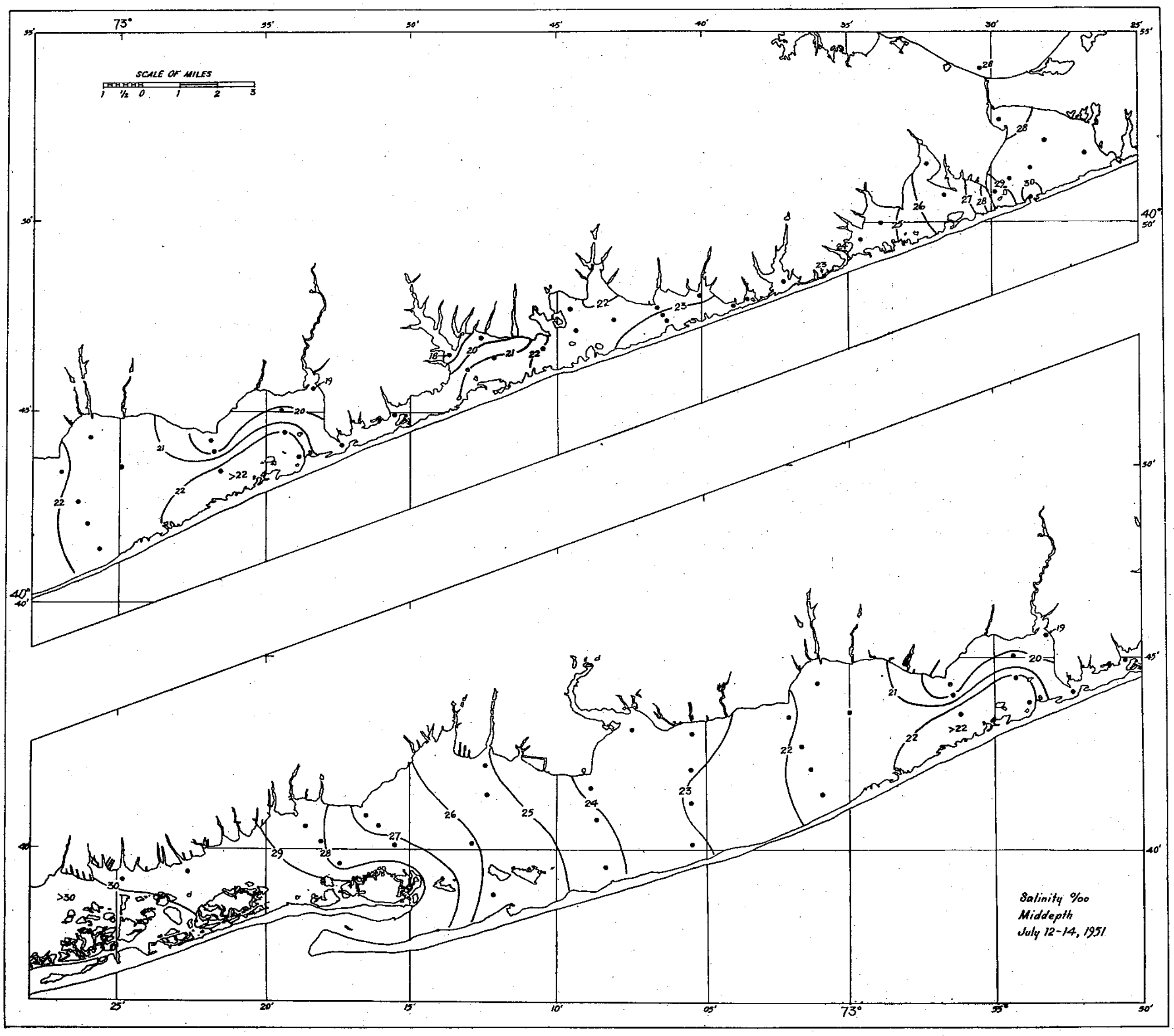

Figure 6 Salinity of Great South Bay, Moriches Bay, and Shinnecock Bay - July 12-14, 1951.

Tides

Prior to the closure of Moriches Inlet the rise of the tide in the bay was due principally to water flowing in from the sea through the inlet. This is shown by the following measurements made by the U. S. Army Engineers on July 13, 1949 (5).

	Million cubic feet per tide	
	Flow Inward	Flow Outward
Via Narrow Bay	11	55
" Quogue Canal	29	24
" Moriches Inlet	106	123
Total	146	202

High water occurred throughout the bay about three and one-half hours after high water at Sandy Hook. Since the tidal wave entering Fire Island Inlet does not reach Bellport Bay until one-half hour later, the current flowed westward past Smith Point during the greater part of the flood. The tidal flows originating at the two inlets appeared to meet in Bellport Bay.

Following the closure of Moriches Inlet, the tidal wave ascending Great South Bay continues past Smith Point across Moriches Bay and reaches its eastern end after a delay of more than two hours. As we have seen, 85% of the flow into the bay is by this route. The current now flows eastward past Smith Point during the period of flood. The conditions of flow at Smith Point are now similar to those described by Whipple for 1908 which are discussed more fully in our 1950 report (7).

The mean range of tide in Moriches Bay has diminished steadily in recent years accompanying the gradual decrease and final closure of Moriches Inlet. The average range at East Moriches Coast Guard Station has been as follows (5):

Year	Range
1940	0.70 feet
1945-46	0.42 "
1946-47	0.36 "
1949	0.22 "
1951	0.22 "

In Bellport Bay the closure of the inlet has not changed the tidal range significantly.

Table IX lists the principal tidal data available for comparing the tidal events as affected by the closure of the inlet.

TABLE IX

Data on the principal tidal events in Moriches Bay recorded before and after the closure of Moriches Inlet

Time is relative to H.W. at Sandy Hook

	Inlet Open		Inlet Closed	
Time of High Water	1949	1950	1908[d]	1951[c]
	h:m	h:m	h:m	h:m
Smith Point		+3:25	+4:00	
Mastic Beach	3:35[a]			+4:15
Potunk Point	3:50[a]			
Oneck				+6:20
Slack Water - Smith Point				
Turns East		+2:30[b]	+0:30	+0:35
Turns West		+8:00[b]	+6:00	+6:30
Mean Range	feet	feet		feet
Bellport Bay	0.80[a]			0.77
Smith Point		0.37[b]		0.56
Mastic Beach	0.35[c]			0.26
Oneck	0.25[c]			0.27
Potunk Point	0.80[a]			0.27

a U.S.C.&G.S. Tide Tables (8).
b Woods Hole Oceanographic Institution (7).
c Suffolk County Highway Department (4 & 5).
d Whipple (6).

Volume exchange

The reduction in tidal range accompanying the closure of the inlet indicates that less water now enters and leaves Moriches Bay during the tidal cycle. This observation is supported by direct measurements of flow through the entrances. The study made by the Army Engineers during one tidal cycle in July 1949, tabulated above, is the only direct measurement available for the period prior to the closure of the inlet. It may be compared with subsequent data on the total tidal exchange as follows:

	Million cubic feet per tide	
	1949[a]	1951[b]
Inward	146	107.5
Outward	202	116.8

a U. S. Army Engineers (5) - 1 tidal cycle
b Woods Hole Oceanographic Institution - 4 tidal cycles

These observations support indications from the tidal data that the tidal exchange has decreased in volume. Since they depend on measurements made during only a single tide prior to the closure of the inlet, and as the daily flow is variable, no exact evaluation of the change can be made.

At the present time the principal tidal exchange takes place by flow past Smith Point. It is consequently of interest to compare the records of this movement before and after the inlet's closure. The available data are as follows:

	Million cubic feet per tide			
	Inlet Open		Inlet Closed	
	1949[a]	1950[b]	1951[c]	1951[d]
Eastward	11	76.3	93	81.8
Westward	55	56.6	100.6	101.6

a U.S. Army Engineers (5) - 1 tidal cycle
b W.H.O.I. (7) - 8 tides Eastward, 4 tides Westward
c W.H.O.I. - 4 tidal cycles
d Highway Department (4) - 215 tides Eastward, 208 tides Westward

It is clear that the tidal exchange at Smith Point has increased, perhaps by fifty per cent. The flow eastward recorded in 1949 and 1950 with the inlet open do not agree well. The greater average flow in 1950 may be due to the gradual reduction in size of the inlet which preceded its closure, or it may be merely the result of temporary conditions on the day of observation.

In the Quantuck Canal the closure of the inlet appears to have reduced the tidal exchange. The Army Engineers observations on July 13, 1949 indicated the flow of 29 million cubic feet westward and 25 million cubic feet eastward. The average movement during four cycles in September 1951 was 14.5 million cubic feet westward and 16.2 million cubic feet eastward. This change is consistent with the reduced tidal range of Moriches Bay, but the flow through the canals is very sensitive to temporary conditions. Consequently, much weight cannot be placed on the comparison.

The available data on the changes which have followed closure of Moriches Inlet agree in indicating a decrease in the total tidal exchange and an increase in the importance of flow past Smith Point in effecting the flushing of Moriches Bay. The best educated guess which can be drawn from the scattered and inadequate data available is that the change in flow due to tidal exchange before and after the closure of the inlet, taking the present total exchange as 100 per cent, is approximately as follows:

	Inlet Open	Inlet Closed
Smith Point	50%	85%
Quantuck Canal	20%	15%
Moriches Inlet	120%	0%
Total	190%	100%

Salinity change

Prior to the closure of Moriches Inlet, the average salinity of Moriches Bay was 28 °/oo, which is about 2 °/oo less than coastal sea water. The closure of the inlet trapped this saline water in the bay. Subsequently, the accessions of fresh water are diluting the bay, which process will continue until the salinity of the bays falls to a level at which the salt brought in by the flood tide equals that lost during the ebb. At that time the salinity of Moriches Bay will be lower than that at Bellport Bay.

When last surveyed in September 1951, the average salinity of Moriches Bay was 19.7 °/oo, or 8 °/oo less than during the preceding summer. The changes in the different parts of the bay are shown in Figure 7. The greatest change, 10 °/oo, occurred in the southern part of the western half of Moriches Bay. In the eastern half the change is less and is small off the mouth of the Quantuck Canal. The influence of the inlet's closure extends into Great South Bay as far west as Patchogue. In Bellport Bay the salinity has fallen 4 °/oo

The rate of flushing

The rate at which the salinity of Moriches Bay is decreasing and the limit which may be reached is indicated by the following figures:

Date	Mean Salinity	Condition of Inlet
July 1950	28.00 °/oo	Open
July 12-14, 1951	22.25	Closed 60 days
July 27-Aug. 2, 1951	21.63	" 75 "
Sept. 24-28, 1951	19.71	" 100 "
Dec. 7, 1907	10.00	" 20 years

By September the salinity had fallen to a value nearly half way between that obtaining when the inlet was open and when it had been closed for years.

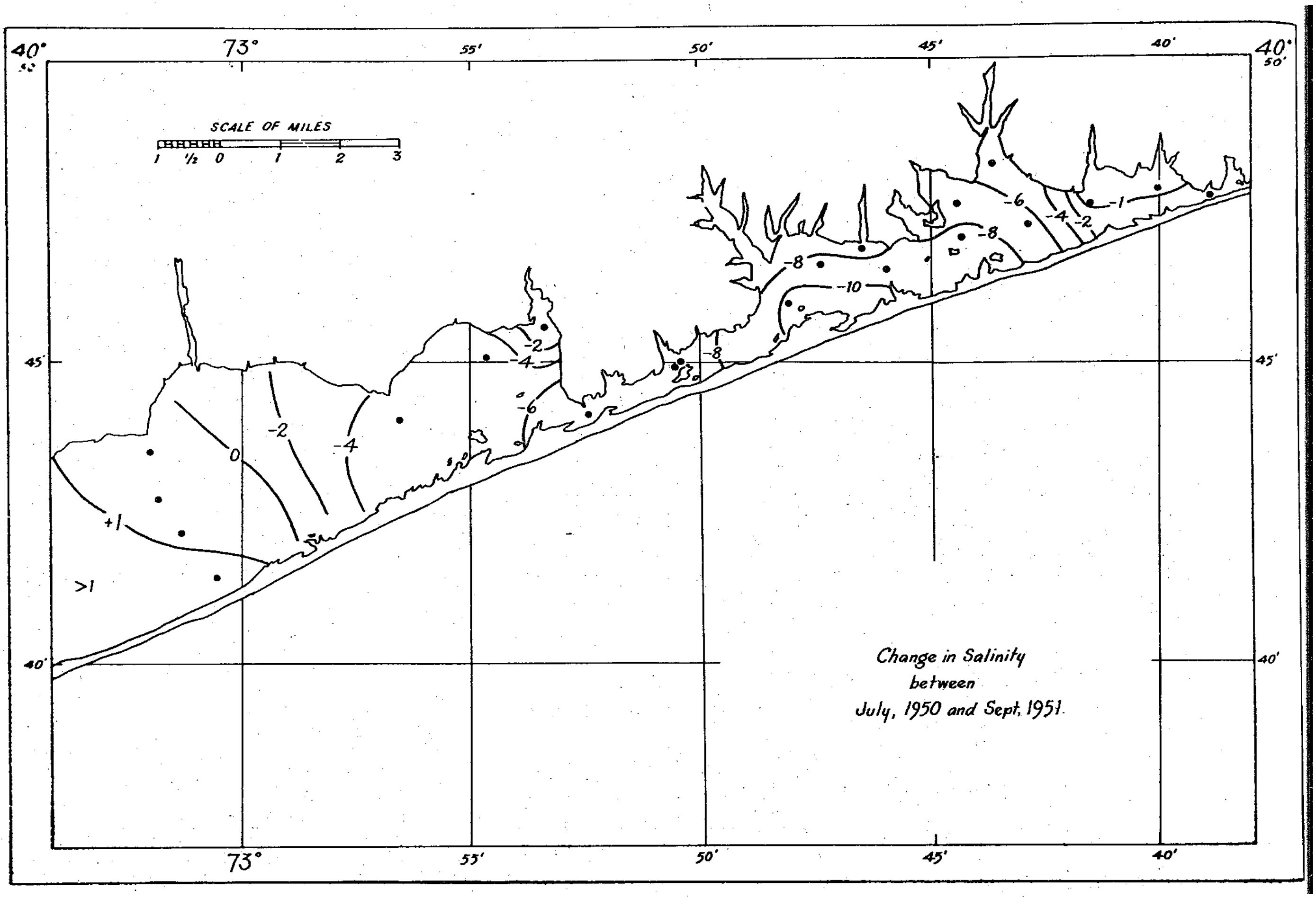

Figure 7 Change in salinity of Moriches Bay between July 1950 and September 1951.

Between July 13 and September 26 the salinity decreased at an average rate of 0.033 °/oo per day. The measurements of salt exchange during four tidal cycles in late September showed a salt loss sufficient to reduce the average salinity by 0.163 °/oo per day. These measurements indicate a rate of freshening five times as great as that which actually occurred during the summer.

The explanation of this discrepancy is too large to be accounted for by errors in measurements. It appears to depend in part on the irregularities in tidal exchange occasioned by winds. It has been pointed out that strong winds may cause the tidal current at Smith Point to fail to reverse and lead to the removal of large quantities of water from Moriches Bay. This water is replaced by water which enters chiefly from Bellport Bay after normal conditions are restored. Since the returning water has a higher salt content than that which escapes, the result is to increase the salinity of Moriches Bay and thus reverse the trend of freshening.

The records of tidal flow at Smith Point, supplied by the Highway Department, show that between July 14 and September 24 the tide failed to reverse and led to ebb flows more than twice the average on six separate occasions. On one of these (August 17-18) the flow at Smith Point was adequate to remove one-third of the water from Moriches Bay.

During heavy storms the surf washes across the beach in the position of the former inlet. This also must introduce substantial quantities of salt water into the bay.

Records of the salinity at a number of places, secured by Mr. Joseph Glancy during the period since the closure of the Moriches Inlet, support the view that the freshening of the bay is being interrupted. Figure 8 shows that the salinity at Smith Point, which reflects that in Moriches Bay, has not decreased regularly. After falling rapidly during the early spring, the salinity actually increased in late May. In July and August, there was a rapid decrease followed by another period of increase which terminated in mid-November, after which the decrease continued. The average drop in salinity over seven and one-half months was 0.025 °/oo per day, which is three-quarters the rate observed during the summer for the bay as a whole.

It should be pointed out that exaggerated exchanges which result from storms and abnormal tides and which

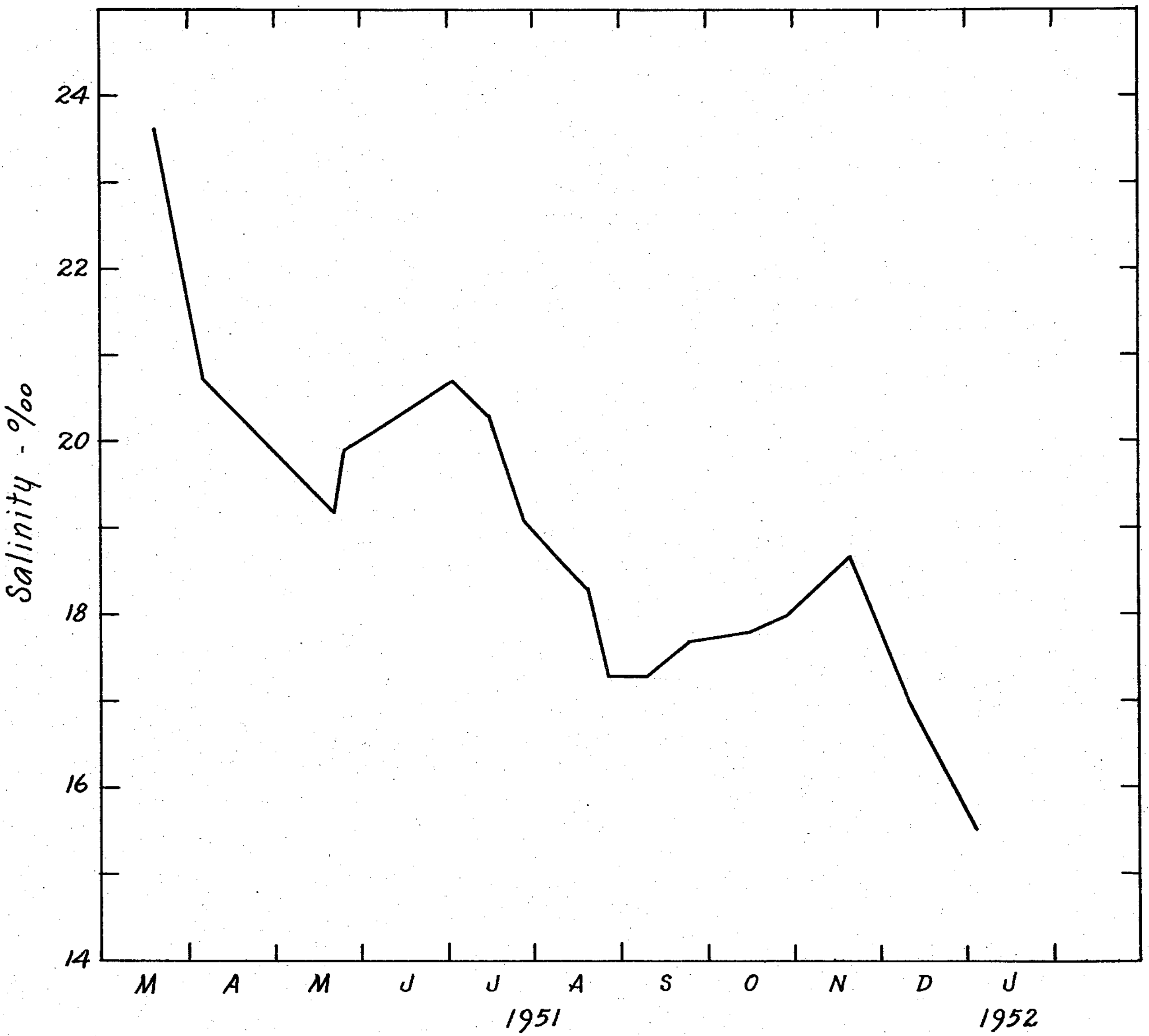

Figure 8 Salinity at Smith Point - 1951.

retard the freshening of Moriches Bay will also result in increasing the rate at which pollutants will be removed from the bay.

It is impossible to estimate the final salinity which will be reached in Moriches Bay, because of the irregularities in circulation discussed above. The best indication is the condition existing in 1907 when the average salinity was about 10 o/oo in Moriches Bay and 12-15 o/oo in Bellport Bay. At that time Shinnecock Inlet was closed and the salinity of the western part of Shinnecock Bay was about 19 o/oo as compared with 25 o/oo at present. It is probable that under present conditions the circulation through the canals will introduce somewhat more salt into Moriches Bay. Consequently, the salinity of Moriches Bay may be expected to reach a final value slightly greater than 10 o/oo if the inlet remains closed.

3. Pollution by the Duck Farms

The duck industry and farm operation

There are forty-five duck farms located on streams tributary to Great South Bay and Moriches Bay which market annually about 4,000,000 ducks. These are distributed approximately as follows:

Moriches Bay	3,400,000
Bellport Bay (Carmans River)	600,000

The peak population of about 1,500,000 birds is present in June. A small number of farms produce year around and a constant population of 80,000 breeders is carried over the winter.

The farms are usually laid out in a series of individual pens extending along the water front and back from it. See Figures 2 and 9. Most farms are provided with concrete throughs which carry fresh water through tiers of pens into the natural waters. The flow is maintained by well water or spring water pumped into the head of the trough. Their purpose is to give the ducks constant access to fresh water.

Many of the droppings go directly into the water carried by the troughs, or into the natural waters which are enclosed in the pens along the water front. The droppings which fall on the dry ground are scraped up

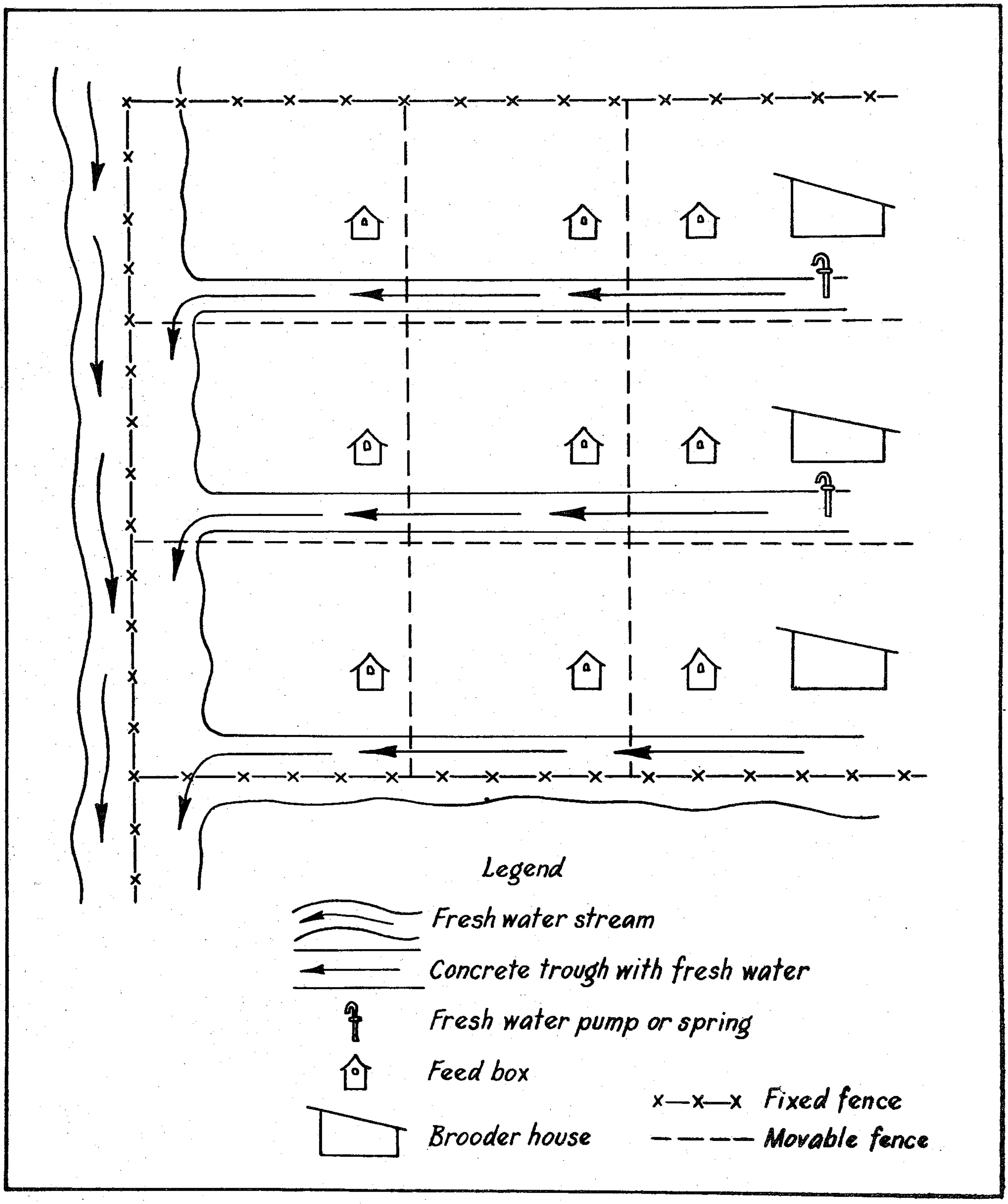

Figure 9 Arrangement of typical duck farms.

and removed from time to time, but much of the material may be washed into the water by rainfall. In these ways large amounts of faecal material are introduced into the natural waters tributary to the bays.

Quantity of waste available

The ducks consume an average of 29 pounds of feed up to the time they are slaughtered. The annual food consumption of four million ducks is consequently 116 million pounds. The duck feed contains 2.9 per cent nitrogen and 0.9 per cent phosphorous. The total food supply consequently contains 3.36 million pounds of nitrogen and 1.04 million pounds of phosphorous.

The ducks are marketed when sixty days old and have an average weight of 5.65 pounds. The body of a duck contains about 2.94 per cent nitrogen (1). The four million ducks of average weight of 5.65 pounds marketed annually utilize a total of 0.665 million pounds of nitrogen, leaving 2.70 millions pounds as waste in the excrement.

Comparable figures for the phosphorous content of the duck are not available. For the human body the phosphorous content is 0.95 per cent (3). Applying this value to the ducks, the marketed crop accounts for 0.216 million pounds of phosphorous which leaves 0.82 million pounds available as waste.

A sample of duck manure analyzed contained four per cent nitrogen and 2.6 per cent phosphorous. Applying this proportion to the estimated total excretion of 2.45 million pounds of nitrogen, the total excreted phosphorous is 1.6 million pounds per year. This is more than the estimated phosphorous content of the food. It is questionable whether the samples analyzed were representative.

Composition of waste

The nitrogen is present in the excreta as uric acid and amino compounds. Nitrates and nitrites are not present in significant quantities.

Uric acid is the principal nitrogenous constituent of the urine of birds. It comprised seventy-two per cent of the total nitrogen in the droppings of a domestic hen fed on fish meal (2). The amino compounds are probably the unabsorbed residues of incompletely digested food protein. Examination of duck faeces leads one to believe that these compounds constitute a larger fraction of the total nitrogen than in birds living on a more normal diet. The ducks having an excess of feed available at all times probably ingest more feed than they can assimilate.

Much of the excreta consists of particulate matter--presumably crude protein, fiber (cellulose), insoluable inorganic matter (bone meal), etc. Attempts to disolve duck manure in water, and inspection of waters effluent from the farms indicates that much of the matter is insoluable. Suspended solids have settled in the Terrell and Forge Rivers to such an extent as to build up deposits more than ten feet deep. The colloidal suspension is precipitated on meeting salt water. It is reasonable to assume that these precipitated solids are attacked by microorganisms and that their constituents are released slowly as inorganic salts in true solution.

Phosphorous may be expected to occur in the faeces as inorganic phosphate secreted in the urine, as undigested residues of bone meal and, to a lesser extent, of protein derived from the food.

Pollutants in the streams adjacent to the farms

The streams immediately exposed to contamination by the duck farms have been examined for the presence of nitrogenous wastes. It is generally recognized that amino compounds are attacked by bacteria to form successively ammonia, nitrite, and nitrate. A laboratory study showed that uric acid is rapidly decomposed by bacteria and that bacteria capable of transforming uric acid to ammonia are generally present in bay water.

Samples of water drawn from a trough passing through a duck farm on the Carmans River contained twenty microgram atoms of uric acid nitrogen per liter on the average and in one sample heavily contaminated with suspended solids 300 microgram atoms were present. In the river off this farm 2.8 microgram atoms of uric acid nitrogen was present and 17.5 microgram atoms of ammonia. Further downstream the uric acid nitrogen had decreased to 1.3 microgram atoms and a small amount of nitrate nitrogen had appeared.

A more complete study was made in a confined basin at the head of Hart Cove which has a single farm on its inner shore. The results of the analysis are given in Table X. Substantial quantities of uric acid are present just off the duck farm, but the concentrations diminish toward the inlet to the basin and fall to a low value outside the inlet. As the uric acid diminishes, its decomposition products, nitrite and nitrate, increase in the middle of the basin but diminish as the water becomes more remote from the source of pollution. This may be explained by the absorption of nitrite and nitrate in the growth of plant cells, where they appear as part of the particulate nitrogen fraction.

In the Terrell River the uric acid content of the water increased as it passes the upper farms and then diminished downstream as the following measurements show:

	Uric Acid Nitrogen microgram atoms per liter	Total Phosphorous, microgram atoms per liter
Mill Pond	0	3.4
Off first farm	1.67	45.8
" second "	3.68	186.0
" fifth "	2.14	108.5
" eighth "	1.43	74.5
Inside river mouth	1.07	65.5
Outside " "	0.71	41.2

In the Forge River estuary uric acid could not be detected. Small quantities of nitrate were present in the water upstream but were absent near the mouth of the estuary. The total nitrogen present was 150-200 microgram atoms--largely in the form of particulate matter, Table XI.

These observations show that substantial quantities of uric acid are present in the water near the duck pens. The uric acid appears to be rapidly decomposed leading to the presence of ammonia, nitrite and nitrate. These again disappear as the bay is approached, as the result of absorption by the populations of living organisms.

The tributary streams on which the farms are located are also well loaded with phosphorous compounds. In the Forge River below Mastic it was found that the total phosphorous amounted to as much as forty-six microgram atoms per liter. At this station the phosphorous was

TABLE X

Nitrogenous compounds in basin at head of Hart Cove
August 1, 1951

	Microgram atoms nitrogen per liter				
Position	Uric Acid Nitrogen	Nitrite Nitrogen	Nitrate Nitrogen	Total Nitrogen	Particulate Nitrogen
Near farm	20.4	--	1.45	--	197
Middle of cove	1.48	14.9	41.6	--	86
Inside Inlet	1.24	0.4	1.45	190	168
Outside Inlet	0.7	0.3	0	157	74

1 microgram atom N = 0.014 ppm N
1 " " N = 0.042 ppm Uric Acid

TABLE XI

Nitrogen and phosphorous compounds in Forge River
estuary, July 27 - August 4, 1951
microgram atoms per liter

	Nitrogen* as			Phosphorous as	
	Nitrate	Particulate	Total	Inorganic	Total
Forge River:					
Below Mastic	0.41	33	195	46.0	42.6
Above Old Neck Creek	0.62	164	194	24.8	33.6
Below Old Neck Creek	0	136	181	21.9	30.3
Off Masury Point	0	18	146	17.1	26.6
Moriches Bay Off Masury Pt.	0	93	89	17.6	19.0

* Uric acid and nitrite not detected
Ammonia not determined
1 microgram atom nitrogen = 0.014 ppm
1 " " phosphorous = 0.031 ppm

TABLE XII

General range in total nitrogen and total phosphorous content of bay water, July 27 - August 4, 1951

	Range in microgram atoms per liter	
	Total Nitrogen	Total Phosphorous
Tributary waters	150 - 200	25 - 40
Moriches Bay	90 - 165	20 - 30
Great South Bay	50 - 75	3 - 10
Fire Island Inlet	20 - 30	2 - 3

evidently almost entirely in inorganic form. Proceeding downstream the inorganic form decreased relative to the total, indicating that it was being utilized by plants and other living cells. See Table XI.

The general range in concentration of nitrogen and phosphorous compounds is highest in the tributary streams and decreases progressively passing seaward toward Fire Island Inlet. See Table XII. This indicates that these tributaries are the source of the abnormal amounts of these substances found in the bays. In the tributaries nitrogen is present in seven times the amount and phosphorous in twelve times the amount found in the relatively pure water of Fire Island Inlet.

The contamination of Moriches Bay by the duck farms

In order to obtain quantitative information on the quantity of duck wastes which actually enter Moriches Bay from the duck farms, an attempt was made to measure the net exchange of nitrogen and phosphorous between the Terrell River and the bay.

The Terrell River is a shallow estuary approximately a mile long. Eight duck farms are located along the eastern shore. These farms market 418,000 ducks annually and thus comprise about ten per cent of the local industry. At peak production these farms contain 160,000 ducks of assorted ages. Assuming an average consumption of 0.5 pound of food per day per duck containing 2.9 per cent nitrogen and allowing for a utilization of nitrogen of twenty per cent, there is available as waste 1850 pounds of nitrogen per day. It may be estimated further that the daily waste of phosphorous would be 576 pounds per day.

On August 4, 1951 hourly measurements were made of the volume of flow, total nitrogen, and total phosphorous content of the water passing the constricted entrance of the Terrell River. Using methods similar to those employed in measuring the water and salt exchange of Moriches Bay, the net loss of nitrogen and phosphorous during twelve hours was found to be 306 pounds of nitrogen and 189 pounds of phosphorous. These numbers may be doubled to give the daily loss to the bay and may be compared with the estimated wastes from the farms as follows:

	Total nitrogen pounds/day	Total phosphorous pounds/day
Estimated waste	1,850	576
Measured loss to Moriches Bay	612	378
Per cent waste lost to bay	33%	66%

While these estimates are probably not very accurate, they agree in the case of both elements in indicating that a substantial part (one-third to two-thirds) of the waste produced in the duck farms along Terrell River is finding its way into Moriches Bay.

The measurements of the discharge of nitrogen and phosphorous from the Terrell River may be used to determine whether the accumulation of these elements in Moriches Bay can be accounted for reasonably by the duck farm wastes. The Terrell River farms comprise about one-eighth of the farms located on tributaries to Moriches Bay. Assuming that the other farms contribute proportionately to the contamination of the bay, their daily discharge would be 4,900 pounds of nitrogen and 3.020 pounds of phosphorous. The following table gives the estimated quantity of these elements in Moriches Bay as a whole, determined from samples collected on August 1, 1952, the daily contamination, and the number of days required for the daily contamination to produce the estimated content of the bay water:

	Nitrogen	Phosphorous
Total content	184,000 pounds	75,000 pounds
Daily contamination	4,900 "	3,020 "
Days accumulation	38	25

It is evident that the nitrogen or phosphorous present in the bay water could be produced by the duck farms in four to six weeks. Since the years' crop of ducks had been in production for several months, its excreta could account quite easily for the amount of contamination present on August first.

Nitrogen and phosphorous content of Moriches and Great South Bays

The waters of the tributary streams on which duck farms are located have been shown to contain abnormally large quantities of nitrogen and phosphorous. These elements are present in materials which are undergoing chemical transformation as the result of biological activity. There is evidence that within the tributaries uric acid is rapidly transformed into ammonia, nitrite, and nitrate, which are readily assimilated by microscopic plants. Most of the nitrogen has been incorporated into the cells of plants and other microorganisms which make up the bulk of the particulate matter. Similarly, the inorganic phosphate, in which form phosphorous is initially introduced, decreases as it is absorbed by the living population of the water.

In the open bays it has been impossible to detect more than traces of uric acid, ammonia, nitrite, or nitrate, except in the immediate effluent of a contaminated tributary. The nitrogenous wastes which are readily decomposed appear to have been absorbed by living organisms. Nitrogen is present either as living cells, or as resistant residues of the decomposition of living cells or of the original wastes.

In an attempt to determine the forms in which nitrogen is present in bay water, samples have been divided into three fractions:

1. Coarse particles - chiefly plant cells and other particulate material which can be removed by the Sharpless centrifuge.
2. Fine particles - chiefly bacteria and large colloidal particles separated by filtration from centrifuged water.
3. Soluable residues- minute colloidal particles and materials in true solution which cannot be separated by filtration.

The result of this experiment indicated a distribution of nitrogen in bay water to be as follows:

	Terrell River	Bellport Bay	Great South Bay off West Sayville
Coarse particles	2%	53%	29%
Fine particles	32%	6%	47%
Soluable residues	66%	41%	24%

We do not feel confident of the accuracy of these measurements but believe they indicate that a considerable fraction of the nitrogen is present in the form of minute microorganisms and as soluable residues. It is noteworthy that centrifuged water, from which all green plant cells have been removed, has a distinct opalescent appearance due to the presence of colloidal material or minute organisms.

The phosphorous content of the bay water is represented by a substantial fraction of inorganic phosphate, in which form it is readily assimilable by plant cells or bacteria. A portion of the inorganic phosphate may be present as particles of relatively insoluable materials such as bone meal, derived from incompletely digested duck food. Another portion may be absorbed on the surface of particulate matter. The remainder is present in inorganic matter either as a part of the structure of living cells and detritus, or as soluable organic compounds. The separation of these fractions has not been successfully accomplished. A rather rough experiment similar to that made in connection with the nitrogenous components gave the following results:

	Terrell River	Great South Bay off West Sayville
Coarse particles	23%	14%
Fine particles	12%	13%
Soluable organic residues	14%	57%
Soluable phosphates	51%	16%

Nitrogen and phosphorous are the only chemical materials detected in the water of the bays of whose origin can be attributed directly to the wastes from the duck farms*. Because of the rapid transformation in the state of these elements due to biological activity, measurement of the total nitrogen and phosphorous is the only useful method of tracing the contamination of the bay water by the duck farm wastes.

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* When the 1950 report was written it was expected that uric acid could be used as a tracer for the duck wastes. Having developed a method sensitive to two parts in 100 million of sea water, it was discovered that uric acid is decomposed so rapidly that it cannot be detected in measurable amounts in the bay water.

Figures 10 and 11 show the total nitrogen and total phosphorous content of the bay water as determined by survey at the end of July 1951. In examining these figures it should be considered that, were the bay uncontaminated, the quantities of nitrogen and phosphorous to be expected would be about thirty microgram atoms of nitrogen and two microgram atoms of phosphorous per liter (0.42 ppm N and 0.06 ppm P). In the case of both elements, the highest concentrations are found in the tributary streams on which duck farms are situated. In the open basin of Moriches Bay the concentration of nitrogen exceeds 125 microgram atoms and of phosphorous 20 microgram atoms per liter. This represents eight or ten times the quantities expected in uncontamined water. The concentrations of both elements diminishes toward the approach to the Quantuck Canal and in Narrow Bay.

High concentrations of nitrogen and phosphorous also occur in Bellport Bay, particularly in the eastern part into which the Carmans River and Narrow Bay drain. West of Bellport Bay the concentrations are lower and are rather uniformly distributed at about sixty microgram atoms of nitrogen and 4.5 microgram atoms of phosphorous per liter, which are twice the quantities to be expected in uncontaminated bay water.

The distribution of nitrogen and phosphorous in the bays provides compelling evidence that the abnormal concentrations of these elements has its origin in the tributaries of Moriches Bay and the Carmans River, from which they spread seaward through the available passages, becoming diluted in the process. In Moriches Bay itself, the accumulation is much greater than in the more remote waters of Great South Bay.

Seasonal changes

Measurements made by the New York State Conservation Department in 1950 inidicated that the total phosphorous content of the water of Great South Bay was about 0.02 ppm (less than one mocrogram atom per liter) in mid-winter and did not become abnormally high until early summer. This was cited in the 1950 report (7) as supporting the view that the abnormal condition of the bay water is related to the seasonal development of the duck crop. To obtain more information on the seasonal development of conditions, water samples were secured from the Forge River, Smith Point, and Green Point at two week intervals, beginning in early April 1951, for analysis for total nitrogen and phosphorous.

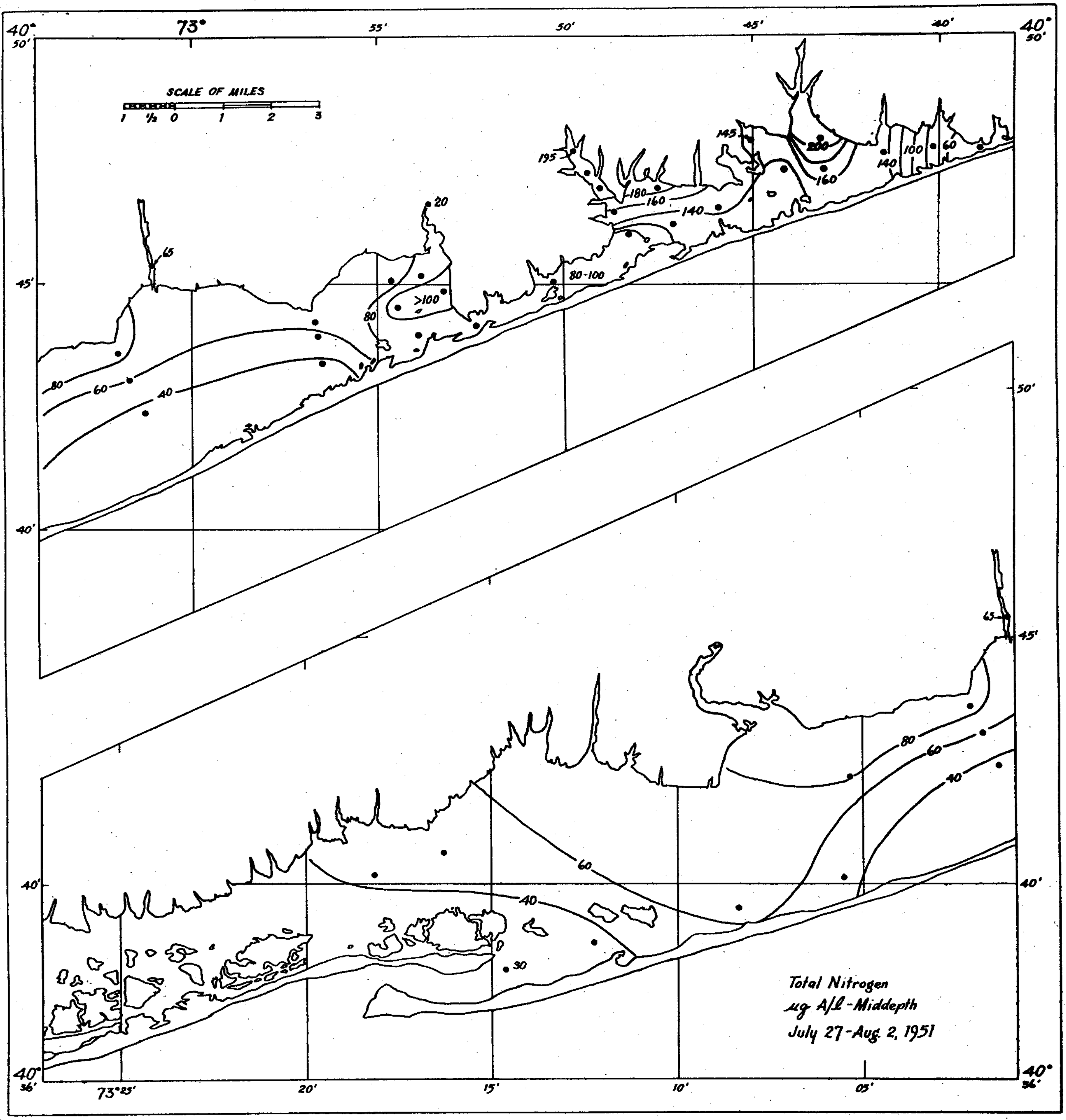

Figure 10 Concentration of total nitrogen in Moriches and Great South Bays, July 27 - August 2, 1951.

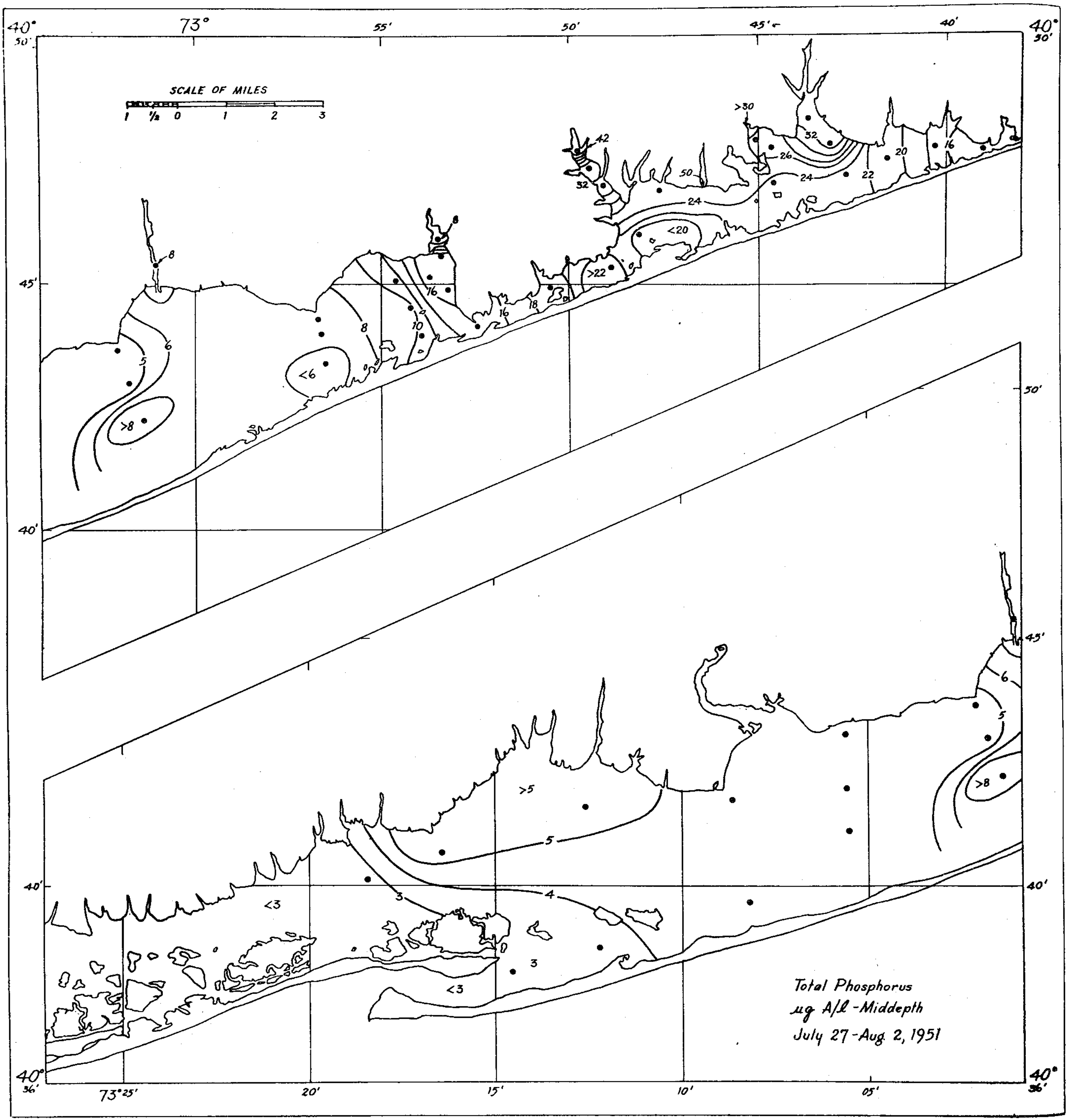

Figure 11 Concentration of total phosphorous in Moriches and Great South Bays, July 27 - August 2, 1951.

The results of this study are shown in Figure 12. In the Forge River, close to the farms the concentrations at all times were higher than in the bay water. On April 9 the quantities of phosphorous present, however, was about one-third that subsequently developed. The increase took place rapidly so that maximal values were present in early June. The measurements in Forge River were very variable because of the differences in the stage of the tide when the samples were collected and because of the influence of temporary variations in the river flow. At Smith Point the concentrations increased more gradually, following the closure of Moriches Inlet on May 15. Maximal values were not reached until August, as might be expected because of the time required for the accumulation of pollutants in Moriches Bay. At Green Point the initial concentrations are somewhat lower than at Smith Point. The concentrations begin to increase about July 1, as at Smith Point, but never reach such high values. Similar results were obtained from analyses for total nitrogen.

After the end of September, the quantities of phosphate diminish rapidly and within two months have leveled off at values not much greater than expected in unpolluted water. At Green Point the decrease is less abrupt, as might be expected from its position in relation to the pollution sources in Moriches Bay.

The seasonal changes in the concentration of nitrogen and phosphorous are such as would be expected if the abnormal quantities were related to the seasonal growth and decline of the population of the duck farms. The concentrations develop and decline with a delay which depends upon the remoteness of the water from the supposed source of pollution.

Quantitative aspects

It is important to inquire whether the quantities of nitrogen and phosphorous which are observed to accumulate in Moriches and Great South Bays are such as could be produced by the annual crop of ducks. It has already been indicated that about one-third of the wastes from the duck farms on the Terrell River enter Moriches Bay daily, and that at this rate the nitrogen and phosphorous content of Moriches represents an accumulation of the wastes produced by the tributary farms in four to six weeks.

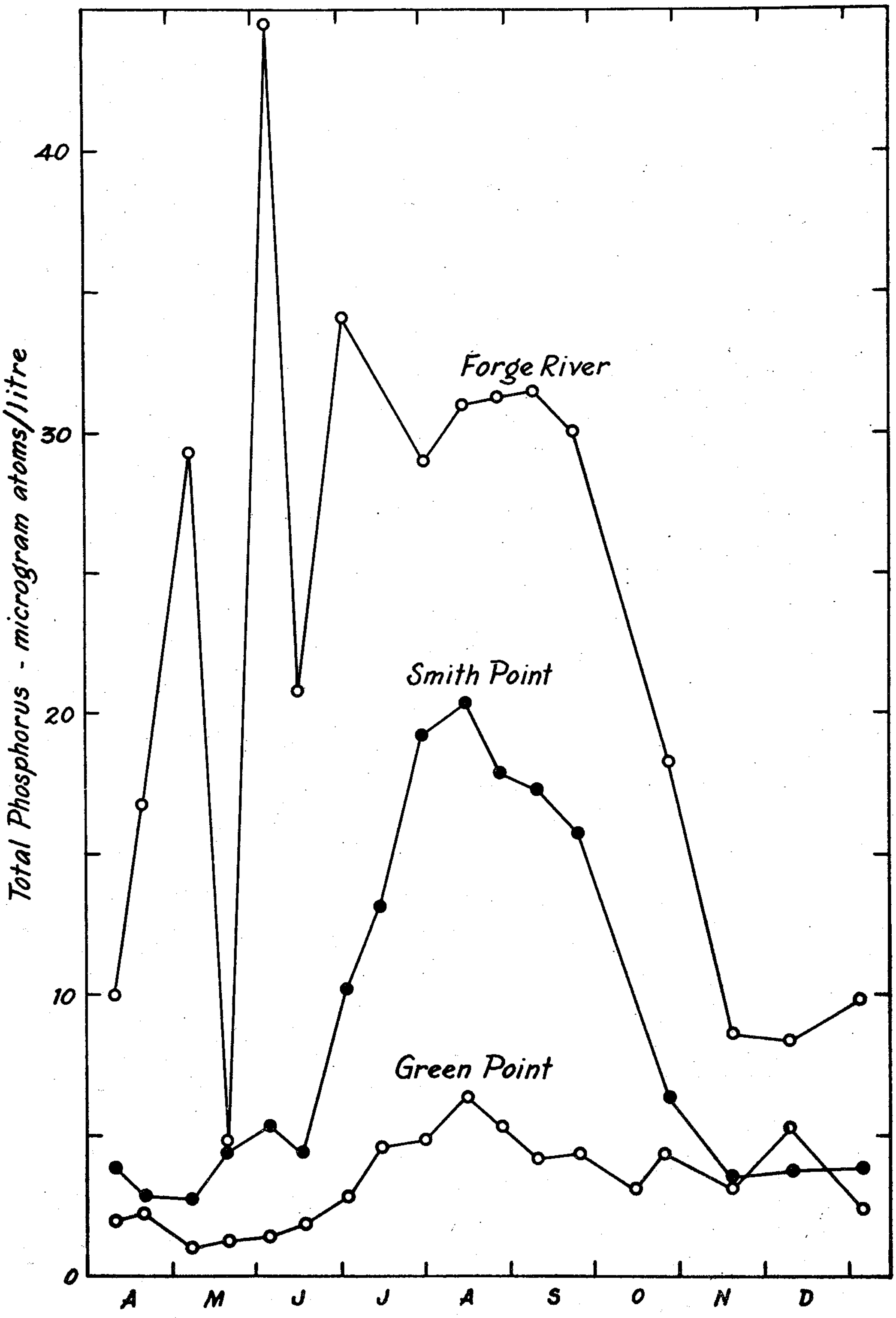

Figure 12 Total phosphorous concentration at Forge River, Smith Point, and Green Point, 1951.

Since the greater part of the duck industry is located on Moriches Bay, we will examine first the rate at which nitrogen and phosphorous escape from Moriches Bay into Shinnecock Bay and Great South Bay. In late September, in the course of measuring the exchanges in the Quantuck Canal and at Smith Point, analyses of total nitrogen and phosphorous in the water were made at regular intervals during four complete tidal cycles. The result of the estimations are as follows:

Net loss from Moriches Bay
pounds per day

	Total Nitrogen	Total Phosphorous
Quantuck Canal	not determined	98
Smith Point	2,225	357

These results are probably not very accurate since they depend on determining the small difference in the large amounts of nitrogen and phosphorous moving back and forth with the tide. The analytical procedures are not precise enough for the purpose. They indicate that the contaminants are being lost at both passages, and that the greater loss occurs at Smith Point. The total loss is much less than the daily introduction of pollutants, as estimated from the exchange at the mouth of the Terrell River a month earlier. It is unlikely that they exaggerate the rate at which nitrogen and phosphorous were escaping from Moriches Bay.

In order to determine if the nitrogen and phosphorous present in Great South Bay could have been produced by the duck farms within a single season, it is necessary to compare the total accumulation with the estimated daily rate of contamination. The total content of Great South Bay has been estimated from a survey made September 24-29, 1951. Allowance has been made for the nitrogen and phosphorous which would be expected in unpolluted bay water, assuming the normal concentrations to be thirty microgram atoms of nitrogen and two microgram atoms of phosphorous per liter. The daily accession of nitrogen and phosphorous is due to the exchange at Smith Point plus an allowance for the contamination from the Carmans River. The latter has been taken as 18 per cent of the measured loss at Smith Point, the proportion of the number of ducks raised on the Carmans River to those on Moriches Bay tributaries. The calculation is as follows:

	Total Nitrogen pounds	Total Phosphorous pounds
Content of Great South Bay	664,000	167,000
Correction for normal content	412,000	61,000
Accumulated contamination	252,000	106,000
Daily accession - Smith Point	2,225	476
- Carmans River	400	86
TOTAL	2,625	562
Time required for accumulation	96 days	189 days

The result indicates that the nitrogen and phosphorous present in Great South Bay at the end of September could have been produced by duck farms in three to six months--that is, the beginning of the growing season.

Finally, we may consider what fraction of the nitrogen and phosphorous available in total wastes from the tributary duck farms appears to accumulate in Moriches and Great South Bays in the course of the summer. The calculation is as follows:

	Total Nitrogen pounds	Total Phosphorous pounds
Total waste available	2,700,000	820,000
Content Great South Bay	664,000	167,000
Moriches Bay	203,000	70,000
TOTAL	867,000	237,000
Per cent available waste in bay water	32%	29%

No allowance is made in this estimation for the nitrogen and phosphorous normally present in bay water. Yet it appears that only about a third of the available waste from the duck farms is needed to account for the unusual concentrations of these elements present in the water in late summer.

4. The Effects of Pollution on the Biology of the Bays

The population of plants

The most obvious abnormality in the bay water is the presence of an unusual number of microscopic plants. These organisms, locally known as "small forms" because of their minute size, have not been satisfactorily identified, but appear to be related to the genus Chlorella, which contains several species common in fresh water. In winter the water contains a sparse population of microscopic plants, chiefly diatoms, and is in no way unusual. The small forms begin to grow in late spring and rapidly comes to dominate the population. Their numbers increase and decrease with the season, and vary with proximity to the duck farm area in a way very similar to the total phosphate content of the water.

In July the small form population extended westward to Babylon, but not into the western end of Great South Bay. It was present in small numbers in the western part of Shinnecock Bay, but occurred only sparsely east of Shinnecock Inlet. The center of abundance was in the Smith Point-Forge River region. From there it declined gradually across Great South Bay. East of Moriches Bay the numbers fall abruptly beyond the canals. See Table XII which contains data supplied by Dr. Lackey.

The numbers of small forms present at Forge River, Smith Point, and Green Point during the latter part of 1951 are shown in Figure 13 which shows the maximum population reached in late summer in the Moriches Bay area. Comparison with Figure 12 shows how the population declines in parallel with the phosphorous content of the water during the late fall. It was shown in the 1950 report that the small form population in Great South Bay begins to grow in the spring as the phosphorous accumulates in the bay water (7).

Nitrogen and phosphorous as plant nutrients

The presence of the unusual bloom of small forms is unquestionably related to the abnormal quantities of nitrogen and phosphorous which arise from the duck farm wastes. This is shown not only by the coincidence of the bloom, in time and in geographical distribution, with the enrichment of the water with these elements; it is also necessitated by quantitative considerations. The plant cells require nitrogen and phosphorous to make

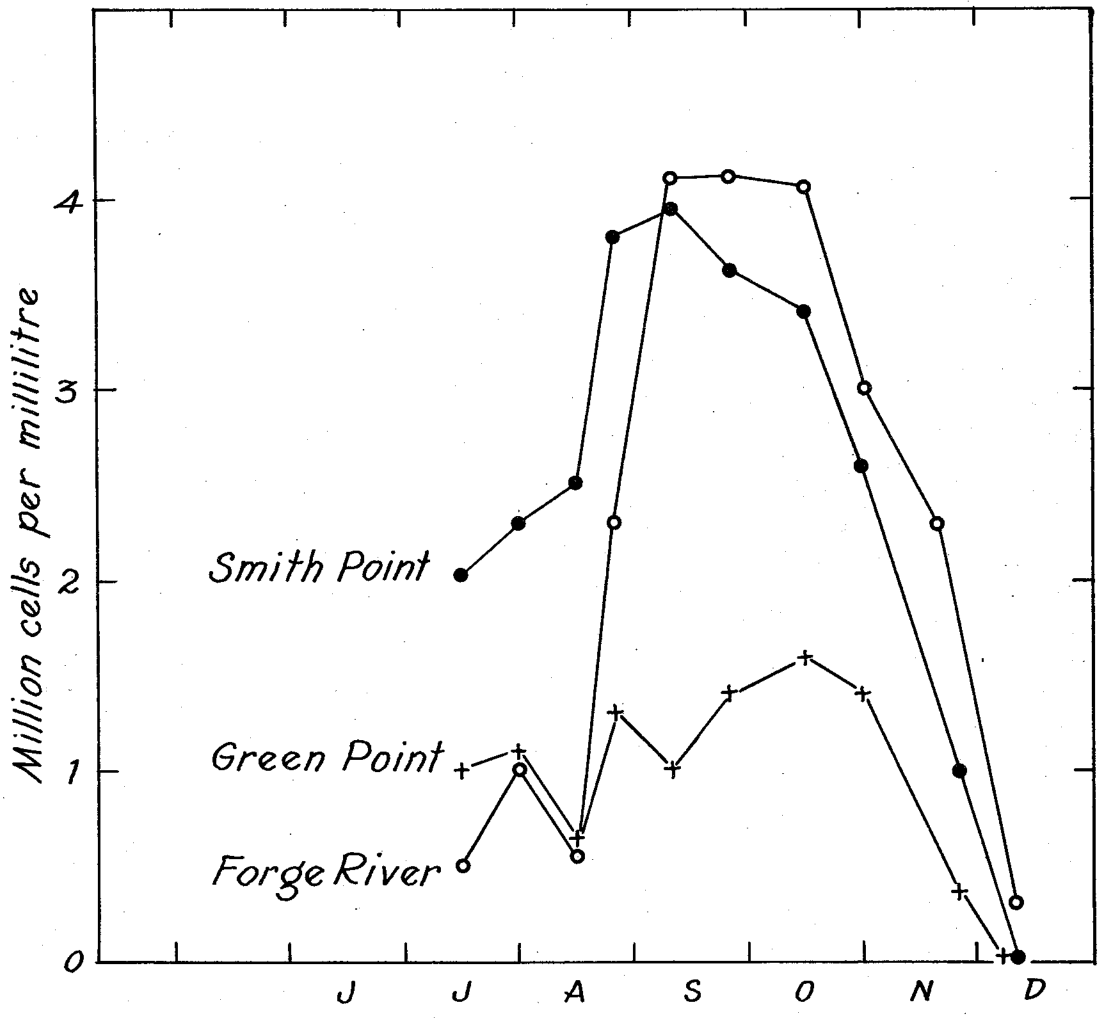

Figure 13 Concentrations of small forms at Forge River, Smith Point, and Green Point, 1951.

TABLE XII

Numbers of small forms present in waters of Great South, Moriches, and Shinnecock Bays
July 13-14, 1952

	Number per Milliliter
Great South Bay: off	
Amityville	0
Babylon Channel, south end	174,000
Conklin Point	117,000
Fire Island Inlet	117,000
Champlin Creek	162,000
Nicoll Point	359,000
Howell Point	205,000
Smith Point	467,000
Moriches Bay: off	
Forge River	396,000
Potunk Point	342,000
Quantuck Canal	535,000
Quantuck Bay	61,000
Quogue Canal	162,000
Shinnecock Bay	
West end	76,000
Tiana Bay	90,000
Highway bridge	64,000
East end	6,400

their substance, and without them cannot grow. Actually, the greater part of the nitrogen and much of the phosphorous in the bay water is combined in the plant cells, and their numbers is a clear indication that the water is contaminated with these materials.

The bay waters have not been found to contain measurable quantities of any of the nitrogen compounds, such as ammonia, nitrite, and nitrate, which result from decomposition of organic matter and which are the usual forms in which plants absorb their required nitrogen. This is interpreted to mean that the plants are absorbing such materials just as fast as they become available through addition as contaminants or the decomposition of organic matter. The growth of the plant population is in fact limited by the availability of nitrogen.

In contrast, substantial amounts of inorganic phosphates are available during the summer throughout the bays. Its presence shows that phosphorous is present in excess of the requirements of the plants which can be produced on the available supply of nitrogen.

This excess of phosphate arises from the proportion of nitrogen to phosphorous in the duck wastes as compared to the proportions required by the plants. An examination of these proportions, and those which occur in various parts of the bay is of interest.

	Average Atomic Ratios Nitrogen:Phosphorous
Duck Food	3.2:1
Duck Wastes	3.3:1
Terrell River discharge	3.6:1
Moriches Bay water	6:1
Great South Bay water	
East of Patchogue	8:1
West of Patchogue	12:1
Unpolluted ocean water	15:1
Plant cells - algae	15:1

These ratios show that the duck wastes contain smaller proportions of nitrogen than are required by plant cells. The ratios in the bay water reflect those in the waste at places close to the source of pollution. At more remote places the ratios increase as the result of admixture with sea water, which when unpolluted, contains nitrogen and phosphorous in nearly the proportions required by plants.

These facts not only provide additional evidence on the source of pollution, but they are important in considering remedial measures. The excess phosphate in the water is in no sense harmful and its reduction up to a certain point cannot be expected to improve conditions in the bay. The nitrogen is the limiting factor controlling the growth of algae. Any reduction in the quantity of nitrogenous waste entering the bay will be immediately effectual in reducing its plant population.

Oxygen supply

Embayments in which an escess of organic matter is produced frequently become unfit for many kinds of life because of a reduction in the available quantity of oxygen. This condition undoubtedly exists within the tributaries on which the duck farms are located. The bottom in these estuaries is covered with a thick layer of soft black muck in which organic matter is decomposing. The black color and the odor indicate that hydrogen sulfide is being produced as the result of bacterial action in the absence of oxygen. We are informed of one instance when the paint on a cottage situated on one of the polluted tributaries was blackened by hydrogen sulfide which escaped from the cove during a period of hot, calm weather.

Analyses of the oxygen content in Hart Cove and Forge River shows that frequently the oxygen in the water was reduced to values ranging from 2 to 30 per cent saturation. In some samples oxygen was much higher, indicating that in these shallow waters photosynthesis by the abundant plant population may be able to restore oxygen as fast as it is depleted.

In the open bays, the water is well enough mixed so that the oxygen content near the bottom is not more than 10 or 20 per cent less than at the surface. In July the water of Great South Bay varied between about 80 and 100 per cent saturation. In Moriches, on the other hand, the water at mid-depth contains less than 75 per cent of the saturation value, and in a large area along the north side of the bay, between Forge River and Seatuck Cove, the water at mid-depth was less than 50 per cent saturated with oxygen (Figure 14). In this region the oxygen content was sharply reduced near the bottom, as the following measurements indicate:

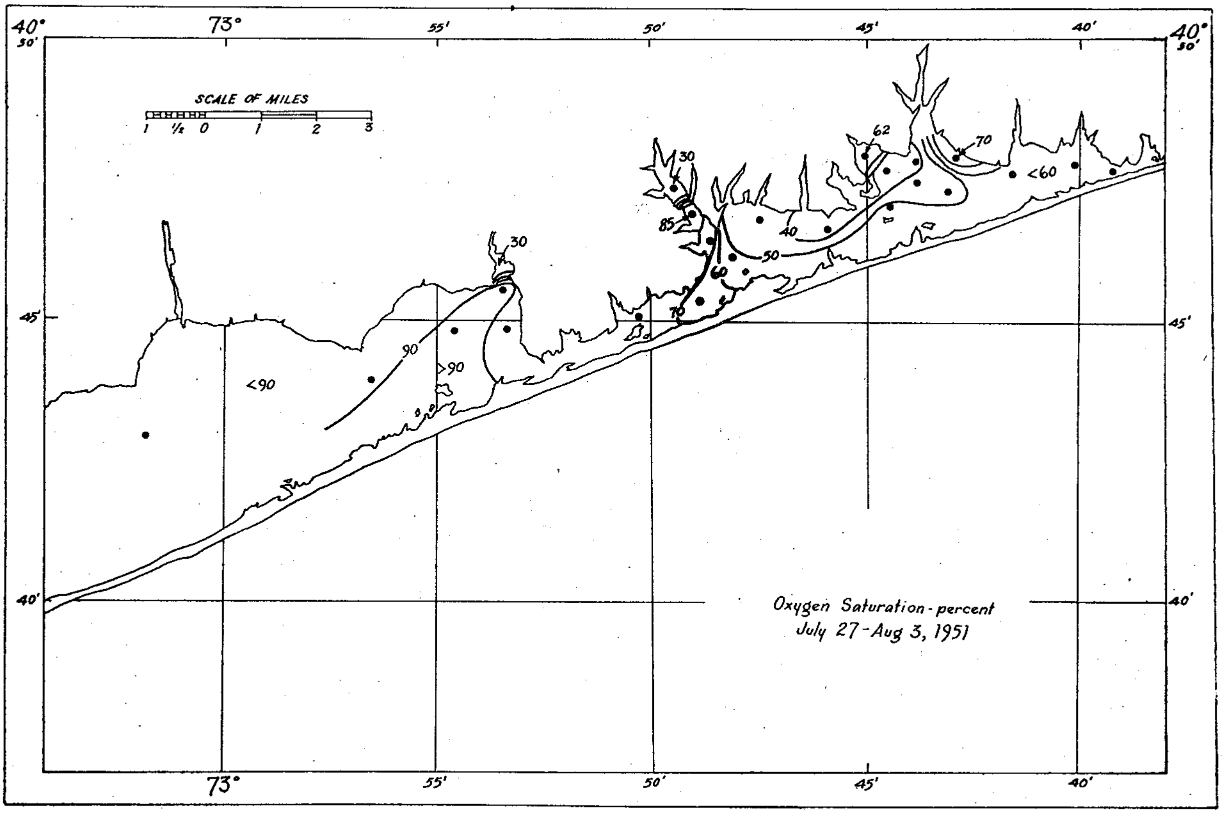

Figure 14 Percentage saturation of oxygen in water of Moriches and Great South Bays at mid-depth, July 27 - August 3, 1951.

Oxygen Saturation	Surface	Mid-depth	Bottom
Off Hart Cove	56%	49%	31%
Off Seatuck Cove	75%	71%	57%

Transparency

The oxygen content of natural waters may be maintained by oxygen produced by the photosynthetic activity of plants, provided these are present in sufficient quantity and that they receive adequate light. In the bays there is such an abundance of plant cells that it is possible they prevent light from reaching the bottom, in which case the plant cells themselves would tend to use up the oxygen.

The small form bloom gives the water a curious golden-brown color and reduces its transparency, so that objects cannot be seen two or three feet below the surface. The depths at which a white disk (Secchi disk) disappears give a measure of the opacity, and roughly of the amount of suspended plant cells and other material in the water. In July, the disk disappeared at depths of 2 - 2.5 feet in Great South Bay; 1.5 - 2 feet in Bellport Bay, Narrow Bay and the western and northern part of Moriches Bay; and less than 1 foot in Forge River. At the eastern extremity of Moriches Bay, the water was more transparent. It may be noted that the transparency of the water is least in the region where the oxygen content is most deficient.

A few measurements have been made to determine the intensity of light at various depths in the bay, using a simple photometer. The results are shown in Table XIII. They show that very large fractions of the incident light are absorbed by the depth of water and bring out the differences characterizing different places. Since the measurements are relative they cannot be used to estimate the photosynthetic rate at different depths. For this purpose, direct measurements have been made.

The procedure was to suspend bottles of bay water containing the natural local population of plant cells at different depths below the surface. The oxygen content of the water was determined at the beginning and after twenty-four hours. Similar bottles covered with opaque cloth showed how much oxygen the plant and other cells used up in the absence of light. The results of the experiment are shown in Figure 15.

TABLE XIII

Depths at which various fractions of incident daylight are absorbed in bay waters

	Great South Bay West Sayville	Narrow Bay	Forge River
Depth of water	5.5'	8'	4'
Secchi disk reading	32"	22"	15"
Depth required for			
90% absorption	5 feet	2.5 feet	1.7 feet
99% "	10 feet*	5.0 "	3.4 "
Fraction absorbed per foot	37%	60%	74%

* Estimated

In Narrow Bay the bottles near the surface contained more oxygen after twenty-four hours than at the start, showing that photosynthesis was exceeding respiration. Below 5.5 feet, however, the oxygen content of the bottles decreased, showing that insufficient light was penetrating to that depth to permit photosynthesis to compensate for the oxygen lost by respiratory activity. In Great South Bay this point was never reached and oxygen increased even to the bottom. It seems probable that in Great South Bay the water is sufficiently transparent to permit oxygen to be produced in excess at all depths in clear weather. Where the pollution of plants is more dense, as in Moriches Bay, the illumination near the bottom may be so weak that oxygen can be renewed only by mixing of the layers of water.

A comparison of the oxygen production in the light with the consumption in the dark at these positions is of interest. The following figures compare the oxygen produced under optimum conditions; i.e., at 1 or 1.5 foot depth with the average consumption in the dark bottles:

ml. O_2/liter/day	Great South Bay	Narrow Bay	Ratio
Maximum O_2 production in light	2.34	3.95	1:1.7
Average O_2 consumption in dark	0.45	1.69	1:3.7

It appears that oxygen production is 1.7 times greater in Narrow Bay than at the Great South Bay station. This may be taken to represent the proportion of photosynthetic plants present at the respective places. The oxygen consumed in the dark is due not only to green plants but to microorganisms such as protozoa and bacteria. In the dark the oxygen consumed is 3.7 times greater in Narrow Bay. This is twice as great as the difference in oxygen production. This observation suggests that the water of Narrow Bay may contain a larger population of protozoa and bacteria.

The data on the oxygen consumption in the dark is interesting in several connections. In the first place, they show how much the oxygen concentration may be expected to drop during the night. In Great South Bay the oxygen disappearing from the dark bottles is 0.45 ml/liter in twenty-four hours. During the night the drop

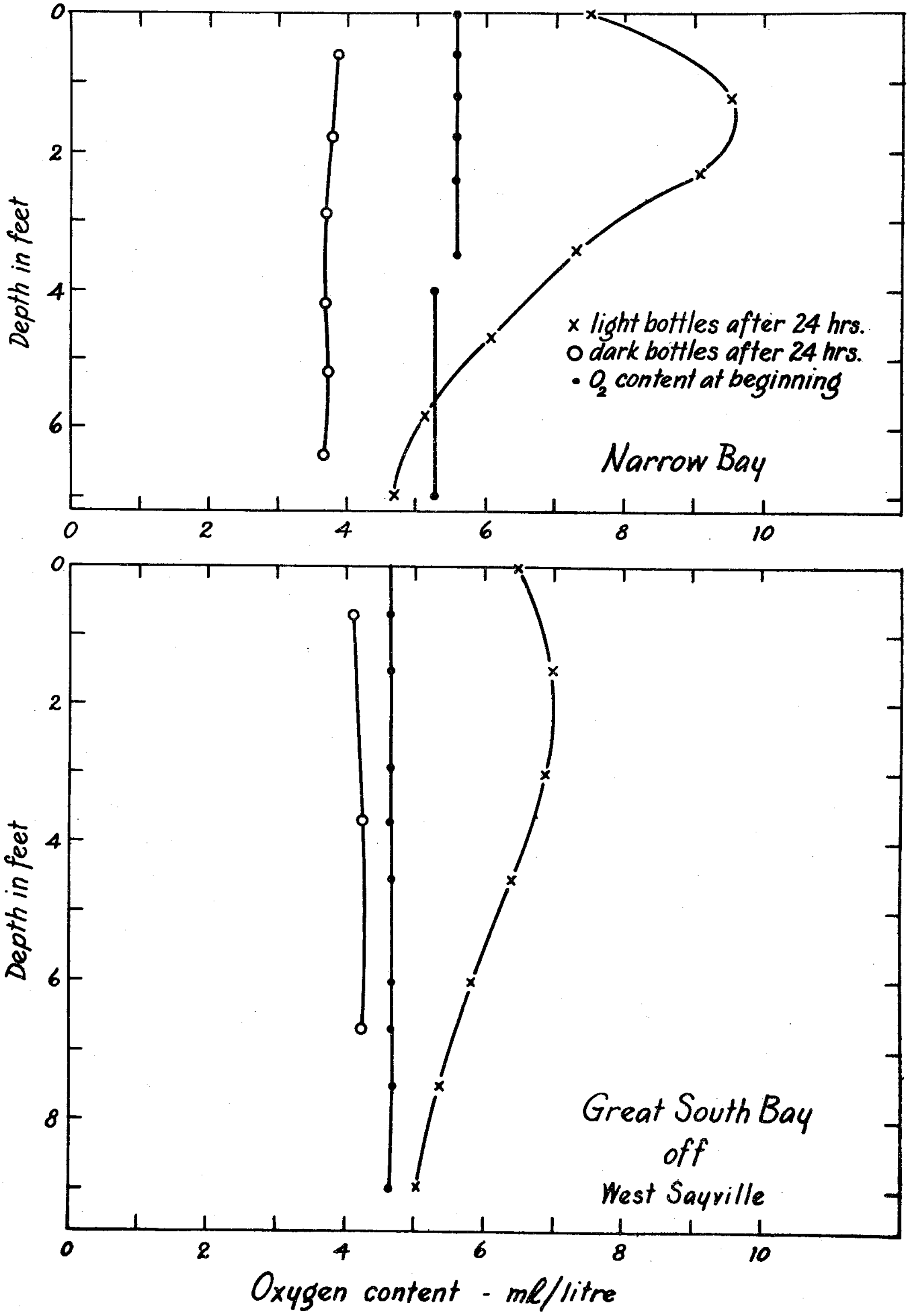

Figure 15 Oxygen production, in light, and consumption in dark at various depths in twenty-four hours, August 1, 1951.

would be about half this, or 0.22 ml/liter. In Narrow Bay the change is 1.69 ml/liter in twenty-four hours or about 0.85 ml/liter each night. These changes would not appear to be important, unless the water was already nearly depleted of oxygen.

The oxygen consumption of 1.69 ml/liter per day, which occurred in Narrow Bay water in the dark, represents a loss of a third the total oxygen content of saturated bay water. It is easy to see from this that in periods of calm weather in places not well stirred by the tide, water near the bottom might very rapidly become devoid of oxygen. Should this occur, wholesale death of the bottom animals would be expected.

Information on the areas in which the oxygen consumption of the water is critically large is given by a series of so-called twenty-four hour B.O.D. determinations. In these tests, samples of water were kept in the laboratory for twenty-four hours in the dark and then tested for the loss of oxygen. These tests were not continued long enough to determine the total quantity of oxidizable material present, which is the usual objective of B.O.D. measurements. They give rather an indication of how fast oxygen will disappear from the water if it is not renewed by photosynthetic activity or by mixing. The range of values obtained in the twenty-four hour B.O.D. tests were as follows:

Off Green Point	0.45 ml/liter/24 hours
Patchogue	1.61
Bellport Bay	1.21 - 2.20
Narrow Bay	1.80 - 1.90
Moriches Bay	1.14 - 1.80
Seatuck Cove	2.45
Hart Cove	3.70
Forge River	4.0 - 4.26

The values at all places east of Patchogue are large enough to produce undesirable effects in case of temporary stagnation. In the more heavily polluted waters of Forge River and Hart Cove the entire oxygen content of the water was consumed in twenty-four hours.

It is concluded from these studies of oxygen that, while only limited parts of Moriches Bay closely associated with the sources of pollution show serious oxygen depletion, the margin of safety in the entire Moriches

Bay region is very slight. Any slight aggravation of the conditions leading to increased oxygen consumption or stagnation of the water might easily cause a disastrous depletion of oxygen in the water over the bottom.

5. The Effect of Moriches Inlet on the Pollution of Moriches and Great South Bays

When the conditions observed in the summers of 1950 and 1951 are compared, it is evident that closure of Moriches Inlet, in May 1951, has had a great effect on the water of Moriches Bay. The most noticeable effect was on the color and transparency of the water, associated with the abundance of plant life.

In 1950 the turbid yellow-green color which was characteristic of Great South Bay water disappeared eastward of Narrow Bay. Off the Forge River the transparency was such that the bottom could be seen at depths of four or five feet and the water had the slight brownish color characteristic of enclosed bays. In contrast in 1951, the water of Moriches Bay was indistinguishable in appearance from that of Great South Bay. Measurements of the transparency of the water show that in 1950 the Secchi disk was visible at depths of 3.5 to 5 feet in the open bay; in 1951, the disk was invisible at 1.5 to 2.5 feet of water.

There is no doubt that the changed appearance of Moriches Bay water is due to the increased density of the population of microscopic plants. Unfortunately, no counts of the number of cells present in 1950 are available for comparison. Measurements of the particulate phosphorous fraction in the water, which is attributable to the content of microscopic animals and plant cells, also indicated a great increase in the abundance of organisms in Moriches Bay in 1951. In 1950, the concentrations of particulate phosphorous ranged from 1 to 3 microgram atoms per liter; in 1951, the values were 20 to 30.

The concentrations of total nitrogen and phosphorous in Moriches Bay water were also much greater in 1951. Thus, total nitrogen increased from a range of 60 - 80 to 90 - 200; total phosphorous from 8 - 10 to 20 - 25 microgram atoms per liter.

There was no clear change in the inorganic phosphate when the two years are compared. The excess of phosphorous present in 1951 has evidently been absorbed into the cells of organisms while the water remains within the bay. In 1950 it appeared that the polluted water moved out of the bay too rapidly for this to occur--as shown by the small fraction of phosphorous present in particulate form (7).

The oxygen content of the water also shows a change such as might be expected from the increased organic content of the water. In 1950 the saturation of the water varied from 70 to 100 per cent; in 1951, the saturation ranged from 30 to 75 per cent.

Within the tributaries of Moriches Bay, it is not evident that the closure of Moriches Inlet has altered the conditions. In these highly contaminated places, there is great local variation and our quantitative measurements are inadequate to bring out any significant change. In the open bay, however, it is clear that the wastes from the duck farms accumulate and are held within the bay much longer than was the case before Moriches Inlet closed. This is to be expected from the changes in circulation which have been described.

The general changes in conditions in Moriches and Great South Bays are given for comparison in Table XIV.

In Great South Bay the closure of Moriches Inlet has not been followed by any notable change in the conditions related to pollution. In the eastern part of Bellport Bay the conditions reflect in some degree the pollution of water moving from Moriches Bay past Smith Point. This region is responsible for such changes as are indicated by the range in conditions in Great South Bay shown in Table XIV.

An estimate, based on surveys made in mid-summer in 1950 and 1951 has been made of the total quantities of nitrogen and phosphorous present in the water of Moriches and Great South Bays. See Table XV. The total accumulation of nitrogen and phosphorous in Moriches Bay is about doubled following the closure of the inlet. In Great South Bay the quantities are about the same in both years.

The totals for both bays do not appear to differ very much as the result of closure of the inlet--the quantity of nitrogen is indicated to be slightly less and that of phosphorous somewhat greater in 1951.

TABLE XIV

Comparison of conditions on Moriches and Great South Bays as observed in mid-summer in 1950 and 1951

	Range in Conditions	
	1950	1951
Moriches Bay		
Secchi disk reading - feet	3.5 - 5	1.5 - 2.5
Total nitrogen μg atoms/liter	60 - 80	90 - 200
Total phosphorous " " "	8 - 10	20 - 30
Particulate phosphorous " "	1 - 3	20 - 30
Oxygen saturation - per cent	70 - 100	30 - 75
Great South Bay		
Secchi disk reading - feet	2 - 2.5	2 - 2.4
Total nitrogen μg atoms/liter	50 - 100	40 - 100
Total phosphorous " " "	3 - 5	3 - 16
Particulate phosphorous " "	3 - 4	3.5 - 15
Oxygen saturation - per cent	60 - 100	70 - 100

TABLE XV

Comparison of total nitrogen and total phosphorous accumulated in Moriches and Great South Bays about August first in 1950 and 1951

	Nitrogen - pounds	
	1950	1951
Moriches Bay	96,000	184,000
Great South Bay	894,000	771,000
TOTAL	990,000	950,000

	Phosphorous - pounds	
	1950	1951
Moriches Bay	26,000	75,000
Great South Bay	145,000	163,000
TOTAL	171,000	237,000

This is a somewhat surprising result since it is to be anticipated that with the inlet open substantial amounts of the pollutants would be carried to the sea by the tidal exchange through the inlet. The evidence is that this was not the case. If it is assumed that the quantity of wastes discharged into Moriches Bay was the same in the two years, the only obvious explanation of the observations is that the tidal mechanism was such as to carry most of the waste into Great South Bay even when the inlet was open.

It is quite possible that the wastes discharged into Moriches Bay by the polluted tributaries on the ebb tide were swept westward by the rising tide which in 1950 flooded westward past Smith Point. If this were the case, the greater part of the pollution from the western part of Moriches Bay might enter Great South Bay, although the inlet was open. Unfortunately, the observations made in 1950 were inadequate to test this possibility and the closure of the inlet prevented the further study which was planned.

It may be concluded from the observations made in 1950 and 1951 that the closure of Moriches Inlet has greatly increased the accumulation of pollutants in Moriches Bay but has not changed in any noteworthy degree the conditions in Great South Bay.

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