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DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

SEA SURFACE CIRCULATION IN THE NORTHWEST APEX OF THE NEW YORK BIGHT - WITH APPENDIX: BOTTOM DRIFT OVER THE CONTINENTAL SHELF

VOLUME I

VOLUME II - PART 1: DIAGRAMS AND DATA FOR INTERFACE DRIFT CARDS
PART 2: DIAGRAMS AND DATA FOR SEABED DRIFTERS

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UNITED STATES DEPARTMENT OF COMMERCE
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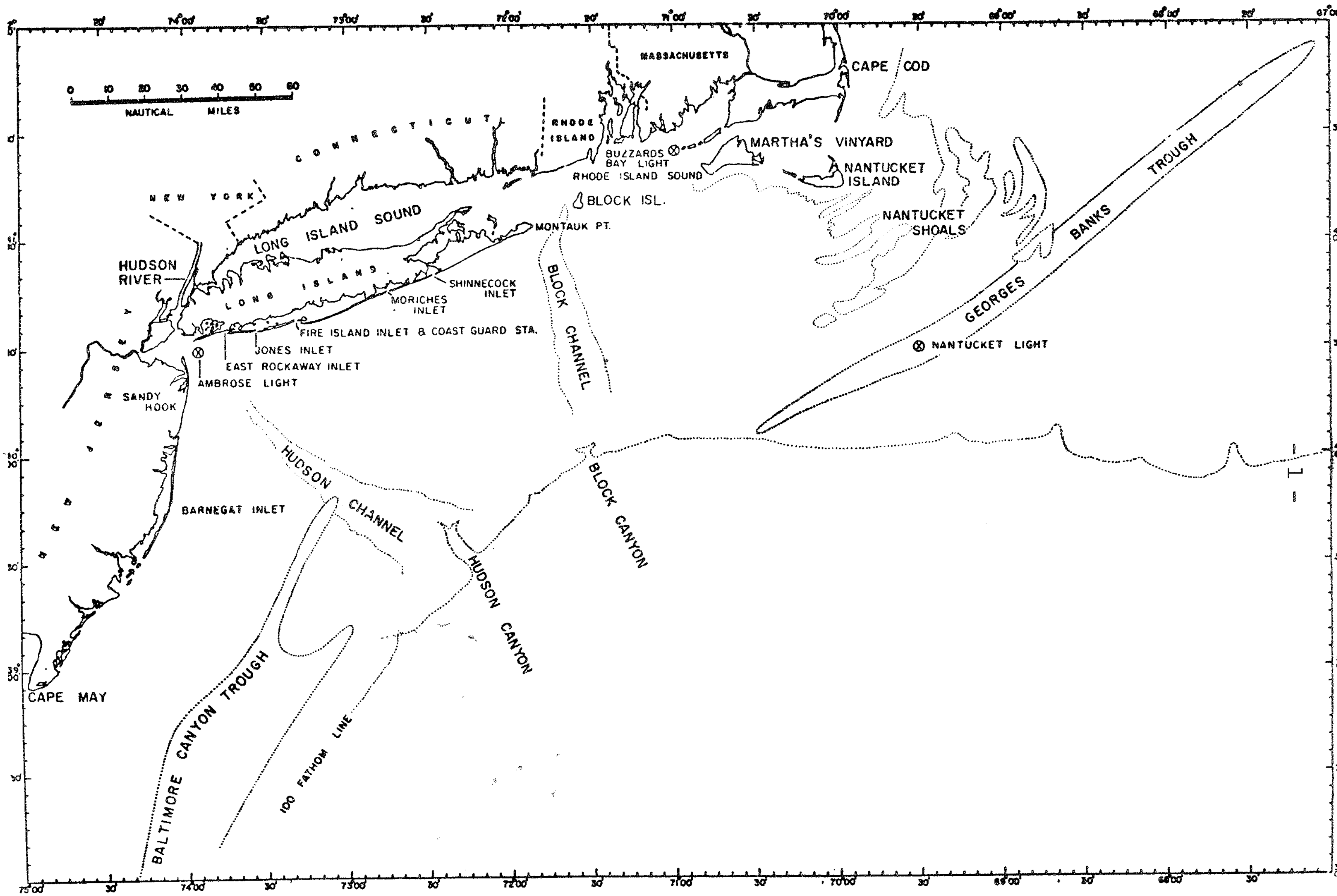

Figure I-1. The New York Bight, showing the Baltimore Canyon Trough and the Georges Banks Trough.

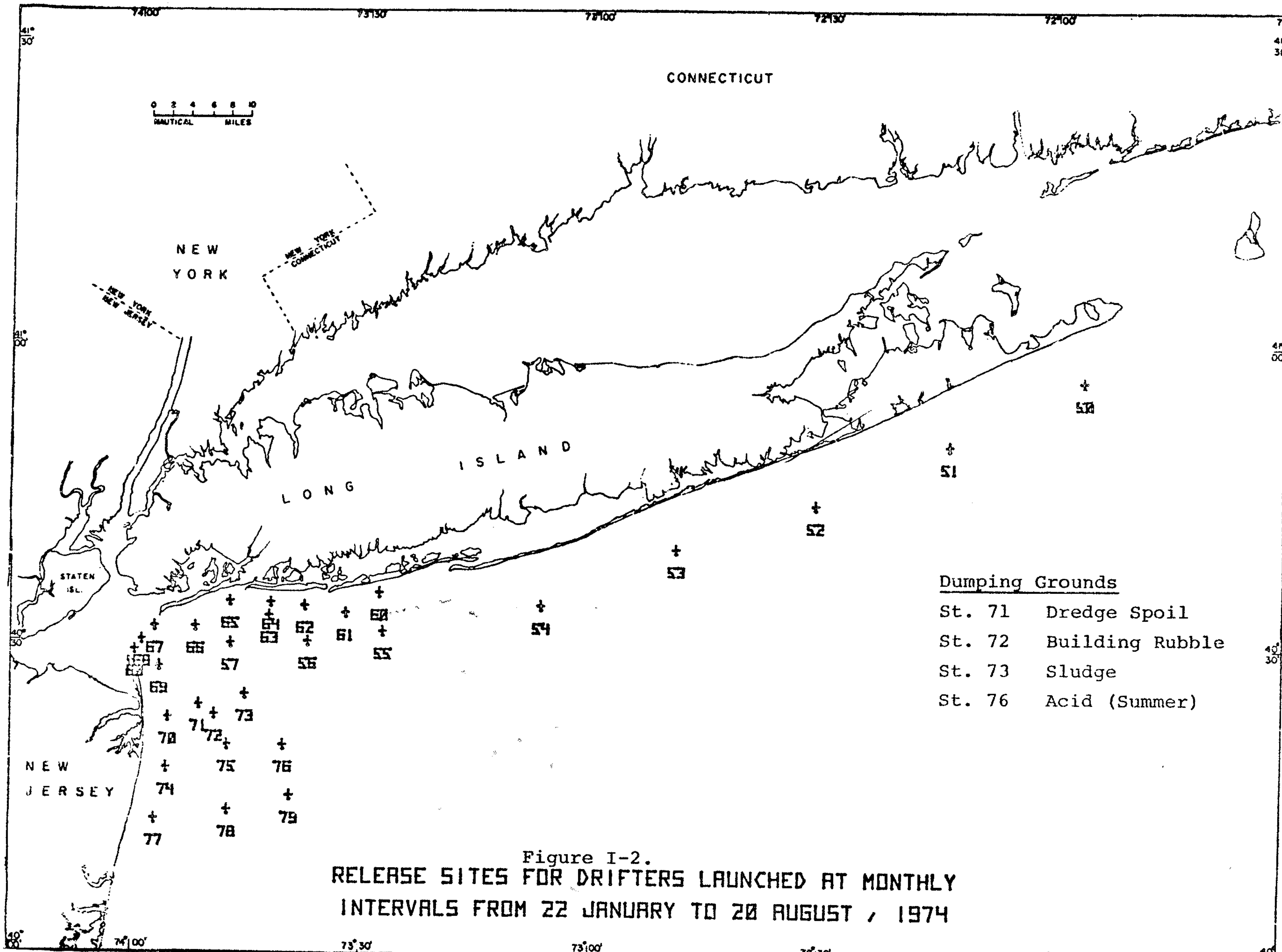

Figure I-2.
RELEASE SITES FOR DRIFTERS LAUNCHED AT MONTHLY INTERVALS FROM 22 JANUARY TO 20 AUGUST, 1974

I. SUMMARY AND CONCLUSIONS

A. Introduction

The movement of simulated sea surface contaminants in the New York Bight was studied in the field by the Marine Sciences Research Center, SUNY at Stony Brook, for an eight-month period between January and August, 1974. This study was undertaken at the request of NOAA-MESA to investigate the risk posed to the shorelines of New York and New Jersey by incidents of oil spillage or sea surface slicks produced as a result of ocean dumping.

Surface contaminants can form films which are either transported to shore or gradually removed from the sea surface by physical, chemical and biological processes. The convergence of waste slicks or spilled oil onto the heavily used beaches bordering the New York Bight can create problems for the management of coastal resources.

The New York Bight is defined in this study as that area of the continental shelf stretching south of Long Island and extending between Martha's Vineyard/Nantucket Shoals to Sandy Hook/Cape May, New Jersey. The seaward limit of the Bight is at the 600 ft (200 m) depth contour which lies 71 nm (131 km) due south of Montauk Point.

The basic features of the general surface circulation within the New York Bight are known and have been summarized by Bumpus (1973). The more specialized displacement of thin layers, such as oil slicks, at the air-sea interface had not been investigated in the field previously although it has been treated using theoretical models (Devanney and Stewart, 1974).

This study is based on eight months of field data that describe the drift histories of simulated slicks under a variety of wind, oceanographic and seasonal conditions. To simulate the movement of sea surface contaminants, such as oil slicks, we manufactured plastic drift cards which were designed to move with the uppermost thin layer of the sea surface. These plastic drift cards were called interface drift cards, in order to distinguish them from traditionally used surface drift devices having deeper draft.

A total of 4,640 interface drift cards was released between 23 January and 20 August, 1974, with 580 drift cards released per each of eight monthly air drops. By 1 December, 1974, 27 percent of interface drifters released were recovered. Interface drift cards were released at 29 release points established in a grid along the coast of Long Island, in the northwest apex of the New York Bight and in the offing of the northern New Jersey coast. An additional total of 21,170 interface drift cards was released in conjunction with the eight routine monthly air drops of the NOAA-MESA study for a concurrent project supported by the Nassau-Suffolk Regional Planning Board. This concurrent Nassau-Suffolk study, conducted by the Marine Sciences Research Center, consisted of 24 release points which extended over the entire region of the New York Bight, including the outer continental shelf. The Nassau-Suffolk study was conducted for the purpose of predicting the movement of oil spills (Hardy et al., 1975). Observations and conclusions based on data derived in both studies are incorporated in this report. The combined data provide an empirical basis for predicting the probability of whether, where and when sea surface contaminants dumped at a specified area within the New York Bight may strand upon the beaches of New Jersey or New York.

Interface drift cards were field tested and found to be capable of moving with an oil patch at winds of up to five knots. A similar test at higher speeds was not made. Our observations indicate that these drift cards, like oil, are more responsive to wind-induced drift and are capable of higher drift velocities than drifters of deeper draft (drift bottles and drogues).

The ratio of the drift speed of the sea surface to the wind speed calculated from interface drifter and wind data (expressed as percent) was 4.4 ± 0.8. This ratio called a wind factor agrees with oil slick drift velocities versus wind speed ratios observed in the North Sea (Tomczak, 1964) but is higher than conventionally used values of 3.0 percent (Devanney and Stewart, 1974).

Previous studies of the surface circulation in the New York Bight measured the average movement of the bulk surface layer of many centimeters' to meters' thickness rather than the thin surface layer at the air-sea interface. Experiments conducted in this study and by others demonstrate a distinct difference in displacement between the uppermost few centimeters of the sea surface and underlying surface layers. The decisive factor in creating this difference is wind stress applied at the air-sea interface.

Although winds are the major driving force producing dispersion of sea surface contaminants, secondary forces which promote surface circulation can modify the influence of winds. Secondary agents include geostrophic flow, estuarine discharge, asymmetrical tidal currents, and nearshore boundary effects caused by land masses. The prediction of the movement of sea surface contaminants cannot ignore local anomalies caused by these secondary influences.

This study correlated the release-recovery results of the drift cards with local coastal weather observations. Long-term New York coastal region weather records showed that winter winds (November to March) blow from the west to north with a 54 percent frequency, whereas in summer (May to August) the west to north frequency declines to 23 percent. The mean west to north wind speed in winter is 8.1 m/sec which is 12 percent greater than the annual mean wind speed from these directions. Winds from southeast to southwest blow 30 percent of the time in winter, which increases to 55 percent in summer (May to August). In general, this study finds that the stranding of slicks on Long Island commonly takes place when the wind blows steadily in the quadrant from the east to south (67° to 202° T).

B. Summary of Field Results

Interface drift cards released and recovered during this study revealed differences in stranding frequencies on

Long Island and New Jersey between winter (November to March) and summer (April to October) which could be correlated with seasonal differences in wind directions.

April, September and October were transitional months between the two seasons and were characterized by winds of variable direction. Prevailing winds were less dominant. Since the release-recovery patterns in these transitional months are most similar to summer, we have included these transitional months with summer, for simplicity.

1. Winter

The prevailing wind for this five-month period (November to March) was west to northwest which imparted a general seaward drift away from the coasts of New York and New Jersey. In the open outer continental shelf, the sea surface motion was generally deflected to the right of the wind by 0^{o} to 10^{o} so that prevailing winds from the west and northwest set up a drift which was seaward from Long Island and New Jersey. The prevailing southwest winds of summer (112° to 247° T) blew toward Long Island. However, the boundary conditions imposed by the land mass of Long Island interfered with the simple downwind transport of the sea surface. This interference deflected downwind advection to sea surface displacements more parallel to the shoreline. In these cases, the release-recovery paths of interface drifters appeared to be deflected from the wind direction by large angles. The southwest wind appeared to cause the sea surface layer to move easterly or parallel to the shoreline without converging on Long Island.

The limited number of drift cards recovered on Long Island or New Jersey between January and March is evidence of a strong net seaward component to the surface drift for this period. Those winter-launched drift cards that stranded onshore within ten days were consistently released from stations nearest the coastline and were subject to short-term winds from other directions than west to northwest.

In general, the drift card data for winter releases showed that only drift cards released in a narrow band approximately 10 nm (18.5 km) in width and paralleling the Long Island coastline were recovered within ten days. The recoveries were all from Long Island. Almost no drift cards were reported found on the coast of New Jersey in winter, with the exception of drift cards released in the offing of Sandy Hook, N.J. This stranding probability did not increase with time. One of three slicks would strand on Long Island within ten days if they were located within 7 to 9 nm (13 to 17 km) seaward of Long Island. Again, this probability showed no significant change after 60 days. The implication of these results is that an oil spill situated only within a ten-mile contour parallel to the Long Island shoreline will strand within ten days or not at all. The majority of cards stranded in either of two areas on the south shore of Long Island. One of these areas is the shoreline between New York Harbor and Fire Island Inlet. The other area is the shoreline between Shinnecock Inlet and Montauk Point. Cards stranding in these areas have generally traveled eastward from their release points.

2. Summer

A significant increase was evident in the incidence of stranding upon Long Island and New Jersey during the seven-month period of summer. We associate this change with an increase in the frequency of winds blowing from east to south-west. Additionally, the summer stratification of the water column reduced the verticle dissipation of wind energy. Wind mixing was limited to the layer above the thermocline and more of the wind energy was transferred in the horizontal direction.

During the summer, a greater than zero percent probability of stranding within ten days contour ran parallel to the Long Island coastline at a distance which was two to three times farther south than the same contour in the winter. Thus, some fraction of sea surface material located within 20 to over 30 nm (37 to 55.5 km) from shore had a possibility of stranding on Long Island in less than ten days. Drift cards which stranded on Long Island in summer generally moved westerly from the release point. Sea surface contaminants located 4 to 15 nm (7 to 23 km) from shore had a greater than 20 percent probability of some fraction stranding on the Long Island shore-line within ten days. These probabilities were based on the vector sum of wind events rather than upon specific wind directions.

The coast of New Jersey was highly vulnerable to landings of drift cards released within the northwest apex of the New York Bight in summer. This was in marked contrast to the almost complete absence of drift card recoveries reported during the winter. One percent of drift cards released in the northwest apex landed on New Jersey within ten days from offshore points as far as 34 nm (63 km) east of the coastline. The greater than one percent recovery contour expanded eastward in time. By the sixtieth day after release, the one percent recovery contour encompassed almost the entire New York Bight. This observation furnished evidence that the combination of the westerly geostrophic flow reinforced by the increased frequency of winds from the east to southwest in summer resulted in the development of a persistent sea surface drift which converged on the coast of New Jersey.

Interface drift cards launched at designated ocean dumping sites in the northwest apex (Stations 71, 72 and 73) had a greater than ten percent recovery on Long Island and New Jersey within ten days. Drift cards released over the waste-sludge dumping ground had a recovery greater than twenty percent within ten days on Long Island. In July, 27 percent of interface drifters released over the waste-sludge dumping ground beached in the vicinity of Jones Inlet within three days of release. In June, 30 percent of the drift cards reached the New Jersey coast in three days from the sludge dumping grounds. These observations suggest that some fraction of slicks produced by dumping and capable of maintaining their coherency for up to ten days will strand on the beaches of New York and New Jersey.

Wind storms over a period of several days of east to southwest winds increased the likelihood that slicks southeast of Long Island and east of New Jersey would threaten their coastlines.

C. Conclusions

1. During winter months the stranding probability of sea surface contaminants on the coasts of New Jersey and New York was at an annual minimum. New Jersey was less vulnerable in winter than Long Island, N.Y. Sea surface contaminants released within a 10 nm (18 km) wide zone parallel to the coast of Long Island had a greater than zero percent probability of reaching shore. Generally, such sea surface material moved in a northeasterly direction before stranding.
2. In summer, the probability of sea surface contaminants reaching the coasts of New Jersey and New York was maximal. This increase was primarily caused by increases in the frequency of winds blowing from the east to southwest. During summer months, the stranding probability of a slick within 30 nm (55.5 km) seaward of Long Island was greater than zero percent within 60 days. Generally, those slicks moving in a northwesterly direction could be expected to strand on Long Island. The coast of New Jersey was exposed to the strandings of sea surface material within 60 days if released within a large area of the New York Bight extending 135 nm (250 km) east of the New Jersey coast.

3. Our observations show that slicks exposed to winds of 9 to 18 nm/hour (4 to 8 m/sec) moved downwind within ten degrees to the right or left of the wind direction at a speed of 4.4 $\pm$ 0.8 percent of the wind speed.

II. INTRODUCTION

A. Need and Importance of Study

The dispersal of surface active and floatable pollutants in the New York Bight has received only cursory attention. This attitude has been fostered, until recently, by the belief that such films did not harbor significant pollutants and by the absence of effective methodologies to measure the biological, physical and chemical properties of slicks. As a result, the biological significance, mechanics and routes of surface film dispersal are poorly understood.

Historically, interest in sea surface transport has been aroused when the economic interests or the environmental quality of coastal communities have been imperiled. A case in point was the nuisance cluttering of beaches in New Jersey with garbage and floatable refuse as the result of ocean dumping as practiced by the City of New York since 1924. New Jersey brought suit in 1931 and the U.S. Supreme Court upheld an injunction to cease the ocean disposal of such municipal wastes.

Presently, citizens and public officials are voicing concern over the potential danger of oil spills ruining the coastal zone bordering the New York Bight. Although a few investigators have studied surface circulation in the New York Bight (Bumpus, 1973) these studies were not intended for and are not generally useful in predicting the dispersion of oil over the sea surface. Therefore, questions concerning the probable trajectories of oil spills under various wind and oceanographic conditions remain largely unanswered. Oil, like other surface active materials, tends to collect at the air-sea interface as a monomolecular layer or in polymolecular layers up to a few millimeters thick. At the interface, these films are exposed to events and forces not found below the interface.

In addition to oil spills, slicks are produced naturally through biological activity or voided from urban areas in the form of sewage sludge or dredge spoil dumping or waste outfalls. Prominent slicks have been observed downwind of the sludge dumping ground in the New York Bight (Pearce, 1969; Hardy and Baylor, 1975). The existence of these slicks presents new problems for those who would design rational systems of ocean disposal.

Surface slicks have recently been found to concentrate heavy metals, chlorinated hydrocarbons (Duce, et al., 1972) as well as bacteria (Blanchard & Syzdek, 1972) and viruses (Baylor, et al., 1975). The sorption and concentration of such substances within surface films permit the transport of many toxic components of waste sludge and dredged spoil away from dumping grounds. The pathways by which these waste slicks and their toxic components are dispersed are cause for concern, and their environmental significance has not been considered in the use of the ocean for waste disposal.

This preliminary study was initiated by the NOAA-MESA program to acquire empirical information on the movement of the sea surface in the New York Bight. The study represents an attempt to observe the movement of simulated slicks under field conditions. These observations are intended to identify and measure those factors dominating sea surface drift for a variety of wind and current conditions, including local anomalies. Based upon these field observations, the study permits preliminary assessment of:

a. the relative risk of coherent slicks converging onto the shore resulting from the operation of working oil fields on the outer continental shelf, from oil tanker and pipeline commerce and ocean dumping;

b. the meteorological and oceanographic conditions which effect whether, where and when slicks will strand on Long Island.

B. Surface Circulation in the New York Bight

Because the pattern of surface circulation effects the movement of sea surface contaminants, such as oil or surface films produced by ocean dumping, we will summarize the basic features observed within the New York Bight. This variable and complex surface circulation has been studied by numerous investigators whose works have been summarized by Bumpus (1973). It must be kept in mind that these previous studies were concerned with investigating the circulation of the bulk of surface water rather than a coherent film spread over the sea surface. Forces acting at the air-sea interface create stresses which differ from those acting upon subsurface water. Thus, the transport of a coherent thin layer at the sea interface may differ from the movement of bulk surface water.

The New York Bight will be defined as that trapezoidal area of the continental shelf bounded by Nantucket Shoals to the east; Rhode Island Sound, Block Island Sound and Long Island to the north; and New Jersey to the west (Figure I-1). The imaginary base of the trapezoid extends from Cape May, New Jersey to the edge of the continental shelf south of Nantucket Shoals.

Nantucket Shoals is a broad archipelago of islands and shallow sand shoals which offers resistance to water movement although it is not impermeable to water flow. Thus, Nantucket Shoals exerts a boundary effect to major water movement similar to a land mass or basin wall. This effect occurs in spite of tidal spillover.

The eastern part of the northern boundary of the New York Bight consists of Rhode Island and Block Island Sounds which front the mainland of Massachusetts, Rhode Island, and Connecticut. Freshwater from the mainland and Long Island Sound discharges through these Sounds as an estuarine system. This is most pronounced in Block Island Sound where the water passes out into the New York Bight between Montauk Point and Block Island.

The land mass of Long Island forms the remaining northern boundary, stretching westward from Montauk Point 110 miles (177 km) to Far Rockaway. Here, at the entrance to New York Harbor the coastline of Long Island intersects with the coastline of New Jersey at essentially right angles. The corner of the intersecting coastlines opens into the New York Harbor complex through which the major source of freshwater to the

New York Bight is discharged. The coasts of both Long Island and New Jersey are for the large part featureless, straight barrier beaches broken only occasionally by inlets to lagoons.

The wide continental shelf is a smooth and gently sloping outwash plain which creates minimal turbulence in currents. Two prominent features which interrupt the uniformity of the shelf are the Hudson Canyon Channel extending southeast from Ambrose Light, as a deep narrow indentation approximately 80 nm (146 km) long, and the broader Block Channel extending south approximately 70 nm (128 km) in length from the passage between Montauk Point and Block Island. These prominent indentations in the topography of the New York Bight allow dense, outer shelf water to move close inshore, near or beneath major fresh-water discharge.

The movement of water in the New York Bight is dependent upon spatially variable factors, such as freshwater runoff, wind stress, tides, temperature distribution and upon such seasonal factors as water column stratification, freshwater runoff, and prevailing winds. This functional dependence on such a variety of interacting factors causes circulation to be variable and confusing, particularly as one progresses toward shore and sources of estuarine discharge.

Freshwater runoff from the mainland creates a density gradient across the shelf to sustain a geostrophic drift to the west or southwest. This westward drift moves parallel to density (isopycnal) contours with lowest density water located landward and to the right of the direction of flow. The geostrophic flow is sensitive to events capable of changing the density field, such as fluctuations in estuarine discharge, and this drift can be modified in intensity or direction by winds or seasonal stratification. Observations (Howe, 1962) suggest that beyond the 100 meter depth contour the geostrophic drift is a permanent feature moving to the west at speeds of 5 cm/sec (Griscom and Sommers, 1969; current meter at 30 m depth) to 13 cm/sec (Webster, 1969; current meter at 10 m depth). Landward of the 90 m depth contour the flow is more variable, weaker (Iselin, 1955; Howe, 1962) and highly responsive to winds.

The importance of winds in modifying the flow over the shelf was shown by Beardsley and Butman (1974; meter moored over 60 m depth contour at 42 m depth) where the average westerly flow at 5 cm/sec could be increased to mean speeds of 45 cm/sec with water mass displacements of 75 km (41 nm) during northeast storms. Westerly winds were found to cause large current oscillations but little net displacement. Beardsley and Butman (1974) were able to calculate sea level changes during easterly storms which indicated that right-directed Ekman fluxes caused the sea level to rise 40 to 60 cm against the coast from Nantucket to Cape May. This combination of an onshore pressure gradient slope coupled with an alongshore current created a strong westerly flow which was in geostrophic equilibrium. A geostrophic flow reinforcement could not be established with westerly winds where the surface Ekman flux is directed seaward.

Although much of the surface circulation over the shelf of the New York Bight is weak and subject to the vagaries of wind stress, nevertheless a band of higher speed current exists nearshore where velocities in a westerly direction can exceed 26 cm/sec (Bumpus, 1973). Particularly in summer, according to Bumpus (1969), surface currents against the shore are subject to reversal that is related to winds and possibly to fluctuations in runoff. In this case, the usual westerly drift is replaced by an easterly flow which is weaker in velocity than currents moving west. This nearshore surface drift reversal is strongest within 16 nm (30 km) of shore. The surface drift reversal is caused by westerly winds, particularly southwest sea breezes. Upwelling along the coast of Long Island is associated with surface drift reversal as the westerly wind exerts an Ekman stress upon the sea surface diverting it seaward. The seaward divergence of the surface layer at these times inhibits the movement of surface material onto the beaches. Conversely, winds from the east cause a surface Ekman flux directed toward the shore, thus increasing the probability of surface material converging onto the beach. In areas of estuarine discharge, the parallelism between the shoreline and the density gradient field is distorted, thus diminishing the accuracy of local surface flow predictions. Additionally, there is, at certain times, a compensating landward drift of offshore water immediately to the east of the outflowing estuarine plume. Two examples of these indrafts of offshore water have been observed: one east of the

New York Harbor discharge by Miller (1952) and the other observed by Bumpus (1973) at Nantucket Shoals where a pronounced northward flow exists in spring and summer to the east of the southerly or southwesterly flow of freshwater from Montauk Point/Block Island.

Ketchum and Keen (1955) observed that inshore the salinity of New York Bight shelf water increases in the direction of the westerly geostrophic drift, thus suggesting that there is considerable flux of freshwater offshore and a compensating indrift of saltwater in a mixing process.

In summary, we can state that the prevailing surface flow in the New York Bight is a geostrophic drift to the west or southwest at a speed of 10 cm/sec beyond the 100 m depth contour. Landward of the 90 m depth contour, the surface circulation is variable and responsive to winds and estuarine discharge. Within 16 nm (30 km) of shore, a narrow band of higher velocity current exists with a flow direction subject to winds. From the 100 m contour shorewards, the major easterly windstorms promote a surface drift which attains speeds greater than 40 cm/sec to the west. Major westerly storms are not capable of inducing a similar surface flow to the east except in a narrow band along the shore.

Two counter-clockwise gyres occur in the New York Bight. The first gyre exists at the northwest apex where the New York Harbor estuarine plume moves south along the New Jersey shore with a compensating northward flow of more saline water to the east. A second seasonal gyre exists at the eastern sector of the New York Bight where a persistent northward flow into

Rhode Island Sound occurs in late spring and summer along the western boundary of Nantucket Shoals. A south or southwesterly estuarine discharge is then displaced out from Montauk Point/ Block Island. The prominence of these cells shows temporal and seasonal variance and is most clearly defined following peak periods of land runoff.

The responsive nature of the surface circulation in the New York Bight to directional wind stress requires an understanding of the seasonal prevailing winds as well as the short-term wind pulses caused by storms.

The most comprehensive summary of marine surface observations in the New York coastal region has been assembled by the National Weather Service Environmental Detachment, Asheville, North Carolina, from shipboard observations. The principal period of record (80% of total observations) was from 1912 to 1968 (U.S. Naval Weather Service Command, 1970). These observations show that over 54 percent of the winds in winter (November to March) were W, N-W and N, whereas in summer (May to August) these winds occurred with a 23 percent frequency (Table I-1). The mean wind speed in winter for W to N winds (8.1 m/sec) was 12 percent greater than the annual mean wind speed (Table I-2). The mean wind speed in summer for all directions (4.9 m/sec) was 36 percent less than the mean wind speed for all directions in winter (7.6 m/sec).

The monthly wind vector sums observed during the period of this study were consistent with the seasonal changes in prevailing winds ascribed to the northeast region. Figure I-3

Table I-1. Monthly Directions and Frequencies of Winds Observed in Region 6, New York Coastal Marine Area (40° N - Coast, 72° W - Coast) for Primary Period 1912 - 1968. (U. S. Naval Weather Service Command, 1970)

Direction	Frequency of Obs (%)												
	J	F	M	A	M	J	J	A	S	O	N	D	Annual
N	11.8	11.5	9.5	7.6	6.0	6.0	4.9	8.4	11.2	11.9	8.9	10.2	8.9
NE	7.3	7.3	10.0	7.9	9.2	7.3	5.7	10.0	12.8	12.3	8.7	6.5	8.9
E	5.7	5.9	9.8	9.0	10.8	9.2	8.4	9.3	11.0	8.5	5.0	4.6	8.3
SE	4.6	5.3	6.8	9.6	10.6	11.2	11.5	8.7	9.3	8.8	5.3	4.9	8.2
S	10.2	10.0	12.1	18.2	20.2	26.6	31.8	24.2	17.7	13.1	14.1	9.0	17.5
SW	13.9	13.3	11.6	16.5	18.6	18.4	19.8	18.9	14.8	13.4	16.7	13.5	15.9
W	23.7	23.1	21.4	18.8	11.1	10.5	9.2	9.7	10.5	14.1	23.9	30.1	16.7
NW	21.0	21.2	16.5	9.8	8.6	5.6	4.8	7.2	8.9	14.3	16.0	19.3	12.4
Var.	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	----
Calm	1.9	2.4	2.1	2.6	4.9	5.2	3.7	3.6	3.7	3.6	1.5	2.0	3.2

Table I-2. Monthly Directions and Average Wind Speeds Observed in Region 6, New York Coastal Marine Area (40° N - Coast, 72° W - Coast) for Primary Period 1912 - 1968.

Direction	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	Mean Wind Speed (m/sec.)												
N	7.3	8.0	7.2	6.6	5.4	5.2	4.7	4.8	6.7	6.7	6.7	7.4	6.6
NE	8.5	7.6	8.2	6.9	6.5	6.3	5.2	6.1	7.3	8.0	8.7	8.6	7.4
E	7.2	6.8	6.8	6.7	5.2	4.8	4.6	4.5	5.4	5.2	7.4	7.0	5.8
SE	6.7	6.4	5.3	5.7	4.8	4.9	4.2	3.9	4.5	5.4	5.5	6.6	5.1
S	6.8	6.1	6.3	6.1	5.3	5.3	5.2	4.8	5.2	5.6	7.0	6.5	5.6
SW	7.2	6.8	6.3	6.2	5.4	5.3	5.1	5.0	5.6	5.7	7.2	7.9	6.0
W	8.7	9.4	7.9	7.2	6.2	5.0	5.2	4.8	6.1	6.7	8.1	8.8	7.4
NW	8.5	9.2	8.1	7.7	5.6	5.7	4.8	5.0	5.9	7.4	8.1	8.5	7.6
Mean Speed	7.7	7.9	7.0	6.4	5.2	5.0	4.8	4.7	5.6	6.2	7.4	7.9	6.3

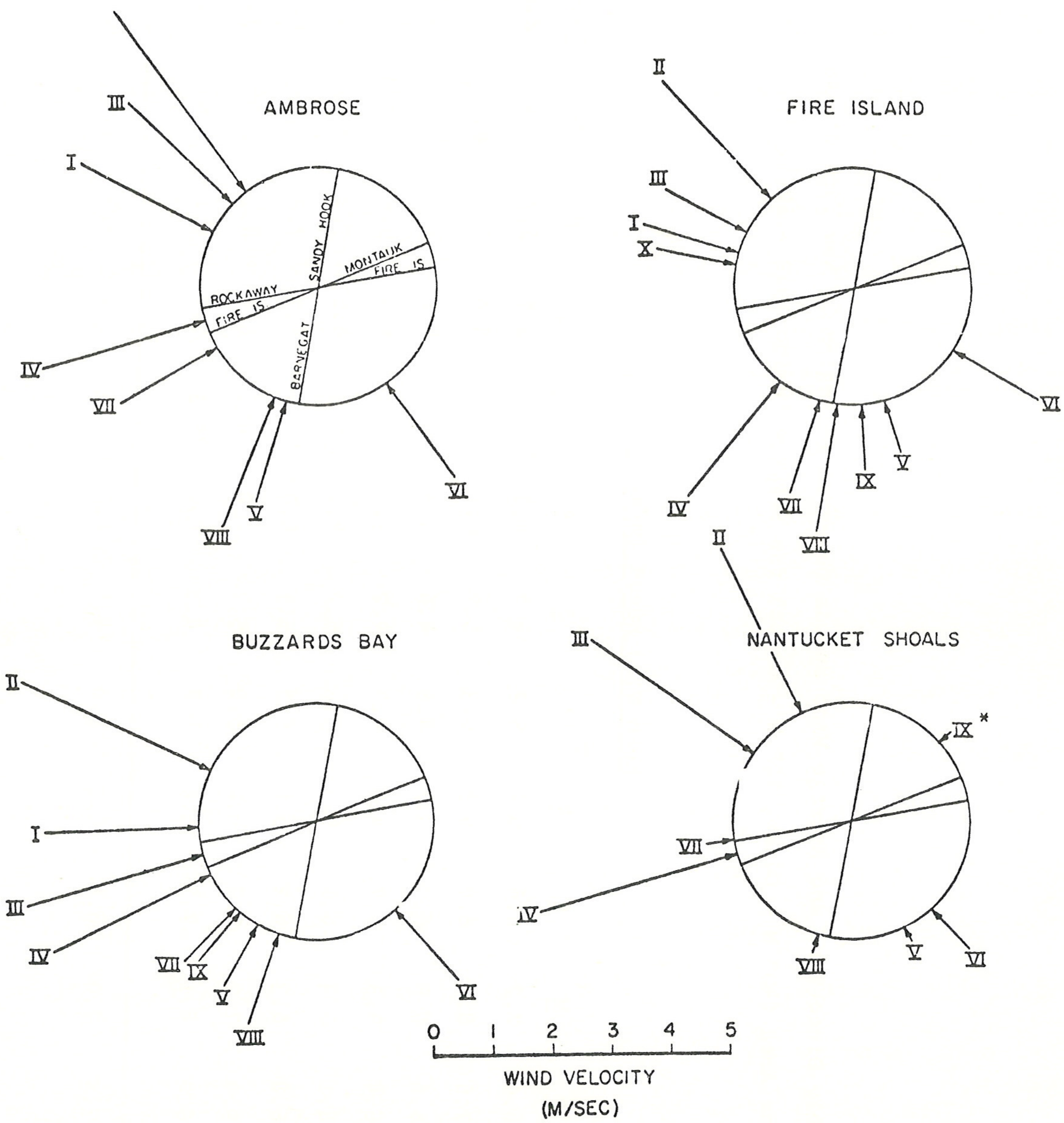

Figure I-3. Mean Monthly Wind Vectors for Selected Coastal Weather Stations in the New York Bight for January - October 1974.

Vector magnitudes are calculated as the vector sum of wind velocities. Months are indicated by Roman Numerals. Lines bisecting circle are tangents to the shoreline as labeled.

(* 1-21 October 1974)

shows the monthly wind vector sums observed between January and October, 1974, at four Coast Guard Stations/Lightships (Ambrose Lightship, Fire Island Station, Buzzards Bay Lightship, and Nantucket Shoals Lightship, whose locations are shown in Figure I-1). The data of Figure I-3 show that the strongest prevailing winds occurred during January, February and March when the resultant wind direction was from the northwest. Wind observations for Nantucket Shoals in January, 1974, and for all stations in November and December, 1974, were unavailable.

The prevailing northwest winds in winter (November-March) impose a seaward surface drift to the south in the Bight (Bumpus, 1969) and appeared to account for the low return of drift bottles released during this season (Bumpus et al., 1973). From April to September, the prevailing wind was from the southwest quadrant. June was an exception where the resultant wind was from the southeast at all four weather stations. Winds from both SW and SE directions apply a northward component upon the westerly geostrophic drift. The higher recoveries of drift bottles demonstrates a stronger landward component during summer (Bumpus et al., 1973).

The major apparent difference between weather stations located offshore, such as Nantucket Shoals, and coastal weather stations, such as Ambrose, Fire Island and Buzzards Bay, was that resultant summer winds (May-October) were weaker at Nantucket Shoals Lightship (located 50 statute miles (80.5 km) south of Nantucket Island) and, hence, without a sea breeze effect. Sea breezes are the result of a thermal gradient existing between the sea surface and adjacent land mass, and this interacting zone extends out to sea approximately 20 nm (37 km) which is well inshore of Nantucket Shoals Lightship.

Winds become decisive agents in causing the uppermost 1-2 cm of the sea surface to move differently from the bulk surface water. This behavior is due to the direct exposure of the uppermost surface layers to wind stress and secondarily to the indirect effect of wave-induced Stokes drift (Kenyon, 1969). Observations show that the upper 1-2 cm move approximately twice as fast as contiguous lower layers, and in a direction closely paralleling the wind (Schwartzberg, 1971; Van Dorn, 1953; Murray et al., 1970; James, 1966). Contaminants contained at the air-sea interface, such as oil slicks, appear to move with the thin surface layer (Tomczak, 1964; Murray et al., 1970).

Numerous observations exist which attempt to correlate wind-driven surface drift with wind speed (James, 1966). These correlations, called wind factors, indicate that the surface layer moves at 1 to 5 percent of the wind speed (see Table I-3). However, the range of these wind factors can be further refined if only measurements of the thin surface veneer of less than 1 cm are considered (paraffin chips, Van Dorn, 1953; drift cards, Tomczak, 1964; Hughes, 1956; Teeson et al., 1970; open ocean or laboratory oil slick movement, Smith, 1968; Schwartzberg, 1971). Wind factors selected on this basis range between 3.3 to 4.3 percent of the wind speed.

Table I-3. Wind Factors Determined by Previous Investigators

Author	Wind Factor (%)	Method of Determination	Water Column Depth Sampled
Thorade (1914)	1.44	ship's drift	ship's draft
Ekman (1905)	1.85	current measurement	surface to 5 m depth
Rossby/Montgomery (1935)	2.53	theory of hydrodynamics	"surface layer"
Stommel (1954)	2.9	drifting buoys	surface to 1 m depth
Hughes (1956)	3.3	drift cards	thin surface layer
Smith (1967)	3.3-3.4	floating oil	thin surface layer
Van Dorn (1953)	3.6	paraffin flakes	thin surface layer
Schwartzberg (1971)	3.7	floating oil in wind tunnel tank	thin surface layer
Hill & Horwood (1974)	3.4-3.8*	drift cards	thin surface layer
Tomczak (1964)	4.2	drift cards	thin surface layer
" "	4.3	oil spill	thin surface layer
This Report	4.4	drift cards	thin surface layer

*(4.2-4.5 if computed for minimum day out cards)

Therefore, wind stress causes a thin layer at the sea surface to move faster and more closely parallel to the wind direction than bulk surface water below. Previous studies of surface circulation in the New York Bight are less useful in forecasting the movement of oil slicks because the surface drifters used (ship's drift, drogues, drift bottles) were designed to be entrained in a section of the sea surface deeper than 1 cm. This report will discuss the movement of drift cards specifically designed to simulate the movement of an oil spill be being retained in the uppermost centimeter of the sea surface.

III. METHODS

A. Field Operations

To imitate the displacement of slicks at sea and to help forecast where slicks might strand upon the shoreline of Long Island, we dropped floating, self-addressed, plastic postcards at selected locations in the New York Bight (Fig. I-2). A total of 5,220 plastic drift cards was dropped in the New York Bight on nine separate flights between 23 January and 20 August, 1974. All drift cards were dropped from U.S. Coast Guard HH-3F helicopters and from a twin engine Aero Commander chartered from Republic Air Charter Corporation, Farmingdale, New York. The aeroplane was fitted with a cargo hatch having a 30 cm diameter Venturi tube, through which drift cards and seabed drifters could be dropped. On each monthly flight, 580 drift cards were released into the sea at 29 release stations, as shown in Figure I-2. Stations 50 to 57 lay on a rhumb line between Ambrose Lightship and Montauk Point. Stations 60 to 80 form a dense release grid at the northwest apex of the New York Bight which includes the dumping grounds and the entrance to New York Harbor.

Twenty cards were released at each station (Table I-4) Release station locations were chosen whenever possible to take advantage of all visual aids to navigation, such as buoys, so that the accuracy of the navigation could be checked during the flight.

Aircraft navigation used VOR and DME which had a conservatively estimated accuracy of $\pm$ 1 nm (1.85 km) offshore

Table I-4.

SURFACE AND SEABED DRIFTER STUDY, 1974

Helicopter Drifter Release Station Data
(NOAA-MESA Segment)

Station #	Latitude	Longitude	Surface Release	Card Quan.
60	40 35	73 27.6	20	
61	40 33	73 32	20	
62	40 33.7	73 37.3	20	
63	40 32.7	73 41.9	20	
64	40 34	73 41.7	20	
65	40 34.1	73 47	20	
66	40 31.6	73 51.5	20	
67	40 31.6	73 56.8	20	
68	40 30.3	73 58.5	20	
69	40 27.7	73 56.2	20	
70	40 22.7	73 55	20	
71	40 24	73 51	20	
72	40 23	73 49	20	
73	40 25	73 45	20	
74	40 17.7	73 55.2	20	
75	40 20	73 47.3	20	
76	40 20	73 40	20	
77	40 12.7	73 56.7	20	
78	40 13.6	73 47.2	20	
79	40 15	73 39.1	20	
80	40 29	73 59.8	20	

Airplane Drifter Release Station Data

Station #	Latitude	Longitude	Surface Release	Card Quan.
50	40 56.5	71 56.0	20	
51	40 50.0	72 13.5	20	
52	40 44.0	72 30.9	20	
53	40 39.5	72 49.0	20	
54	40 33.8	73 06.5	20	
55	40 31.2	73 27.1	20	
56	40 30.2	73 36.9	20	
57	40 30.0	73 46.9	20	

and within $\pm\frac{1}{2}$ nm (0.93 km) nearshore. The helicopter employed an AYN-1 navigational computer to determine position. This system used Loran, Tacan and Doppler navigational aids. The accuracy was conservatively estimated at ± 0.25 nm (0.5 km). The combined flight time to cover the total study area was three hours at a speed of 180 knots for the aeroplane and 54 to 100 knots for the helicopter.

The behavior of the drift cards dropped into the ocean was observed prior to the study. A trial flight was conducted using our research vessel as a target. Drift cards were released from three altitudes: 1,000 feet, 500 feet and mast height. Cards released at all altitudes landed within a few hundred yards of the vessel with the accuracy inversely proportional to altitude. On the basis of this trial we decided to drop the cards during the study at an altitude of 500 feet.

B. Interface Drifters

Previous circulation studies in the New York Bight have relied upon instruments or devices which sampled the water column over depths greater than the upper few millimeters. These studies were concerned with understanding the general mass transport of surface water rather than the specific movement of the sea surface interface. By contrast, it was necessary in this study to use a drifter which would simulate the behavior of slicks at the sea surface for several months. Additionally, it had to be returnable by the finder when it finally stranded upon a beach. For this purpose, we designed and manufactured a plastic drift card which was 10 cm x 15 cm and laminated front and back with 0.09 mm thick polyethylene. The total thickness of the card was 0.4 mm. One polyethylene surface was matte finished so that the finder of the card could conveniently write requested information. This plastic drift card was similar to that used by Tomczak (1964) to study the drift velocity of oil in the North Sea, except that Tomczak protected his cards with double plastic envelopes, whereas our cards were laminated.

Because plastic drift cards of this nature are designed to ride flat at the sea surface, we call them interface drift cards to distinguish them from so-called surface drifters (i.e. ballasted drift bottles, surface drogues, etc.).

Some criticism has been leveled against the use of drift cards as an indicator of surface interface transport. Teeson et al. (1970) claim that drift cards are suitable only under calm conditions because the cards' edges would protrude from the wave surface and act as sails in the wind. Teeson et al. (1970) used polyethylene film disks of 0.47 m diameter and 0.08 mm thickness. They experienced difficulty with such disks wrinkling and crumpling up on the sea surface upon launching. This was only resolved by launching each drifter individually. Such disks would not be useful when launched from aircraft or where many drifters must be launched per station.

We observed the movement of our drifters in winds of up to 25 knots. No drift card was lifted out of the water by the force of the wind. The cards rode at the surface slightly awash and occasionally rolled slowly in the water due to turbulence.

An important premise of this study was that the plastic drift cards would reasonably simulate the transport of an oil slick. We could find no previous field experiments in which the movement of oil and cards was compared. Tomczak (1964) apparently assumed that relationship for his mathematical model, and Teeson, et al. (1970) found that polyethylene film duplicated oil movement in a test tank.

We conducted one field test on 12 August 1974 when our drift cards were released in an oil spill (1 qt. of 30 wt. SAE motor oil containing powdered aluminum). Winds from the west ranged between 3.5 and 5 knots. The drift cards remained within the oil slick for the two-hour period of observation, but a second field test at higher wind velocities should be conducted. In addition, such a field test should consider releasing interface drifters nearby, but not within, the oil slick. This procedure would permit observations on the ability of interface drifters to simulate slicks in the absence of changes to the physical state of the air-sea interface caused by the slick. Wind shear stresses which drive the interface drifters may differ significantly over the smooth sea surface of an oil slick than over the rougher surface texture characterizing a clean sea surface under similar wind conditions.

To demonstrate the fact that surface interface drifters move differently than surface drifters of greater draft, we conducted an experiment comparing the release-recovery paths of our drift cards with ballasted surface drifters.

The ballasted surface drifters (which we will henceforth refer to as subsurface drifters) were made by modifying Woodhead seabed drifters so that a 4 gram brass ferrule was attached under the umbrella rather than the standard practice of attaching a 7 gm brass weight at the stem tip. The seabed drifter so weighted floated sideways in seawater so that only a small edge of the umbrella (0.5 cm) and the tip of the stem protruded above the water. The diameter of the umbrella was 18 cm which is assumed to be the draft depth. Wind tended to blow the drifter below the sea surface and minimized the windage.

The two types of surface drifters were launched together on 24-25 June, with 100 subsurface and 520 surface interface drifters released at 20 stations (Figs. I-4, I-5). We chose release stations which were nearshore on the basis that past experience indicated that highest recoveries could be expected. Five subsurface drifters and 20 interface drifters were launched at each station, except at Station 1 (100 cards), Station 12 (50 cards), Station 20 (25 cards), and Station 23 (25 cards). Winds for the first four days after launch were northeast to east and occasionally reached observed speeds of 13 m/sec (25 knots) on 24-25 June. The wind shifted to the southwest for the balance of the initial ten-day period. Therefore, the wind regime during the period immediately following the launch set up a surface drift which moved southwesterly along the Long Island shore and southerly along the coast of New Jersey.

The general sense of this drift pattern is demonstrated in the release-recovery paths (Figs. I-4 and I-5). A total of 11 subsurface drifters and 106 interface drifters were recovered. Despite the fact that five times as many interface drifters were released, the frequency of recovery was ten times greater for these drifters than for subsurface drifters. Recoveries of the subsurface drifters were limited to five stations in the northwest apex of the New York Bight while interface drifters were recovered from 13 stations over a more extensive area. Ten of the subsurface drifters were recovered within 1.1 to 4.1 days (the eleventh was found at sea 34 days out, approximately 15 nm (42.75 km) south of its release point, Station 70). Forty-six interface drifters were found within 0.3 to 4 days from nine stations. Eighty interface drifters were recovered by the tenth day.

With the exception of one return from Station 64, no subsurface drifters landed on the New York shoreline. All subsurface drifters which stranded did so in the first four days. Such was not the case for the interface drifters where 26 drifters were recovered on Long Island, lower bay of New York Harbor and the New Jersey coast, after ten days. Thus, the interface drifters were recovered over a much longer period. We conclude that both drifters responded to the initial four-day easterly wind which set up a strong southwesterly-southerly surface drift in the New York Bight. When the wind shifted to the southwest, the subsurface drifters continued to flow southerly with the geostrophic current. The

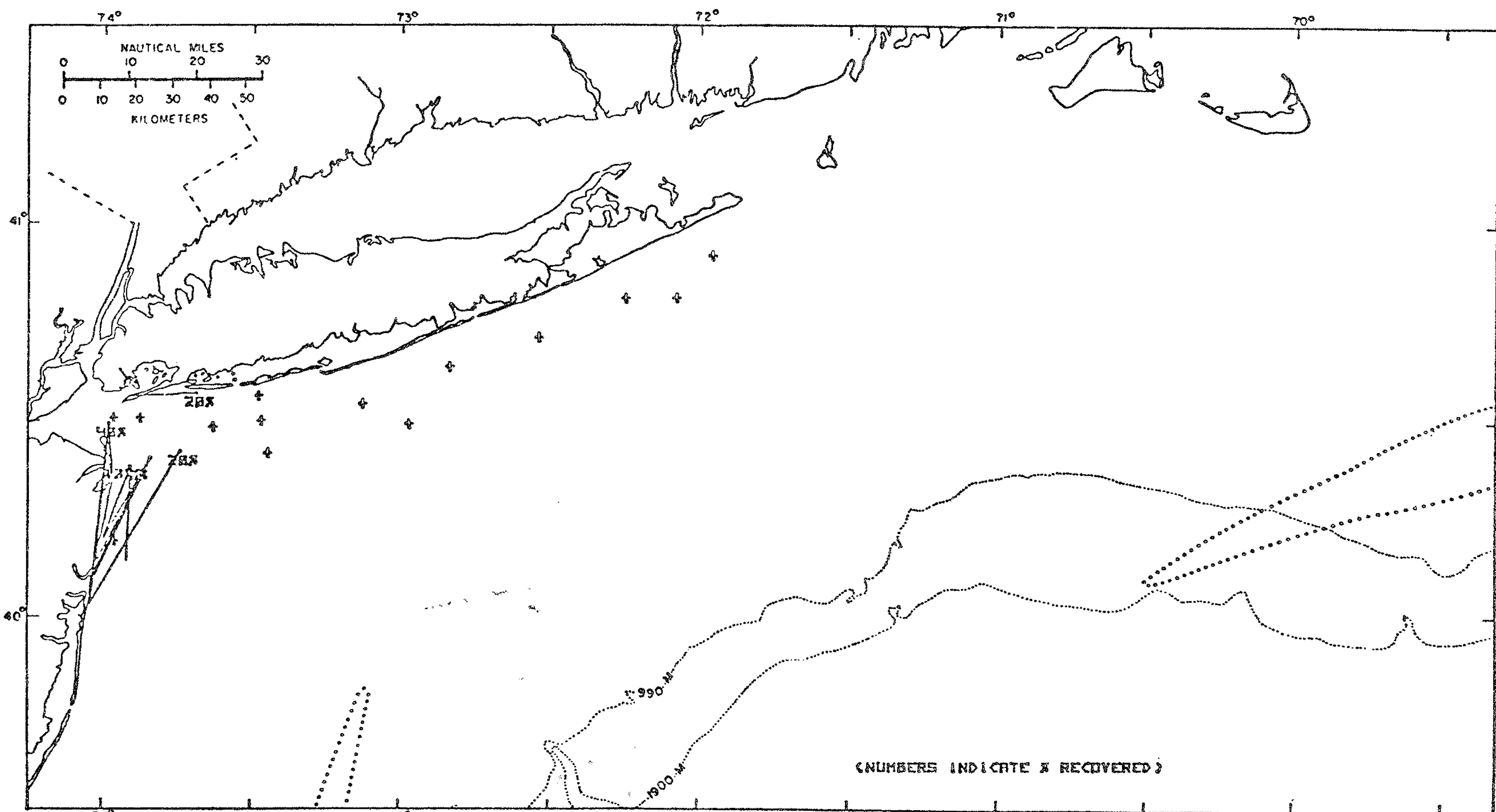

Figure I-4.
TRAJECTORIES OF ALL SUBSURFACE DRIFTERS
RELEASED ON 24-25 JUNE AND RECOVERED BY 1 DECEMBER 1974

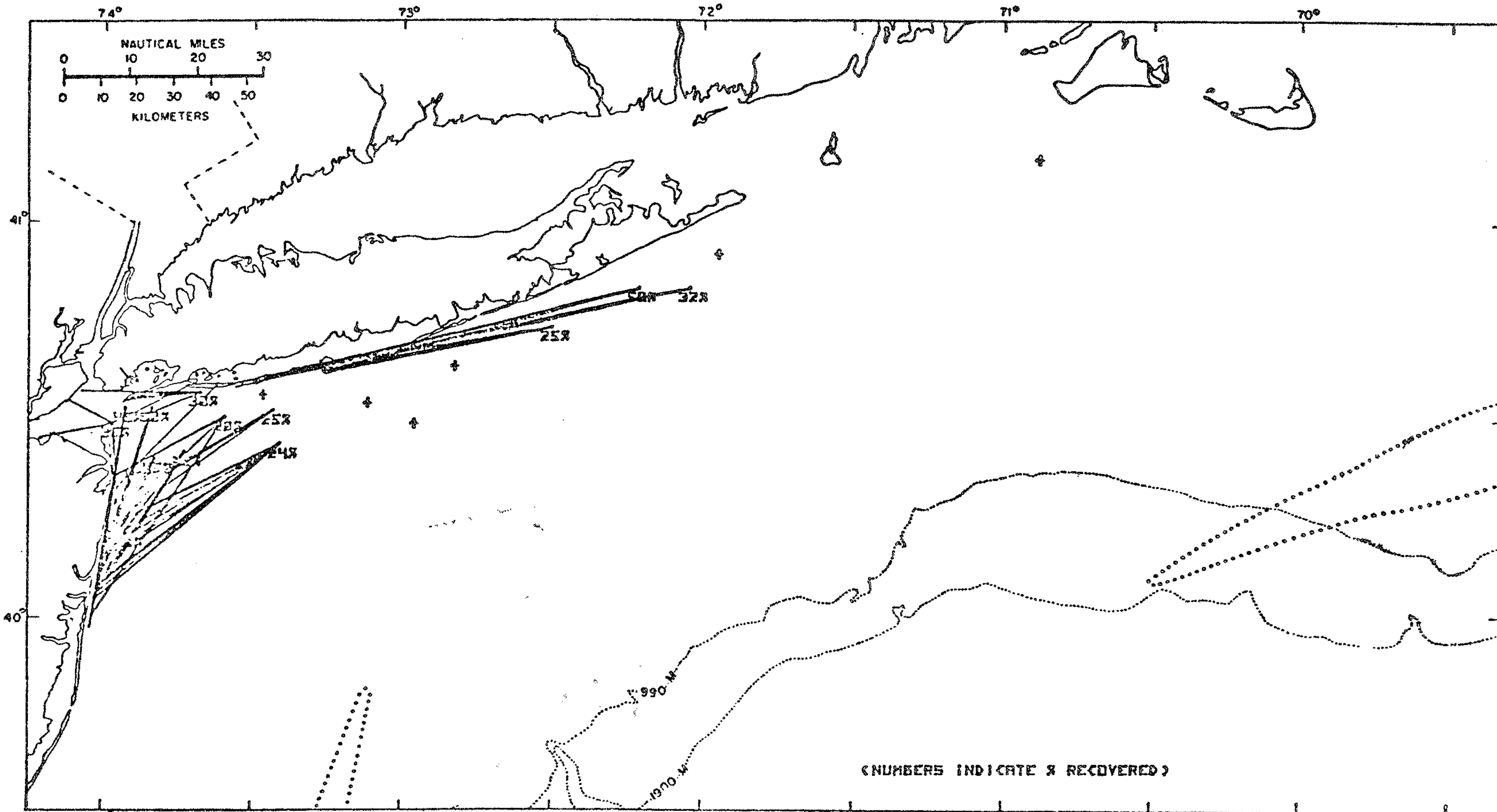

Figure I-5.
TRAJECTORIES OF ALL SURFACE INTERFACE DRIFTERS
RELEASED ON 24-25 JUNE AND RECOVERED BY 1 DECEMBER 1974

interface drifters were more responsive to the stress of the southwest wind, causing their southerly movement to be checked or slowed. In this manner, depending on tides and the vagaries of eddies, the interface drifters continued to be stranded in the general area of the other recoveries for a longer period after release.

This experiment strongly suggests that circulation studies accomplished by drifters extending below the surface could not be usefully employed in studies where the movement of the sea surface interface was the object of concern.

C. Calculation of the Wind Factor

The ratio of the sea surface drift speed to the wind speed when multiplied by 100 to express it as percent is called the wind factor. The wind is measured at or interpolated for a 10 m elevation above the sea surface.

According to previous studies, the sea surface moves at less than one to nearly five percent of the wind speed. The variability of the wind factor has been ascribed to a number of parameters, such as the draft of the drifter and the quality of the wind observations. The data of Table I-3 show that those measuring devices which move with the thinnest layer of the sea surface have the largest wind factor and that this factor is equal to or greater than 3.3 percent. Few of the investigators measuring the thin surface layer used direct or local wind observations. Hughes (1956), Smith (1968) and Tomczak (1964) used weather maps or isobaric charts of gradient winds at 2,000 ft (610 m) from which the surface wind speed and direction were estimated. Schwartzberg (1971) used a wind tunnel over a test tank with wind speeds measured at 7 to 30 in (17.8 to 76 cm) elevation.

The errors in estimating the wind factor of drift cards in the field are difficult to determine where only the points of release and recovery are known. Some of the more critical errors include:

1. Lag time between card landing and recovery.
2. The quality of the surface wind observations.
3. The fact that the actual trajectory the card moved between points of release and recovery is unknown.
4. Surface drift resulting from factors other than wind, such as tides, littoral drift, density gradients, and waves.
5. The uncertainty of whether drift cards simulate oil movement under all wind and weather conditions.

The lag time of the drift card on the beach is the most critical for velocity calculations during the first few days after launching, particularly in cases where the card strands upon the beach in early evening and remains unseen until the following day. We have assumed in this study that no cards are found before 0800 hours and that no cards are found after 1800 hours. With the exception of the day of launch, all drift card speed calculations are based on the assumption that the cards landed at 1200 hours of the day found. If a card landed on the day of launch, it was assumed that it was recovered at 1800 hours.

Because of the degree of uncertainty inherent in estimating the ground speed of winds from regional weather maps, we elected to utilize local weather observations from lightships and Coast Guard Stations located in or around the New York Bight. Such weather logs are available from the National Climatic Data Center at Asheville, North Carolina. The weather instruments on lightships and shore stations are located approximately 33 ft (10 m) above the sea surface. There are certain errors inherent in these observations. The observers are Coast Guard seamen who are not necessarily experienced observers. The wind measurements are neither continuous nor averaged readings but represent fixed readings at three-hour intervals. However, these observations represent the best local observations and reveal local differences within the New York Bight area. As shown in Figure I-2, we have arbitrarily assigned drift card release stations to wind sectors which represent the weather station nearest that sector (i.e. Ambrose Light, Fire Island Station).

In order to cull from those cards which were most meaningful to use in determining a wind factor, a total of 2,740 drift cards recovered by 1 December, we established the following specific criteria:

1. <u>Consistency of Wind Direction</u>

In order to determine those launch periods during which the winds were most uniform in direction, the progressive wind vectors of Ambrose and Fire Island weather were inspected for the three-day and six-day periods after card launch. Satisfactory periods were found to be April 15-17, April 16-18, April 20-23, May 21-23, June 24-26, July 22-28, and August 20-23. Only drift cards launched and recovered within these periods were used in determining the wind factor. The above data for the wind factor estimate include cards launched in a separate study for the Nassau-Suffolk Regional Planning Board.

2. Periods of Low Resultant Wind Velocity

It was apparent that drift cards released and recovered during periods when the resultant wind was less than 3 m/sec were responding to forces not explainable by winds alone. Wind factors calculated using these cards often exceeded 10 percent. Other factors, such as deflections from reported wind directions, were unexplainable. The cards used satisfied the criteria established above, principally in the range of wind speeds between 4 to 8 m/sec.

3. Day of Launch Recovery Lag

Some cards were recovered on the day of launch. Cards at all stations in the study were launched in the general period of ± 3 hours before or after noon. The return information directions on the card did not ask for the time of recovery. We therefore assumed a recovery at 1800 hours. The error of a few hours over such a short release-recovery period may introduce a large error in the card drift velocity. We therefore eliminated all cards recovered on the day of the launch in our wind factor estimate.

4. Variable Errors from Prolonged Recovery Periods

The longer the period of release-recovery, the greater is the possibility that the card is subject to wind and oceanographic forces which are not taken into account. To minimize this source of error, we selected only those cards recovered the first, second and third day after the day of launching.

5. Low Wind Factors

Some cards satisfying the above criteria may nevertheless have had an excessive lag period between stranding on the beach and recovery by the finder and, therefore, exhibit anomalously low wind factors. Other anomalously low wind factors occurred when the resultant wind was calculated from winds of variable direction. Therefore, we arbitrarily discarded drift cards which had wind factors less than 3.0 percent.

Using this set of standards, we were able to select 83 cards from the 2,740 cards recovered. The mean wind factor calculated was 4.38 with a standard deviation of $\pm$ 0.83. Our results are in good agreement with those of Tomczak (1964) who found a wind factor of 4.2 for drift cards and 4.3 for an oil spill. As the result of our observations, we shall use a wind factor of 4.4 percent in relating the drift rate of slicks to observed wind speeds.

A second and important relationship was observable in these selected cards. When the set of the wind was from the west (158° to 247°) the deflection of the cards was to the right of the wind. When the wind was east (45° to 158°) the apparent deflection was generally to the left of the wind. The apparent lefthand deflection is caused by the wind-driven surface layer being superimposed upon the westerly geostrophic current with the movement of the sea surface closely paralleling the coastline.

The wind factor is determined by $u = kW$ (Ekman, 1905), where u is the wind-induced surface current, W is the wind speed at a 10 m elevation, and k is the wind factor. The wind-induced surface current, u, is calculated from the release-recovery history of the interface drifters. No distinction is possible between net displacement entirely due to wind stress and displacement due to drift caused by tidal and nontidal forces. A few investigators (Tomczak, 1964; Smith, 1968; Hill and Horwood, 1974) have attempted to exclude residual currents by introducing a corrective expression based on measurements using current meters, tidal current tables, or residual current estimates. Such measurements and estimates invariably describe the net displacement of surface water over a depth measured in meters. The residual net displacement of the upper few millimeters of the sea surface appears to be significantly more responsive to wind stress than bulk surface water (Schwartzberg, 1971). The manner and degree of this response by the thin surface layer is not well understood so that a quantitative application of a corrective factor for net residual current is open to speculation.

In addition the high degree of variability of current in the inner reaches of the Bight (90 m depth contour) makes it impossible to determine such a corrective factor. As available evidence suggests that displacement of the thin surface layer is dominated by wind stress, we have assumed that residual current error is small. A simple test was made to determine whether the wind factor, as derived from minimum stranding times of cards driven by easterly winds (341° to 160° normal to Long Island south shore) differed significantly from the wind factor induced by westerly winds (161° to 340°).

The wind factor, as derived from drift cards under the influence of easterly winds (N=73) was 4.4 $\pm$0.8 percent. Whereas, the wind factor obtained for westerly winds (N=10) was 4.0 $\pm$1.1 percent. Owing to the small sample size of drifters under the influence of westerly winds, the data do not permit the conclusion that a significant difference exists in wind factors. However, the larger wind factor for easterly winds is consistent with previous studies which indicate that easterly winds reinforce the westerly geostrophic flow.

It is apparent from the drift card data of this study that residual currents do assume importance when winds are gentle. Wind factors under these conditions were often enormously large, indicating that the drifter cards had a higher velocity than could be accounted for by reasonable wind factors. Also, the release-recovery paths under gentle winds tended to be erratic and presumably were influenced by directional components of residual current. A similar pattern of unpredictable relations between drift cards and wind direction could be seen in areas of significant estuarine discharge.

D. Beach Seeding Experiment

Data from drift devices requiring recovery on the shoreline are always dependent upon these devices being found and reported. Several investigators (Bumpus and Lauzier, 1965; Woodhead and Lee, 1960; and Harrison, et al., 1967) have expressed concern over this degree of uncertainty. The probability of recovery on the beach can be assumed to be dependent upon the density of traffic on the beach, which is related to such diverse factors as access to the beach, season, day of week, population density in proximity to the beach, and habits of the visitors.

The 120-nm long (222 km) coastline of the south shore of Long Island ranges from heavily-used public beaches to beaches of limited access. In general, the beaches of western Long Island (Queens, Nassau and western Suffolk County) are used by the public throughout the year. The Fire Island Barrier Beach is regularly patrolled by the National Park Service. Eastern Long Island, however, has extensive shoreline of limited access, and beach traffic in general declines in winter.

We made an effort to estimate the probability of recovery by seeding drift cards along the outer beach of Long Beach and along a continuous length from Gilgo Beach to Montauk Point (Fig. I-6). Two seeding experiments were conducted, one representing winter (February 20 - Long Beach; March 5 - Gilgo Beach to Montauk Point), and one summer (July 22 - Long Beach; August 6 - Gilgo Beach to Montauk Point). The

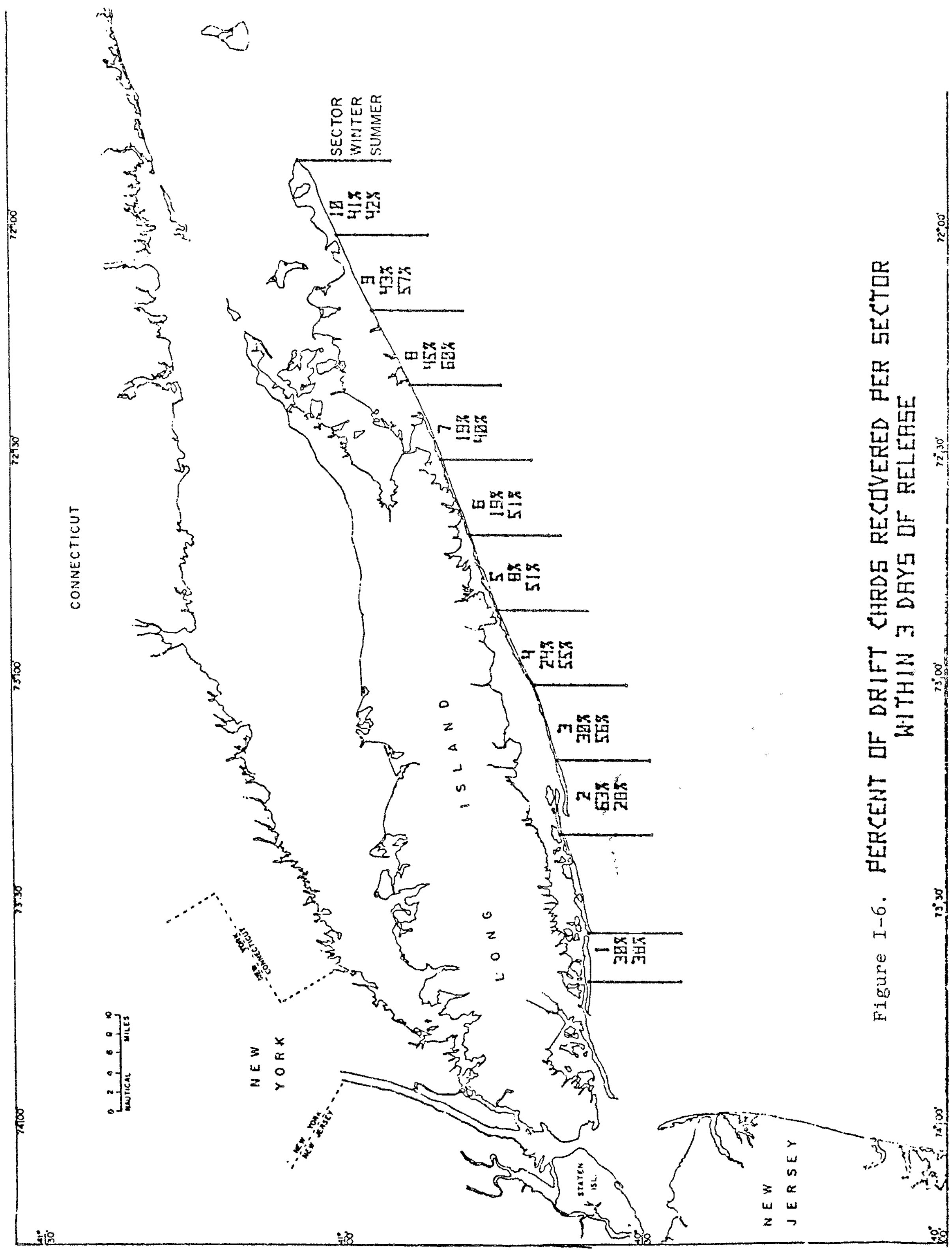

Figure I-6. PERCENT OF DRIFT CARDS RECOVERED PER SECTOR WITHIN 3 DAYS OF RELEASE drift cards were dropped from helicopters (U.S. Coast Guard, Suffolk County Police Department) at 50-ft altitudes with the flight path adjusted to allow the cards to land in the swash zone. The helicopter flights were made before 0800 hours on weekdays to minimize beach witnesses to the event. A total of 1,000 drift cards was dropped during each winter and summer flight, with cards dropped one by one, with 210 to 320 ft (65 to 100 m) intervals between each card.

Variations in the probability of recovery as a function of geographic location are shown in Figure I-6. In this diagram, the south shore of Long Island is divided into ten sectors of 10 min longitude (14 km) or 6 min Longitude (8 km) in the case of Long Beach (Sector 1). The percent of drift cards recovered per section within three days of release is shown with winter and summer percent recoveries compared.

The total percent recovered for the winter drop was 47 percent, and 59 percent for summer. The data of Figures I-7 and I-8 show that 62 percent of drifters recovered in the winter and 73 percent of the drifters recovered in the summer were found on the day of launch.

Long Beach (Sector 1) where the back beach is heavily residential and beach traffic is heavy in both winter and summer, consistently had low returns. However, this is one of the few western beaches without a full-time cleaning crew and cards could be overlooked amidst other flotsam and jetsam.

Sectors 4, 5, 6 and 7, which comprise the barrier beaches of Fire Island, Moriches and Shinnecock, had low recoveries

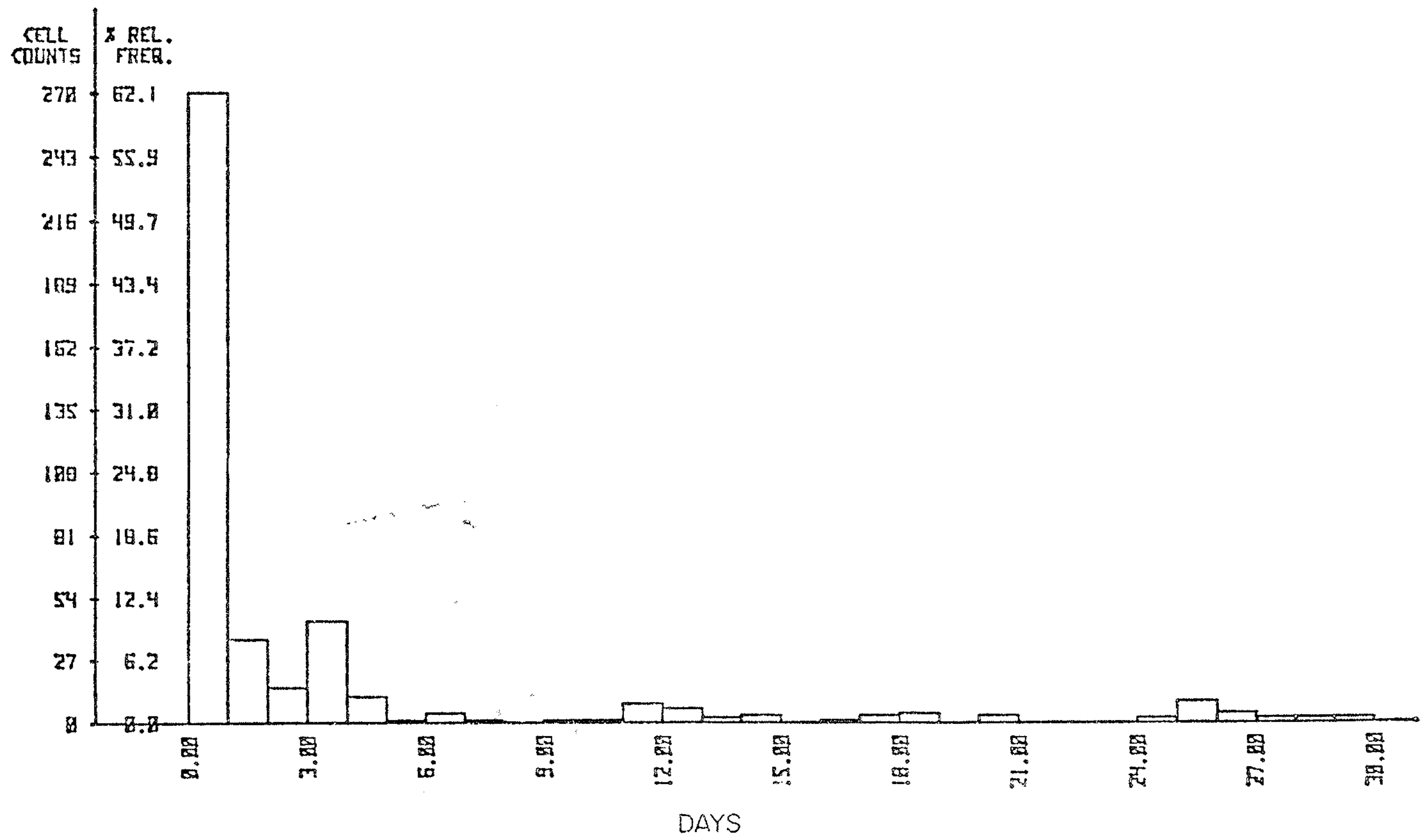

FIGURE I-7. BEACH - SEEDING EXPERIMENT COMPARING NUMBER AND PER CENT OF SURFACE INTERFACE DRIFTERS RECOVERED TO DAYS OUT, IN WINTER, LONG BEACH AND GILGO BEACH TO MONTAUK POINT, LONG ISLAND, NEW YORK.

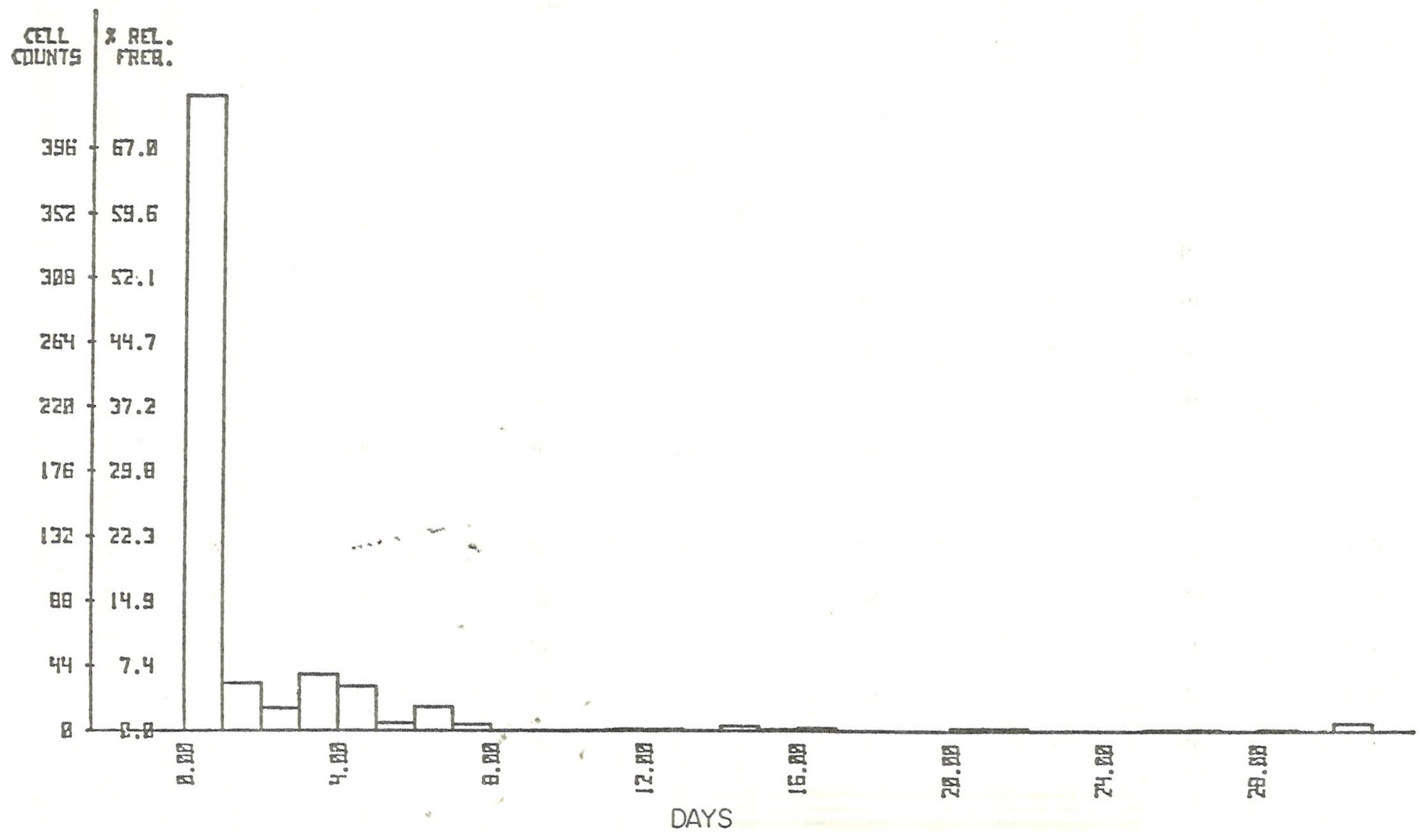

FIGURE I-8. BEACH - SEEDING EXPERIMENT COMPARING NUMBER AND PER CENT OF SURFACE INTERFACE DRIFTERS RECOVERED TO DAYS OUT, IN SUMMER, LONG BEACH AND GILGO BEACH TO MONTAUK POINT, LONG ISLAND, NEW YORK.

in winter of 8 to 24 percent. These areas are difficult to gain access to in winter when ferries from the mainland are curtailed or stopped. In summer, these barrier beaches endure heavy recreational use, which is reflected by a significant increase in reported findings. Sector 2 (Gilgo Beach/Robert Moses Beach) had an anomalously low return of 28 percent, which we cannot explain since this area has a heavy beach usage in summer.

The results of this experiment indicate that approximately 29 to 43 percent of drift cards stranded on the Long Island south shore beaches will be reported as found on the day of stranding with the lower range expected in winter. The percent probability of recovery on the day of stranding is reduced to approximately 16 percent for barrier beaches of limited access in winter.

E. Computer Methods

Computer programs written for an IBM 370 and a Hewlett Packard 9830A Desk Calculator were used to facilitate analysis of the interface drifter data and weather observations. Data were stored on tape cassettes for processing on the Hewlett-Packard and on computer cards for processing on the IBM. The four basic programs employed were the standard listing, weather analyzer, progressive vector plotter, and drifter trajectory plotter. These programs are obtainable from Marine Sciences Research Center.

Distance and direction traveled between the points of release and recovery were computed by the Great Circle navigation method. The total release to recovery time in the modified program was automatically calculated and refined to include fractions of days. This was done by utilizing the exact time of launch and an assumed recovery hour of 1200 hours for all cards, except those found on the day of their launch which had an assumed recovery at 1800 hours.

The weather analyzing program determined the associated weather histories for each of the drifters. These weather histories, with their vector sums of wind speed and direction, were utilized in the calculations of the wind factors and angles of deviation. This program excluded all cards which drifted for periods of greater than ten days and/or landed on areas outside of Long Island, New York.

The Hewlett Packard Model #9830A was employed to plot the progressive vector diagrams of the wind displacement at four different weather stations (Fire Island, Ambrose, Nantucket, and Buzzards Bay). The program utilized the weather records which were stored on the computer tape cassettes. Each progressive vector plot utilizes the entire day's weather record. The card displacement by the wind was determined from the vector addition of the orthogonal components of the wind's velocity multiplied by the appropriate time constant. For weather stations which sampled 8, 6 and 4 times a day, the constants equaled 3, 4 and 6 hours, respectively.

The shortest release-recovery paths of all the returned drifters were also plotted on the HP 9830A. The plots assume straight-line paths for convenience and, hence, cross over peninsulas instead of going around, except when drifters were recovered within New York Harbor or Long Island Sound. In these instances, drifter tracks were channeled via center points where land areas would not be crossed.

IV. RESULTS

A. January

A total of 580 interface drifters was air-dropped on 22-23 January over the 29 stations forming the release grid (Fig. I-2).

Thirty-eight interface drifters or 6.5 percent were recovered by 1 December 1974. Of these, 23 were recovered within six days (Vol. II, Figures 4 and 6).

The vector sum of the winds for the three-day and six-day periods following release was respectively from west and southwest (Vol. II, Figures 5 and 7). Details of the daily winds for the ten-day period after launch are shown in Table I-5 and progressive wind vectors are found in Volume II, Figures 5, 7 and 9.

Gentle to moderate southwest to northwest winds prevailing during the first three days tended to move drifters easterly parallel to or southeasterly away from Long Island. Strong southwest winds over 7 m/sec (13.6 knots) on the fourth day (27 January) were sufficient to drive ashore interface drifters released at Stations 55, 60 and 64 as shown in Volume II, Figures 4 and 6.

All drift cards recovered within 60 days of release moved east from their release point (Vol. II, Figure 12). Only Station 65 had a reported recovery on the New Jersey coast after 128 days.

Minimum day out recoveries in January were only from release stations nearest land and could be correlated to

Table I-5. Daily Wind History for 10 Day Period Commencing 23 January 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
23*	SW	3.6	SW	5.3	S	7.2	SW	9.4
24	NW	5.0	W	2.6	W	4.2	NW	6.7
25	SW	3.2	SW	4.6	SW	4.5	NW	3.0
26	SW	2.2	S	1.5	S	2.8	W	2.7
27	SW	10.2	SW	7.7	SW	9.8	SW	7.4
28	S	0.9	SE	1.7	SW	4.9	SW	3.5
29	NW	5.5	W	3.1	W	4.6	W	6.1
30	S	2.2	SE	2.7	S	3.5	E	3.7
31	SW	8.3	SW	4.3	S	7.0	S	6.0
1	NW	7.7	NW	6.2	W	11.3	NW	10.2
2	NE	8.8	NE	9.6	NE	6.5	E	6.5

*1200 hrs to 2400 hrs

increases in wind speed from the southwest. West to southwest winds having speeds ranging between 1.5 to 7.7 m/sec (2.9 to 15.0 knots) displaced drift cards from Station 55 northeast at a rate of 3 nm/day (5.5 km/day).

B. February

Interface drift cards were launched on 18-19 February. A total of 115 interface drifters or 19.8 percent was recovered by 1 December 1974. Of these, 45 cards were recovered on Long Island within six days of release (Vol. II, Figs. 13 and 15).

The vector sum of the winds for the initial ten-day period shows the winds were from the west. The ten-day wind history is shown in Table I-6 and progressive wind vectors for 4, 7 and 11-day periods are shown in Volume II, Figures 14, 16 and 18.

During that ten-day period, a major storm occurred on 22-23 February when a moderate to fresh gale blew from the south to west at reported velocities of 10 to 20 m/sec (20-40 knots).

Drift cards blown ashore of Long Island within three days of release on 19 February from Stations 61, 62, 63, 64, 65 and 66 moved north under the stress of southerly winds (Vol. II, Fig. 13). This southerly wind had a vector sum velocity of 6.7 m/sec (13 knots) (Table I-6, Ambrose) which displaced the drift cards at a rate of 1.1 to 5.2 nm/day (2.1 to 9.7 km/day).

A strong south wind on 22 February blowing at a vector sum velocity of 13.1 m/sec (25.5 knots) caused the stranding

Table I-6. Daily Wind History for 10 Day Period Commencing 18 February 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
18*	NW	6.0	NW	3.9	NW	8.1	NW	10.6
19	S	6.7	SE	5.0	SE	3.8	NW	1.8
20	NW	9.8	W	5.4	SW	5.5	SW	5.0
21	NW	2.8	W	2.2	W	7.4	NW	8.2
22	S	13.1	S	9.7	S	7.3	S	3.9
23	W	18.2	W	13.1	SW	14.5	SW	11.9
24	N	3.1	NW	1.8	W	8.5	W	10.8
25	N	7.8	N	6.0	NE	5.4	NE	5.4
26	NW	7.9	NW	6.1	NW	6.4	N	7.3
27	W	3.1	SW	3.1	W	3.3	N	3.2
28	SW	7.9	S	7.2	S	6.0	SW	3.0

*1200 hrs to 2400 hrs

of a second group of drift cards on Long Island on the fourth and fifth day of release (Vol. II, Fig. 15). With the shift of winds to blow from the north and northwest, stranding was noticeably reduced until after ten days from release (Vol. II, Figs. 17 and 19). All strandings within 60 days of release occurred on Long Island with one exception (Vol. II, Fig. 20). Drift cards released at inshore stations from Sandy Hook, New Jersey, to Tobay Beach, Long Island, moved generally north to northeast. A drift card release at Station 74, off Long Branch, New Jersey, reached Fire Island Inlet in 19 days at a drift rate of 3.5 km/day. Recoveries after the sixtieth day were primarily on the coast of New Jersey or at sea.

C. March

Interface drift cards were released on 19-20 March. A total of 51 drift cards or 8.8 percent was recovered by 1 December. Of these, 31 cards landed on Long Island and one landed on New Jersey within six days of release.

Winds for the ten-day period tended to be variable with offshore stations (Ambrose, Nantucket Shoals) reporting a greater frequency of west to northwest winds. The ten-day wind history is shown in Table I-7 and the 4, 7 and 11-day progressive wind vectors are shown in Volume II, Figures 23, 25 and 27.

Many cards were driven ashore on Long Island on the day of launch by southeast winds which caused the drift cards to move northwest or downwind (Vol. II, Fig. 22). Recoveries

Table I-7. Daily Wind History for 10 Day Period Commencing 20 March 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
20*	SE	3.4	SE	3.1	SW	1.9	W	7.2
21	W	0.1	S	0.9	SE	7.6	W	7.2
22	NW	7.8	W	5.0	W	8.8	NW	11.1
23	S	6.4	S	4.3	S	6.3	S	4.4
24	W	2.9	NW	2.6	SW	3.2	S	4.3
25	NW	3.7	W	1.5	W	6.5	N	7.5
26	SW	6.6	S	5.5	S	5.3	SE	2.3
27	NW	7.1	W	5.6	W	8.5	NW	10.3
28	NE	4.2	N	4.7	NW	6.5	NW	6.8
29	E	11.9	NE	10.5	NE	4.8	NE	6.9
30	E	19.7	NE	15.5	E	15.1	E	12.6

*1200 hrs to 2400 hrs

on Long Island from the third to sixth day after release tended to be recovered northeast of their release point as the six-day progressive wind vector was from the west (283° T.) (Vol. II, Figs. 24 and 25). In general, release stations comprising the northwest apex of the New York Bight (Stations 60 to 80) had no reported recoveries on Long Island. One recovery from Station 80 on the New Jersey coast suggested that drift cards released in the northwest apex had drifted south and southeast. The month of March commences a period of high runoff from the Hudson River watershed which forms a seaward dispersing plume from the New York Harbor entrance and moves south along the New Jersey coast.

Few additional recoveries were reported after the sixth day of release (Vol. II, Figs. 26, 28 and 29). The vector sum of the wind direction for the 11-day period at Ambrose Lightship was northwest (320° T.) which caused a general seaward drift throughout the study area (Vol. II, Fig. 27).

D. <u>April</u>

Interface drift cards were launched on 15-16 April. A total of 77 interface drifters or 13.3 percent was recovered by 1 December. Of these, only three cards were recovered on Long Island, and one at sea,within six days of release (Vol. II, Fig. 33).

Often strong, west to northwest winds for two to three days following card release blew the drift cards east to southeast (Table I-8). A shift of wind to the northeast

Table I-8. Daily Wind History for 10 Day Period Commencing 15 April 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
15*	W	13.1	SW	10.1	SW	11.4	SW	9.7
16	NW	10.7	W	6.4	W	8.7	W	9.7
17	W	4.1	SW	4.0	SW	6.2	W	6.5
18	W	6.2	SW	4.4	SW	6.4	SW	5.0
19	NE	4.3	NE	3.8	NE	4.9	N	1.2
20	SW	1.5	S	0.7	NE	0.7	NE	7.7
21	SW	8.7	SW	7.3	SW	7.7	SW	2.0
22	SW	9.8	S	6.9	SW	9.2	W	7.9
23	W	7.0	SW	6.8	SW	5.9	SW	7.7
24	N	6.9	SW	3.8	NW	4.8	W	6.6
25	N	2.3	NE	2.3	N	8.0	N	11.2

*1200 hrs to 2400 hrs

followed by southwest winds was responsible for blowing a few cards ashore east of their release location after the third day. Progressive wind vectors for 4, 7 and 11-day periods are shown in Volume II, Figures 32, 34 and 36.

Drift cards released in the inshore area between East Rockaway Inlet to Jones Beach continued to be blown ashore on Fire Island barrier beach by west winds to the ninth day after release. Displacement rates for the eastward drift of the cards during this period were 5.5 to 11.4 km/day.

Recoveries of drift cards on Long Island continued after the tenth day (Vol. II, Figs. 35, 37 and 38).

Drift cards released in the northwest apex of the New York Bight east of the New Jersey coast began to be recovered along the coast of New Jersey south of 40°00' N latitude after the twenty-fifth day.

While winds from the west and southwest dominated the wind history for the first ten days, the pattern was intermittently interrupted by winds from the north and northeast which could dampen any tendency for a rapid easterly drift. We speculate that the interface drift cards were driven slowly eastward by the westerly mean monthly winds of April. Recoveries on New Jersey began to appear after the twenty-seventh day out, when the winds in May and June tended to become more southerly and easterly. Thus, it would appear that the drift cards were caught between the westerly and southwesterly geostrophic current and the resultant of westerly winds, so that the cards were not flushed from the region for a two-month period after release.

E. May

Interface drift cards were launched on 20-21 May. A total of 271 interface drifters or 46.7 percent was recovered by 1 December. Of these, 71 cards were recovered within three days on Long Island and Staten Island with no recoveries from New Jersey (Vol. II, Fig. 40). For the six-day period following card release 119 cards were recovered on both the New York and New Jersey shores (Vol. II, Fig. 42). The initial drift direction for cards landing on Long Island was northeast whereas cards stranding on New Jersey drifted south.

The daily vector sum of the winds for the ten-day period shows that the winds were variable over the region. A breakdown of daily winds for the first ten days after launch is shown in Table I-9 and progressive wind vectors for 4, 7 and 11 days are shown in Volume II, Figures 41, 43 and 45.

At Ambrose Lightship, winds during 21-23 May were from the southwest and shifting to the southeast on 24 May. Drift cards released in the northwest apex were driven ashore on the western Long Island coastline by this combination of winds (Vol. II, Figs. 40 and 42).

Drift rates for cards released at Stations 70, 71 and 72 located in the vicinity of the waste dumping grounds, which were recovered on Long Island within three days, were 24.4 to 31.5 km/day. Southwest winds were capable of causing a very rapid downwind drift in the northwest apex.

Recoveries on the coast of New Jersey increased significantly after the sixth day, as well as on eastern Long Island

Table I-9. Daily Wind History for 10 Day Period Commencing 20 May 1974.
(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
20*	S	6.9	S	4.9	S	4.1	NE	7.3
21	SW	7.0	SW	5.2	SW	3.0	W	3.4
22	SW	5.9	SW	5.9	S	6.8	SE	1.6
23	SW	1.6	SE	1.3	N	4.3	W	5.3
24	SE	3.7	E	3.6	NE	1.6	NE	3.4
25	NW	4.2	NW	1.5	N	0.8	S	1.2
26	W	2.6	W	1.5	N	1.2	NE	2.3
27	NE	7.3	NE	6.8	NE	6.8	NE	6.0
28	NW	2.7	SW	2.0	NW	5.0	N	6.1
29	SW	5.5	SW	3.9	SW	3.6	W	1.7
30	SE	5.6	E	4.8	E	1.3	N	1.9

*1200 hrs to 2400 hrs

(Vol. II, Figs. 39, 42, 44, 46, and 47). The trend of the drift direction shifted west along the coast of Long Island after the tenth day and southwest along the coast of New Jersey (Vol. II, Fig. 46). This drift direction appears accounted for by the increasing frequency of southeast winds in June.

F. June

Interface drift cards were released on 24-25 June. A total of 176 drift cards or 30.4 percent was recovered by 1 December. Of these, 110 were recovered exclusively along the coast of New Jersey within six days (Vol. II, Figs. 49 and 51). All drift cards recovered during this period were released in the northwest apex.

The resultant winds for the ten-day period were southeasterly. The daily wind history for the first ten days after release is shown in Table I-10 and progressive wind vectors for 4, 7 and 11-day periods are shown in Volume II, Figures 50, 52 and 54.

Winds blew from northeast to southeast during the first three to four days following drift card release (Table I-11, Ambrose). The early northeast component set up a southwesterly sea surface drift which excluded drift cards from stranding on Long Island.

Observed drift rates driven by these easterly winds were approximately 23 to 34 km/day. Recoveries diminished on both New Jersey and Long Island after ten days (Vol. II, Figs. 53, 55 and 56).

Table I-10. Daily Wind History for 10 Day Period Commencing 24 June 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
24*	SE	5.9	E	4.5	NE	8.6	NE	4.6
25	NE	9.8	NE	9.2	NE	14.0	NE	4.8
26	NE	1.8	NE	1.3	N	6.4	NE	3.9
27	SE	4.4	E	3.5	E	2.1	NE	1.5
28	E	14.0	NE	10.9	E	6.8	E	4.8
29	SW	7.3	S	5.3	S	4.1	SE	2.6
30	SW	7.3	SW	6.5	SW	7.1	SW	4.2
1	SW	4.2	SW	5.6	SW	4.1	SW	4.1
2	SW	6.1	SW	6.1	SW	4.2	SW	4.2
3	SW	6.0	SW	6.1	SW	4.0	SW	4.0
4	SW	6.5	SW	5.8	SW	4.0	SW	4.0

*1200 hrs to 2400 hrs

We conclude that the interface drifters at all stations were displaced toward the southwest during the first five days following release. Those beaches particularly in New Jersey located within a small arc of approximately 48 to 80 nm (90 to 130 km) (radius downwind of the release stations) reported drift card landings. When the wind changed to blow from the southwest, the interface drifters were blown away from shore, and moved generally southeast to south.

G. July

Interface drift cards were released on 22-23 July. A total of 267 drift cards or 46 percent was recovered by 1 December. Of these, 131 were recovered within three days and 183 were recovered within six days. The greatest number stranded on Long Island during the first three days.

The average wind vector for the ten-day period following release was from the southeast. The ten-day wind history is shown in Table I-11 and progressive wind vectors for 4, 7 and 11-day periods are shown in Volume II, Figures 59, 61 and 63.

Moderate east to southeast winds blew over the region for seven days following the drift card launching before shifting to southwest (Table I-11). Drift cards released south of Long Island were driven west with a net displacement rate of 13.5 nm (25 km) per day.

A regional dichotomy in drift direction existed where drift cards released off Long Island between Jones Inlet and Montauk Point were displaced northwest or essentially downwind

Table I-11. Daily Wind History for 10 Day Period Commencing 23 July 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
23*	SE	5.1	SE	4.4	E	1.8	E	1.8
24	E	7.7	E	6.2	NE	2.6	E	2.2
25	E	4.6	E	6.1	SE	3.0	E	2.0
26	E	4.1	E	4.1	SE	1.2	NE	2.8
27	SE	4.0	E	4.2	SE	3.7	E	1.4
28	SE	3.5	SE	2.8	SE	2.6	E	1.7
29	S	5.1	SE	4.0	SE	3.1	E	1.8
30	S	3.7	SE	3.9	SE	1.8	NE	3.0
31	SW	2.9	S	4.2	SW	3.5	N	2.3
1	SW	4.7	SW	4.5	SW	5.3	W	1.3
2	S	4.9	S	4.3	SW	3.6	SW	1.0

*1200 hrs to 2400 hrs

during the six days following release (Vol. II, Figs. 58 and 60). Drift cards released in the northwest apex were more variable in drift direction which could not be always correlated with wind direction. Drift directions in these cases ranged from southwest to northeast.

With the wind shift to the southwest after the sixth or seventh day, further recoveries on Long Island were generally north or northeast of the release point (Vol. II, Figs. 57, 62, 64 and 66). Such circumstantial evidence supports the contention that the interface drifters are driven before the wind. Drift cards to the east of the Hudson Canyon drifted towards Long Island whereas cards released further west were recovered on the New Jersey coast. Surface advection caused by forces other than direct wind-induced drift appeared to exist in the northwest apex.

H. August

Interface drift cards were released at all stations on 19-20 August. A total of 279 drift cards or 48.1 percent was recovered by 1 December. Of these, 189 were recovered within three days and 233 were recovered by the sixth day. Recoveries occurred on both the Long Island and New Jersey coasts during the initial three-day period.

The vector sum of the wind directions for the ten-day period following release was from the south. The ten-day record of daily winds is shown in Table I-12 and progressive wind vectors for 4, 7 and 11-day periods are shown in Volume II, Figures 68, 70 and 72.

Table I-12. Daily Wind History for 10 Day Period Commencing 20 August 1974.

(Speed, meters/sec. Vector Addition)

	Weather Stations							
	Ambrose		Fire Island		Buzzards Bay		Nantucket Shoals	
Day	Direct.	Speed	Direct.	Speed	Direct.	Speed	Direct.	Speed
20*	S	3.9	SE	3.8	SE	3.2	E	1.0
21	E	5.6	E	5.3	SE	1.9	E	2.0
22	SE	5.7	E	4.6	SE	2.7	E	1.6
23	S	2.3	S	3.2	S	1.7	SW	1.3
24	SW	4.2	SW	4.8	SW	5.7	SW	3.1
25	NW	1.4	NE	1.3	W	1.0	NW	1.3
26	S	4.8	SE	3.4	SE	4.5	NE	2.2
27	S	9.9	S	8.4	S	5.4	SE	0.7
28	S	6.7	S	6.3	SW	5.8	SW	5.0
29	S	5.2	S	4.5	SW	1.0	SW	4.8
30	NW	1.8	N	1.3	SE	1.0	SW	4.0

*1200 hrs to 2400 hrs

Moderate to gentle south to east winds blew for one to two days following drift card release. This wind set up a westerly to northwesterly drift to the sea surface which is indicated by the fact that cards recovered on Long Island by the third day were west or northwest of their release point (Vol. II, Fig. 67). Drift rates were 8 to 10.8 nm (15 to 20 km) per day. By the third day the wind shifted to the south and southwest. Recoveries after the third day display regional differences in the direction of the release-recovery paths. Release stations south of Long Island and east of Shinnecock Inlet continued to have a small number of recoveries west of their point of release for six, ten and 20-day periods (Vol. II, Figs. 67, 69 and 71). However, stations west of Shinnecock Inlet showed a different release-recovery path, where recoveries after the fourth day were generally north and northeast of their point of release.

We can speculate that the difference is the result of a surface drift reversal (easterly drift) which was set up along the south shore of Long Island between East Rockaway Inlet and Moriches Inlet. This current reversal was apparently caused by southerly sea breezes which were observed to be of greater velocity at Ambrose and Fire Island than at Buzzards Bay and Nantucket Shoals.

V. DISCUSSION

A. General Observations of Surface Interface Drift

The net flow direction of surface water in the New York Bight is west to southwest over the outer continental shelf but parallel to the coastlines in the inner reaches. This geostrophic current is driven by density gradients with lower density water to the right (landward) of the direction of flow. Superimposed upon this basic unidirectional drift are short-term variations in the direction and speed of sea surface movement caused by such forces as winds and tides. These short-term (less than ten days) sea surface movements are capable of significant deviations from the basic drift pattern.

The geostrophic current is deflected to the southwest in winter (November to March) under the stress of strong prevailing winds from the northwest to west (Fig. I-3; Table I-13).

The frequency of winds from the north, northwest and west was 53.6 percent during the five winter months but changed to 22.9 percent during the four summer months (May to August) (Table I-13). These prevailing winter winds tended to deflect the sea surface to the south and southeast. Thus, the winter winds provided a pronounced seaward movement of the surface water layer which almost precluded the stranding of drift cards on Long Island or New Jersey beyond the tenth day after release. In winds up to and possibly greater than 10 knots interface drift cards moved at the same speed as oil slicks. Therefore, our evidence shows that the threat of sea surface contaminants stranding on Long Island is minimized in winter.

Table I-13. Comparison of Winter and Summer Wind Direction Frequencies in Region 6, New York Coastal Marine Area (40° N - Coast, 72° W - Coast) for Primary Period 1912 - 1968. (Adapted from U. S. Naval Weather Service Command, 1970).

	Frequency of Observation (%)			
Direction	Winter (Nov.-March)	Spring to Fall (April-Oct.)	Summer (May-Aug.)	Annual
W	24.4	12.0	10.1	16.7
NW	18.8	8.4	6.5	12.4
N	10.4	8.0	6.3	8.9
NE	8.0	9.3	8.0	8.9
E	6.2	9.4	9.4	8.3
SE	5.4	10.0	10.5	8.2
S	11.1	21.7	25.7	17.5
SW	13.8	17.2	18.9	15.9
Calm	2.0	3.9	4.3	3.2
Total %	100.1	99.9	99.7	100.0

The seasonal progression from spring through summer brings changes in both the character of the winds and in the physical structure of the water column which, acting together, modify the nature of the sea surface drift.

The prevailing winds began to shift in April. Blowing with increasing frequency from the southwest to southeast, they became appreciably diminished in velocity compared to winter winds (Fig. I-3, Table I-3). Winds from the southwest, south and southeast blow 30.3 percent of the time in winter (November-March) but in summer (May-August) the frequency was 55.1 percent (Table I-13). This pronounced change in seasonal wind direction introduced a wind stress component which was directed landward toward Long Island. The effect of this change can be seen in the release-recovery paths of drift cards released after March and recovered more than ten days after launching. A dramatic increase in the frequency of stranding is obvious for the twenty-day, sixty-day and total release-recovery paths shown in Volume II of this report. The summer wind field in concert with the westerly geostrophic flow tends to move nearshore slicks to the northwest along the New York shoreline and southwesterly along the coast of New Jersey.

The wind drift component exerted by southwest to south-southwest winds should push drift cards northeast to east. A displacement in this direction would tend to move the drift cards essentially parallel to the Long Island shoreline and away from the New Jersey coast (Vol. II, Fig. 40). A second coastal process occurs under these conditions which tends to encourage a seaward drift. Under the frictional stress of southwest to south-southwest winds, the sea surface deflects to the right or seaward and upwelling of colder and denser bottom water occurs. This slow divergence of the surface layer away from shore inhibited the stranding of surface material on Long Island and New Jersey with the exception of cards from areas close to shore in the northwest apex of the New York Bight (Stations 11 and 12). Our evidence therefore implied that in summer with winds from the south-southwest to west, stranding of drift cards on Long Island and New Jersey was improbable with the exception of nearshore stations between New York Harbor entrance and Jones Inlet. If we included the winter months, stranding became unlikely if the wind blew through a swing of the compass clockwise from south to north. Thus, wind directions most likely to cause the stranding of material onto Long Island and New Jersey, if released off Fire Island to Montauk Point, were limited to that clockwise arc of the compass from north to south. Winds from the north to south occurred only 41.0 percent of the time in winter, but in summer they occurred 60.0 percent (Table I-13). The summer winds blowing with increasing frequency from the northeast to southeast quadrants of the compass caused drift card stranding on Long Island and New Jersey.

B. The Stranding of Interface Drift Cards upon the Long Island and New Jersey Coastlines.

The probability of an interface drift card stranding on the coasts of Long Island or New Jersey depended upon the proximity of the card release station to shore, the wind speed and direction after the card was released, hydrographic conditions, and the angle of the coastline in relation to wind direction. Because these factors differ throughout the study region, we can expect differences in the numbers of cards recovered as a function of their release location in the Bight.

To show these differences, we have contoured the percent of drift cards recovered on the New York and New Jersey coasts in winter and for summer for each launching station (Vol. II, Figs. 75 to 86). These figures incorporate release-recovery results from both the NOAA-MESA study and from a concurrent study for the Nassau-Suffolk Regional Planning Board, New York. The Nassau-Suffolk study comprised 23 launching stations distributed throughout the New York Bight. These stations are indicated in Figure I-9.

Percent recovery contours identify those zones or areas offshore of New Jersey and New York from which drift cards moved to the beach under the conditions of the specified period. Secondly, the contours provide a sense of the intensity of shoreward displacement by indicating the fraction (percentage recovery) of total drift cards released at each station which was recovered on shore.

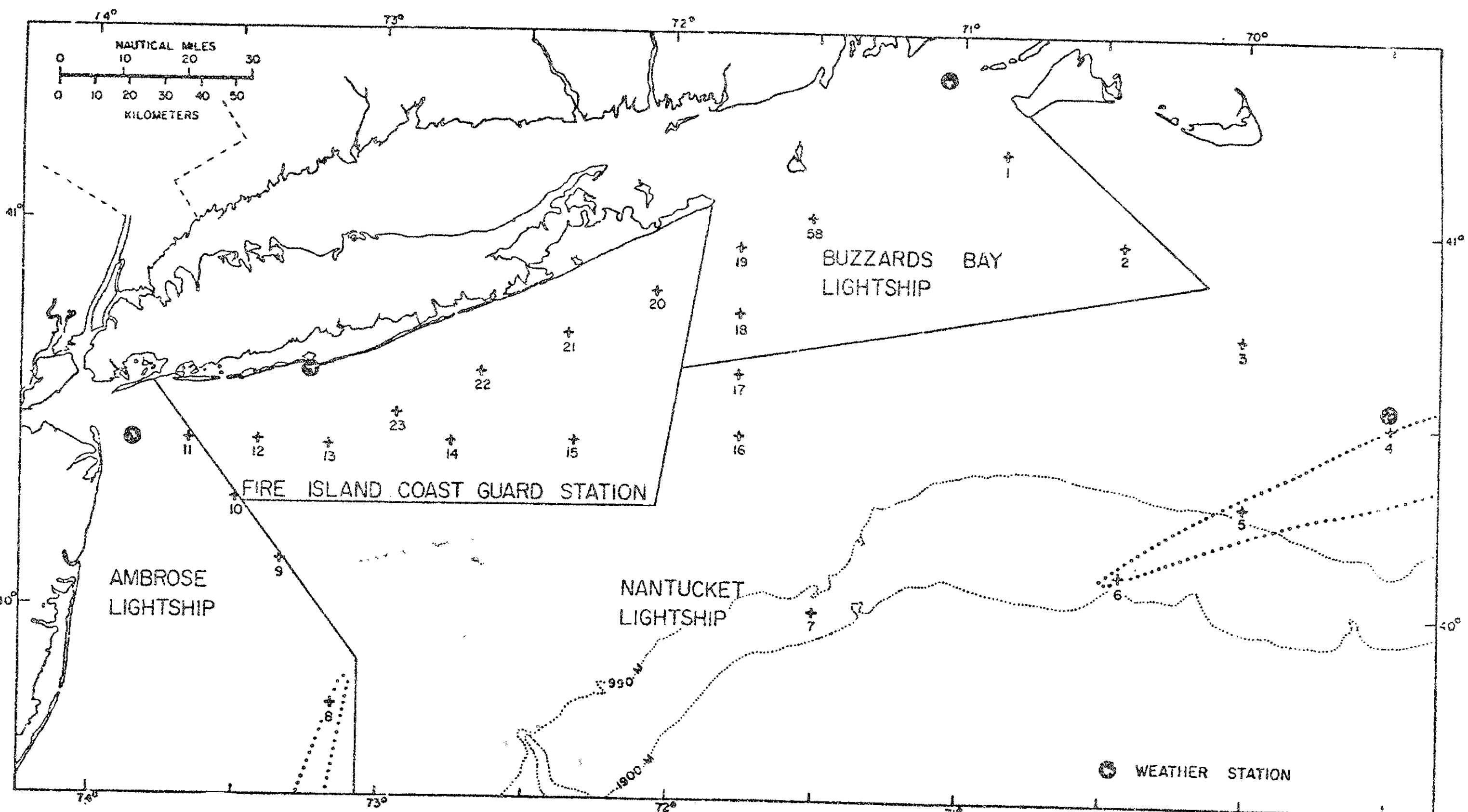

Figure I-9. Drift Card Release Stations for the Nassau-Suffolk Regional Planning Board Study.

For convenience, we will discuss the percentage recovery contours for winter (January to March) and for summer (April to August) for, respectively, the New Jersey and New York shorelines.

1. Winter

Regional prevailing winds in winter blow from the northwest as shown by monthly vector additions of observed winds from the coastal weather stations used in this study (Fig. I-3). Northwest winds exert on the sea surface a frictional stress that is directed seaward away from the Long Island and New Jersey coastline.

This strong seaward displacement in winter is reflected in the percentage recovery contours (Vol. II, Figs. 75 to 80) where the stranding of drift cards was limited to the south shore of Long Island. No recoveries were reported within 60 days from New Jersey. The drift cards essentially stranded on Long Island within ten days, or not at all. Those drift cards released within 9 nm (17 km) of shore that did strand on Long Island did so during short-term periods when the winds blew from directions other than the prevailing west to north direction. Thus, cards recovered in winter came from release points located in a narrow band parallel to the Long Island coastline.

During January and February, at the time of or within one day of launching, the wind blew from the south or southwest (Tables I-5 and I-6, Ambrose). Drift cards stranding on Long Island had moved northeasterly or northerly and thus essentially downwind and parallel to the resultant seven-day wind direction (Vol. II, Figs. 7 and 16, Ambrose). Nearshore release points south and west of Jones Inlet had a high incidence of recoveries on Long Island under these wind conditions (Vol. II, Figs. 75 to 77).

The March drift card release took place during a southeast wind which shifted to the west the following day (Table I-7). The vector sum of the wind directions for the seven-day period following the card release was directed from the west (283^{o} T). During the six-day period 67 percent of the total number of cards recovered were stranded. Early recoveries on shore had moved northwesterly apparently under the influence of the southeast wind.

The absence of returns from the dense drift card release grid encompassing the entrance of New York Harbor and East Rockaway and the nearshore zone of the northern New Jersey coast may be influenced by the seaward advection of the spring discharge of the Hudson River. The general absence of recoveries from stations located near New Jersey and at distances greater than 7 nm (13 km) from the Long Island coast must be attributed to the winds which blew with only occasional exceptions from the northwest and northeast for the ten-day period after launching (Table I-7).

These data suggest that during the winter, meteorological conditions severely limit the probability that a slick will strike the New Jersey coast and to a lesser extent the south shore of Long Island.

2. Summer

The percent recovery contours for summer (April to September) (Vol. II, Figs. 81 to 86) differed from winter months in three respects. Recoveries persisted beyond ten days after the launch. Recoveries came from stations further offshore as well as nearshore. A greater number of drift cards was recovered from the New Jersey coast.

These effects appeared to stem principally from the increased frequency of winds blowing from the southeast to southwest in summer (Table I-13).

The percent recovery contours for the New York shoreline extend further out to sea than the recovery contours for winter (Vol. II, Figs 75 to 77 and 81 to 83). However, there is little positional change in the percent recovery contours after ten days, which implies that recoveries of drift cards on Long Island occurred primarily within ten days of their release.

The most frequent recoveries on Long Island during the initial three days following release were from nearshore stations immediately south of East Rockaway Inlet to Jones Beach, but also included stations from further offshore under suitable wind conditions. Such winds, for instance from the southwest (Vol. II, Fig. 41), were capable of displacing drift cards released over waste dumping grounds (Fig. I-2, Stations 71 and 72) within two days to strand on Long Island between East Rockaway Inlet and Fire Island Barrier Beach (Vol. II, Fig. 40).

Southeast winds (Vol. II, Figure 59) averaging 6 knots (3.1 m/sec) over a four day period displaced drift cards from the sludge dumping grounds (Figure I-1, Station 73) to Jones Inlet in three days (Vol. II, Figure 58).

All release stations comprising the NOAA-MESA sampling grid (Fig. I-2) had a greater than one percent recovery within 20 days on the New York shoreline (Vol. II, Fig. 82). Drift cards released over the dredge spoil, cellar dirt, and waste sludge dumping grounds (Fig. I-1, Stations 71, 72 and 73) had a greater than ten percent average recovery on Long Island within ten days (Vol. II, Fig. 81).

The most profound seasonal change in percent recovery contours occurred for recoveries on the New Jersey coast. Whereas the incidence of drift card stranding on the New Jersey shoreline was severely limited in winter (Vol. II, Figs. 78 to 80), recoveries dramatically increased in summer (Vol. II, Figs. 84 to 86). By the sixtieth day after drift card release, the one percent recovery contour encompassed an area comprising almost the entire New York Bight. The westerly geostrophic flow reinforced by periods of winds blowing from the northeast to southeast caused the New Jersey beaches to be particularly vulnerable to collecting sea surface material. The effectiveness of northeast and south-east winds to drive drift cards onto New Jersey beaches in summer can be demonstrated in the three-day release-recovery paths for June, July and August (Vol. II, Figs. 49, 58 and 67).

The continued eastward progression of the one, ten, twenty and thirty percent contours for the ten, twenty and sixty-day period following drift card release suggests that the inexorable westerly surface movement characterizing the New York Bight dominates sea surface drift in the absence of prevailing northwest winds (Vol. II, Figs. 84 to 86).

C. The Relation of Winds to the Stranding of Sea Surface Material on the Coasts of New York and New Jersey

Winds provide the dominant force influencing the movement of the uppermost layer of the sea surface. The influence of winds can be modified, however, in local areas where strong advection is caused by forces other than winds. Within the study area, strong advection was observed in the offing of major estuarine discharges, such as that from New York Harbor and that from Long Island Sound at Montauk Point.

A second, less understood modifier of pure wind drift is the boundary effect created by the right-angle intersection of the New York and New Jersey coasts. The northwest apex acts as a corner where littoral movements along two straight coastlines meet. Such factors introduce a complexity in the circulation of this sector of the New York Bight which moved Redfield and Walford (1951) to conclude: "The circulation patterns are quite variable, ranging from the most common type, which indicates that the river effluent escapes in a narrow band along the New Jersey coast, to one in which the river effluent is distributed widely over the surface area.

Although five of the six distributions observed can be accounted for by the associated oceanographic forces and the winds, so many variables contributed to the circulation that predictions are not feasible." However, these authors were concerned with general circulation processes which differ from the movement of the thin sea surface layer.

With the exception mentioned above, the surface circulation in the New York Bight is dominated by winds and the westerly drift of the geostrophic current. The responsiveness of the uppermost sea surface layer to winds usually over-rides the secondary influences of other advective forces and shows up clearly in the release-recovery paths of this study. This responsiveness is dependent upon wind speed and direction particularly upon whether the wind direction reinforces or opposes the geostrophic current.

Other investigators have noted that the windwind trajectory of drift cards or oil spills in open water is commonly within plus or minus ten degrees of the wind direction (Schwartzberg, 1971; James, 1966). This simple relation was complexed in this study by the boundary effects of the long and straight coastlines of Long Island and New Jersey. In the final act of the drift card stranding, the drift is subject to littoral movements, including surface drift reversal (Bumpus, 1969), river discharge, and to upwelling. These processes can move the drift cards parallel to the beach at considerable deflections from the wind direction or, in the case of upwelling, introduce a seaward component which complexes the stranding event. The final stages in the actual stranding of a drift device are poorly understood and could not be accounted for in this study. Our observations indicate that the interface drift cards were driven essentially before the wind. Large deflections occurred when the wind direction blew toward the shore at large incident angles. In general, for recoveries along the Long Island shore, when the wind blew from the east, the deflection was to the left of the wind, and to the right when the wind blew from the west.

For the purposes of predicting whether or not a sea surface material will strand on the coastline of Long Island or New Jersey, we can arbitrarily set up two categories of wind directions: (1) wind directions which cause sea surface material to miss Long Island or New Jersey and, conversely, (2) winds which converge the sea surface layer onto Long Island or New Jersey.

1. <u>Wind directions which result in a low stranding potential</u>

Wind directions which blow seaward or parallel to shore so that the right-directed Ekman surface flux is seaward minimize the risk of oil slicks stranding on shore. Such a correlation is suggested by the data of Figure I-10 where observed wind directions which resulted in no strandings of drift cards on Long Island or New Jersey are compared with all observed wind directions at Fire Island and Ambrose Light for the six-day period following each card release.

The wind roses in the lower right of Figure I-10 give the combined six-day vector sum of wind directions observed

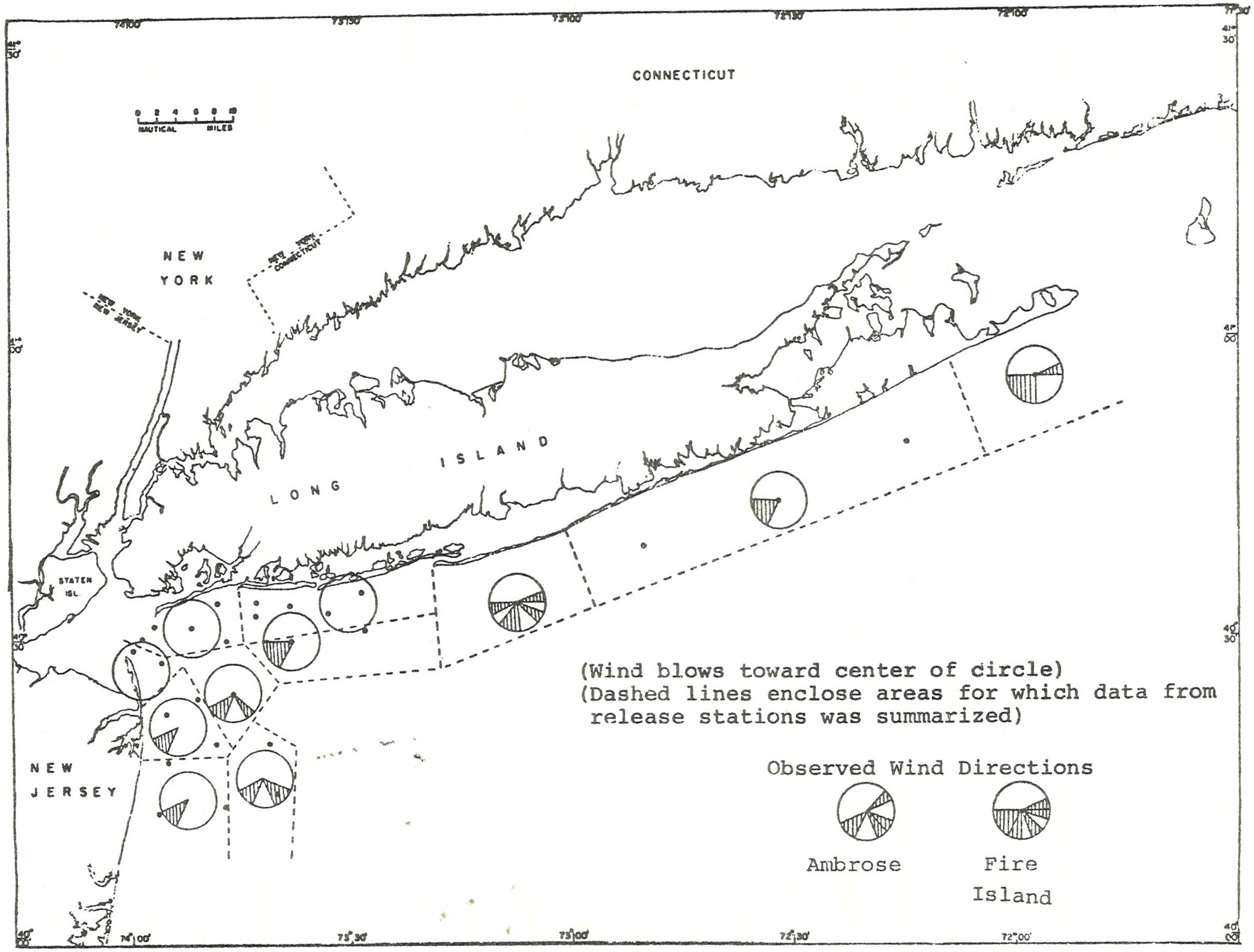

Figure I-10. A Summary of Wind Directions Which Resulted in No Strandings on New York or New Jersey of Drift Cards Within 6 Days of Release During the Period January to August 1974 at each weather station following each air drop of cards. Those wind roses show the total variation of the combined data describing the six-day wind directions encountered during the study period. The wind directions are shown as black wedges in a wind compass divided into sixteen sectors. The wind blows toward the center of the wind rose. Of 16 possible wind directions, only five to six were observed in any weather sector (Fig. I-2) because the number of air drops never exceeded nine for any one station during the study period and because there was duplication of wind directions following respective air drops.

In Figure I-10, the total wind direction variability observed at each weather station is presented for comparison with the wind rose histories of indicated drift card release areas (approximated by dashed lines) for which the six-day winds caused no strandings on Long Island. Winds that caused strandings are omitted. Thus, Figure I-10 shows the difference between the actual wind history of each weather sector and the wind histories which did not cause drift cards to beach on Long Island or New Jersey.

The data show a low frequency of stranding from nearshore stations paralleling Long Island's south shore with wind directions from a large arc proceeding clockwise from 180° T to 67° T. Since winds from the northwest to the north were not observed for the six-day period after drift card release we have assumed that the net sea surface displacement in such winds is away from Long Island and New Jersey.

Figure I-10 suggests that both the northwest prevailing wind in winter and, to a lesser extent, southwest prevailing winds in summer create sea surface drifts which tend to preclude sea surface material from stranding on Long Island or New Jersey.

Certain areas south of Long Island (Stations 50 and 54) indicated a residual seaward displacement implied by the limited wind directions which were observed capable of stranding the drift cards ashore. Elsewhere along the coast of New York, such as the New York Harbor entrance to Fire Island Inlet and Shinnecock Inlet to Moriches Inlet, a tendency to converge toward shore is suggested by the stranding of drift cards over a greater range of observed six-day wind directions. The presence of seaward and shoreward residual surface displacements driven by factors other than directly explainable by winds suggests the presence of gyres or eddies. Miller (1952) observed the presence of eddies along the south shore of Long Island which he explained as caused by density flow adjusting to seaward migrations of estuarine discharge.

The location of seaward and shoreward residual currents observed in our data is not inconsistent with the surface circulation proposed by Miller (1952).

2. <u>Wind directions having a high potential of stranding sea surface material on the New York and New Jersey coasts</u>

The data of Figure I-11 show the wind histories of selected drift cards that were recovered within six days on Long Island and New Jersey from the indicated release areas. Arrows extending from the center of the wind rose for each station mark the

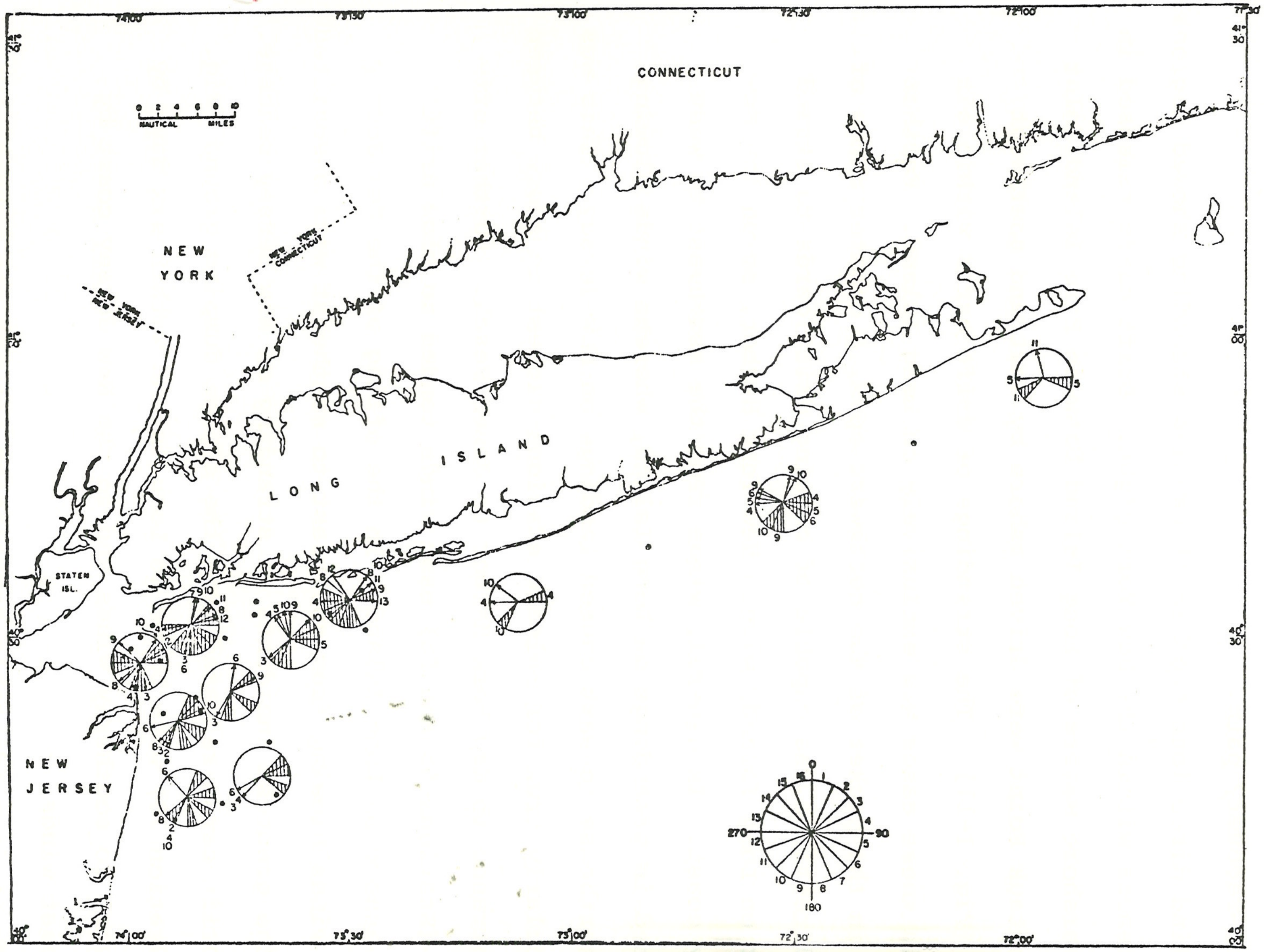

Figure I-11. Relationships Between the Directions of the Wind and the Directions Taken by the Drift Cards that Stranded on Long Island and New Jersey Within 6 Days of Their Release. Wind blows toward center of circle and is indicated by wedge-shaped sectors. The directions taken by drift cards are indicated by arrows. Numbers on the arrows indicate the wind direction sectors that blew the cards.

observed angle of deflection from the wind of the drift card release-recovery path.

Wind directions capable of causing stranding showed regional differences within the New York Bight. Drift cards released in the nearshore waters of Long Island between Fire Island Inlet and Montauk Point were driven ashore by east and southwest winds (Fig. I-11). The strandings of drift cards within six days in these cases was exclusively on Long Island. Further west, in the pocket of the northwest apex, a greater range of wind directions was capable of causing drift cards to strand either on Long Island, within New York Harbor, or on the New Jersey coast. In general, winds from the southeast to west resulted in strandings on Long Island, whereas winds blowing from northeast to east caused landings on New Jersey. This was particularly true for release stations closest to shore between the entrance to New York Harbor to Jones Beach. Further offshore (Stations 55 and 56) east winds tended to blow drift cards ashore on Long Island. In the offing of the New Jersey coast winds blowing from northeast to southeast were associated with the greatest incidents of stranding on New Jersey beaches.

Drift cards released over the sludge dumping ground (Fig. I-2, Station 73) were blown to Long Island within six days by southeast to southerly winds and to the New Jersey coast by northeast winds.

There is predictable correlation between the progressive vector diagram of the wind and the beaching of drift cards. The estimated wind directions that strand sea surface material on Long Island are shown in Figure I-12 and on New Jersey in Figure I-13. Winds blowing from the east to south to southwest strand flotsam and jetsam on Long Island. The prevailing winds of summer blow from these directions (Table I-13) and are the primary cause for the increased stranding on Long Island during the summer. Southwest winds exert a lesser influence in causing the sea surface layer to converge on Long Island and appear limited to release stations less than ten miles from the shore.

At the northwest apex, drift cards released nearest the Long Island shore were beached by west winds. Drift card strandings, within six days, on the New Jersey shore were driven by northeast to east winds. Southeast to southwest winds became more effective in causing stranding as the distance of the drift card from release point became nearer to the New Jersey coast.

D. Observed Rates of Sea Surface Drift

The data of Figure I-14 show selected drift vectors of interface drift cards that stranded on Long Island and New Jersey within six days of their release. These vectors were selected both on the basis of maximum drift velocities of a group of drift cards recovered in minimum times and by the average recovery direction. Cards from some release stations exhibited a considerable variation in drift direction and in these cases several vectors are indicated on the figure. These vectors summarize drift rates observed during the study period.

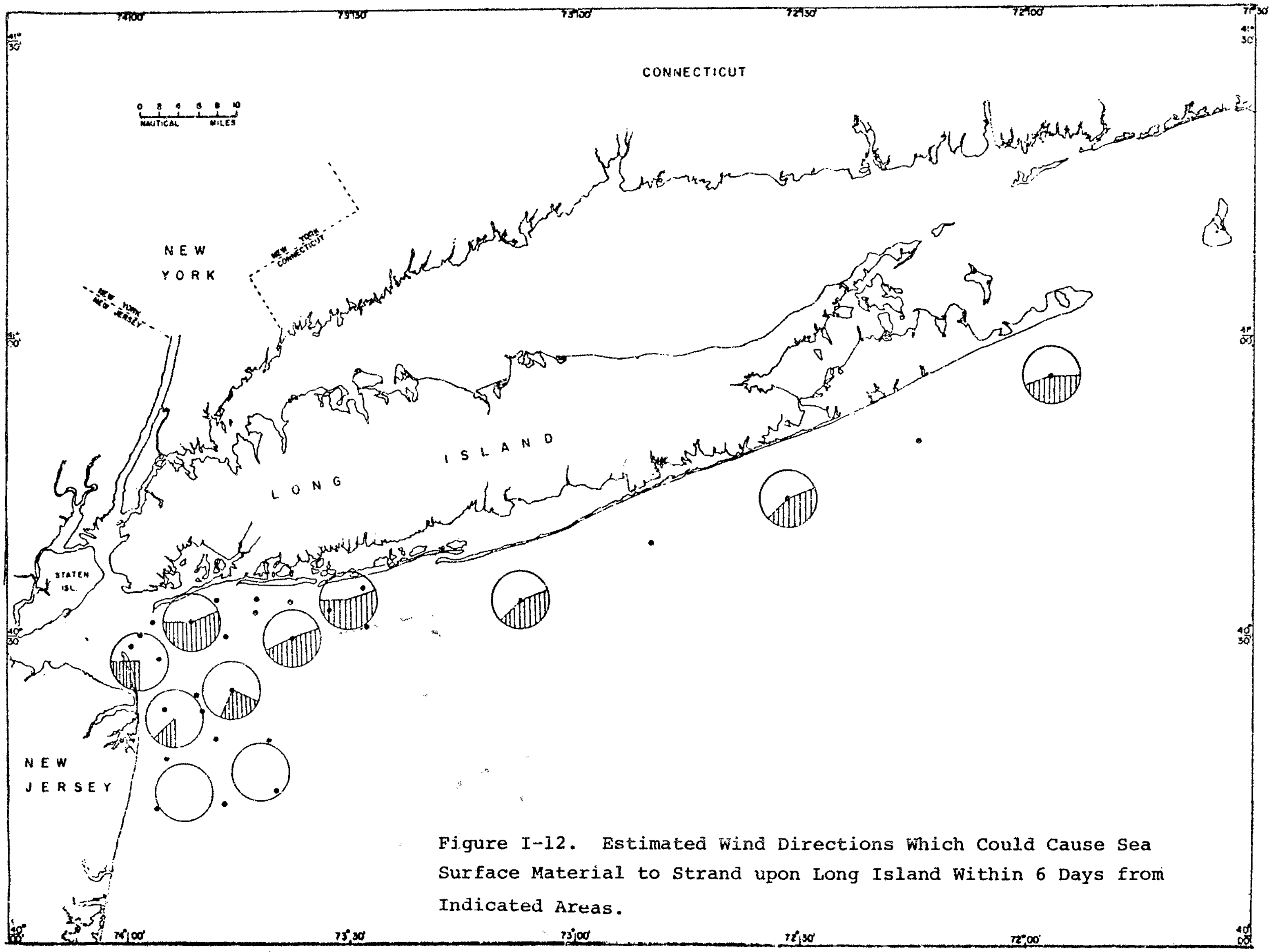

Figure I-12. Estimated Wind Directions Which Could Cause Sea Surface Material to Strand upon Long Island Within 6 Days from Indicated Areas.

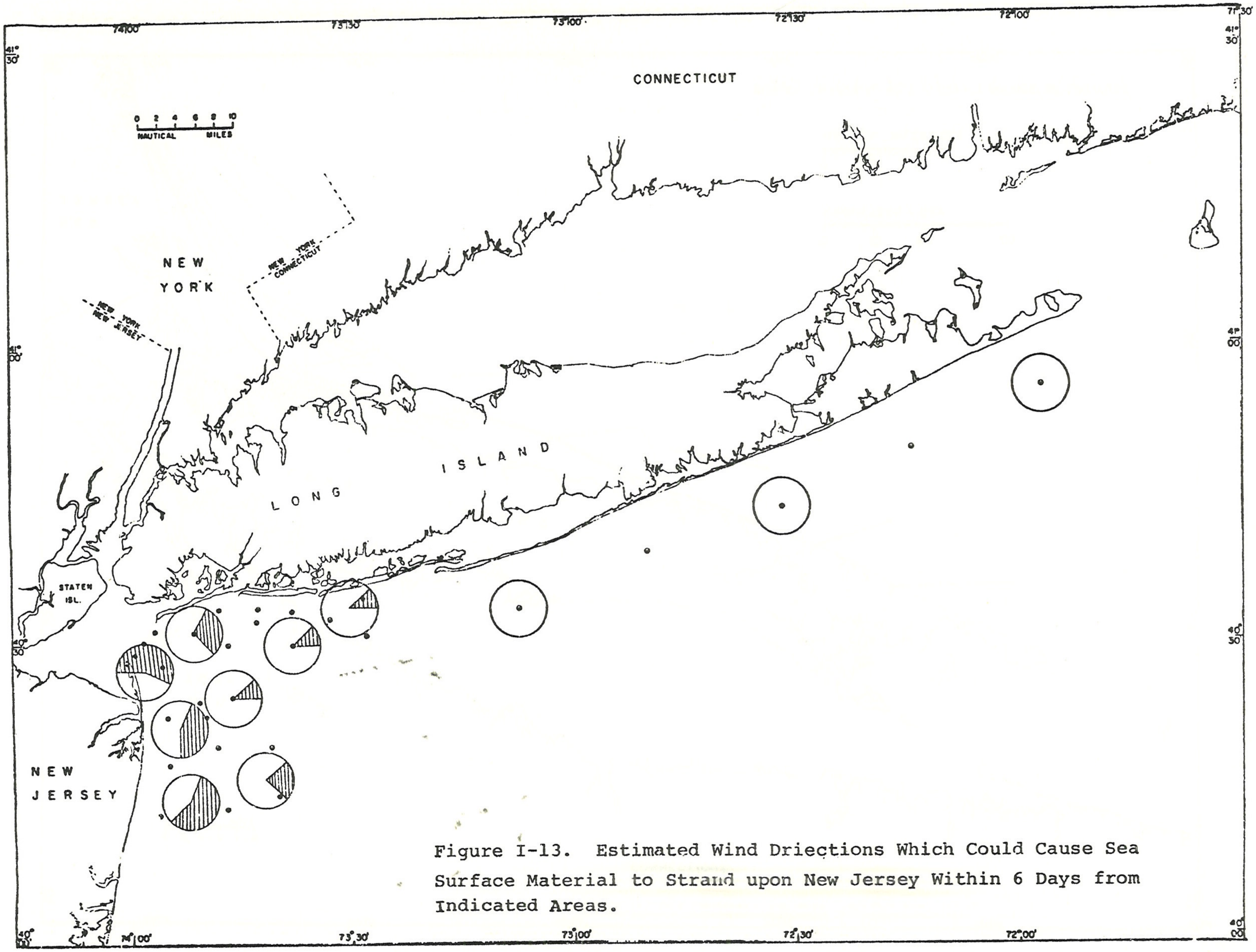

Figure I-13. Estimated Wind Driections Which Could Cause Sea Surface Material to Strand upon New Jersey Within 6 Days from Indicated Areas.

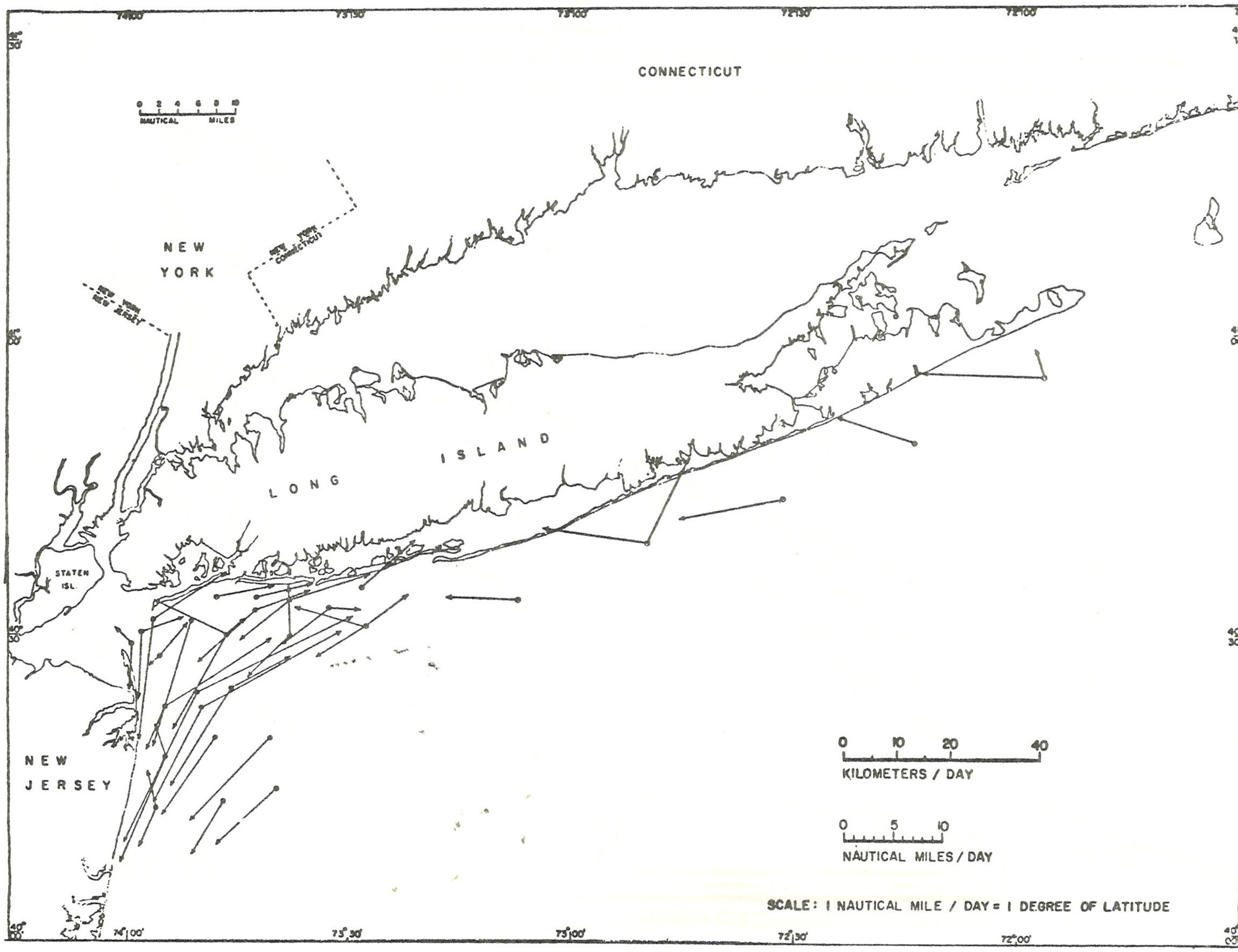

Figure I-14. Observed Displacement Rates of Selected Minimum Day Out Interface Drift Cards Reaching Long Island or New Jersey Within 6 Days.

The observed drift rates were variable, usually ranging between 10 to 15 cm/sec with occasional maximum drift speeds exceeding 35 cm/sec. Maximum drift speeds most often occurred when the direction of the surface drift was west under the stress of easterly winds, although in the northwest apex of the New York Bight southwesterly winds could drive drift cards at comparable velocities.

The most constant drift vectors causing stranding within six days existed in the offing of the New Jersey coast. The greatest variation in vectors appeared in the northwest apex of the New York Bight.

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Appendix 1

Bottom Drift Over The Continental Shelf Of The New York Bight

Appendix I

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I. Introduction

The northwest apex of the New York Bight (Figure I-1) receives massive daily discharges of urban wastes, because of its geographic proximity to the New York-New Jersey megalopolis. This urban-complex discharges in excess of 8×10^6 tons (7.2×10^6 metric tons) per year of solid wastes to become the major sediment source in the New York Bight (Gross, 1970). At present, the major portion of these generated wastes (sewage sludges, dredge spoils, building rubble and industrial (chemical) wastes are deposited in defined dumping grounds south of Ambrose Light (Figure I-3). Solid waste dumping practices generally assume that the wastes remain in the area of discharge.

Recent studies (National Marine Fisheries Service, 1972) observe that these wastes have not always been contained within the dump site boundaries. Public concern has been aroused by reported instances of material believed to be sewage sludge, moving onto or near Long Island beaches, north of the dump sites. A residual bottom drift by which such suspended bottom material could be transported toward shore has been observed (National Marine Fisheries Service, 1972; Bumpus, 1965; Charnell and Hansen, 1974). The sequence of physical events necessary to displace deposited sludge to Long Island has not been described. The mass balance description and quantification of this apparent dispersal of dumped wastes has received inadequate attention.

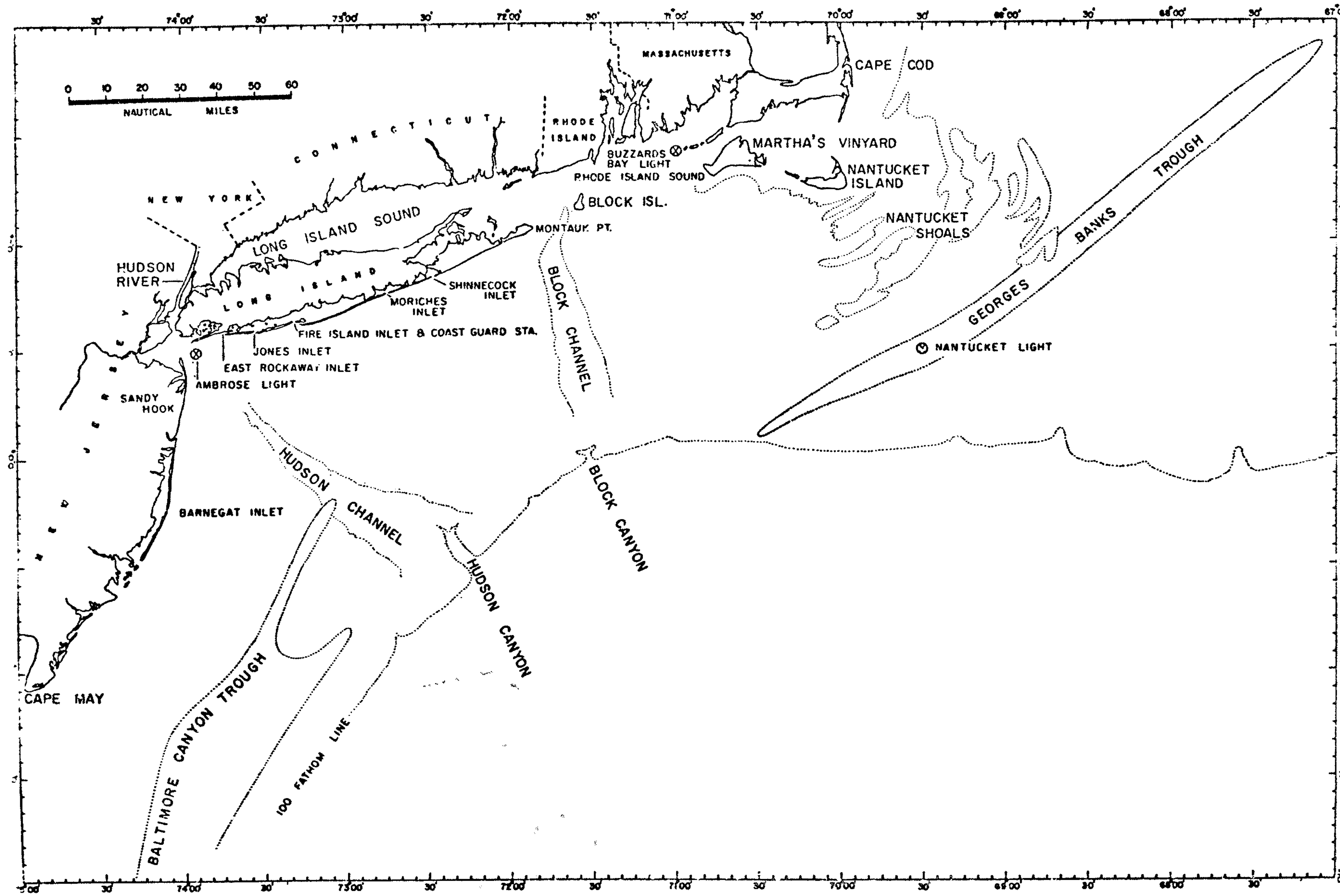

Figure I-1. The New York Bight, showing the Baltimore Canyon Trough and the Georges Banks Trough.

This field study was initiated to furnish observations on the rate and direction of movement of simulated waste materials released in the New York Bight including present dumping sites.

Seabed drifter data are included in this report as an appendix with minimum interpetation. Available funding did not cover a detailed analysis of bottom currents and sewage sludge transport.

II. Literature Review

Bottom circulation over the Middle Atlantic Bight has been described by Bumpus (1965), who employed seabed drifters (Woodhead and Lee, 1960) to measure the net residual drift. While the bottom drift in the Middle Atlantic Bight displayed variability, Bumpus (loc. cit.) was able to discern persistent patterns from the release-recovery paths of the seabed drifters. Bumpus observed that the net bottom drift over much of the New York Bight had strong westerly and southerly components. Inshore, within a zone between the shore and the 180 to 210 ft (55 to 64 m) depth contour, the residual drift was shoreward and most variable. The residual drift rate of the seabed drifters ranged between 0.09 and 0.7 n miles/day (0.2 and 1.5 cm/sec).

A landward bottom drift was most pronounced in the vicinity of estuarine discharges specifically from Long Island, Block Island Sounds (Bumpus, 1973) and the New York Harbor estuary (Charnell and Hansen, 1974). Seaward of this inshore zone the net drift appeared to be directed offshore.

Charnell and Hansen (1974) reported the results of circulation studies in the Northwest Apex of the New York Bight where seabed drifters and a few current meters were employed. Fixed current meters in the offing of the Long Island and New Jersey coasts showed a net vector displacement of bottom water to the northeast and east whereas in Sandy Hook Channel the net vector displacement was northwest into New York Harbor. The northeast trend toward Long

Island and away from New Jersey is implied by the large number of recoveries of seabed drifters launched east of the Hudson Channel. Charnell and Hansen found that 67% of all recovered seabed drifters were stranded on Long Island with 18% found on the New Jersey coast. These authors hypothesized that the low recovery of seabed drifters within New York Harbor (11%) resulted from the heavily developed shoreline consisting of docks, piers, bulkheads, etc., which prevented the landing of drifters instead of indicating a weak estuarine circulation.

These investigators described a clockwise gyre in the Northwest Apex which was superimposed upon the landward movement of bottom water into the New York Harbor estuary as modified by short term dispersive processes such as tide and wind currents. Descriptive details of this clockwise gyre are unclear and the mechanisms by which such an anticyclonic motion is driven have not been established.

A seabed drifter study in conjunction with fixed current meters between Jones Inlet and Fire Island Inlet, New York, showed a bottom drift directed shoreward in the presence of southwest to northwest winds (Marine Sciences Research Center, 1973). Northerly displaced seabed drifters had speeds of 0.06 to 0.8 n miles/day (0.12 to 1.8 cm/sec) which agree with the range reported by Bumpus (1965). The average residual drift for seabed drifters recovered within ten days on Long Island was 0.47 n miles/day (1 cm/sec) (Marine Sciences Research Center, 1973). During periods of upwelling along the Long Island shore, fixed current meters recorded bottom drift speeds of 1.8 n miles/day (3.8 cm/sec) (average of 6-day period) or more (Marine Sciences Research Center, 1973). These data imply that bottom residual drift speeds may be higher than indicated by seabed drifters.

Morse, et al. (1969), Halliwell (1972) and Crickmore (1972) indicated that the pattern of return exhibited in their seabed drifter studies, appeared to generally agree with the displacement of radioactively labeled sediments. Charnell and Hansen (1974) found that the distribution of organic carbon in the sediment surrounding the sludge dumping ground was consistent with the direction of net bottom drift indicated by seabed drifters.

Calibration studies of the movements of seabed drifters relative to the actual bottom current movement have been attempted under laboratory conditions in a tank (Woodhead and Lee, 1960; Ellet, 1962) and throughout field observations (Jones, et al., 1973). Woodhead and Lee (1960) found that seabed drifters tended to move at the same speed as the water when current speeds were above 25 cm/sec. At lower speeds their rate was less (at 5 cm/sec only 85% of water speed). Ellet's (1962) tank studies indicated that at speeds ranging from 0.15 kts to 0.85 kts (8 cm/sec to 44 cm/sec), seabed drifters moved at a speed defined by the equation $y = 1.099x + 3.90$; where x equals the drifter speed and y equals the actual current speed.

Jones, et al., (1973), employed side-scanning sonar to track, in situ, the movement of a seabed drifter fitted with an acoustic transponding tag. The results of this study indicated that when near bottom currents exceeded speeds of 30 cm/sec, seabed drifters "hopped" from the bottom with amplitudes ranging to 30 ft (10 m) above the sea floor and for periods ranging to 15 min.

These observations demonstrate that tidal or wave-induced turbulence can generate current speeds capable of causing seabed drifters to be moved up from the sea floor. Such factors complicate the question of how closely seabed drifters simulate the net residual drift of bottom waters as well as, sedimented and dumped wastes.

It is clear that greater effort is required in the future use of seabed drifters for calibrating their drift efficiency and behavior relative to a discrete water parcel and under a graded series of current speeds and turbulent states.

III. Materials and Methods

A. Field Techniques

At each station, a bouquet of usually ten Woodhead seabed drifters was released monthly from either a chartered twin engine aircraft (Stations 50 to 57) or a U. S. Coast Guard HH-3F helicopter (Stations 60 to 80) on separate but consecutive days. Seabed drifter release locations are shown in Figure I-2.

Aircraft navigation used VOR and DME which had a conservatively estimated accuracy of ± 0.27 nm (0.5 km) furthest offshore and within ± 0.16 nm (0.3 km) nearshore. The helicopter employed an AYN-1 navigational computer to determine the location. This system used Loran, Tacan and Doppler navigational aids. The accuracy of this system was conservatively estimated at ± 0.27 nm (0.5 km).

The behavior of the package of seabed drifters dropped from the aircraft into the ocean was observed prior to the study. On a trial flight using the Marine Sciences Research Center of SUNY's R/V MICMAC as a target, packages of seabed drifters were released from altitudes of 1000 ft (305 m), 500 ft (152 m) and mast height at an airspeed of 180 kts (333 km/hr). Drifter packages thus released, all landed within 300 ft (92 meters) of the target. On the basis of this trial, we decided to release the drifters from the aeroplane at an altitude of 500 ft (152 m). Drifters were released from the helicopter at an altitude of 50 ft (15 m).

A total of 4,341 Woodhead seabed drifters (Woodhead and

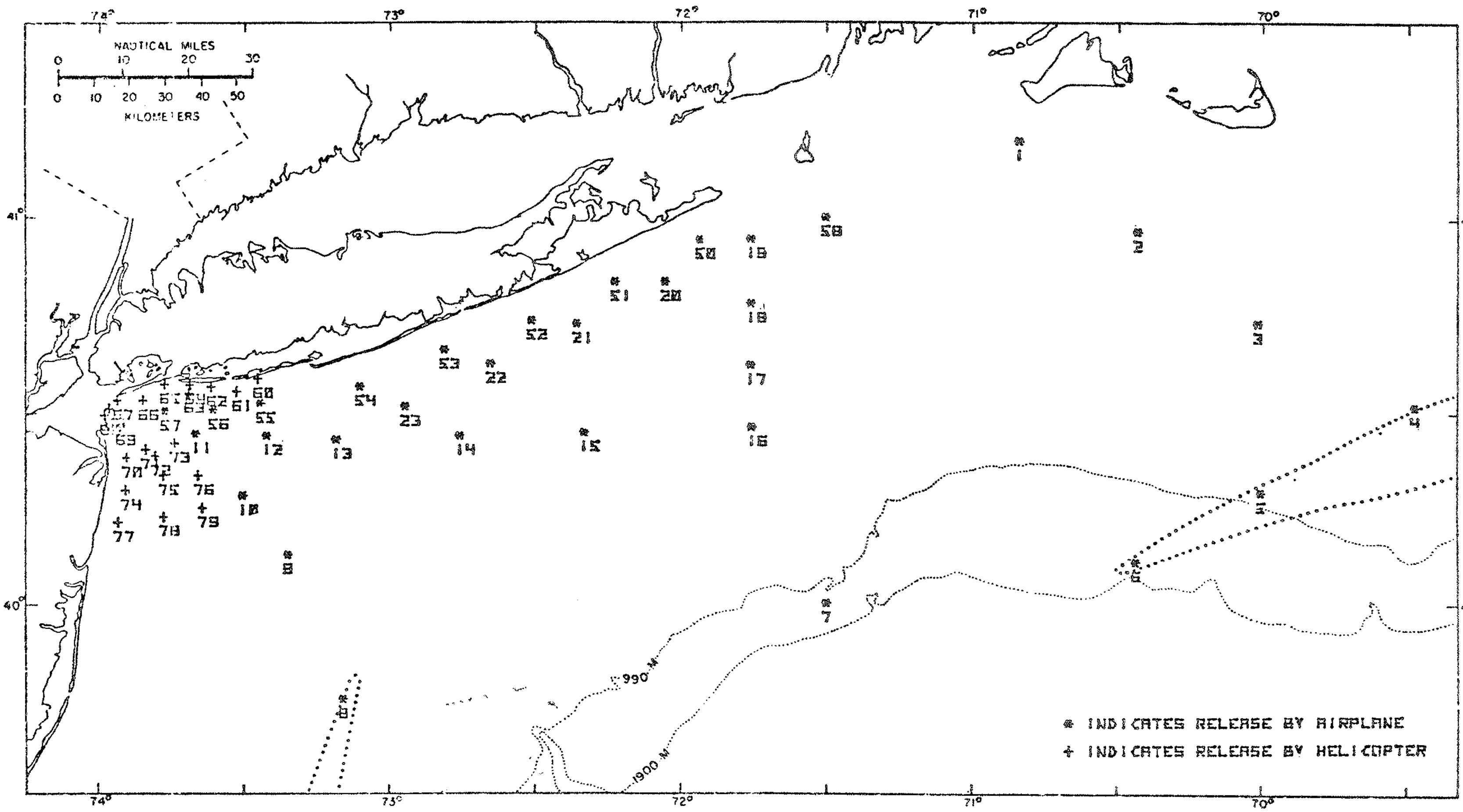

Figure I-2. RELEASE SITES FOR DRIFTERS LAUNCHED AT MONTHLY INTERVALS FROM 22 JANUARY TO 6 SEPTEMBER 1974

Lee, 1960) was released within the New York Bight on twelve flights between 22 January and 16 September 1974. The sampling grids for this study (Figures I-2 and I-3) consisted of fifty-three release stations sampled on a monthly basis and fifty odd stations sampled just once (See Vol. II). Stations were situated at the dredge spoil (Station 71), cellar dirt (Station 72), sludge (Station 73) and summer acid dumping grounds (Station 75) and near the diffuser of the Wantagh ocean outfall (Station 60). Table I-1 lists the latitudes and longitudes of the launch stations sampled monthly; Table I-2 lists the dates of launch.

B. Data Analysis

An IBM 370 and a Hewlett Packard (HP) 9830A were used to analyze the drifter data. Data were stored on tape cassettes for processing on the Hewlett Packard which plotted drifter trajectories. The IBM 370 listed the data from card decks.

The data listing program for the IBM calculated the distance and direction traveled by the Great Circle navigation method. The release to recovery time was calculated from the exact time of launch to an assumed recovery time of 1200 hrs on the day of recovery for all drifters, except those found on the day of their launch, which had an assumed recovery time of 1800 hrs.

The shortest release-recovery paths of the returned drifters were plotted on the Hewlett Packard 6830A. The

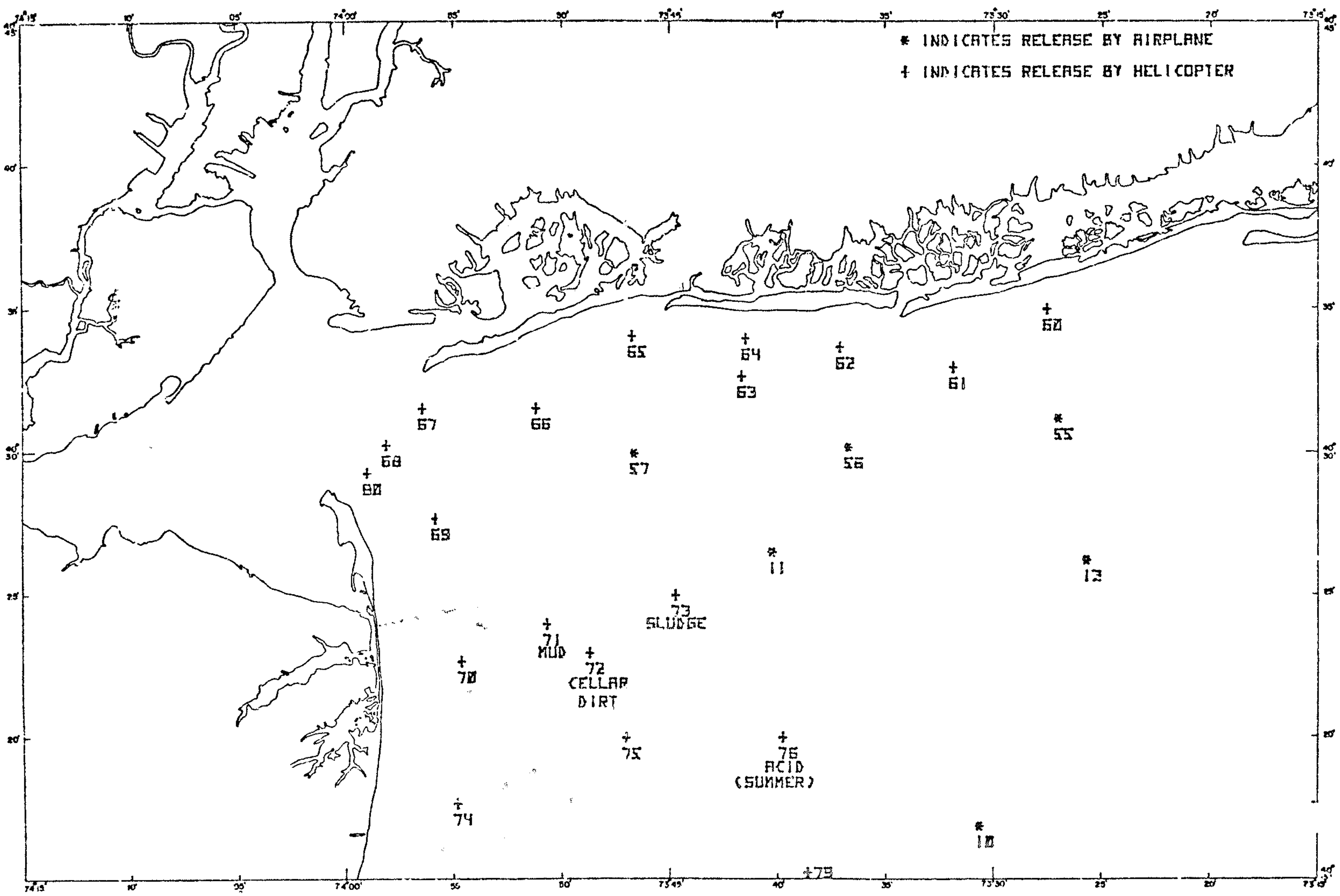

Figure I-3. RELEASE SITES FOR DRIFTERS LAUNCHED AT MONTHLY INTERVALS FROM 22 JANUARY TO 6 SEPTEMBER 1974

Table I-1. Seabed Drifter Release Station Data

Station #	Latitude		Longitude		Release Quantity*
	Release Locations				
1	41	12.0	70	50.0	10
2	40	57.6	70	25.4	10
3	40	43.2	70	00.5	10
4	40	30.0	69	28.2	10
5	40	17.0	70	00.0	10
6	40	6.2	70	26.0	10
7	40	00.0	71	30.0	10
8	39	45.0	73	10.0	10
9	40	07.6	73	21.4	10
10	40	16.9	73	30.8	10
11	40	26.5	73	40.5	10
12	40	26.2	73	25.8	10
13	40	25.6	73	11.4	10
14	40	26.2	72	45.8	10
15	40	26.7	72	20.0	10
16	40	27.5	71	45.4	10
17	40	37.0	71	45.6	10
18	40	46.6	71	45.4	10
19	40	56.6	71	45.5	10
20	40	50.0	72	03.2	10
21	40	43.5	72	21.5	10
22	40	37.3	72	39.4	10
23	40	30.7	72	57.2	10
50	40	56.5	71	56.0	10
51	40	50.0	72	13.5	10
52	40	44.0	72	30.9	10
53	40	39.5	72	49.0	10
54	40	33.8	73	06.5	10
55	40	31.2	73	27.1	10

Table I-1. Seabed Drifter Release Station Data

cont'd.

Release Locations

Station #	Latitude		Longitude		Release Quantity*
56	40	30.2	73	36.9	10
57	40	30.0	73	46.9	10
58	41	3.2	71	30.0	5**
60	40	35.0	73	27.6	10
61	40	33.0	73	32.0	10
62	40	33.7	73	37.3	10
63	40	32.7	73	41.9	10
64	40	34.0	73	41.7	10
65	40	34.1	73	47.0	10
66	40	31.6	73	51.5	10
67	40	31.6	73	56.8	10
68	40	30.3	73	58.5	10
69	40	27.7	73	56.2	10
70	40	22.7	73	55.0	10
71	40	24.0	73	51.0	10
72	40	23.0	73	49.0	10
73	40	25.0	73	45.0	10
74	40	17.7	73	55.2	10
75	40	20.0	73	47.3	10
76	40	20.0	73	40.0	10
77	40	12.7	73	56.7	10
78	40	13.6	73	47.2	10
79	40	15.0	73	39.1	10
80	40	29.0	73	59.8	10

*only 5 seabed drifters were released per location in January and February at Stations 1 to 57; in April at Stations 1 to 5.

**only released in April, May, June and July plots assume straight line trajectories for convenience and cross land areas except when drifters were recovered within New York Harbor or Long Island Sound. In these instances, drifter tracks were channeled via center points so that land areas would not be crossed.

IV. Results

A total of 4,341 seabed drifters was released from aircraft between 22 January and 16 September 1974. The majority of these were released during routine monthly flights at the fifty-three release locations of the basic study grid shown in Fig. I-2. Four additional air drops were conducted on 20 April, 6, 9, and 16 September either to observe the effect of forecasted storms on circulation or to release drifters along the Georges Bank and Baltimore Canyon troughs.

Thirty-one per cent or 1,346 of these drifters were returned by 1 December 1974. Of the 1,346 drifters recovered, seventy-one per cent stranded on the New York shoreline. Twenty per cent stranded on the New Jersey shoreline, four per cent on the Connecticut, Rhode Island, and Massachusetts shorelines and five per cent were found at sea. Seven per cent of all seabed drifters released were recovered within the New York harbor complex.

Seabed drifters released within the northwest apex of the New York Bight which we will consider as including stations 10-12, 55-57 and 60-80 (Figure I-3), had a total of 740 recoveries which comprised fifty-five per cent of all seabed drifters returned. Of these, sixty-three per cent stranded on New York shores with thirty-five per cent recovered on New Jersey. Thirteen per cent of seabed drifters released in the northwest apex were found in New York Harbor - Raritan Bay.

The data of Table I-2 show an analysis of drifters launched and number and per cent recovered as a function of each drifter release drop.

Table I-2. Comparison of the Per Cent Recovery of Seabed Drifters Each Month to 1 December 1974.

Launch	# of Drifters Released	# of Drifters Recovered	% Recovered
January, 22-23	260	80	31
February, 18-19	229	75	33
March, 19-20	517	198	38
April, 15-16	525	151	29
April, 20	155	92	59
May, 20-21	515	148	29
June, 24-25	525	192	37
July, 22-23	515	145	28
August, 19-20	525	141	27
September 6	240	92	38
September 9	160	19	12
September 16	175	13	7
Total	4341	1346	31

Release-recovery paths of all seabed drifters released for each air drop and recovered by 1 December 1974 are shown in Volume II, Figures 3 to 52. We have plotted those seabed drifters released in the northwest apex (Stations 11, 12, 55 to 57 and 60 to 76) separately from those released elsewhere in the New York Bight. In addition, the release-recovery plots for seabed drifters released in the northwest apex are reported in time intervals of ten days, twenty days, forty days and total period to 1 December 1974 whereas release locations elsewhere in the New York Bight are shown only for a forty day period and a total release-recovery period to 1 December 1974. For convenience, we will discuss the data results of these two areas separately.

A. New York Bight (exclusive of the northwest apex)

All seabed drifters released in the ocean within 10 n miles (18 km) of the south shore of Long Island and recovered by 1 December 1974 were recovered on Long Island generally within sixty days (Vol. II, Figures 3, 7, 11, 15, 20, 24, 28, 32 and 36). Minimum release-recovery periods for seabed drifters released approximately 10 n miles (18 km) from shore was eighteen days (Vol. II, Figure 3 [Station 22]). The net drift speed in this case was 0.43 n miles/day (0.9 cm/sec). More typically the release-recovery period of seabed drifters launched 18 km south of Long Island ranged between thirty and forty days. Seabed drifters released within 6 n miles (11 km) of shore could be recovered on Long

Island within six or seven days (Vol. II, Figure 32 [Stations 51 and 19]). The drift speeds were 3.4 n miles/day (7.5 cm/sec) and 2.2 n miles/day (4.7 cm/sec). At distances greater than 10 n miles (18 km) from shore, landings were less frequent and generally required more than one hundred days after release. These observations indicate that the net residual drift of bottom water is landward in a zone between the beach and the 121 ft (37 m) depth contour.

South of Montauk Point a strong estuarine circulation is evident where a bottom replacement current moves northward into Long Island Sound. Seabed drifters released at Stations 17, 18, 19 and 50 had high incidences of recovery on both the Gardiner's Bay and the Long Island Sound's shores of Southold town, Long Island (Vol. II, Figures 3, 7, 11, 15, 20, 24 and 36). A seabed drifter released at Station 17 located 48 km (26 n miles) south of Montauk Point was recovered on Orient Point, New York forty-five days after release (Vol. II, Figure 3). Other seabed drifter recoveries in Long Island Sound such as at the mouth of the Housatonic River, Connecticut (Vol. II, Figure 11) in 167 days or at Wading River, New York (Vol. II, Figure 24) in 61 days indicate that a well-developed estuarine circulation transports bottom water into the central basin of Long Island Sound. Displacement rates in these cases often exceed 0.9 n miles/day (2 cm/sec). The central core of this northerly directed bottom replacement current appears to follow the axis of Block Channel (Figure I-1).

B. The Northwest Apex (Figure I-3)

Seabed drifter recoveries reveal a persistent bottom drift that is directed toward the New York Harbor complex. This bottom replacement current responds to the seaward flow of freshwater discharged from the New York Harbor watershed. Frequently, seabed drifters released in the northwest apex were recovered deep within Raritan Bay or in Upper New York Bay (Vol. II, Figures 11A, 15A and 36A) which furnishes evidence that this upstream drift of saline water is well-developed. The transport of seabed drifters into the harbor complex demonstrates that this replacement current is capable of transporting particulate matter from the nearshore ocean into the harbor.

Upon this dominating estuarine circulation is imposed other factors, such as tides, wind-induced drift and littoral currents, which modify the simple dispersion of seabed drifters entrained in the bottom drift. The bottom drift shoreward appears most developed along the axis of the Hudson Channel. Seabed drifters released in the Hudson Channel (Station 75) showed a consistent drift to the northwest whereas adjacent stations on the shoulders of the Hudson Channel were more variable in drift direction (Stations 71, 72 and 73).

Of particular interest are recoveries from dredge spoil, cellar dirt, sludge and acid dumping grounds. The data of Table I-3 summarize the results of the recoveries from these stations and show that the majority of recoveries from the sludge and acid dumping grounds stranded on the New York shorelines whereas a majority from the dredge spoil and cellar dirt dumping grounds stranded on the New Jersey shoreline.

Table I-3. Recoveries of Seabed Drifters Released at Dumping Grounds in the New York Bight.

			Number Recovered			
		Total %				N.Y.
Station	Launch Site	Recovered	N.Y.	N.J.	at sea	Harbor
71	Dredge Spoil	51	7	28	1	5
72	Cellar Dirt	27	6	11	2	4
73	Sludge	31	18	3	1	2
76	Acid	23	11	5	0	0

The sludge dump (Station 73) and acid waste dump (Station 76) are located east of the Hudson Channel whereas the dredge spoil dump (Station 71) and cellar dirt dump (Station 72) are west. The Hudson Channel appears to form a boundary of divergence where the bottom drift east of the channel, as demonstrated by recovered seabed drifters, is northwest to northeast toward Long Island. West of the Hudson Channel the bottom drift is southwest to northwest toward New Jersey. Some conclusions as to drift direction can be in error since seabed drifters not recovered provided no data input.

C. Bottom Drift Vectors and Percentage Returned

Figures I-4 and I-5 are diagrams of the averaged vectors of release-recovery paths for seabed drifters having the shortest recovery time. The averaged data in these figures indicate that the residual drift in the area surveyed ranged from a minimum of 0.14 n miles/day (0.3 cm/sec) to a maximum of 0.96 n miles/day (2.1 cm/sec) with the average net drift rate for all seabed drifters returned between 0.01 and 0.014 kts (0.5 and 0.7 cm/sec). Areas of higher than average speed were found near sources of estuarine discharge, as the mouth of New York Harbor and on those stations located on the transect running south from Montauk Point.

The data of Figure I-4 indicate a uniform drift to the northwest from those stations located outside of the Northwest Apex and to the south of Long Island. Drift in the Northwest Apex was more variable, but nevertheless, dominated by a strong northward movement.

We have summarized the average percentages of seabed drifters returned to the New York and New Jersey shorelines by 1 December 1974 in Vol. II, Figures 69 and 72. Several prominent features may be observed in these plots. These features include:

1) The contour line of one percent recovery lay approximately 30 nautical miles (56 km) off the Long Island

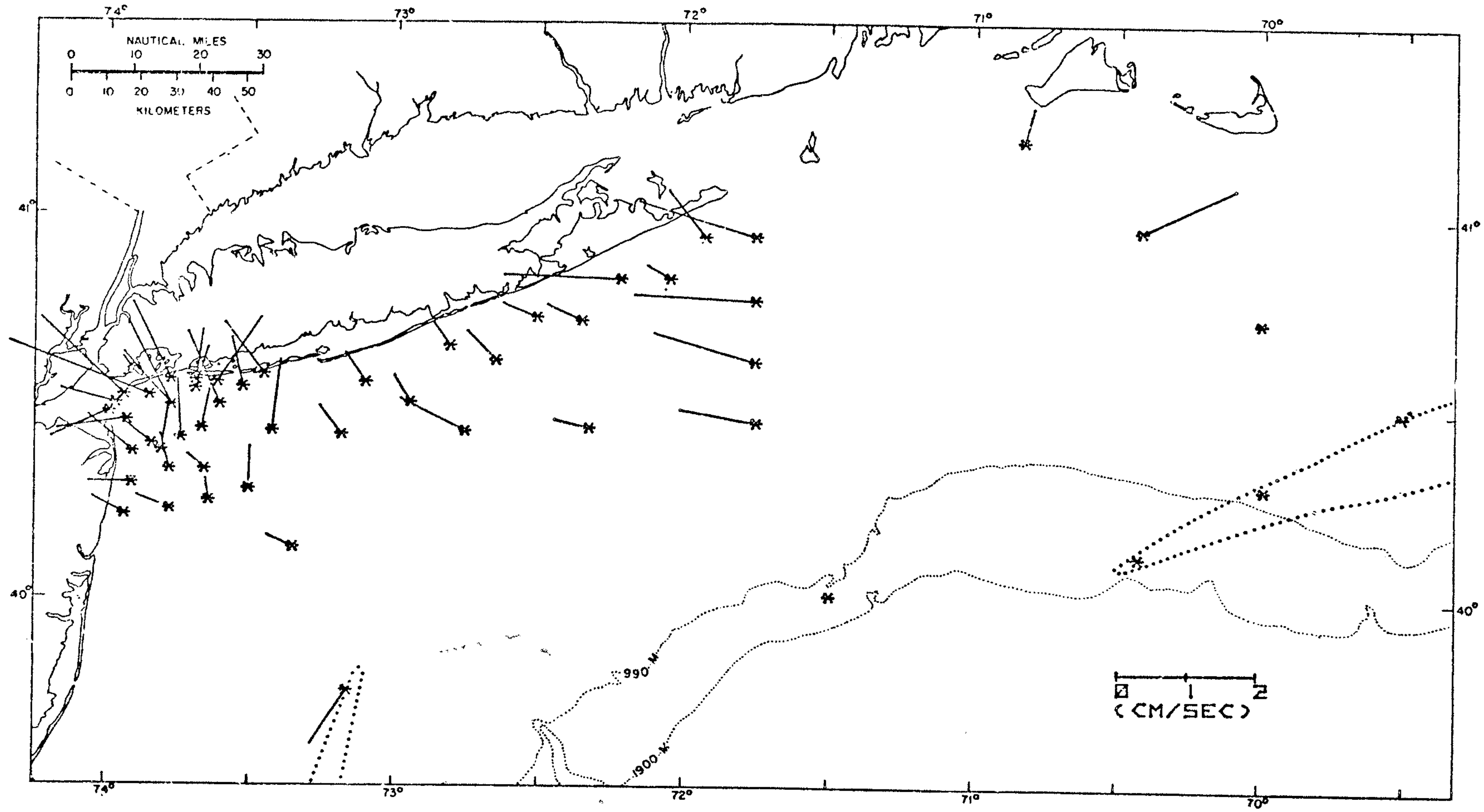

Figure I-4. Observed Net Residual Drift in the New York Bight as Measured by Woodhead Seabed Drifters from 22 January 1974 to 6 September 1974.

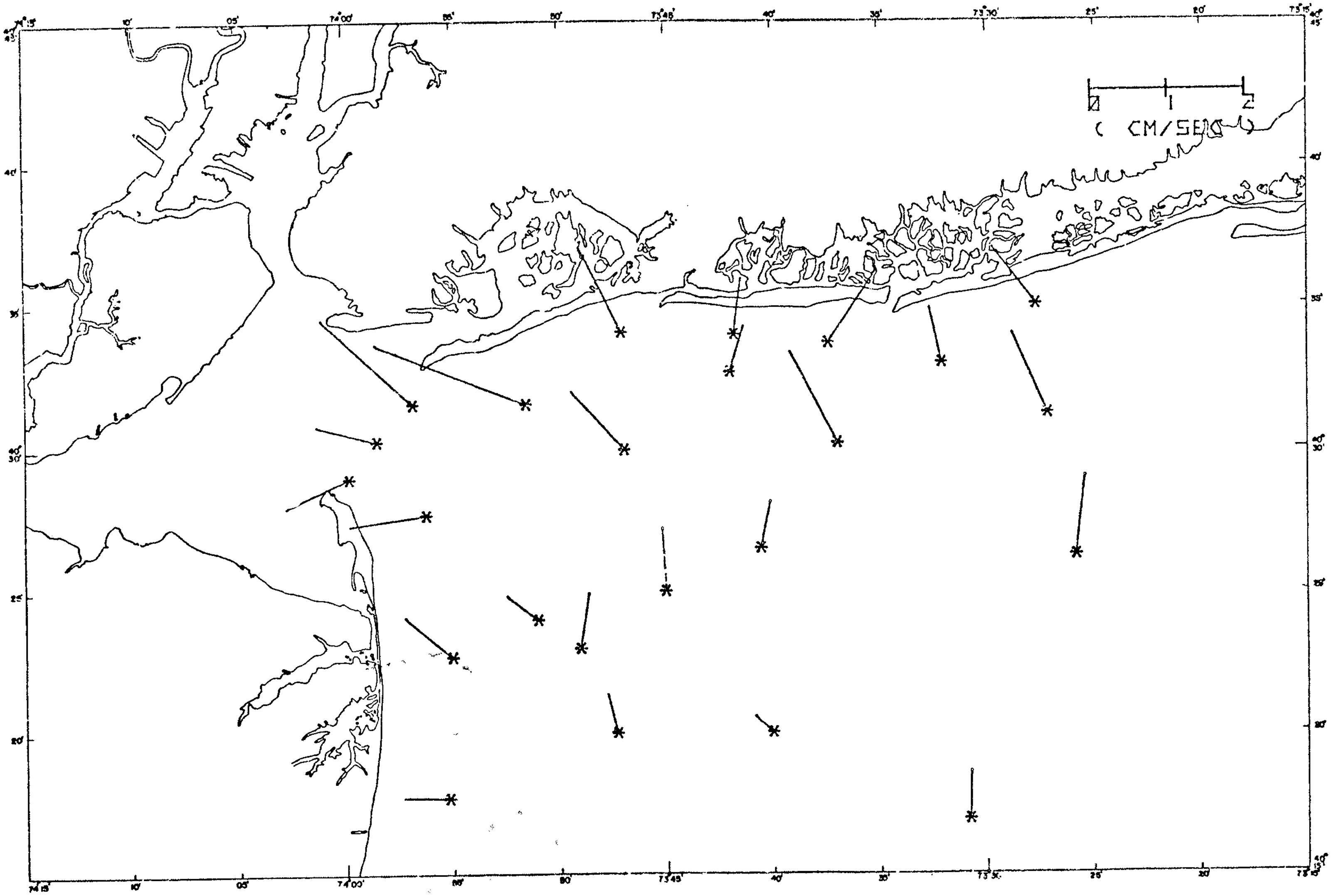

Figure I-5. Observed Net Residual Drift in the Northwest Apex of the New York Bight as measured by Woodhead Seabed Drifters from 22 January 1974 to 6 September 1974.

shoreline and from 10 to 31 nautical miles (19 to 56 km) off the New Jersey shoreline.

2) The contour line of ten percent recovery lay approximately 18 nautical miles (33 km) off the Long Island shoreline and 9 nautical miles (17 km) off the New Jersey shoreline.

3) The maximum average percentage of recovery was sixty percent on the New York shoreline and fifty percent on the New Jersey shoreline.

In Vol. II, Figures 70, 71, 72 and 73 we have summarized the average percentages of drifters stranding upon the New York and New Jersey shorelines for periods of 10 and 20 days following their launching. These contours indicated the following:

1) The contour of one percent recovery for the ten day period lay approximately 7 nautical miles (13 km) off the Long Island and New Jersey shorelines.

2) The contour of ten percent recovery for the twenty day period lay approximately 10 nautical miles (18 km) off the New York and New Jersey shorelines.

3) More than one percent of the seabed drifters launched from the cellar dirt, mud and sludge dumping grounds stranded upon the New York shoreline in periods greater than ten days and less than twenty days.

4) More than one percent of the seabed drifters launched from the cellar dirt and mud dumping grounds stranded upon the New Jersey shoreline in periods greater

than ten days and less than twenty days.

A compilation of all cards recovered is included in the listing in Vol. II. A summary of the pertinent recovery data for Stations 1 to 23, 50 to 58 and 60 to 80 is included in Appendix A, Tables A-1 to A-12 of this report. In the tables the columns are station numbers and the rows are the dimensions of the variables. The tables show station of release compared with, bearing in degrees; distance in kilometers; time out in day; speed in centimeters; and region of recovery on the New York and New Jersey shorelines.

V. Discussion

A. Circulation

A review of the release-recovery paths (Vol. II, Figures 3 to 46) and percent recovery contours for stranding (Vol. II, Figures 53 to 74) of the seabed drifter returns indicated that the near sea bottom circulation of the New York Bight had a strong onshore component where more than ten percent of the seabed drifters, released within 20 n miles (37 km) south of Long Island, were recovered on shore in less than eleven months. The seaward limits of the shoreward drift extends to the 90 to 140 ft (27 to 42 m) depth contours. Bumpus (1965) noted that shoreward migration extended to the 180 ft (54 m) depth contour. This difference can be attributed to the longer duration of his study where seabed drifter histories were observed over a period of several years compared to the less than one year release-recovery record of this study.

It has generally been conceded that the driving mechanism of the bottom circulation on the continental shelf of the New York and Middle Atlantic Bights is the geostrophic drift which is largely controlled be spatial variations in temperature and salinity. Geostrophic flow can also be modified by the two-layered estuarine circulation which occurs near the mouths of the estuaries (Norcross and Stanley, 1967; Mead, 1969; Charnell and Hansen, 1974) and by winds (Marine Sciences Research Center, 1972; Beardsley and Butman, 1974). The influence of the two-layered estuarine circulation which results in the increased movement and entrainment of near-bottom waters towards the mouths of the estuaries, due to the effect of the salt wedge, was qualitatively confirmed by the large percentage of drifters moving into the Hudson River and the Long Island Sound estuaries (Vol. II and Figures 7 to 12). Winds may affect the near-bottom drift in coastal waters by causing upwelling and/or the mass movements of the entire water column. Marine Sciences Research Center (1972) has shown, from data gathered by moored current meters, that upwelling occurred along the south shore of Long Island when winds blew from the southwest to the north-northeast (see Literature Review). A recent study (Beardsley and Butman, 1974), using moored current meters located 1 and 18 m from the bottom in 60 m of water, indicated that strong northeast storms may account for approximately two-thirds of the net transport on the continental shelf during the winter. These winds increased the current speeds some ten times their normal drift. Winds from the west were shown to have less effect.

In this study, we attempted to correlate drifter returns with various wind events. However, we were not able to demonstrate any such relationship. It is probable that we could not demonstrate these effects from the drifter returns because the average times out of all the drifters exceeded by many days the effects of any one wind event.

The Hudson River plume, a major driving mechanism of this estuarine circulation in the New York Bight, which discharges south along the New Jersey shoreline also appeared to inhibit the movement of the near-bottom waters towards this shoreline. The percent of seabed drifters returned on the New York shoreline which was approximately double that of the New Jersey shoreline qualitatively confirmed the existence of this mechanism. This concept agrees with that hypothesized by Morse, et al. (1969), for movement of the near-bottom waters defined by seabed drifter returns into the mouth of the Columbia River estuary on the west coast. In the Morse study, returns were also significantly higher on the shoreline opposite the plume. Salinity data collected on transects traversing the mouth of the New York Harbor inlet (O'Connors, et al., 1975) confirm that the near-bottom waters preferentially moves into the harbor at its eastern edge near Rockaway Point (Figure I-1).

Charnell, et al. (1972), and Charnell and Hansen (1974) have indicated that the near-bottom circulation within the northwest apex is dominated by a clockwise gyre. These authors have indicated that a seaward moving extension of this gyre must exist within the near-bottom waters of flow. We cannot interpret the release-recovery data of seabed drifters in this study as supportive to a clockwise gyre hypothesis. We must speculate that an apparent clockwise gyre may exist during periods of surface drift reversal with winds from west to southwest. Under these conditions upwelling along the Long Island shore occurs with bottom water moving north to northeast toward Long Island.

B. Implications of the study results to sludge dumping activities

Sewage sludge has been dumped at the present designated site since 1924. The latest report on the impact of sludge dumping (Charnell, 1975) indicates that there has not been any significant accumulation of these materials at this site. The fate of the sludges after their release and the reasons for the lack of accumulation are not quantitatively known. However, it has been assumed that the combined effects of the following mechanisms are largely responsible for the breakdown or transport of the sludges.

1. Advection and diffusion of those sludges suspended in the water column immediately after their disposal or resuspension due to storm events.

2. Advection and diffusion of the deposited sludges.

3. Biological and chemical decomposition.

Quantification of the role played by each of these mechanisms is unknown at the present time.

With respect to advection and diffusion, it is of interest to note that the study results have clearly indicated that the sludge dumping grounds are located within areas where substantial inshore movement has been observed. This inshore movement was exemplified by the thirty-one percent return of the seabed drifters launched from the sludge dumping ground and recovered on the adjacent shorelines during the eleven-month study period.

Given the long history of sludge dumping at this site, the studies by Morse, _et al_. (1969) and Jones, _et al_. (1973), both indicating the correlation between the movements of the seabed drifters and deposited sediment or sludge and the reported lack of accumulated sludge on the bottom (Charnell, 1975), it must be concluded that some fraction of these materials is transported away from the dump site and towards the New York shoreline.

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