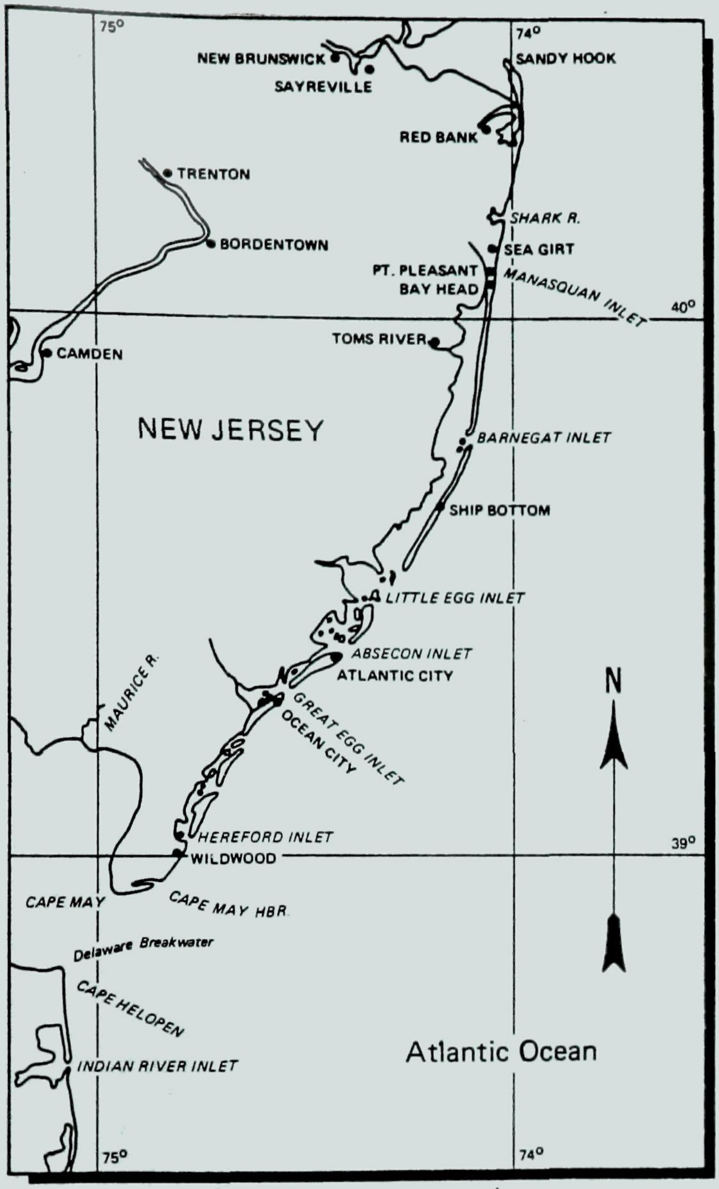

Green Tide Environmental Inventory 1986

An Environmental Inventory
of the New Jersey Coast / New York Bight
Relevant to Green Tide Occurance

U.S. Environmental Protection Agency Region II, October 1986

AN ENVIRONMENTAL INVENTORY
OF THE NEW JERSEY COAST/NEW YORK BIGHT
RELEVANT TO GREEN TIDE OCCURRENCE

(Short Title: Green Tide Environmental Inventory)

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SUMMARY OF FINDINGS

Recent data from the nearshore Middle Atlantic Bight and the New Jersey nearshore (0-20 m) regions clearly document high rates of primary production (about 500 g C/m^2-yr) that are much greater than the mean annual production for the continental shelf of the New York Bight (about 300 g C/m^2-yr). Anthropogenic nutrient loading and non-point source runoff from the New Jersey coastal zone undoubtedly contribute to such high rates of primary production. Nutrient loading is, however, only one factor in the occurrence of such high rates of summer phytoplankton production. The time scales associated with flushing and dispersive mixing are critical factors in determining the fate of nutrient inputs to the nearshore coastal zone. Nutrient enrichment, eutrophication and oxygen depletion are consequences of nutrient loading to the New Jersey coastal zone from anthropogenic and natural sources.

Historical data sets for the New York Bight were compiled to generate composite bottom oxygen distributions averaged over July to September from 1977 to 1985. The distribution of the minimum values of dissolved oxygen clearly documents the presence of hypoxic areas along the nearshore New Jersey coast. The effect of the Hudson plume is evidenced by progressively low oxygen (<1 ml/l) water extending south from Sandy Hook, NJ. A second hypoxic area is centered around the southern New Jersey coast north of Cape May to Atlantic City out to about the 20 m isobath. The southern nearshore hypoxic area is essentially the region where the green tide of 1984 and 1985 occurred. The similarity in the spatial distribution of nearshore hypoxia and the occurrences of green tide blooms, as well as other seasonally recurrent phytoplankton blooms along the New Jersey coast, suggests common physical processes that could account for these observed features.

Observations and numerical models of circulation processes indicate the occurrence of generally weak flow reversals over the nearshore/midshelf New Jersey coast during summer with return flow towards the south seaward of about the 40-60 m isobaths. The available data suggests, the occurrence of large scale clockwise weak gyres over the New Jersey midshelf during south-southwest wind events that are conducive to upwelling and the setup of flow reversals along the nearshore New Jersey coast. Such a circulation pattern would result in an increase in the residence time of a water mass over the New Jersey shelf such as was documented during the 1976 anoxic event. A key factor in the onset of localized (e.g., 1968, 1974) and widespread (1976) anoxic conditions off the New Jersey Coast is the occurrence of persistent winds from the southwest.

An increase in the residence time of a water mass in the nearshore southern New Jersey area would result in the accumulation of nutrients, particulate organic matter and patchy populations of a variety of phytoplankton species groups. If the time scale for the growth rate of the phytoplankton was less than the time scale for flushing of the water column, then a phytoplankton bloom could be initiated, assuming that nutrients were available and light and temperature were in the optimal range for a particular phytoplankton group.

Wind data from Atlantic City, NJ for July to August 1985 was used to predict water movement which was plotted as a progressive vector diagram (PVD). Total excursion of a particle during July, 1985 was seen to be on the order of 150 km. In August, however, a particle would have been retained within a relatively local area with a total excursion of only 30-50 km. The Atlantic City wind data suggest that the residence time water in the nearshore coastal area would have been significantly increased in August in comparison to July, 1985. The relatively persistent SW winds during July would have set up a flow reversal that possibly continued into August, 1985.

The results of this analysis suggest that wind driven transport patterns over the southern New Jersey coast may have been important causal factors in the development of the green tide blooms of 1984 and 1985. Periodic flow reversals of varying magnitude and duration, resulting from fluctuations in wind forcing, would be characterized by variable residence times of nutrients in the water column. The onset of water quality problems (e.g., algal blooms, hypoxia-anoxia) in the nearshore region are related to the respective time scales for biological and chemical reaction rates in relation to those for flushing of the water column by advective transport and mixing.

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1. INTRODUCTION

1.1 PROBLEM LOCALE

During the summers of 1984 and 1985, algal blooms in the nearshore New Jersey area from Ocean City to Atlantic City resulted in greenish discoloration of the water and complaints from recreational users of these highly popular beach areas. Swimmers reported skin reactions, respiratory problems, nausea, sore throat, eye irritation, fatigue, dizziness, fever and lung congestion as a result of exposure to the algal bloom. Localized hypoxic areas and fishkills were also reported coinciding with the decay of the bloom.

Unconfirmed identification of the causative organism by the New Jersey Department of Environmental Protection (NJDEP) and National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) Laboratory at Sandy Hook identified the green tide organism is a small dinoflagellate, *Gyrodinium aureolum*. Identification confirmation, cultures, and physiological/nutritional studies of the organism are yet to be completed. A literature review of *Gyrodinium aureolum* has been prepared by the NMFS and NJDEP.

Coincident with the occurrence of the green tide in 1984, the Cape May County Utilities Commission municipal sewage treatment plant came on-line with a discharge of 7.6 million gallons per day (mgd) into the Atlantic Ocean at Ocean City. Numerous other coastal outfalls discharge wastewater directly into the Atlantic Ocean or into several New Jersey inlets and bays (e.g., Egg Harbor).

Control strategies for management of the occurrences of future green tides should be developed. If it can be shown that anthropogenic nutrient sources were a significant factor in the outbreak of the algal blooms in 1984 and 1985 (specifically the new wastewater discharge from the Ocean City treatment plant), then National Pollution Discharge Elimination System (NPDES) permit limits, or other management strategies, can be prepared and implemented to control, for example, the discharge of nitrogen into the nearshore New Jersey coastal ecosystem.

A number of naturally occurring physical, chemical and biological processes also serve to control primary productivity and the outbreak of algal blooms such as the green tide. Nutrient budgets and analyses of interannual variability of physical, chemical and biological processes are required to evaluate the relative significance of anthropogenic and natural factors in controlling the development of the green tides. Data on physiological behavior and the nutritional response of *Gyrodinium auroleum* will greatly assist in this evaluation.

1.2 OBJECTIVES

The primary objective of the environmental inventory is to characterize existing data and information on physical, chemical and biological processes within the New York Bight. The characterization will focus on the (1) continental shelf of the New York Bight and (2) the nearshore coastal waters off southern New Jersey. The characterization will address those factors relevant to the occurrence of nearshore and coastal shelf phytoplankton blooms.

1.3 BACKGROUND

Biological productivity of continental shelf ecosystems is dependent on nutrient inputs, available light, seasonal temperatures, and the extent of coupling between the benthic-pelagic components of the food web. Because of intermittent upwelling and a relatively broad shelf, primary productivity (300 g C/m^2yr) and fishery yields (10 $tons/km^2yr$) of the New York Bight continental shelf are comparable to major shelf-sea ecosystems such as the Bering Sea and the upwelling region off the Oregon shelf. The New York Bight/Middle Atlantic Bight ranks as one of the more biologically productive coastal ecosystems of the world oceans (O'Reilly *et al.*, in press). By contrast, relatively constant upwelling off the Peru coast results in an order of magnitude higher fishery yield with primary production rates about fivefold higher than the New York Bight (Walsh, 1980).

During the past 30 to 40 years, however, anthropogenic nitrogen loading to the New York Bight (Figure 1.1) has increased by an order of magnitude because of deforestation, sewage disposal and the use of agricultural fertilizers (Walsh *et al.*, 1981). Recent estimates indicate that anthropogenic nitrogen loading has increased phytoplankton production within the Apex/Hudson plume by about 30% (Malone, 1984). Direct measurements of primary production

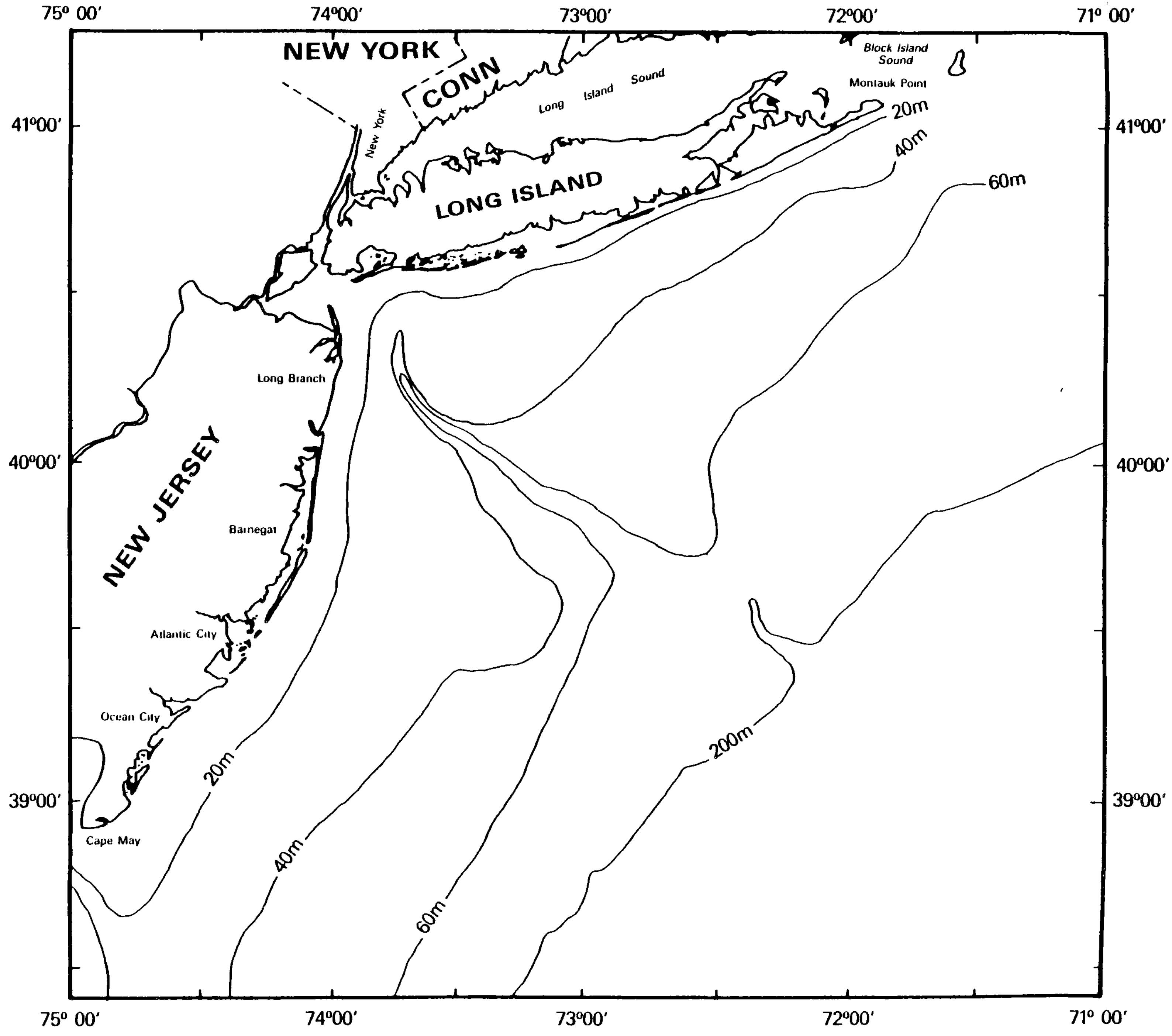


Figure 1.1. Geographic extent of the New York Bight.

in the nearshore (< 20 m) of the Middle Atlantic Bight have documented a highly enriched coastal ecosystem with annual primary production estimates of 505 g C/m^2yr (O'Reilly et al., in press).

A number of water quality problems have been well documented in the New York Bight over the past 10-15 years (e.g., Segar and O'Connor, 1982; O'Connor et al., 1977). Problems have included: nutrient enrichment, eutrophication, oxygen depletion, fish kills, fin rot and fish diseases, pathogens, toxicants in sediments/biota, floatables/debris, and oil spills. Specific problems documented for the New York Bight include, for example:

1951	fish kill off Long Island
1968	localized hypoxia/fish kills off New Jersey, red tides
1971	localized hypoxia/fish kills off New Jersey
1972	red tides
1974	localized hypoxia/fish kills off New Jersey
1976	debris washup on Long Island beaches
1976	shelf-wide bloom of *Ceratium tripos*
1976	shelf-wide anoxia/fish kill
1980	localized hypoxia/fish kill, red tides in Northern New Jersey, green tides in Long Island
1984	green tide off New Jersey and Long Island
1985	green tide off New Jersey
1985	brown tide in the bays of Long Island

2. CIRCULATION

2.1 HYDROGRAPHIC REGIONS OF THE NEW YORK BIGHT

The New York Bight (Figure 1.1) (NYB) is defined as the region bounded by the New Jersey and Long Island coasts between 38°50' and 41°N latitude from 71°W longitude shoreward of the 200 m isobath. The major hydrographic features of this area strongly influence the relative distributions of nutrients, plankton and dissolved oxygen between the nearshore, coastal and oceanic boundaries.

The most significant of the hydrographic features were identified by Malone et al. (1983) as (1) coastal plumes from the Hudson-Raritan and Delaware estuaries in the Bight Apex and off the southern New Jersey coast (Malone, 1984; Bowman, 1978; Bowman and Wunderlich, 1977), (2) bottom topography, tidal mixing and upwelling within the coastal boundary layer (Scott and Csanady, 1976; Csanady, 1976), and (3) a summer cold pool within the bottom layer bounded by the 40-80 m isobaths (Wright, 1976; Ketchum and Keen, 1955).

For the characterization of processes relevant to the occurrence of the green tides, the New York Bight will be considered as geographical regions of two spatial scales: (1) the continental shelf of the NYB (0-200 m) from Cape May, NJ to Montauk Point, NY and (2) the nearshore (0-20 m) southern New Jersey coast from Little Egg Inlet to Cape May (Figure 2.1).

Emphasis is placed on the nearshore New Jersey region for the following reasons: (1) the green tides of 1984 and 1985 appeared to be limited to the nearshore area within 3-6 miles of the coast, and (2) physical transport processes in the nearshore region are quite different from transport processes within the deeper coastal shelf region of the NYB (Csanady, 1976; Scott and Csanady, 1976; Hopkins and Dieterle, 1983; Hopkins and Swoboda, 1986). The seaward extent of the nearshore region is variable and depends primarily on the characteristic bottom depth (e.g., 20-30 m). Aggregations of similar oceanographic data into isobath dependent regions have been used previously to characterize oxygen depletion (Stoddard, 1983), nutrient distributions, and primary production (Malone et al., 1983; O'Reilly et al., in press) in the New York Bight.

Figure 2.1. The nearshore New Jersey region (0-20 m) of the New York Bight.

2.2 HYDROGRAPHIC CHARACTERISTICS OF THE NEW YORK BIGHT

Well-defined seasonal cycles of temperature, salinity and density in the New York Bight reflect seasonal forcing functions such as winds, solar heating, evaporation/precipitation, freshwater runoff, ocean currents and shelf/slope exchange. Bowman and Wunderlich (1976, 1977) summarize these data. The overview presented in this document is based on their summary, O'Connor et al. (1977), and Ecological Analysts and SEAMOcean (1983).

2.2.1 Temperature

The seasonal variation of sea surface temperatures at Sandy Hook and over the New Jersey shelf reflects seasonal variation in air temperatures and is closely correlated with air temperature at Atlantic City (Figure 2.2).

The variation in sea surface temperatures causes the water column to be well-mixed during the winter-spring (November to April), with thermal stratification developing in April-May. The stratified water column that develops in spring persists through September to October. Surface cooling and wind mixing erode the seasonal thermocline in September or October. Because of strong vertical gradients during the summer, the annual maximum bottom temperature in the Apex typically lags the surface layer by about 1-2 months (Figure 2.3).

During the summer, surface layer temperatures exhibit relatively weak spatial gradients over the Bight ranging from 20-24°C. Cooler water exists towards the coast. Bottom temperatures, by contrast, are characterized by strong cross-shelf gradients with temperature isopleths generally following bottom topography. A cold pool (< 7.5°C), a bottom water mass with origins in the Gulf of Maine, is a recurrent feature during summer. (Ketchum and Corwin, 1964; Colton and Stoddard, 1973; Beardsley et al., 1976; Hopkins and Garfield, 1979). The mean distribution of bottom temperature for August-September (Figure 2.4) shows the spatial extent of the cold pool extending from Georges Bank to Cape Hatteras.

2.2.2 Salinity

The annual cycle of salinity in the New York Bight results from the annual cycle of freshwater discharges and cross-shelf exchange of slope/shelf

Figure 2.2. Monthly mean air and sea surface temperatures for Atlantic City, Sandy Hook and the New Jersey shelf. (Source: Armstrong, 1979).

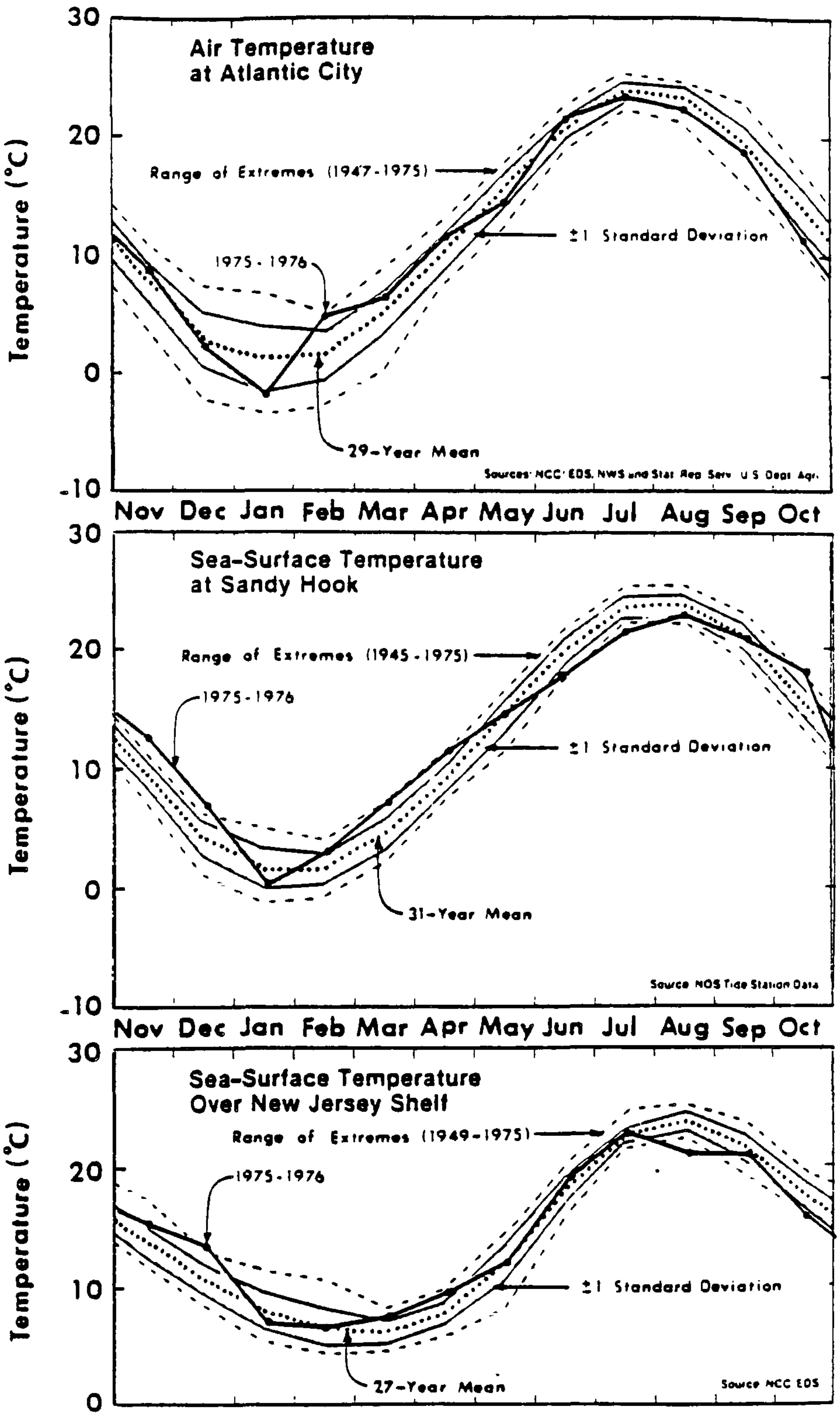


Figure 2.3. Seasonal pattern of Hudson River discharge, surface and bottom temperature, surface and bottom salinities for the New York Bight. (Source: O'Connor _et al._, 1977)

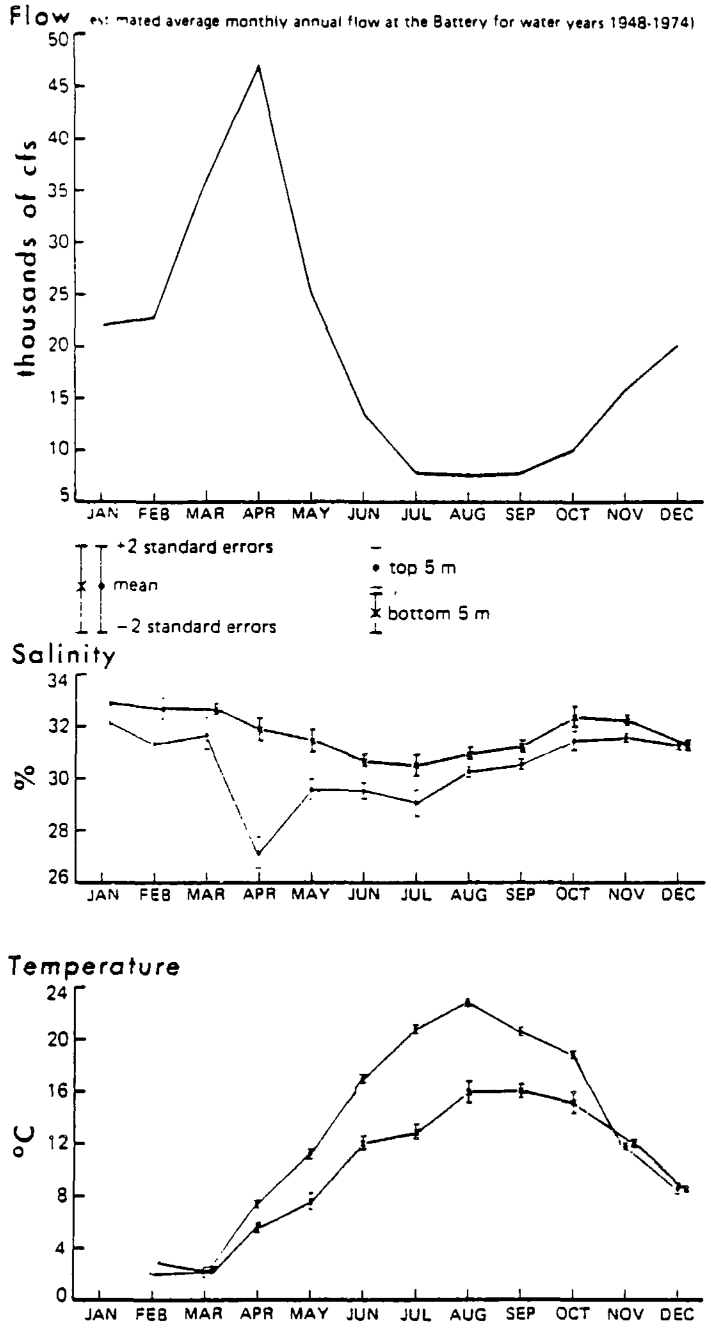
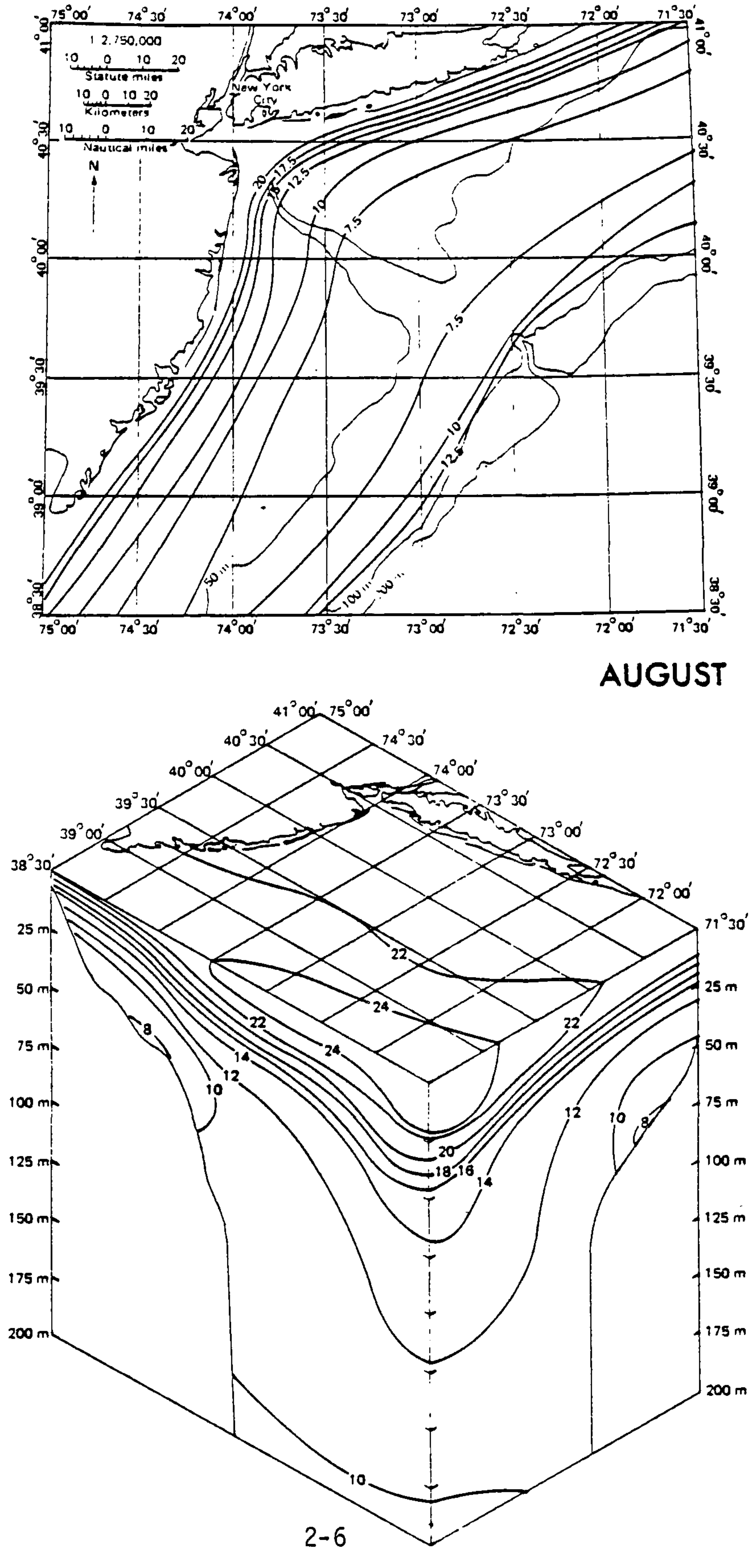


Figure 2.4. Bottom temperatures for the New York Bight in August. (Source: Bowman and Wunderlich, 1977).



water masses. Seasonal salinity data compiled for the Apex clearly shows the relationship to freshwater discharge from the Hudson River and Raritan Estuary.

During the spring period of peak runoff, surface salinity in the Hudson plume ranges from 28 ^{o}/oo to 30 ^{o}/oo, while bottom salinity ranges from 31 ^{o}/oo to 33 ^{o}/oo. (Figure 2.5). Salinity fields for summer (Figure 2.6) are characterized by the Hudson plume (S < 32 ^{o}/oo). In the bottom layer, salinity ranges from 33 o/oo over the shelf break to 31 ^{o}/oo within the Hudson plume. As with temperature, vertical profiles of salinity indicate that water masses are well mixed during winter and stratified during the spring and summer. (Figure 2.7).

2.2.3 Density

Water density, dependent on temperature and salinity, also follows a recurrent annual cycle within the New York Bight. Maximum density occurs during winter and minimum density occurs during summer. Winter water columns exhibit well-mixed conditions with neglegible differences between surface and bottom (Figure 2.8). In contrast, cross-shelf and vertical profiles of density during summer are characterized by strong gradients from surface to bottom and the development of a strong pycnocline during stratification.

The seasonal variability of vertical density stratification (density difference from surface to subpycnocline) for the New Jersey shelf is pronounced, with maximum stratification occurring from July-September. (Figure 2.8). The depth of the pycnocline varies across the shelf with a shallower pycnocline inshore and a progressively deeper pycnocline in the offshore direction (Figure 2.9). The depth of the pycnocline also varies seasonally as stratification of the water column progresses during the summer. Maximum stratification results on a relatively shallow pycnocline depth during July-August within the New Jersey midshelf region.

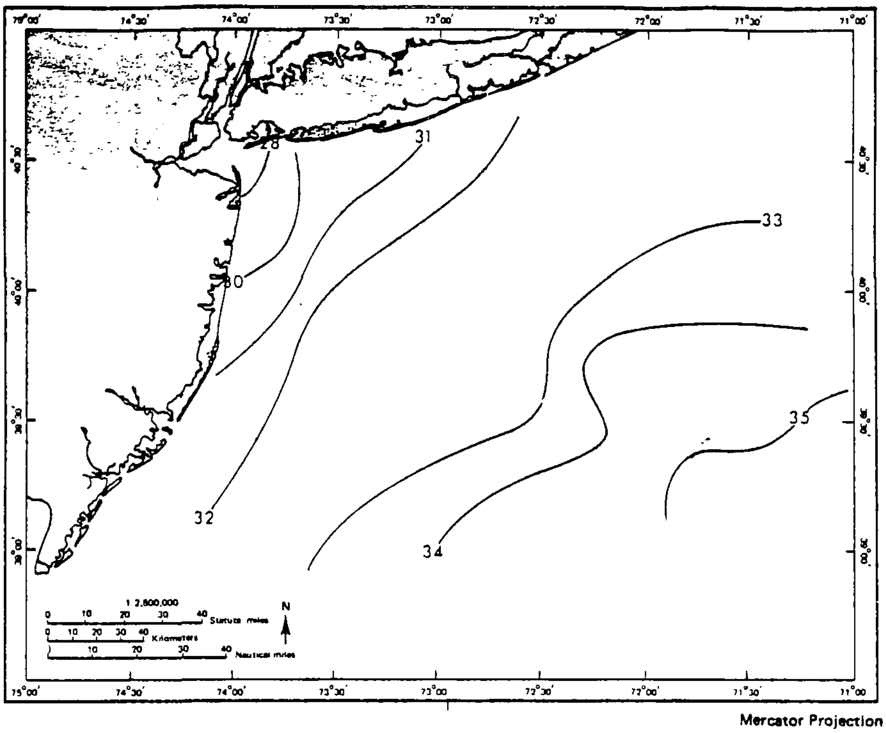
2.3 GENERAL TRANSPORT

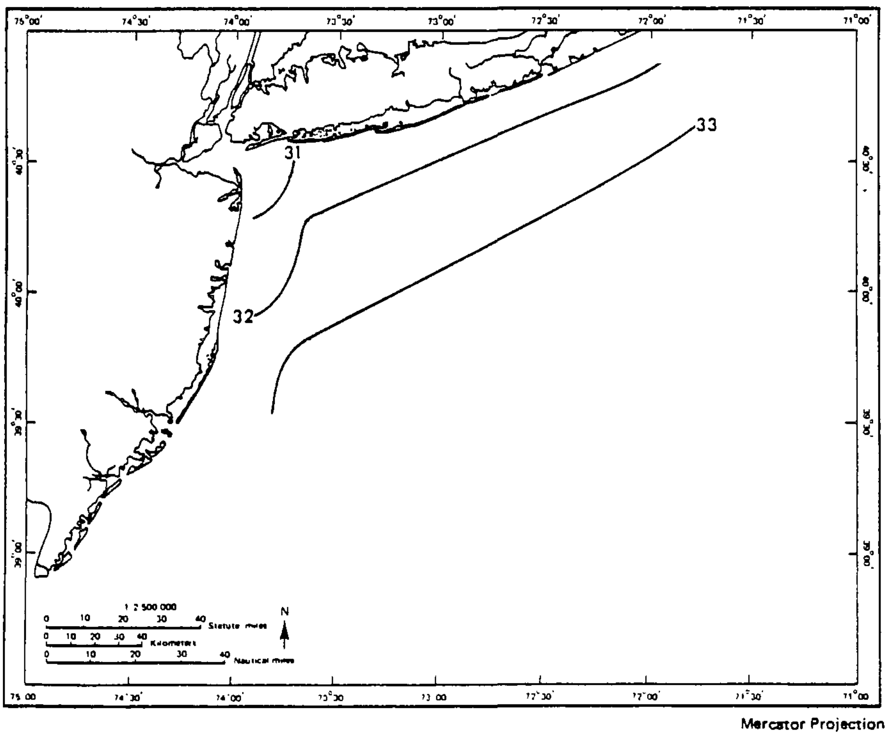
Physical transport within the New York Bight is characterized by (1) tidal flow and (2) non-tidal residual drift caused by winds, freshwater inputs and geostrophic effects. The combination of tidal and non-tidal residual drifts results in the overall circulation patterns of the continental shelf.

Figure 2.5. Spring surface and bottom salinities for the New York Bight. (Source: O'Connor et al., 1977).

surface salinity (°/oo)

spring averages
(April, May, June)





bottom salinity (°/oo)

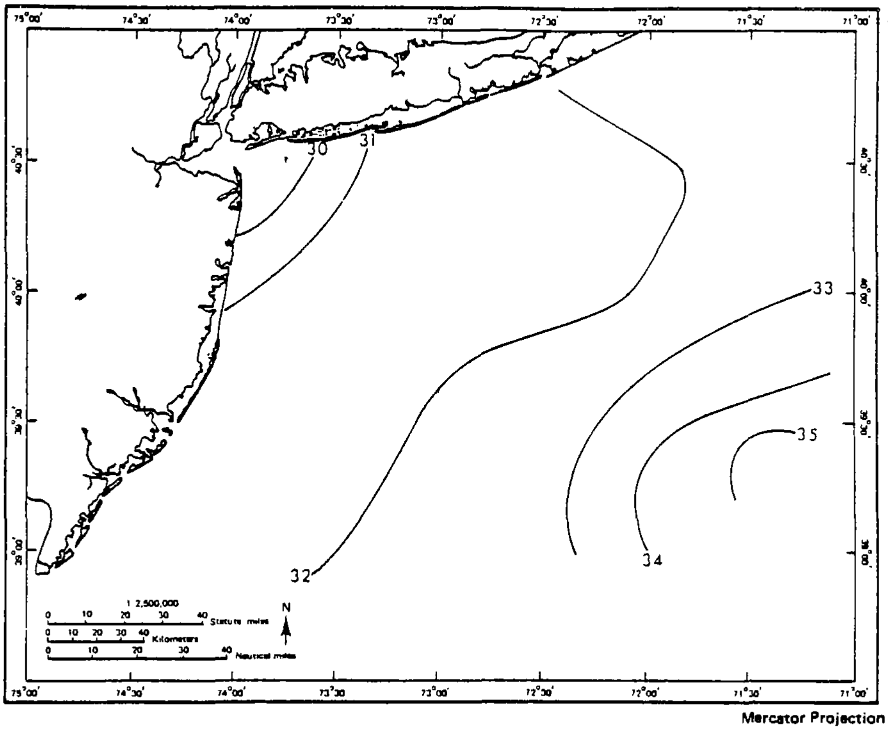
spring averages
(April, May, June)

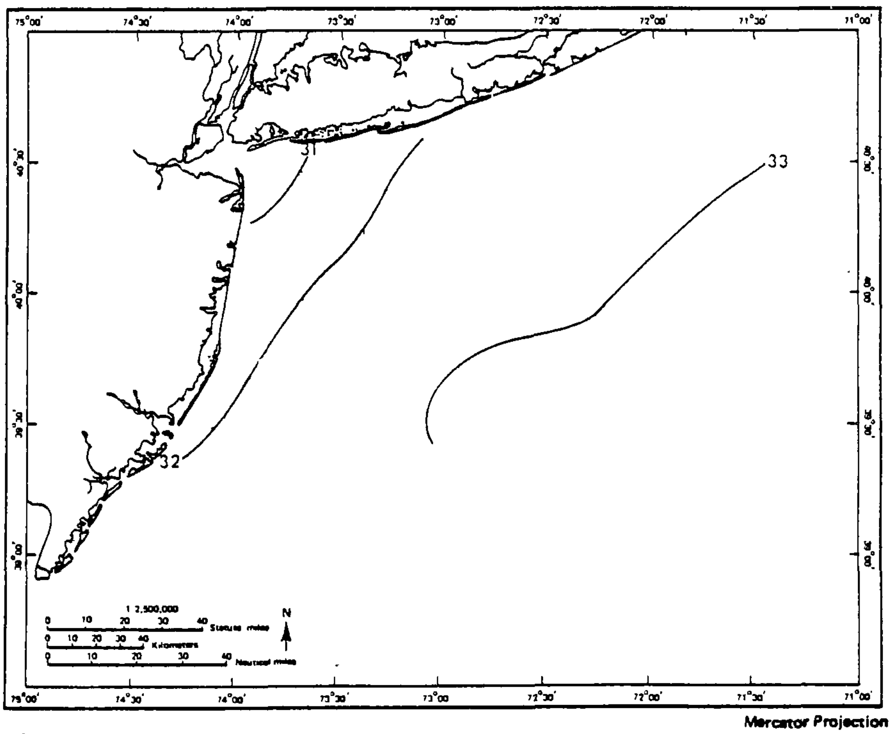
Figure 2.6. Summer surface and bottom salinities for the New York Bight. (Source: O'Connor et al., 1977).

surface salinity (°/oo)

summer averages

(July, August, September)





bottom salinity (°/oo)

summer averages

(July, August, September)

Figure 2.7. Typical salinity profiles on the continental shelf at the 12-Mile Site. (Source: Ecological Analysts and SEAMOcean, 1983).

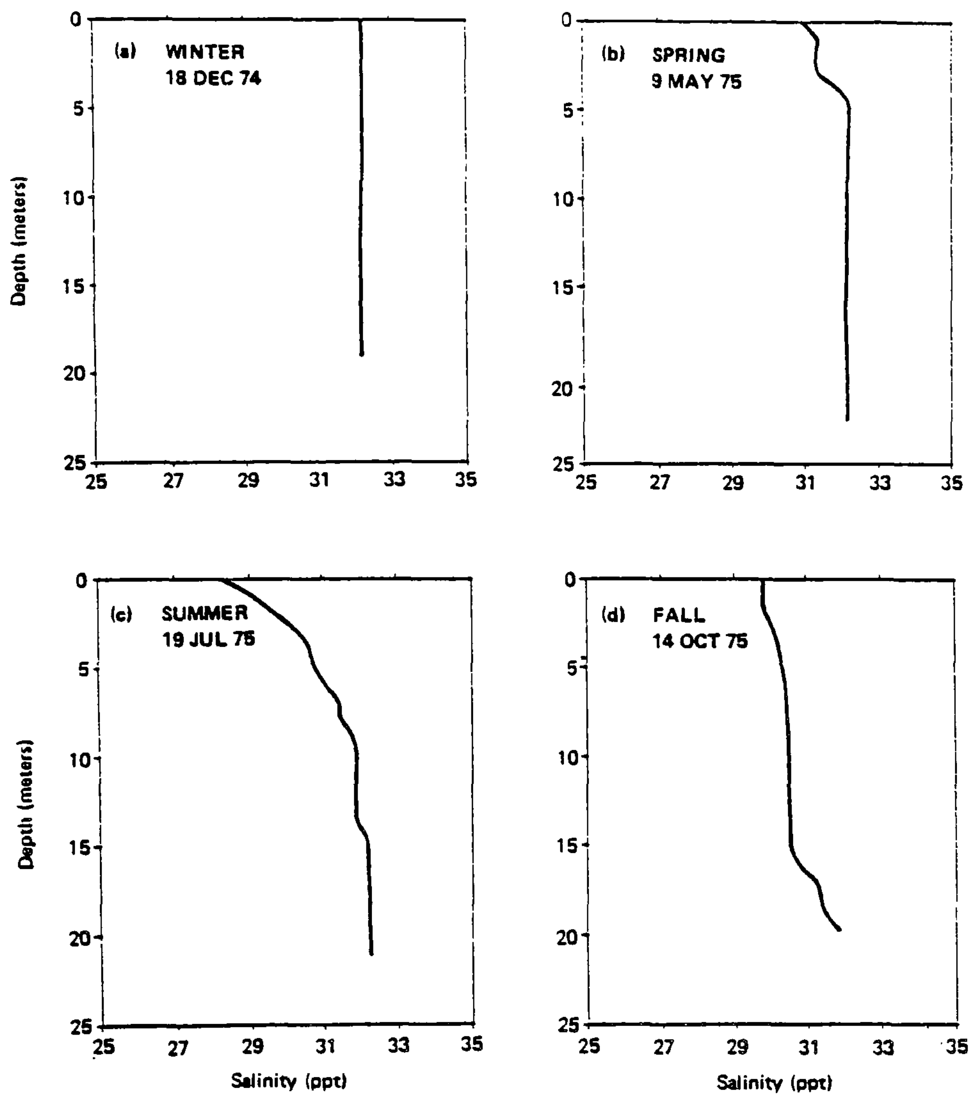


Figure 2.8. Annual cycle of density profiles for New York Bight. (Sources: Armstrong, 1979; Stoddard, unpublished).

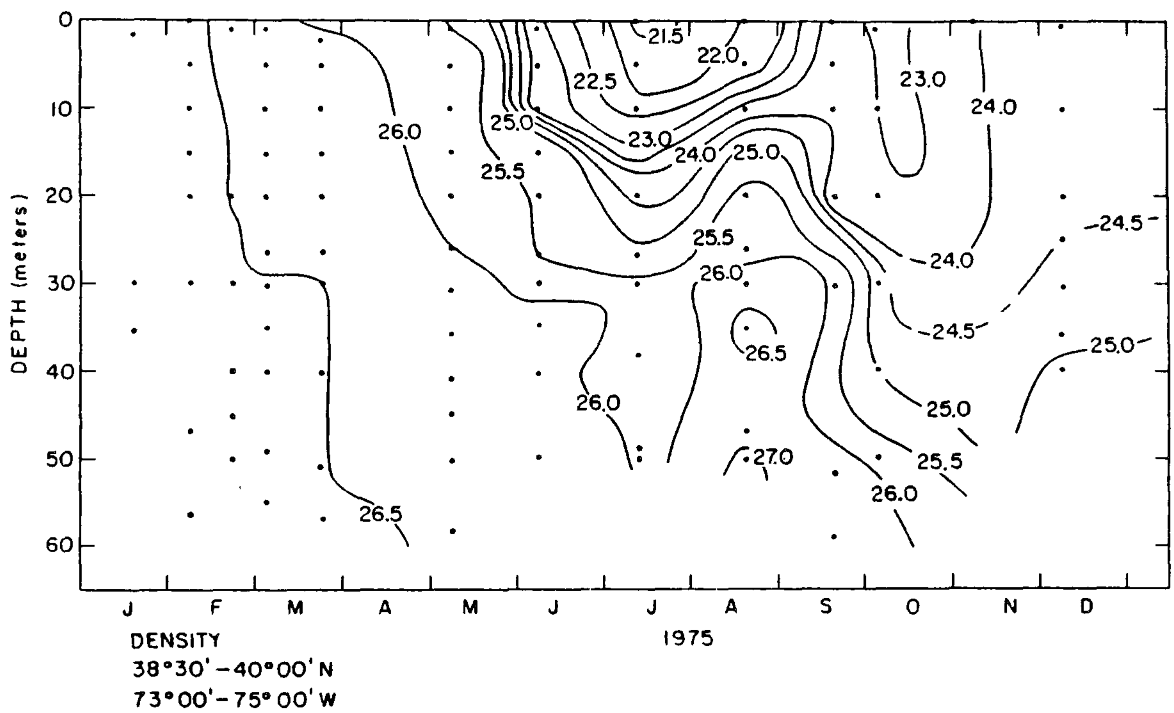
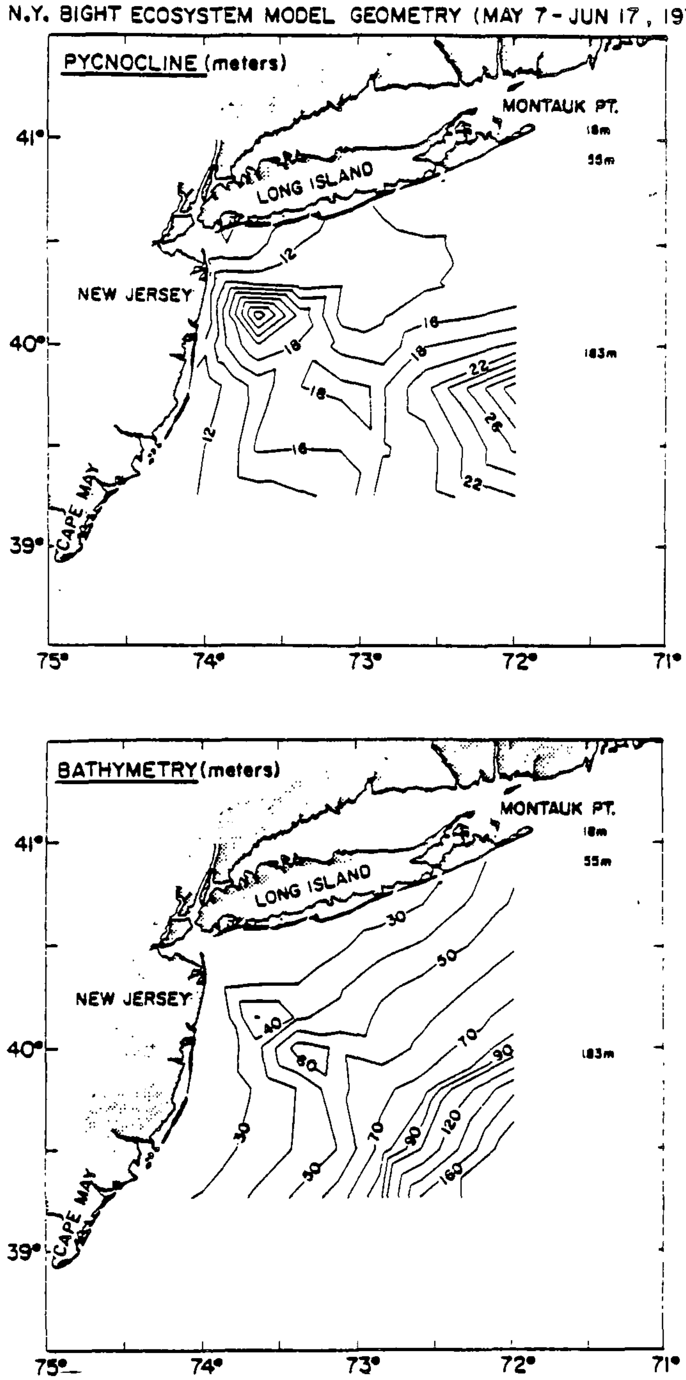


Figure 2.9. Spatial variation of pycnocline depth within the New York Bight. (Source: Stoddard, 1983).



An extensive literature describes circulation processes in the Middle Atlantic Bight. These circulation processes have been inferred from (1) drift card, dye and drogue studies (e.g., Bumpus and Lauzier, 1965; Bumpus, 1973; Bumpus, 1969); (2) hydrographic observations (Ketchum et al., 1951; Ketchum and Keen, 1955; Gordon et al., 1976; Gordon and Aikman, 1981; Neidrauer and Han, 1980; Hopkins, 1982), (3) current meter deployments (e.g., Boicourt and Hacker, 1976; EG&G, 1975) and (4) theoretical and numerical models (Han et al., 1980; Hopkins and Dieterle, 1983; Csanady, 1976; 1977). Summaries of circulation in the New York Bight are presented in Hansen (1977) and Bumpus (1973). Bumpus, in particular, details a lengthy history of drift card, drogue and dye studies conducted in the Middle Atlantic Bight since the early 1950's (e.g., Miller, 1952).

The general southwesterly net drift (approximately 5-10 cm/s) observed in the New York Bight (e.g., Bumpus, 1973; Beardsley et al., 1976) is generally alongshore from Cape Cod, MA to Cape Hatteras, NC. Near-bottom flow tends to be directed towards the coasts of New Jersey and Long Island at speeds of about 1-2 cm/s (Hansen, 1977).

The drifter studies of Bumpus (1973), (Figures 2.10, 2.11, 2.12, 2.13), and current meter observations Beardsley et al. (1976) (Figure 2.14) characterize the general southwesterly drift of water across the open shelf. A simple geostrophic flow model confirms that a southwesterly flow exists from cross-shelf density gradients resulting from freshwater inputs along the coast (e.g., Hudson-Raritan estuary; Delaware estuary). However, superimposed on the dominant southwesterly drift is a weaker cross-shelf circulation pattern similar to patterns of estuarine flow (Gordon et al., 1976; Aikman and Posmentier, 1985). Lower salinity, less dense surface water tends to flow seaward above the pycnocline with a corresponding landward flow of higher salinity water below the pycnocline. (Figure 2.14).

Nearshore Circulation

Transport processes within the New Jersey nearshore region are complex, resulting from the interaction of tides winds and oceanic transport. Circulation processes within the nearshore, coastal boundary layer (Csanady, 1976; Scott and Csanady, 1976) are distinctly different from circulation further offshore. The width of the coastal boundary layer off New Jersey is on the order of 10 km (Csanady, 1976) and is bounded by the 20m isobath.

Figure 2.10. Inferred surface drift, July, 1960-1970.
(Source: Bumpus, 1973).

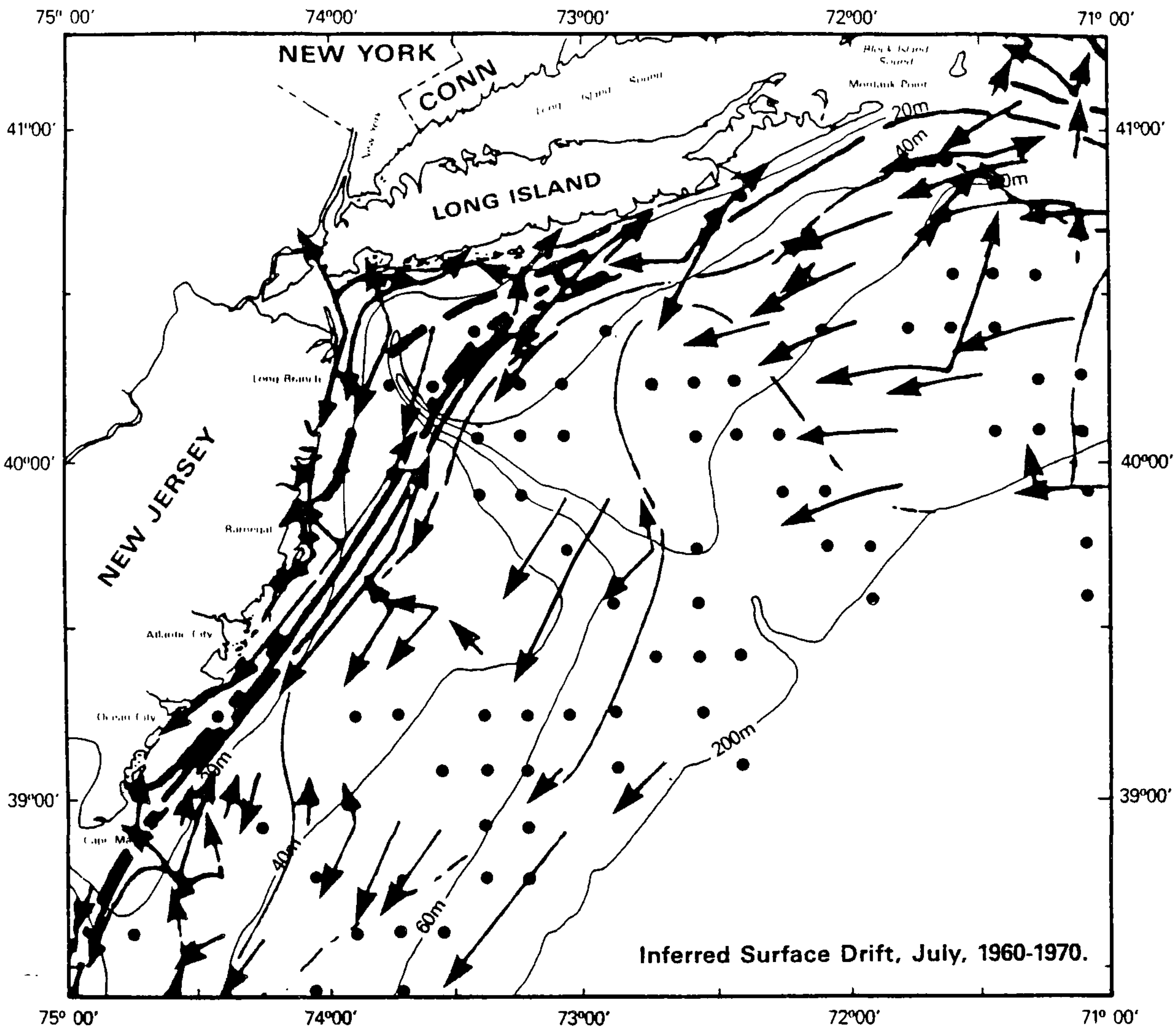


Figure 2.11. Inferred surface drift, August, 1960-1970.
(Source: Bumpus, 1973).

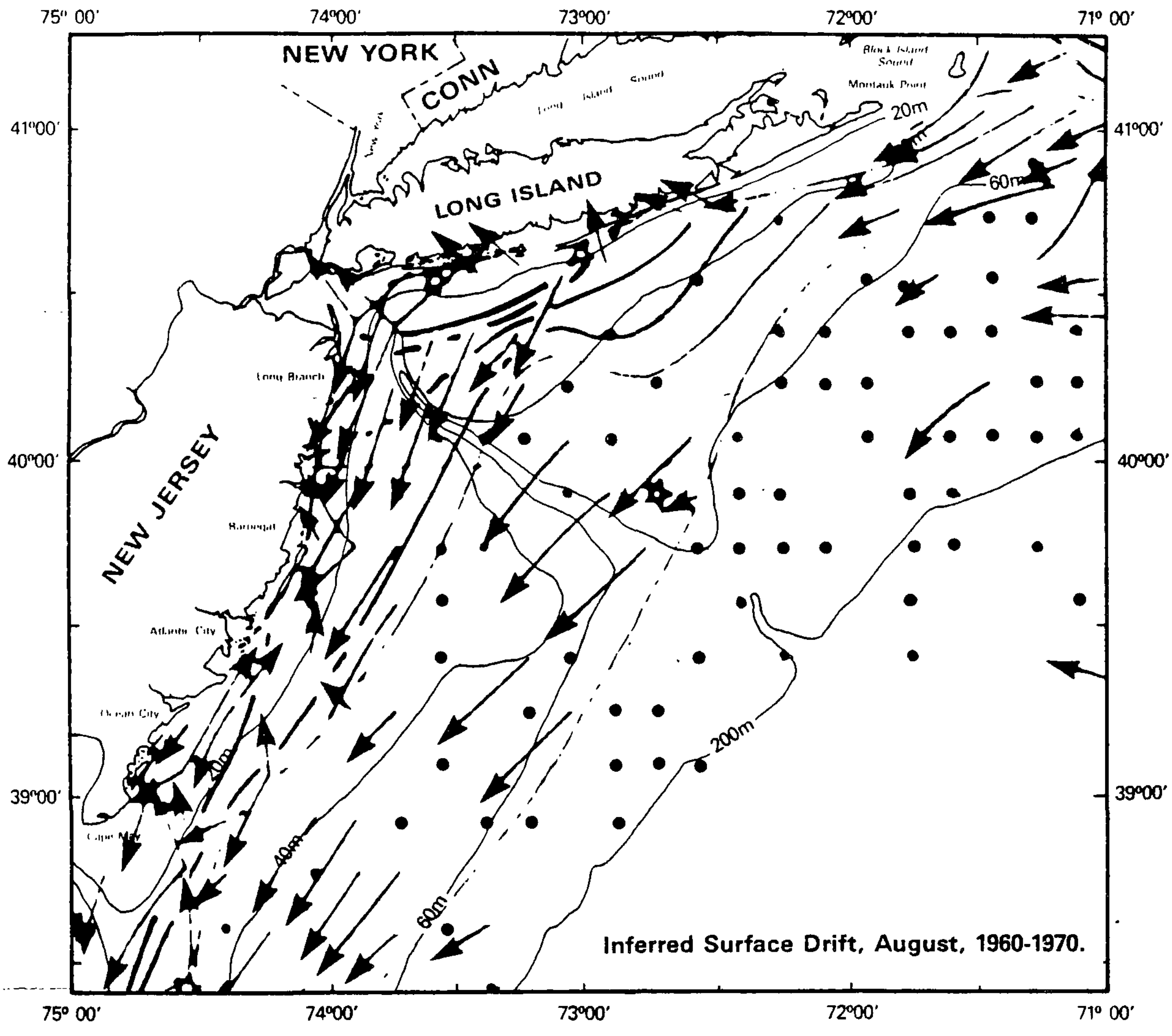


Figure 2.12. Inferred bottom drift, July, 1961-1970. (Source: Bumpus, 1973).

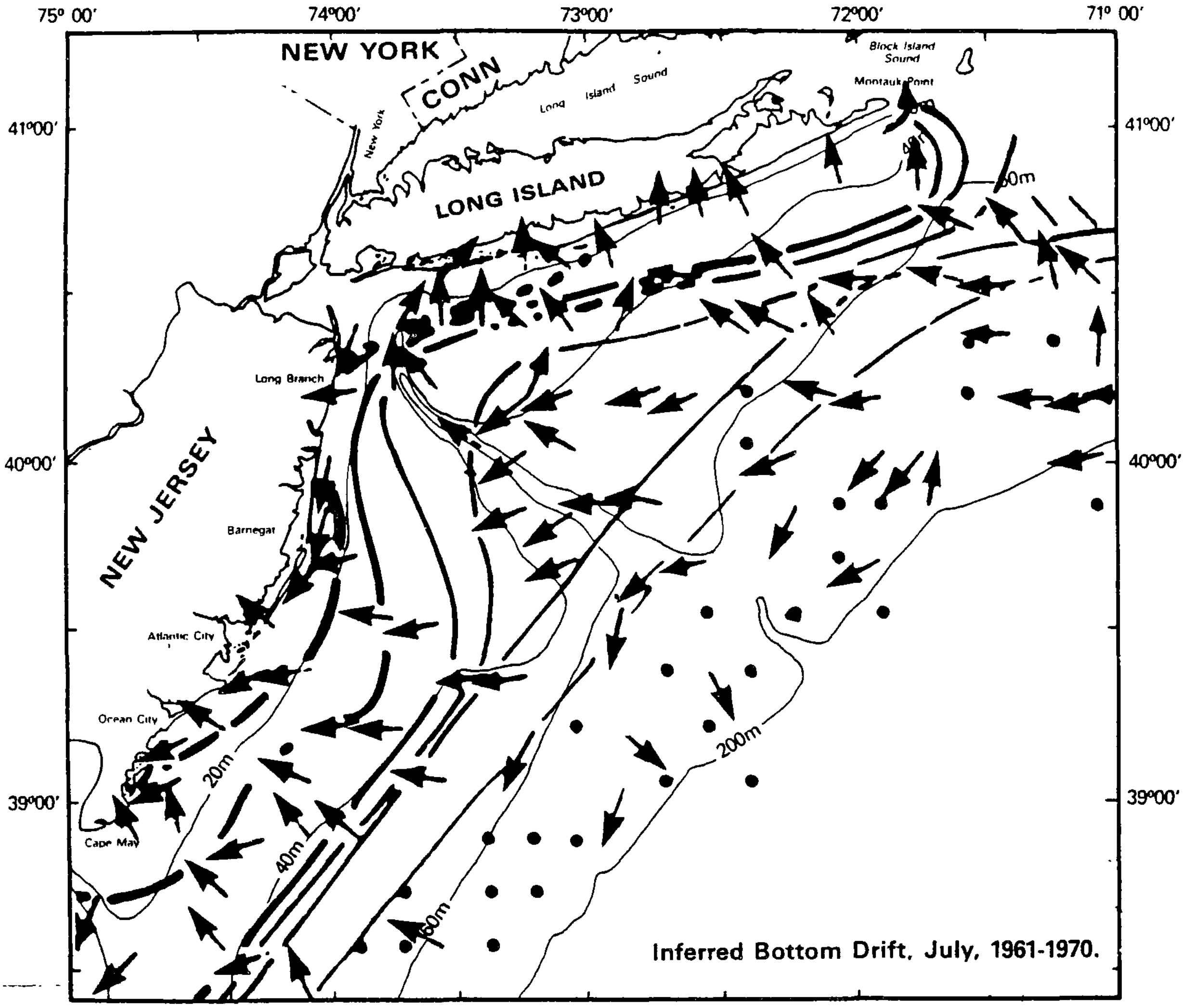


Figure 2.13. Inferred bottom drift, August, 1961-1970. (Source: Bumpus, 1973).

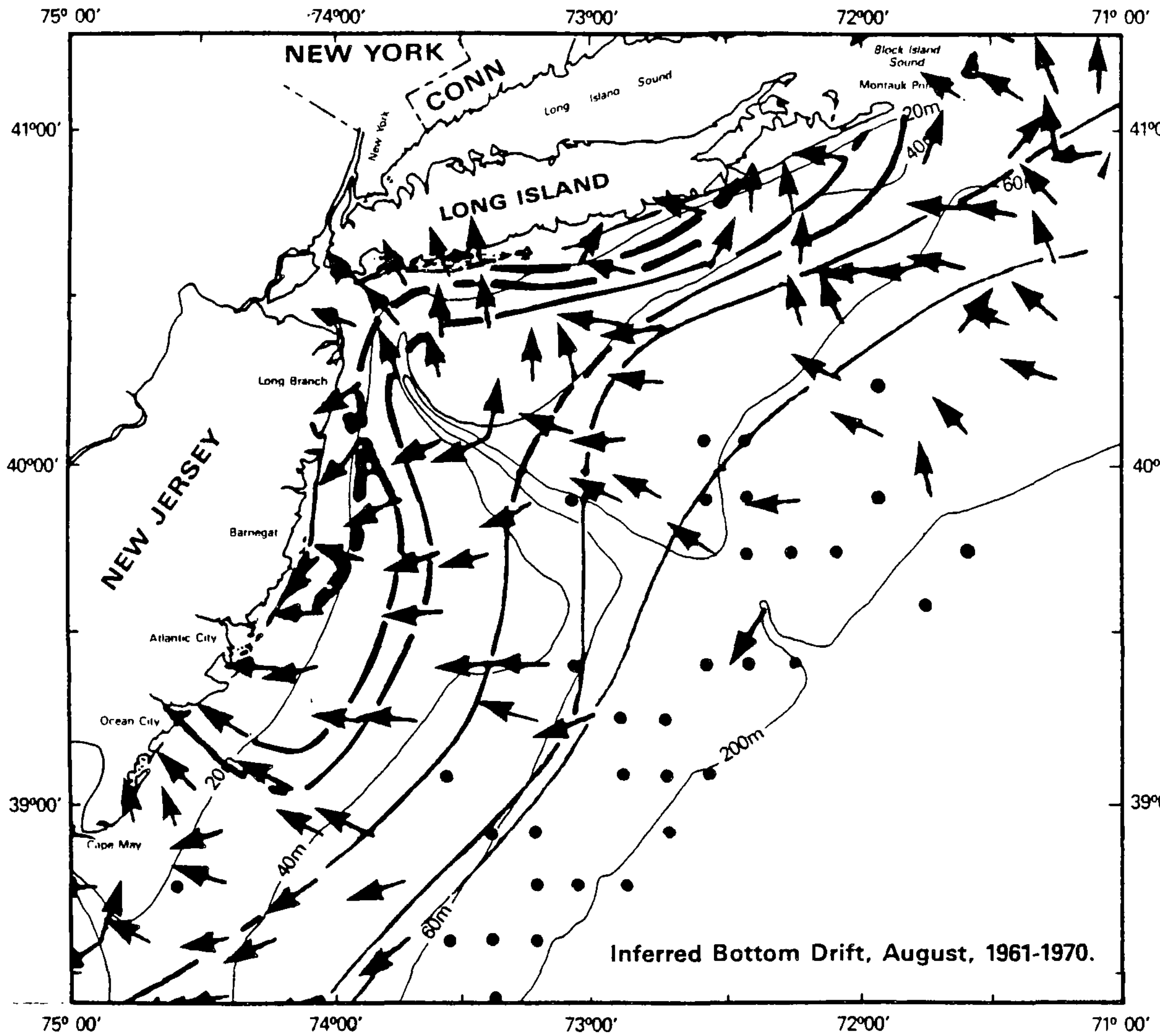
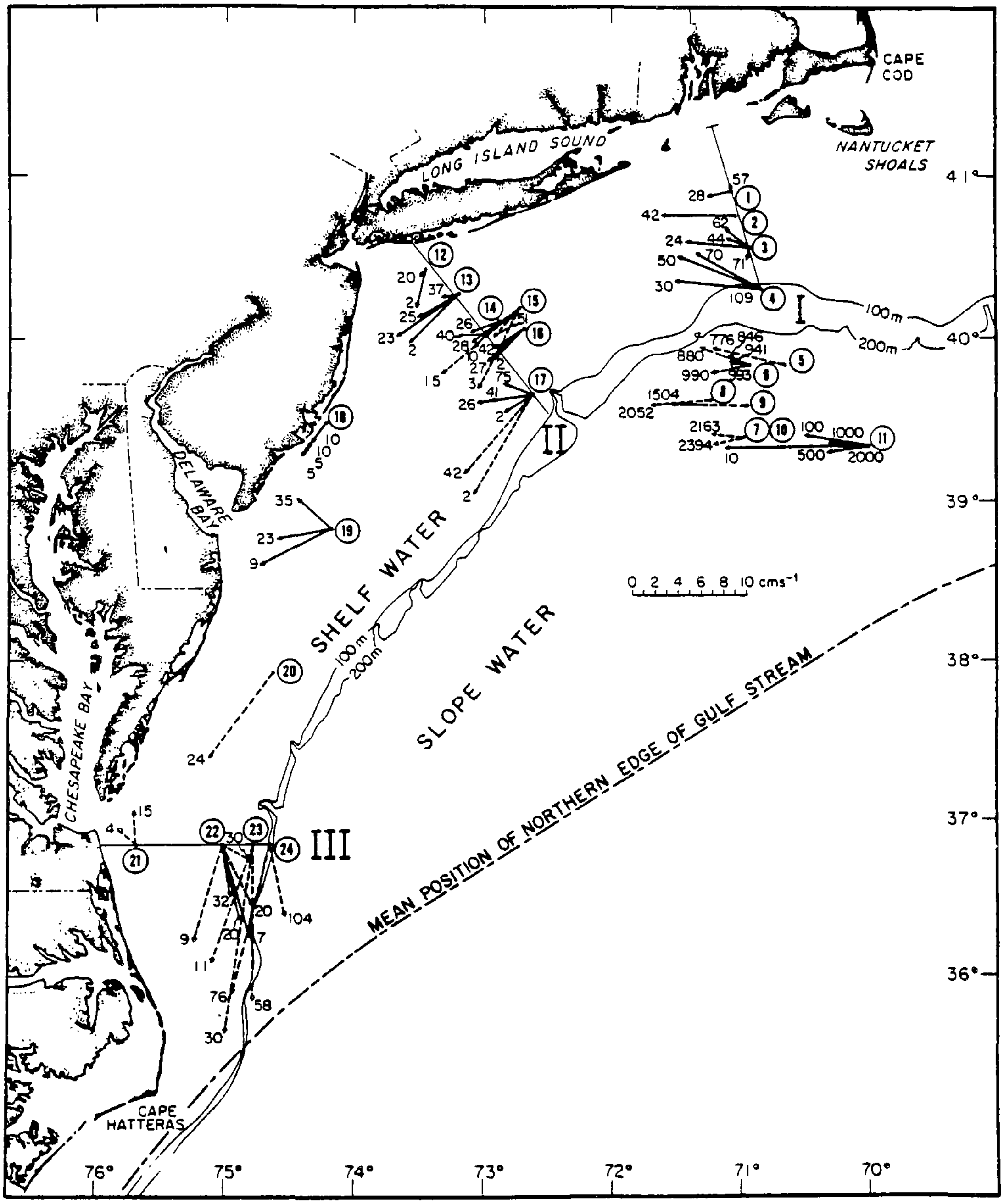


Figure 2.14. Mean velocities as measured by current meters. Winter measurement: solid arrows; summer measurement: dashed arrows. (Source: Beardsley *et al.*, 1976).



The general southwesterly flow pattern of the nearshore zone is often reversed (i.e., towards northeast) for periods of 1-3 months, typically during summer (Bumpus, 1973; Hansen, 1977). Such flow reversals, observed off Atlantic City in August, 1974 at a water depth of 12m (EG&G, 1975), are clearly seen in the 10-year summary of drift card results (Bumpus, 1973) for August (Figure 2.11) along the nearshore southern New Jersey coast. Southwesterly winds, generally found in August, result in offshore, surface layer transport with upwelling and corresponding shoreward flow in the near-bottom layer. This flow results in decreases in surface layer water temperature in the nearshore zone as the deeper water replaces surface waters. (Ingham and Eberwine, 1984).

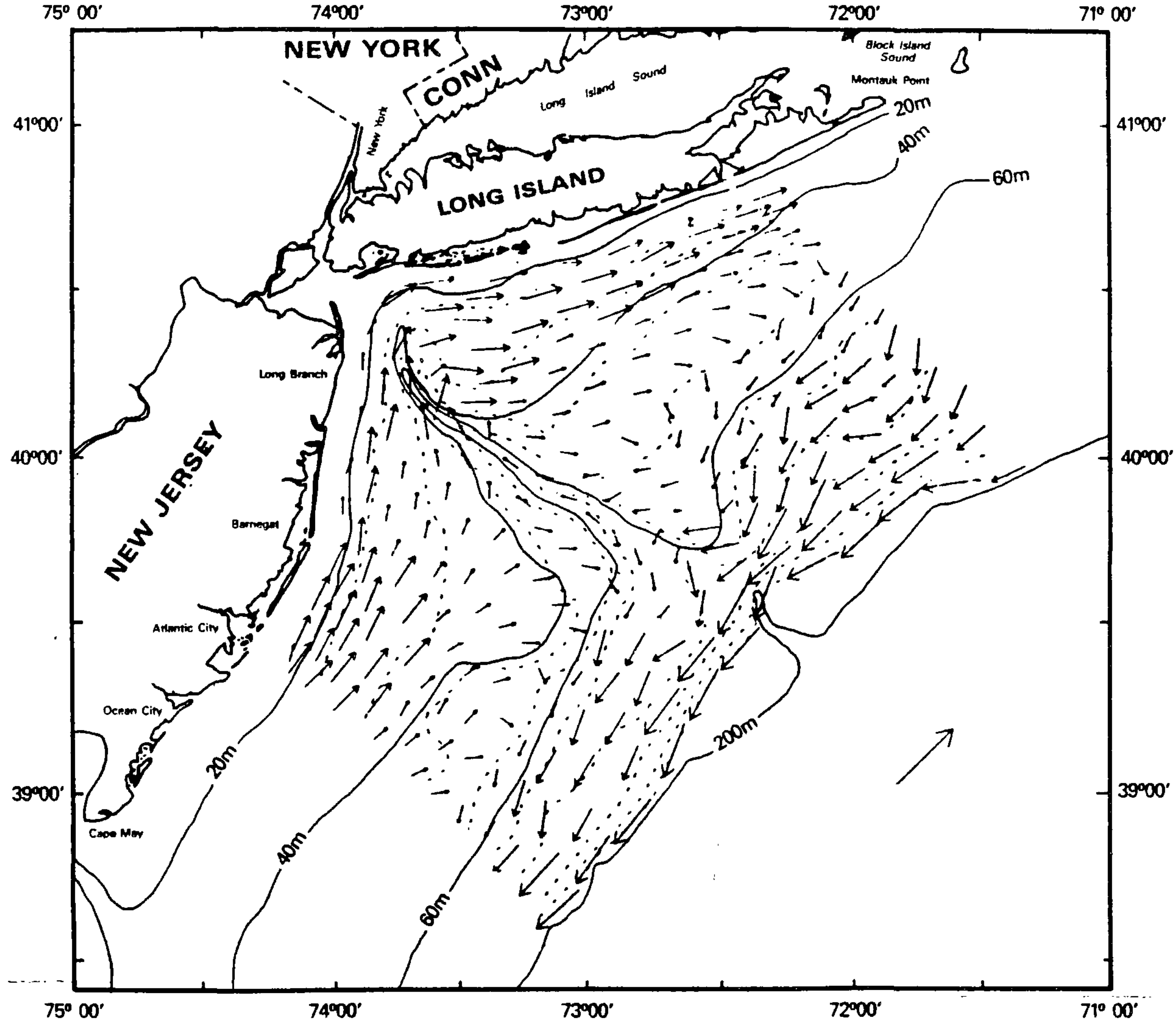
A numerical circulation model (Hopkins and Dieterle, 1983) also indicates a nearshore flow reversal along the New Jersey coast inshore of the 40m isobath influenced by southwesterly wind forcing and balanced by stronger southwesterly flow seaward of the 60m isobath. (Figure 2.15)

The tendency for late summer flow reversals in the nearshore New Jersey region has significant implications for nutrient enrichment, phytoplankton production and oxygen depletion. Flow reversal results in an increased residence time of water masses in the nearshore New Jersey coast and a convergent accumulation of particles (Han et al., 1979) and oxygen-demanding materials. Accumulations of shellfish larvae, for example, in the New Jersey nearshore region have been related to the occurrence of southwest winds and reversal of the flow field (Haskins, personal communication, 1986). Persistent southwesterly winds during June and July, 1976 resulted in a reversal of the nearshore flow field, accumulation of debris on the south shore of Long Island (Swanson et al., 1978), and the accumulation of the dinoflagellate Ceratium tripos and subsequent widespread anoxia related to decay of the bloom (Swanson and Sindermann, 1979; Mayer et al., 1979).

2.4 NEARSHORE TRANSPORT

In the nearshore coastal region, transport processes are strongly influenced by winds, waves, coastal topography and tides. The coastal current regime consists of unidirectional and oscillatory flow components. Oscillatory wave generated currents do not result in significant net transport although storm generated waves do increase the dispersiveness of a local coastal

Figure 2.15. Predicted currents in the New York Bight during summer for the southwest wind stress of 1.0 dyne cm^{-2}. (Source: Hopkins and Dieterle, 1983).



environment. Significant net transport results, however, from unidirectional currents. In the shallow, inshore area, the water column tends to be well-mixed to a depth of about 7 or 8 meters even during summer as a result of winds, waves, and tidal mixing. Further offshore, the water column becomes stratified and the pycnocline depth increases with total water column depth.

Along the southern New Jersey coast, tidal current characteristics vary according to the location of tidal inlets and the distance from the mouth of Delaware Bay. The irregular geometry and numerous bays and inlets of the southern New Jersey barrier island coastline cause localized reversing tidal currents and complex coastal circulation.

Along the nearshore zone out to about 20 m depth, weak rotary tidal currents of about 10 cm/s and a net southwestward drift of about 5 cm/s are typical (DeAlteris and Keegan, 1977). Wind is also a significant forcing component of net transport in this zone (Csanady, 1976). The alignment of the New Jersey coast is such that winds from the west or south quadrants (270-180 degrees) cause upwelling across the shelf. The strength of such upwelling is dependent on the magnitude and duration of southwest wind events. Upwelling events have been observed during the summer stratified period off Atlantic City, NJ (EG&G, 1975; Ingam and Eberwine, 1984), Great Egg Inlet (Garlo et al., 1979), and the Maryland coast (Walsh et al., 1978; Scott and Csanady, 1976). Spatial variation in the extent of the summer cold pool (Ketchum and Corwin, 1964) reflects the variability in summer wind events and the resultant upwelling or downwelling conditions.

Cross-shelf transport is not the major component of net flow over the New Jersey shelf. Longshore flow parallel to the coast is dominant in net transport patterns. As a general rule, the overall net drift in the New York Bight is southwesterly along the coast at about 5-10 cm/s (Bumpus, 1973; Beardsley et al., 1976). Frequent storms from the north-northeast during the winter-spring period coupled with the decreasing sea surface (pressure) gradient from Boston to Atlantic City (Csanady, 1976) cause this net transport.

During summer, storm events with winds from the north-northeast resulting in southerly flow along the coast are less frequent. In this season, dominant winds are from the southwest quadrant at about 4-6 m/s (Lettau et al., 1976). This is evidenced by the monthly mean resultant wind directions between 1941 and 1970:

June	140 deg
July	260 deg
August	200 deg
September	270 deg

Based on these data (Ingham and Eberwine, 1984), one would expect differences in net transport during the month of August, particularly if wind driven flow is a dominant component of coastal shelf transport.

The surface drift data for August (Figure 2.11) indicates flow towards the north along the southern New Jersey coast in the nearshore region (0-20 m). By contrast, surface flow for July (Figure 2.10) indicates net drift south along the coast. These drift card results tend to confirm that inshore flow reversals during August are recurrent patterns. The component of nearshore flow that is apparent in the August drift results is consistent with wind driven flows caused by the southwest winds observed during August.

In a year long study for the New Jersey Public Utilities Service Commission related to the proposed Atlantic Generating Station off Atlantic City, EG&G deployed a string of inshore current meters (Figure 2.16) and monitored nearshore currents and water quality between 1973 and 1974. EG&G (1975) reported flow towards the north-northeast during August and September, 1974. Frequency spectra for the EG&G current meters at Site A in Beardsley et al. (1976) are presented in Figure 2.17. The dominant frequency is 0.5 days reflecting tidal period forcing at the inshore station. The second peak frequency is at 3 to 5 days, reflecting the energy input from storm events in the New York Bight (Walsh et al., 1978).

Data for early September, 1974 from the EG&G current meter deployments off Atlantic City are shown in Figures 2.18a-c. The relationship between wind and net transport is apparent in these figures. Currents tend to respond quickly to changes in wind direction. Winds from the southwest result in nearshore northeast flow parallel to the southwesterly drift for the New York Bight.

Theoretical and experimental physical oceanography studies in the New York Bight have indicated the dominance of the wind-driven flow component on overall net transport within the coastal shelf (Scott and Csanady, 1976; Csanady, 1976; Kohler and Han, 1982; Han et al., 1980; Hopkins and Dieterle,

Figure 2.16. Station locations for current meter locations. (Source: EG&G, 1975).

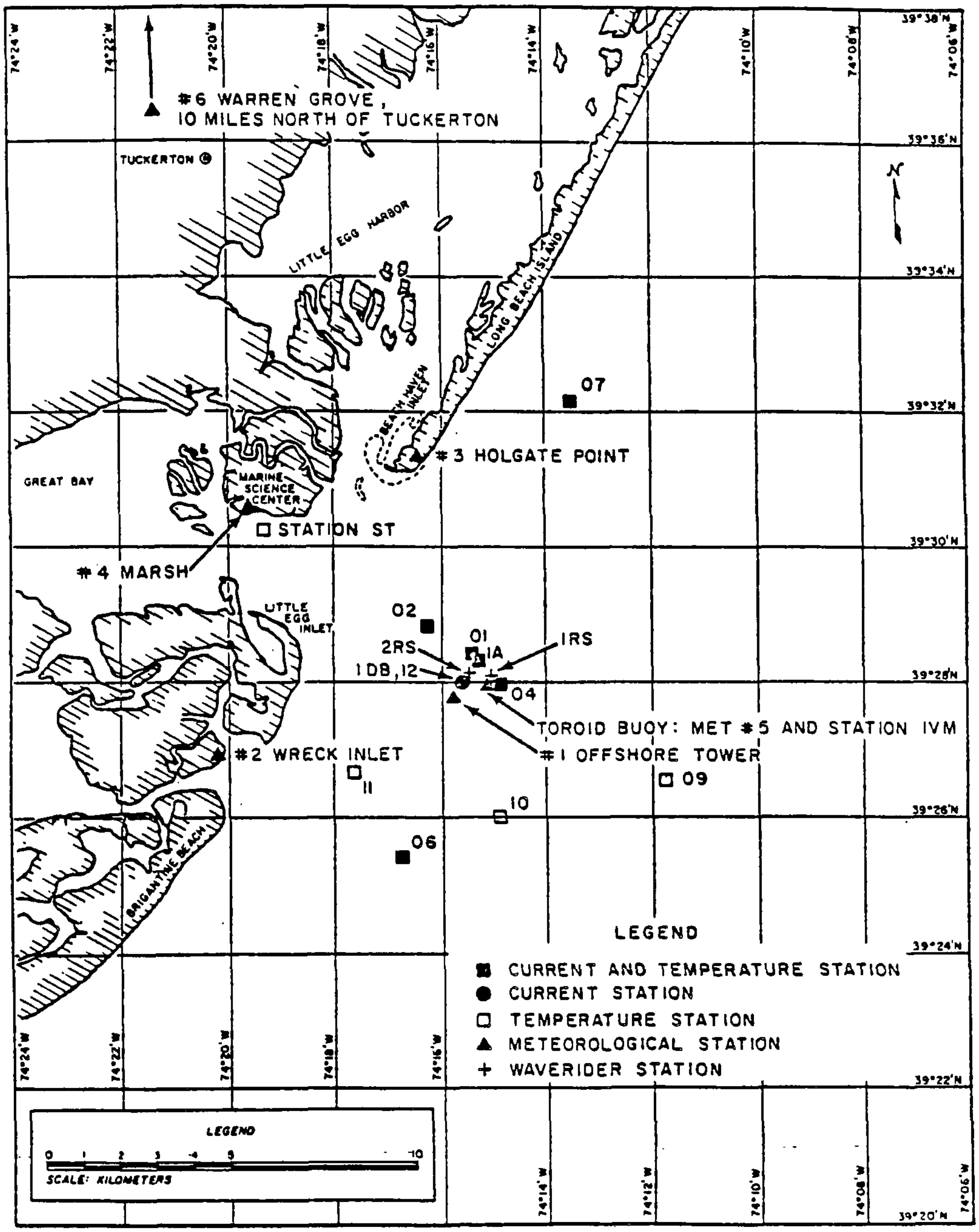
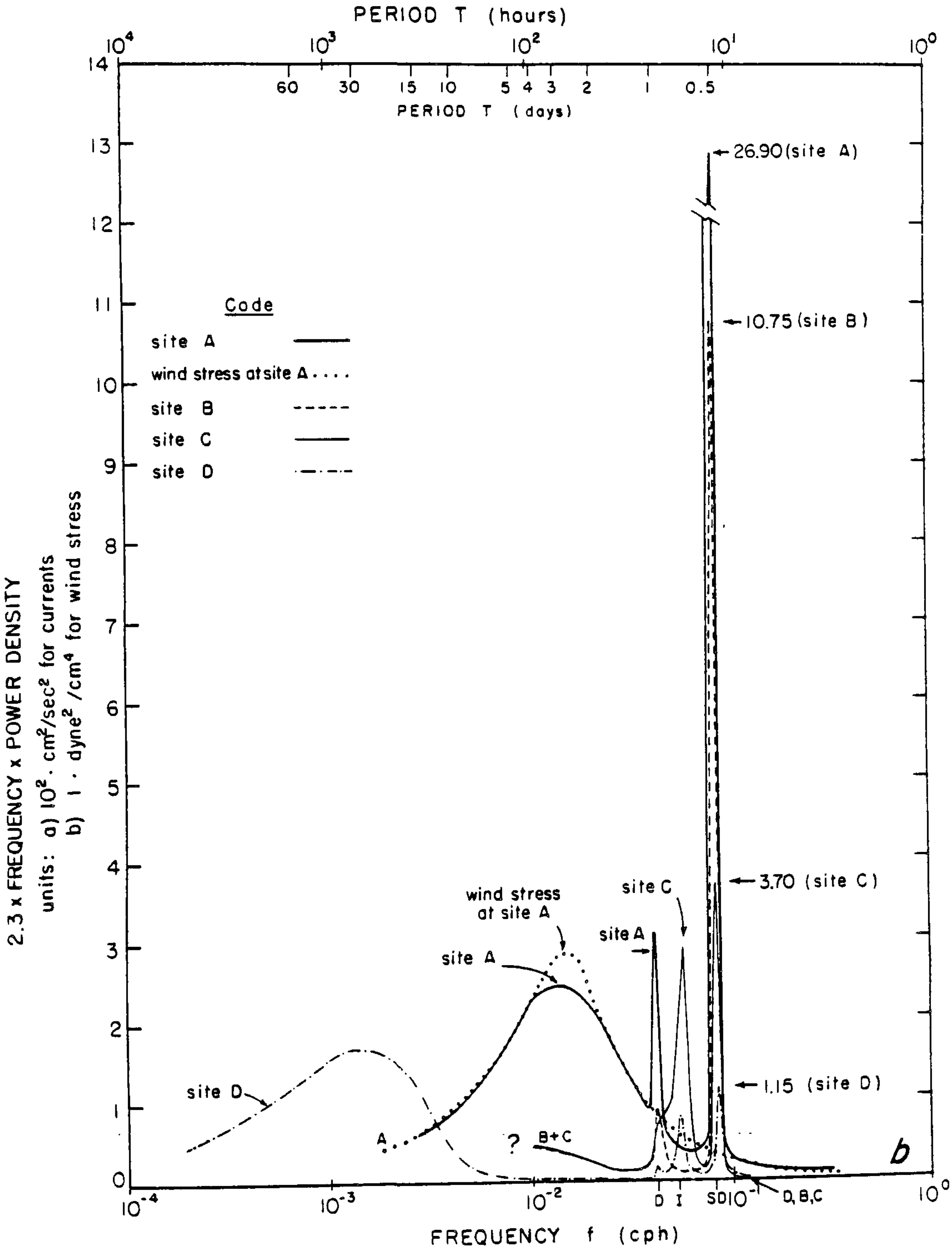


Figure 2.17. Frequency spectra for currents off southern New Jersey. (Source: EG&G, 1975).



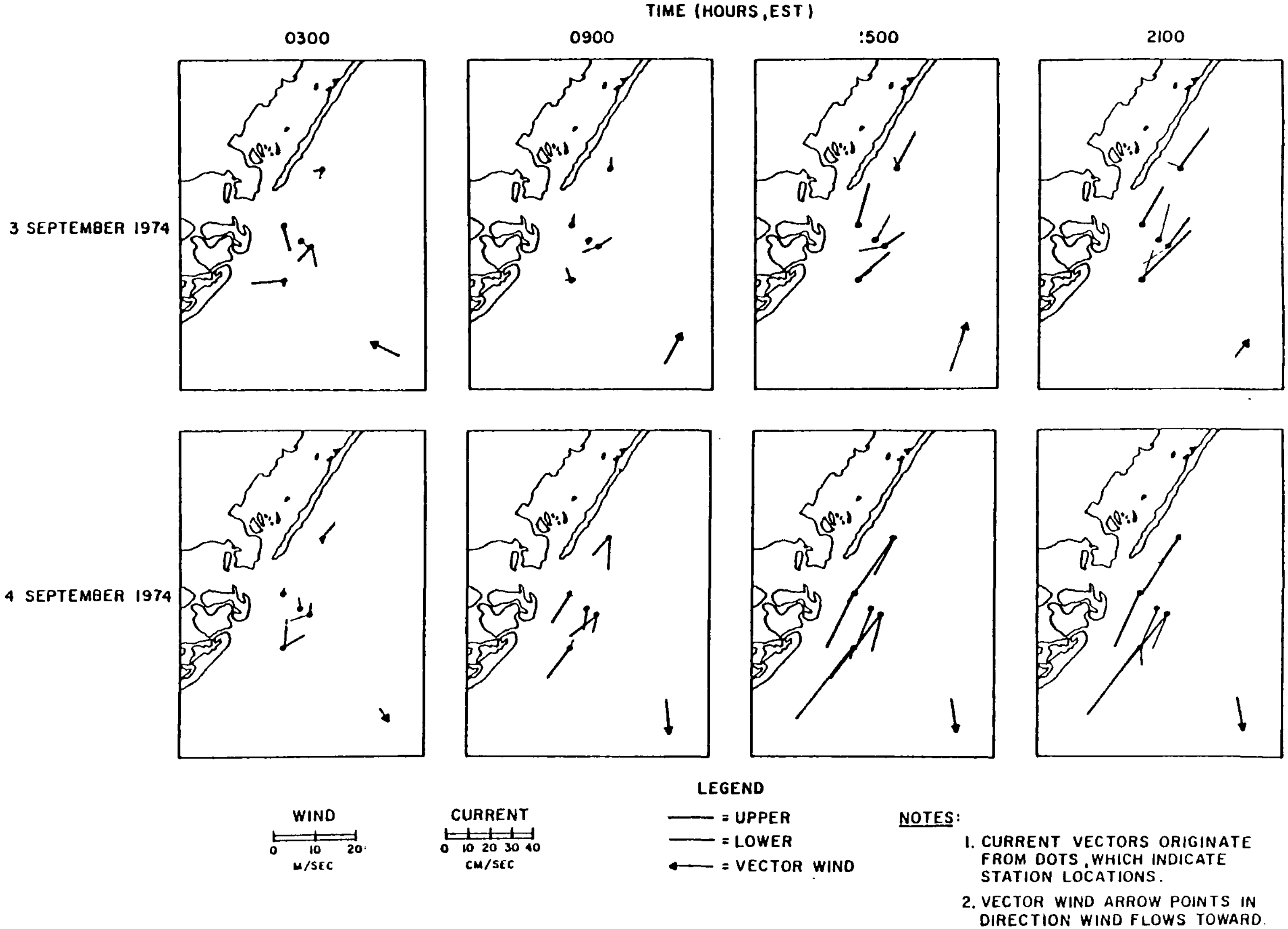


Figure 2.18a. Vector current maps, 3 and 4 September, 1974. (Source: EG&G, 1975).

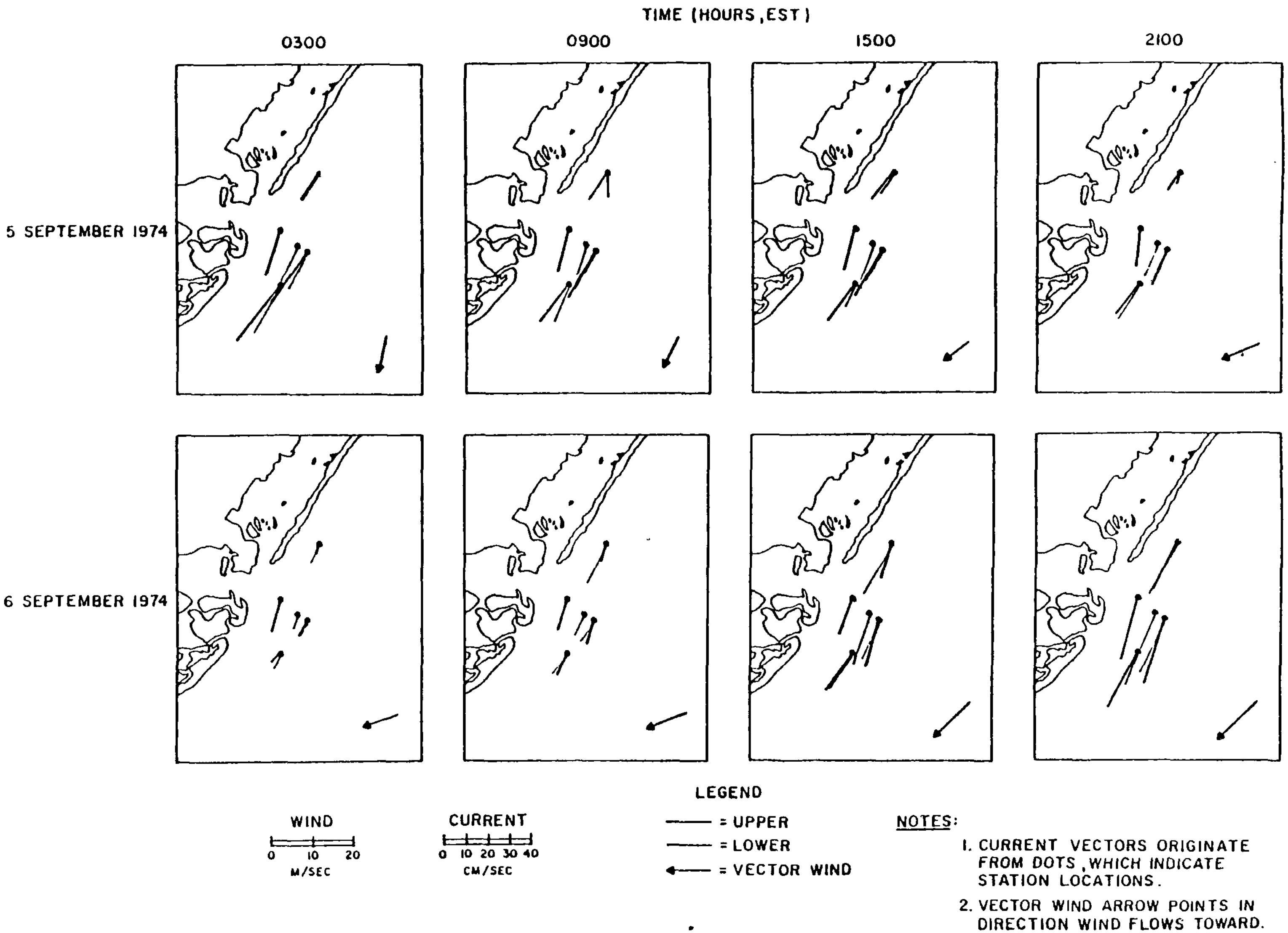


Figure 2.18b. Vector current map, 5 and 6 September, 1974.
(Source: EG&G, 1975).

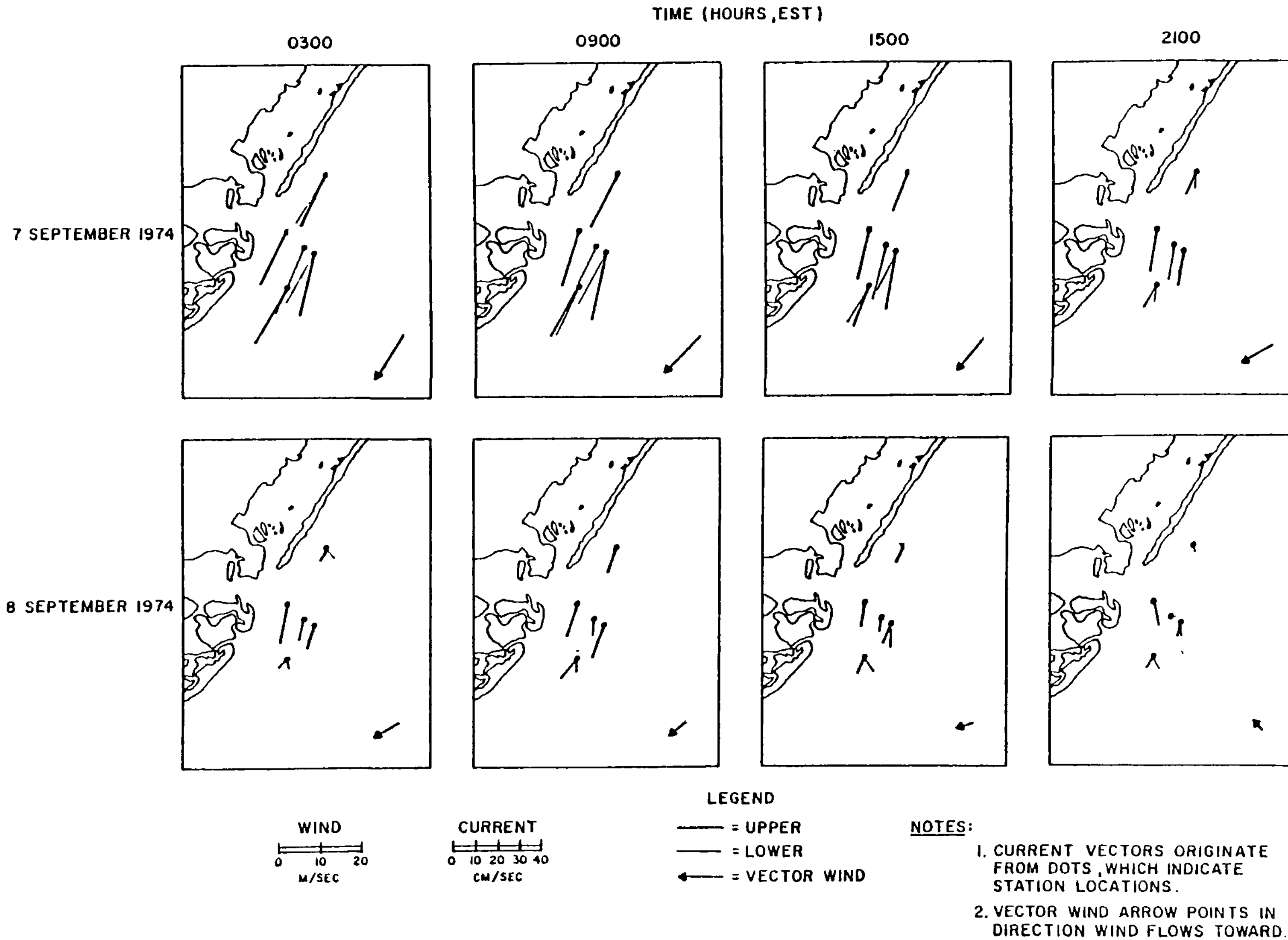


Figure 2.18c. Vector current maps, 7 and 8 September, 1974. (Source: EG&G, 1975).

1983). Numerical models of circulation in the New York Bight also clearly demonstrate weak flow reversals along the southern New Jersey coast during southwest wind events under summer conditions (Figure 2.15). During these southwest wind events, return flow towards the southwest is between the 60 m and 200 m isobaths. The circulation pattern results in an increased residence time of water masses in the water column in the nearshore southern New Jersey region.

2.5 CONSEQUENCES OF NEARSHORE TRANSPORT PATTERNS

During a wide-spread anoxic episode in the New York Bight during the summer of 1976, winds from the southwest were persistent from early June through mid-July resulting in a large scale reversal of the flow field over the New Jersey shelf extending to about the 60 m isobath (Figure 2.19). The flow reversal resulted in accumulation of particulates, including the dinoflagellate, *Ceratium tripos*, and a significant increase in the residence time of these and other materials in the water column (Han *et al*., 1979). The combination of high oxygen demands from decay of the *Ceratium* bloom and sluggish flushing of the midshelf region resulted in anoxic conditions and shellfish mortality over a wide area of the New Jersey shelf (Swanson and Sindermann, 1979).

An increase in the residence time of the nearshore southern New Jersey area would result in the accumulation of nutrients, particulate organic matter and patchy populations of a variety of phytoplankton species groups. If the time scale for the growth rate of the phytoplankton was less than the time scale for flushing of the water column, then a phytoplankton bloom could be initiated.

Common summer observations of freshwater ponds and streams demonstrate the effect of reduced flow (i.e., stagnant conditions or drought conditions) on the growth and accumulation of enormous mats of surface algal blooms (e.g., *Cladophora*, *Euglena*, etc.) in the surface layer of these water bodies. The physical and biological principles are similar for the coastal ocean. The open seaward boundary and advective transport in and out of a particular nearshore region make the identification of cause and effect relationships particularly difficult without extensive synoptic physical, chemical and biological data.

Figure 2.19. Estimated currents in the New York Bight during June, 1976. Arrows indicate water flow between sectors; width of arrows proportional to velocity. (Source: Han et al., 1979).

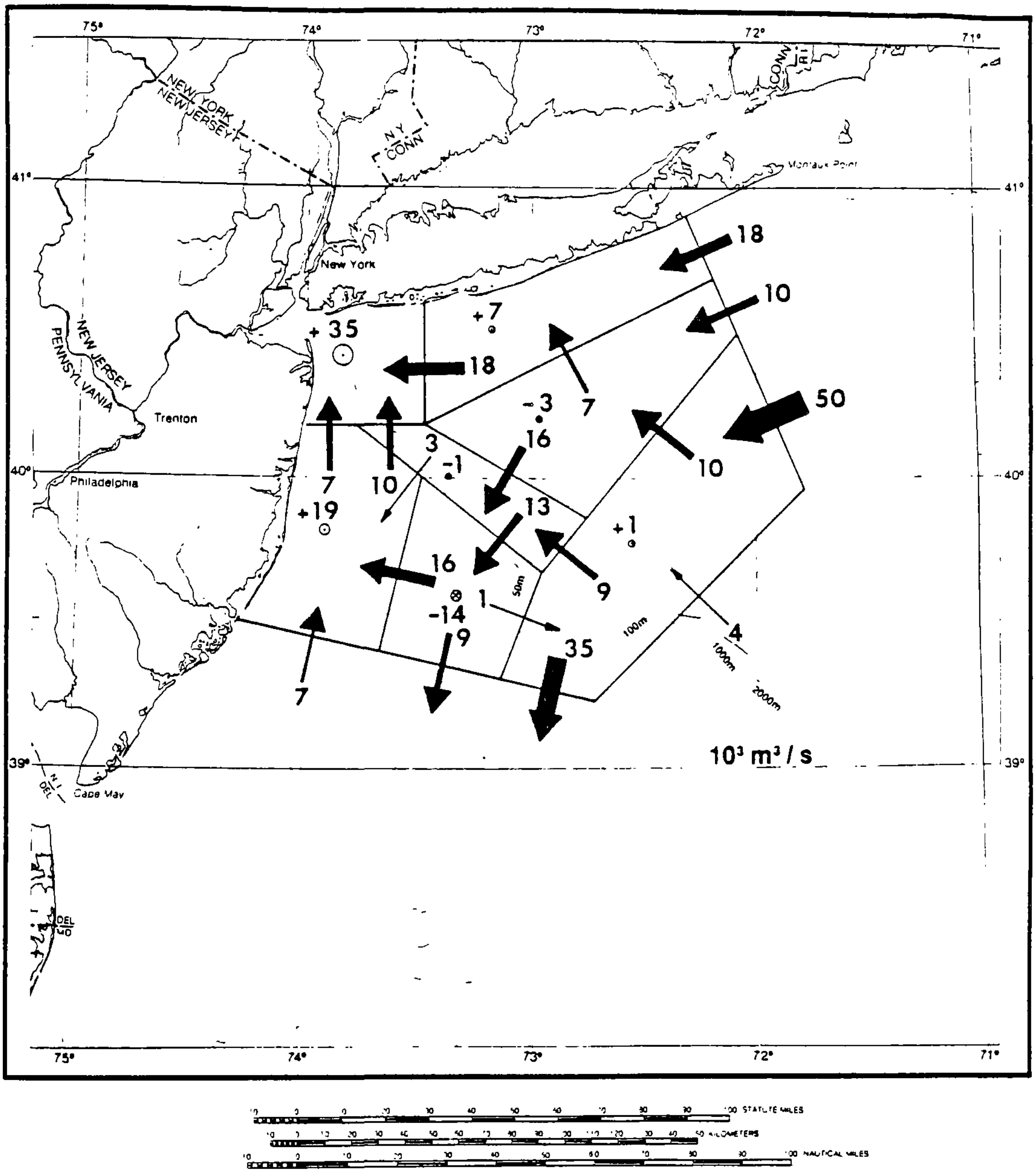


Figure 2.20a. Progressive vector diagram of currents for July, 1985, beginning at Atlantic City, NJ.

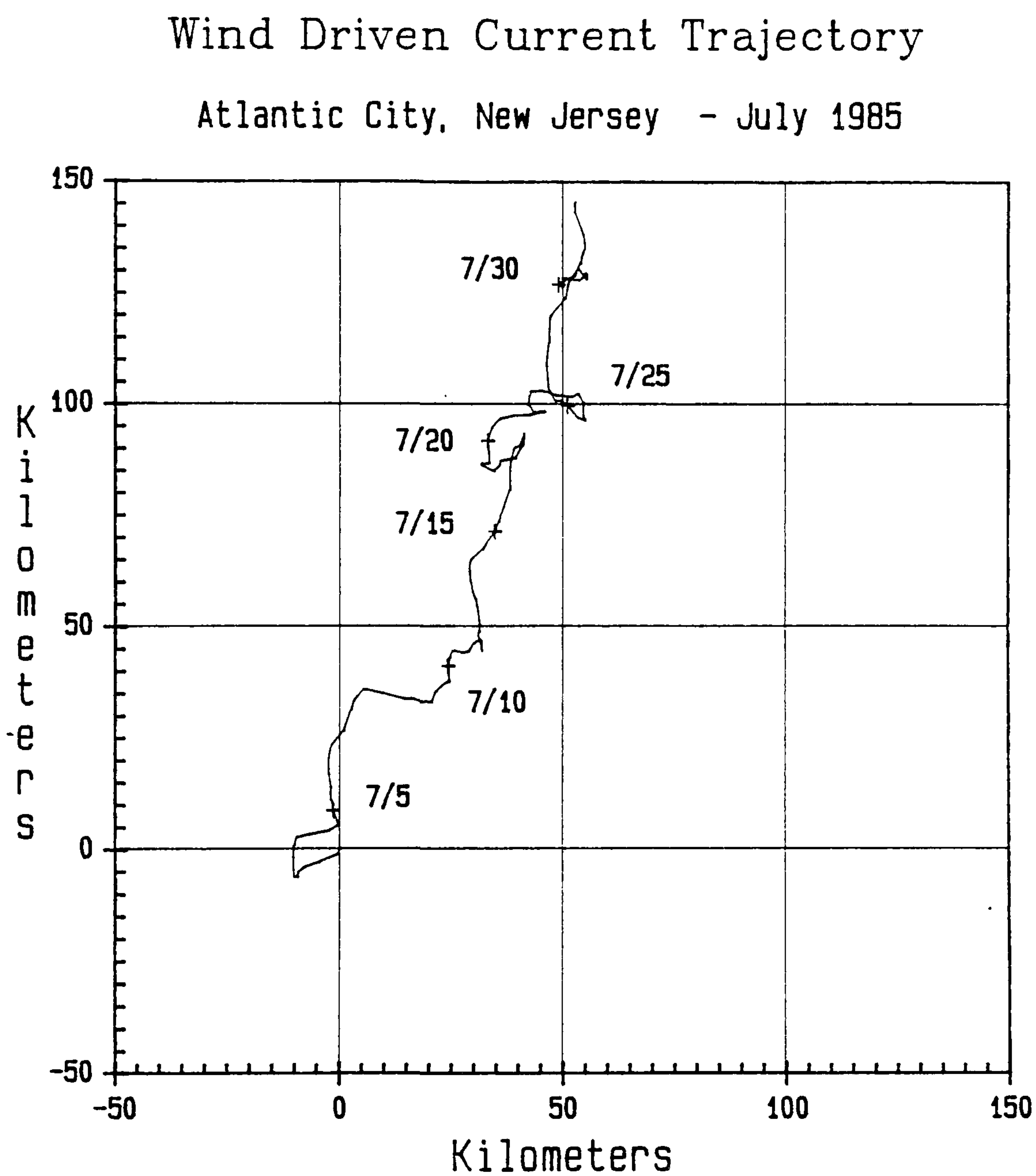
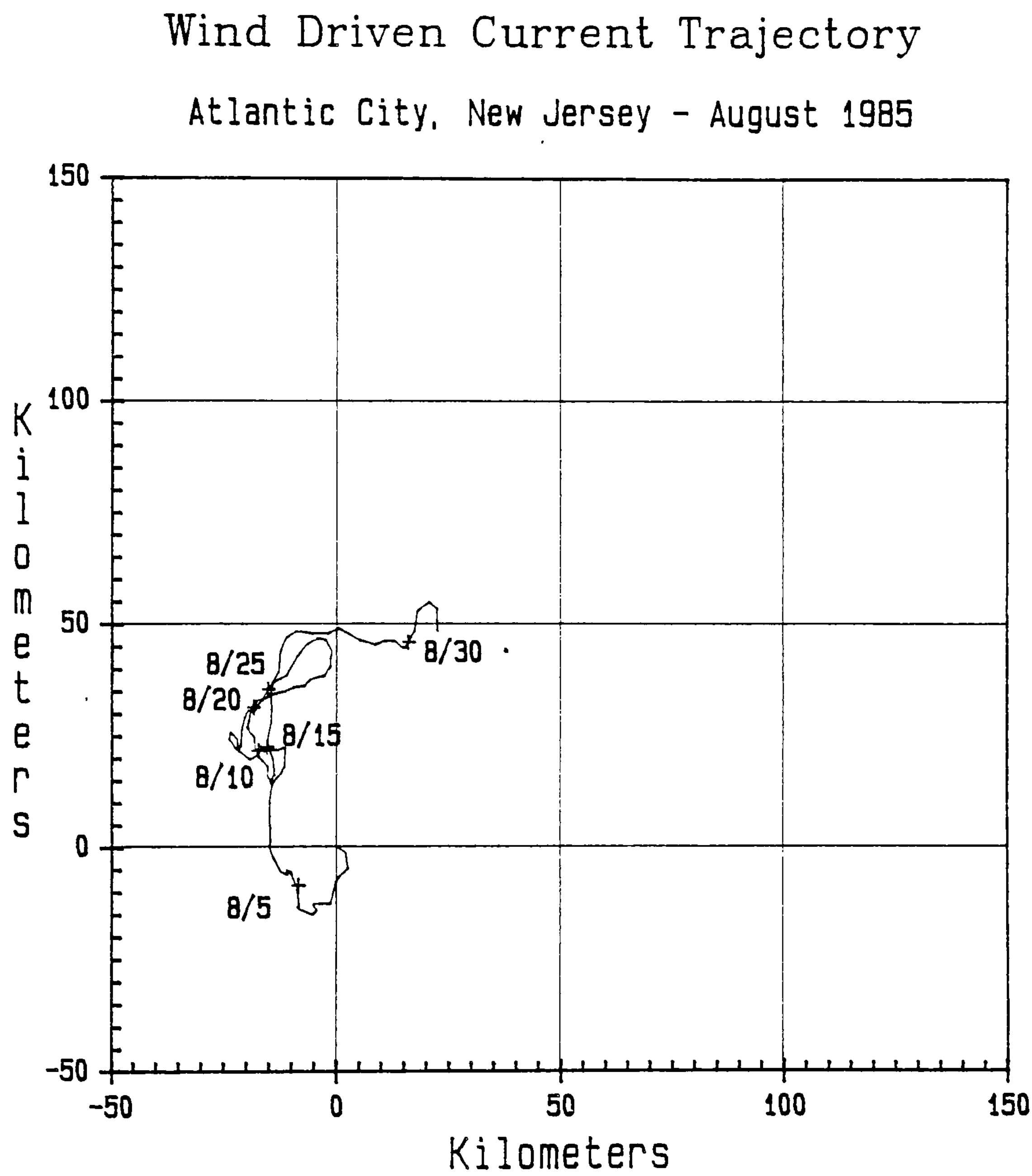


Figure 2.20b. Progressive vector diagram of currents for August, 1985, beginning at Atlantic City, NJ.



(Figures 2.20 a and b) and the account of the 1985 green tide episodes. In order for a bloom to occur, it is assumed that an abnormally high level of nutrients must be supplied to the area of the bloom. The sources of nutrients in this case derive from one or more of the following:

1. Upwelling of colder, nutrient laden deep water in response to offshore transport of surface water: This upwelling can be a result of wind stress causing the surface current to reverse from its normal southerly direction. As the water moves northerly along the coast the Coriolis effect will cause the nearshore water to move offshore requiring replacement with bottom water. Evidence of this effect in the summer is shown by a sudden drop of nearshore water temperature (Ingham and Eberwine, 1984). If an algae bloom is caused by this mechanism, an observable drop in water temperature accompanying the bloom would be expected.

2. Transport of nutrients concentrated in point source or non-point source discharges into the bloom area by currents: in order for the bloom to occur, the concentration of these nutrients must be sufficient for algal growth. This will require an increase in the normal residence time (or a decrease in flushing rate) for the bloom area. In the summer months, the normal southerly transport of water in the nearshore areas is opposed by winds coming from the southwest. This situation may set the stage for longer residence when a northeasterly wind transport is approximately equal in magnitude and opposite in direction to the prevailing tidal transport to the southwest.

The correlation of 1985 observations with tabulated meteorology is striking. During July, there were reports of coloration of the water at Barnegat Bay, Island Beach and Long Beach Island. This color was described as yellow-brown or greenish. However, no samples taken were found to contain species identified as Gyrodinium aureoleum, the causative organism for green tide. Rather Nannochloris sp., Cyanea sp., and Katodinium rotundatum were identified. Between July 21 and 29, an upwelling of cooler water was observed. Temperatures dropped from about 24°C to between 14 and 16°C. The wind record for this period shows that this event occurred at a time when transport caused by wind was directly offshore at a rate of approximately

4 km/day (5 cm/sec). The net wind component of transport for the month of July was approximately 5 km/day (6 cm/sec). This figure is somewhat larger than estimates of net tidal transport in this area.

In late July, the first observations of Gyrodinium aureolum were reported. The abundance of the species "peaked in mid-August." In addition to Gyrodinium, Nannochloris sp. was reported to be "ubiquitous and clearly dominant almost everywhere" in the area from Sandy Hook to Cape May County. The August wind driven trajectory (Figure 20b) was markedly different from that of July. In August, the wind was more variable, had a net shoreward component for most of the month, and accounted for only about one third of the transport that was attributed to the winds in July. The net transport for this period was estimated at about 2.4 km/day (3 cm/sec) directed to the northeast. A current of this velocity may counter tidal transport and thus may increase residence time (decrease flushing) of the waters along the New Jersey shore during this time.

Based on the previous discussion, it is possible to offer the following hypothesis: The supply of nutrients necessary to support the green tides does not come from upwelling of nutrient rich offshore bottom waters but rather comes from local sources (point and/or non-point) and is transported to the beach areas by wind driven currents.

The results of this preliminary analysis suggest that wind driven transport patterns over the southern New Jersey coast may have been important causal factors in the development of the green tides of 1984 and 1985. Periodic flow reversals of varying magnitude and duration, resulting from fluctuations in wind forcing, would be characterized by variable residence times in the water column. The onset of water quality problems (e.g., algal blooms, hypoxia-anoxia) in the nearshore region would be related to the respective time scales for biological and chemical reaction rates in relation to the time scale for flushing of the water column by advective transport and mixing.

Recent data from the nearshore Middle Atlantic Bight and the New Jersey nearshore (0-20 m) regions document high rates of primary production (about 500 g C/m^{2}yr) (O'Reilly et al., in press; J.E. O'Reilly, personal communication) that are much greater than the mean annual production for the continental shelf of the New York Bight (about 300 g C/m^{2}yr) (Walsh et al., 1981; Malone et al., 1983). Anthropogenic nutrient loading and non-point source drainage from the New Jersey coastal zone undoubtedly contribute to such high rates of production. Nutrient loadings are, however, only one factor in the occurrence of such high rates of summer production. The time scales associated with flushing and dispersive mixing are critical factors in determining the fate of nutrient inputs to the coastal zone.

Historical data for the New York Bight were compiled to generate composite bottom oxygen distributions averaged over July to September from 1977 to 1985. The mean value distribution (Figure 2.21) portrays a pattern that is generally well known: low oxygen water in the Apex (<3 ml/l) and off the New Jersey nearshore coast (<4 ml/l); relatively high (>4-5 ml/l) over the mid-shelf and offshore.

The distribution of the minimum O_2 values (Figure 2.22) however, clearly documents the presence of hypoxic areas along the nearshore New Jersey coast. The effect of the Hudson plume is defined by seen with progressively lower oxygen concentrations (<1 ml/l) in water extending south from Sandy Hook. A second hypoxic area is centered off the southern New Jersey coast north of Cape May to Atlantic City and extends to about the 20 m isobath with minimum oxygen values less than 1 ml/l. The southern hypoxic area is essentially the area where the green tides of 1984 and 1985 occurred. The similarity in the spatial distribution of nearshore hypoxia and the occurrences of green tides, as well as other recurrent phytoplankton blooms along the coast, suggests common physical processes that could account for the observed features.

Comparisons of the distribution of anoxia in 1976 (Figure 2.23) with the minimum bottom water oxygen values for the summers of 1977 to 1985 shows that the spatial extent of minimal values of oxygen is similar to the spatial extent of the widespread anoxia of 1976. Minimum oxygen values of less than 2 ml/l were observed at various times during 1977 through 1985 as far offshore as the 40m isobath. Offshore of the 40-50 m isobath off New Jersey, minimum bottom oxygen was greater than 2 ml/l. Recent studies by NMFS indicate strong DO gradients within the bottom meter of water. These data indicate the observed DO levels for bottom water presented in Figure 2.23 are probably overestimates. The remarkable similarity in the spatial extent of recurrent hypoxia between 1977 and 1985 over the New Jersey shelf with the 1976 anoxic

Figure 2.21. Mean bottom oxygen concentrations in New York Bight, July to September, 1977-1985. (Source: Stoddard et al., 1986).

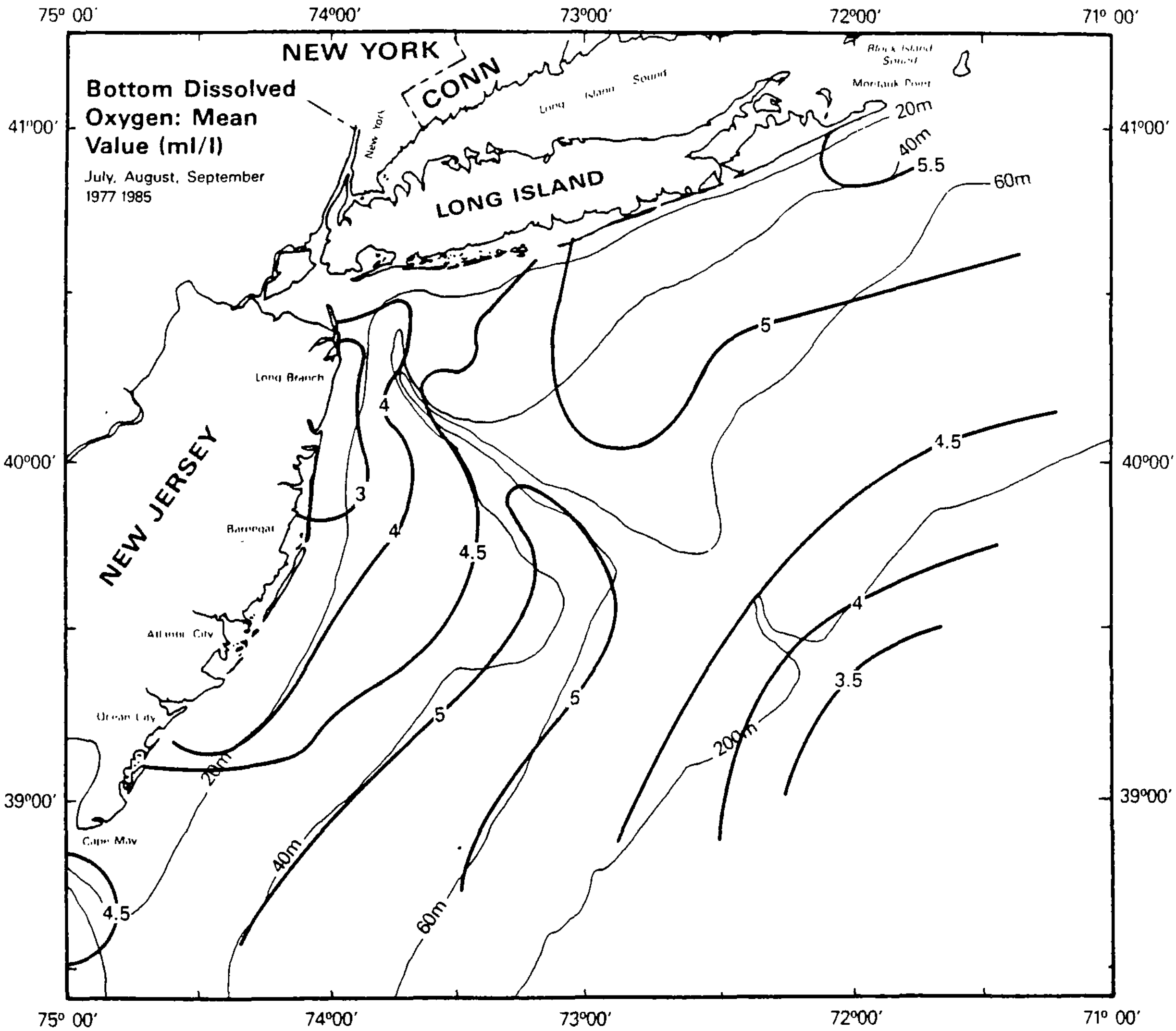


Figure 2.22. Minimum dissolved oxygen concentrations in New York Bight, July to September, 1977-1985. (Source: J.E. O'Reilly, unpublished data).

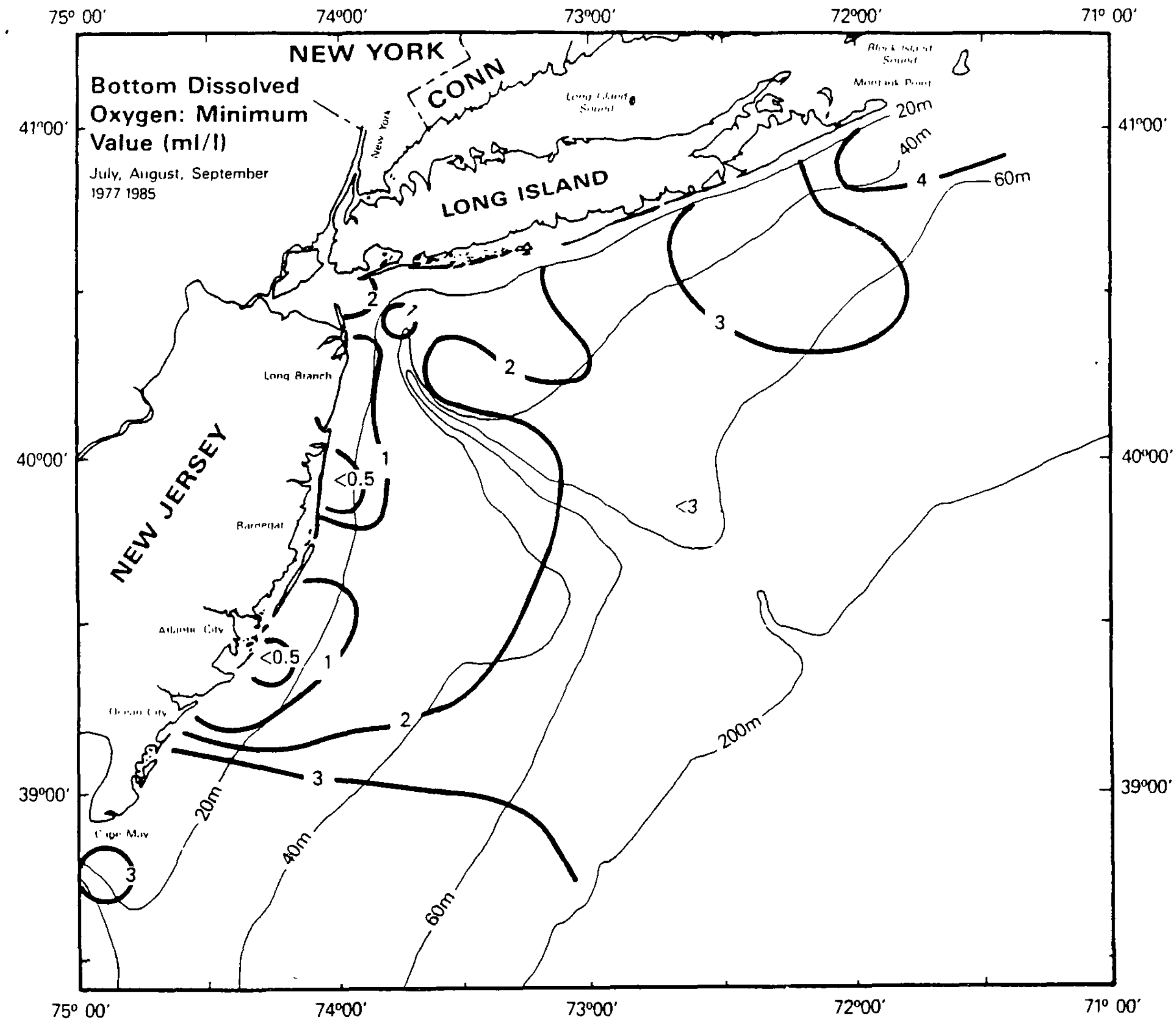
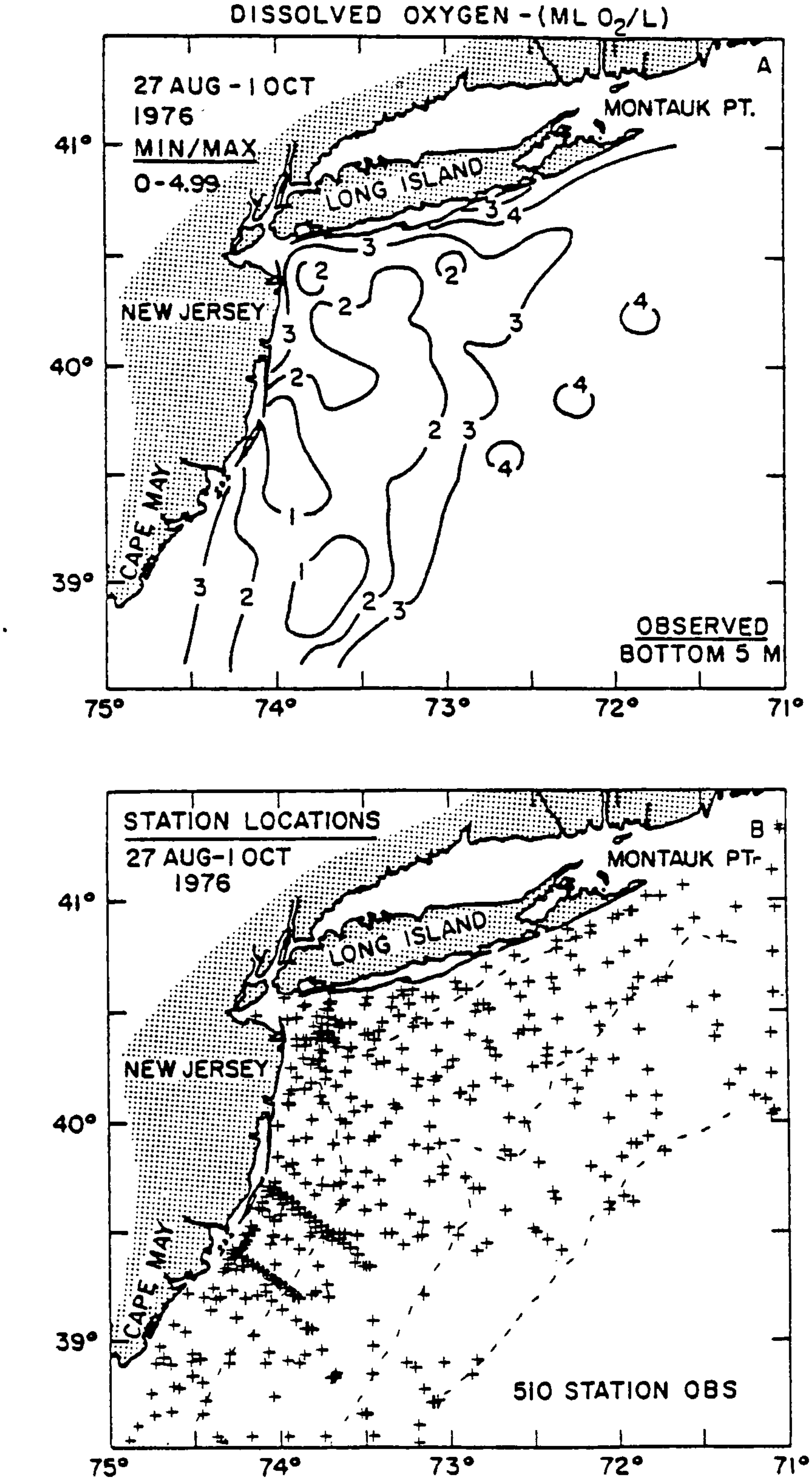


Figure 2.23. Distribution of anoxia in New York Bight, Summer, 1976.
(Source: Stoddard, 1983)



Wind data are available from a National Weather Service station about 16 km inland from Atlantic City. Data tapes of wind data for specific years of record are available from NOAA's National Climatic Center (NCC) in Asheville, NC. Wind data for 1985 were readily available for reduction and analysis. Data tapes for 1983 (reference year) and 1984 (green tide year) are currently on order from the NCC.

The wind data for July and August, 1985, were reduced and plotted as a progressive vector diagram (PVD) (Figure 2.20 a and b). The analysis presented in this report represents a zero-order attempt at constructing a simple particle trajectory model for the nearshore New Jersey coast. The time-varying drift of a particle in the nearshore coastal zone is dependent on tidal currents, mean net drift along the coast, and wind driven flow.

Data describing the variation of tidal currents with time are readily available from NOAA/National Ocean Service (NOS) tidal current tables for New Jersey. The mean net drift along the southern New Jersey coast is in the range of 5 cm/s parallel to the coast. Wind driven flow is commonly estimated at 3% of the wind speed. The direction of flow has been estimated at 14 degrees to the right of the wind direction (Hansen, 1977). This correction is required because the Coriolis effect causes moving objects to apparently turn right in the northern hemisphere.

The data presented in Figure 2.20 are for the wind driven flow component. Total excursion of a particle during July, 1985, is seen to be on the order of 150 km. In August, however, a particle would have been retained within a relatively local area with a total excursion of only 30-50 km. The wind data clearly suggest that flow in August was relatively weak and northerly along the coast. These data indicate that the residence time of water masses in the nearshore coastal area would have been significantly increased in August in comparison to July, 1985. The relatively persistent southwest winds during July would have also set up a flow reversal during July that possibly continued into August.

The New Jersey Department of Environmental Protection, Division of Water Resources Bureau of Monitoring & Data Management Biological Services Unit has written a Summary of Phytoplankton Blooms and Related Events in New Jersey Coastal Waters, Summer, 1985 (Unpublished). A synopsis of this document appears in Table 6.1. Some correlations can be made between the wind data event suggests critical factors in determining the interannual variability of oxygen depletion below the pycnocline.

There are generally weak flow reversals over the nearshore/midshelf New Jersey coast during summer with return flow towards the south seaward of about the 40-60 m isobaths. The available data suggest the occurrence of weak large scale, clockwise gyres over the New Jersey midshelf during south-southwest wind events that are conducive to upwelling and the establishment of flow reversals along the nearshore New Jersey coast. Such a circulation pattern would result in an increase in the flushing time over the New Jersey shelf such as was documented for the 1976 anoxic event (Han et al., 1979). Falkowski et al. (1980) indicated that a key factor in the onset of localized (1968, 1974) and widespread (1976) anoxic conditions is the occurrence of persistent winds from the southwest.

3. CONTAMINANT INPUTS

3.1 INTRODUCTION

The New York Bight has a number of contaminant inputs from the New York metropolitan area and the New Jersey and Long Island coasts (Figure 3.1). The majority of waste materials are discharged into the Apex through wastewater inputs into the Hudson-Raritan Estuary, sewage outfalls, and ocean disposal at four sites. Within the New Jersey coastal region, a number of municipal wastewater treatment plants in the vicinity of Atlantic City-Ocean City discharge into embayments or directly into the Atlantic Ocean through ocean outfalls. Although the New York Bight receives large discharges of waste materials, most of the mass loading and assimilation of the contaminants occurs in the Apex and in the Hudson plume along the northern New Jersey coast. Waste loadings from the Hudson-Raritan Estuary and ocean dumping in the Apex then has a minor effect on water quality along the southern New Jersey coast. Emphasis is therefore placed on characterizing the point-source waste discharges south of Barnegat Inlet to Cape May that influence coastal water quality in the southern region of the state. (Figure 3.2)

Mueller et al. (1976) and Mueller et al.(1982) have estimated contaminant inputs to the New York Bight from the Hudson-Raritan estuary, sewage outfalls, ocean dumping, atmospheric deposition and non-point source runoff. Additional loading estimates have been compiled by Ecological Analysts and SEAMOcean (1983) and NOAA (1986).

3.2 NEW JERSEY COASTAL ZONE

Mueller et al. (1976) compiled contaminant loading data for the various drainage basins of the New York-New Jersey region. Loading data are summarized in this report for the eight county drainage basins in the New Jersey coastal zone (Figure 3.3). The total drainage area for this region is 2,000 sq. miles, with mean annual precipitation of about 44 inches (Mueller et al., 1976). Surface topography of the flat coastal plain ranges in elevation from about 400 feet above sea level to sea level. A large portion of the drainage basin is less than 100 feet elevation. The coastline is characterized by barrier beaches and several shallow embayments and inlets.

Figure 3.1. Direct New York Bight discharge zone.

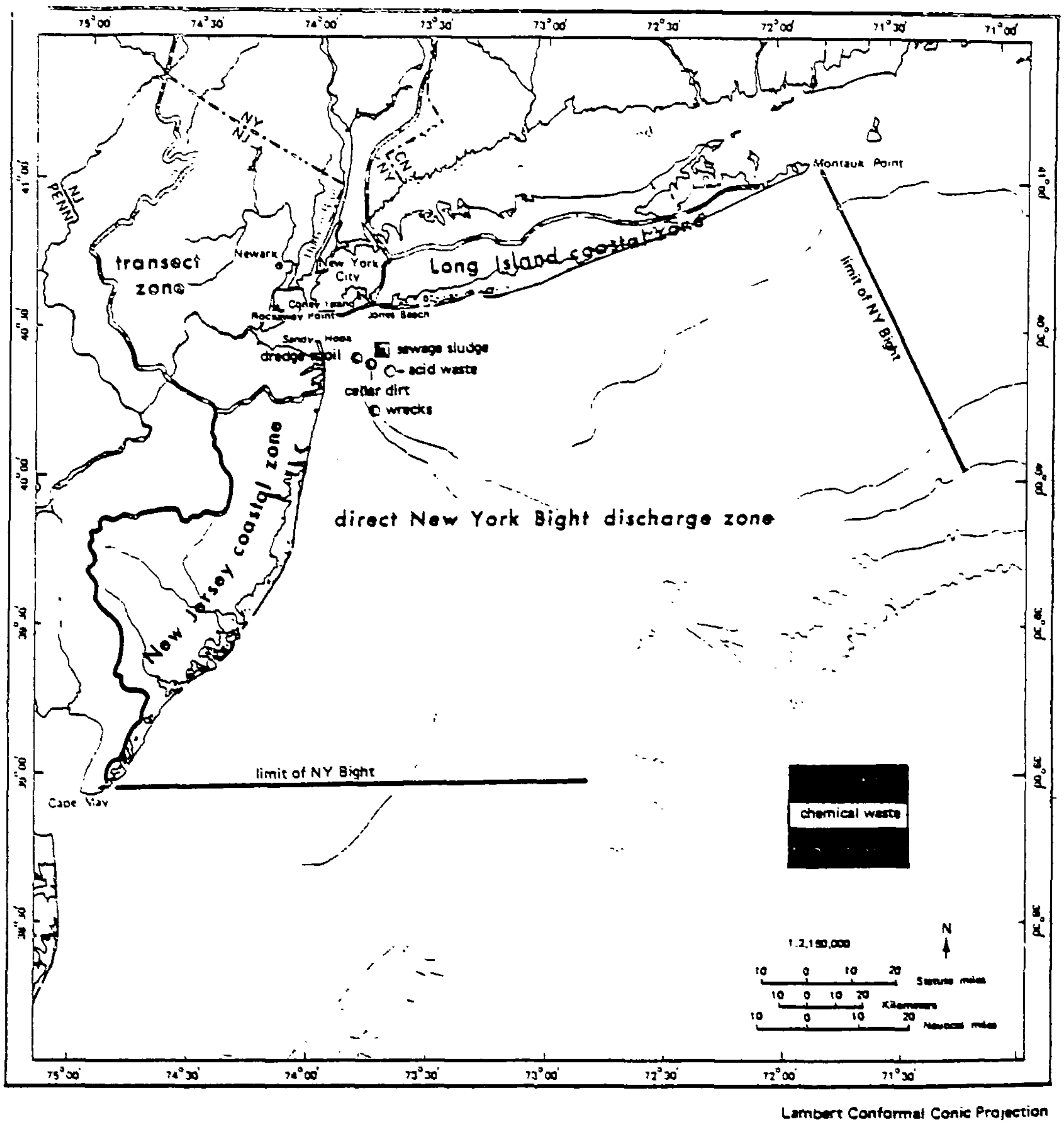
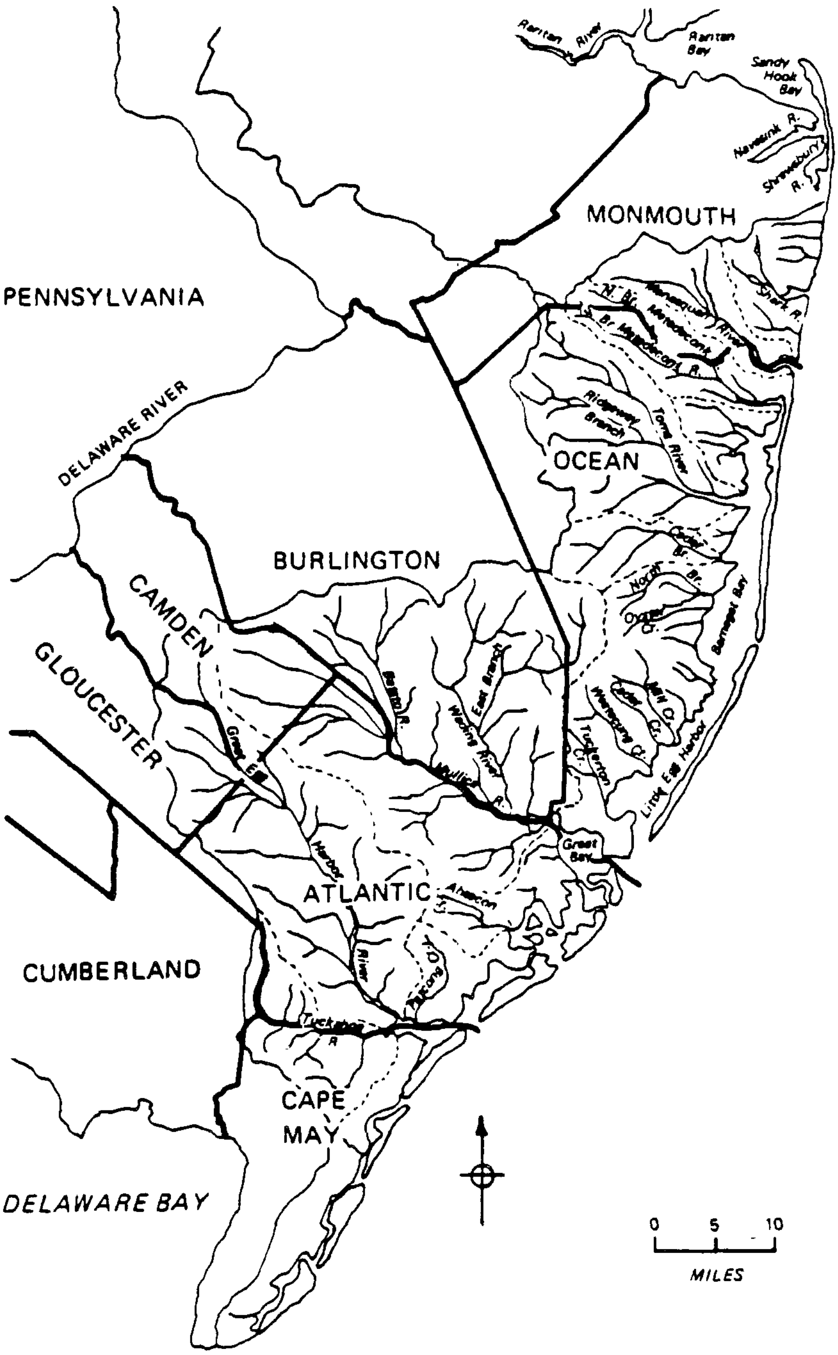


Figure 3.2. Point source discharges along southern New Jersey coast. (Source: EPA STORET)

Key to Figure 3.2

No.	Name	Discharges to
24	Atlantic County S.A.	Atlantic City Island
27	Atlantic City Electric	Atlantic City Island
28	Atlantic City Electric	Great Egg Harbor Bay
29	New Jersey Water Company	Great Egg Harbor Bay
30	New Jersey Water Company	Great Egg Harbor Bay
48	Borough of Avalon	Atlantic Ocean
49	City of Wildwood	Atlantic Ocean
50	City of North Wildwood	Atlantic Ocean
51	City of Sea Isle City	Atlantic Ocean
52	Borough of Stone Harbor	Atlantic Ocean
53	Borough of Wildwood Crest	Atlantic Ocean
54	Middle Township S.A.	Atlantic Ocean

Figure 3.3. New Jersey coastal zone counties.
(Source: Mueller et al., 1976).



In the evaluation of the green tides of 1984 and 1985, the contaminants of concern are the various compounds that can provide a nutrient source for algal growth. Anthropogenic and natural sources of nutrients to the drainage basin include: 1) non-point source runoff from tributaries, 2) point source loads, and 3) atmospheric deposition.

3.3 POINT SOURCE DISCHARGES

An inventory of point source dischargers (National Pollution Discharge Elimination System, NPDES, permitted industrial and municipal direct dischargers) in New Jersey from Sandy Hook to Cape May Point was compiled. The following sources were used to determine point source dischargers in the drainage basin:

- o EPA Permit Compliance System (PCS) database
- o SAIC Statewide Pretreatment Project Files (1984-present). Information included:
  - List of Publicly Owned Treatment Works (POTWs) in New Jersey. Computer printout provided by State that included permit number and address.
  - Direct Discharger report identified partial list of direct dischargers in study area.
  - POTW trip reports and accompanying SAIC files. POTW visits conducted as part of the program. Pertinent information included Discharge Monitoring Report Data, description of operations permit number, address, flow, level of treatment.
- o Contact with New Jersey Department of Environmental Protection Industrial Permits Division and Municipal Permits Division obtained pertinent information on industrial and POTW dischargers.
- o Environmental Information Inventory prepared by NJDEP in 1986 (unpublished). This report provided a list of permitted direct dicharges in New Jersey.
- o 208 Studies conducted for Ocean County, Atlantic County, and Cape May County. These studies estimated loadings from point and non-point source discharges.
- o NOAA Technical Memoranda

The inventory of point-source dischargers in the New Jersey coastal zone

Table 3.1a. Point source discharges to the Atlantic Ocean, Atlantic County.

POTW DISCHARGE DATA
COUNTY: ATLANTIC

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,P Range (mg/l)	Data Source
NJ0021393	Hamilton TWP MUA	2040302010 Great Egg Harbor			Tertiary	0.65	Perodic testing not required	N/A	5
NJ0024473	Atlantic County S.A.	2040302021 Ocean	39 22 59	74 26 58	Secondary	1.84-23	Yes	TN-3.2 TP-2.0	2,7
NJ0024589	City of Egg Harbor	2040301046 Mullica River			Secondary	0.37	No	N/A	5
NJ0025160	Town of Hammonton	2040301054 Hammonton Creek							

1) Mueller and Anderson. 1978. Industrial Wastes.
2) NOAA. 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

Table 3.1b. Point source discharges to the Atlantic Ocean, Burlington County.

POTW DISCHARGE DATA
COUNTY: BURLINGTON

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,P Range (mg/l)	Data Source
NO DISCHARGERS IN DRAINAGE BASIN ----> ATLANTIC OCEAN									

1) Mueller and Anderson. 1978. Industrial Wastes.
2) NOAA. 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

Table 3.1c. Point source discharges to the Atlantic Ocean, Cape May County.

POTW DISCHARGE DATA
COUNTY: CAPE MAY

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,F Range (mg/l)	Data Source
NJ0005444	Atlantic City Elec.	2040302021 Atlantic City Is.				14.3			1
NJ0005461	Atlantic City Elec.	2040302016 Great Egg Harbor By							
NJ0020371	City of Cape May	2040204001 Atlantic Ocean							
NJ0021385	Borough of Avalon	2040302018 Atlantic Ocean	39 05 30	74 43 51	Secondary	1.42-1.7		TN-0.2 TP-0.2	1,2
NJ0022811	City of Wildwood Bd of Comm.	2040302020 Atlantic Ocean	38 59 41	74 49 30	Primary	1.4-3.2	No	TN-0.2 TP-10.1	2
NJ0023515	City of North Wildwood	2040302020 Atlantic Ocean			Primary	1.02-3.0			1
NJ0023680	City of Sea Isle City	2040302018 Atlantic Ocean			Primary	0.28-3.3	No	N/A	1
NJ0026581	Borough of Stone Harbor	2040302019 Atlantic Ocean/ Great.Channel			Primary	0.3-0.73	No	N/A	1
NJ0027171	Borough of Wildwood Crest NJ	2040302020 Atlantic Ocean			Primary	1.92-2.59			1
NJ0027286	New Jersey Water Company*	2040302016 Great Egg Harbor By	39 00 00	74 49 29	Secondary	7.6			2
NJ0028037	Middle Township S.A.	2040302020 Atlantic Ocean			Primary	0.18			1

*Ocean City - POTW on line in 1984

1) Mueller and Anderson, 1978. Industrial Wastes.
2) NOAA, 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

Table 3.1c. Point source discharges to the Atlantic Ocean, Cape May County (continued).

POTW DISCHARGE DATA
COUNTY: MONMOUTH

(continued)

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,P Range (mg/l)	Data Source
NJ0026204	Borough of Highlands	2030104007 *A			Primary	1.7			1
NJ0026735	Northeast Monmouth City Reg. S.A.	2030104014 Atlantic Ocean	40 20 05	73 57 56	Secondary	2.5			1
NJ0030899	City of Long Branch	2030104015 Atlantic Ocean							
NJ0031887	Marlboro MUA	2030104008 Navesink River							

1) Mueller and Anderson, 1978. Industrial Wastes.
2) NOAA, 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

Table 3.1d. Point source discharges to the Atlantic Ocean, Monmouth County.

POTW DISCHARGE DATA
COUNTY: MONMOUTH

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,P Range (mg/l)	Data Source
NJ0022535	Aberdeen Township MUA	2030104005 Raritan Bay				0.89			1
NJ0022543	Aberdeen Township MUA	2030104005 Raritan Bay							
NJ0022829	Aberdeen Township MUA	2030104006 Sandy Hook Bay							
NJ0023191	Borough of Deal	2030104015 Atlantic Ocean			Primary	0.37			1
NJ0024520	Township of Ocean S.A.	2030104014 Atlantic Ocean	40 15 19	73 59 12	Secondary	2.2			1
NJ0024562	South Monmouth Regional S.A.	2030104015 Atlantic Ocean	40 10 00	74 02 30	Secondary	2.93			1
NJ0024694	Monmouth Co. Bayshore Outfall	2030104014 Atlantic Ocean							
NJ0024708	Bayshore Regional S.A.		40 26 29	74 09 33	Secondary	8.46			1,2
NJ0024783	Long Branch Sewerage Authority	2030104014 Atlantic Ocean	40 18 44	73 59 07	Secondary	4.0			1
NJ0024872	Township of Neptune STP	2030104015 Atlantic Ocean	40 11 25	73 59 22	Secondary	4.0			1
NJ0024881	Township of Neptune STP	2030104015 Atlantic Ocean			Primary	1.7			1
NJ0025241	City of Asbury Park	2030104015 Atlantic Ocean	40 13 39	73 59 44	Primary	2.9			1
NJ0025356	Township of Middletown S.A.		4- 25 53	74 04 57	Primary	4.9			1
NJ0025402	Borough of Atlantic Highlands	2030104013 Sandy Hook Bay			Primary	0.18			1
NJ0025437	Borough of Union Beach W.D.	2030104006 Sandy Hook Bay							

1) Mueller and Anderson. 1978. 'Industrial Wastes.
2) NOAA. 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

Table 3.1e. Point source discharges to the Atlantic Ocean, Ocean County.

POTW DISCHARGE DATA
COUNTY: OCEAN

NPDES #	Facility Name	Receiving Water	Latitude	Longitude	Treatment	Flow (MGD)	Monitor Effluent (N,P)	N,P Range (mg/l)	Data Source
NJ0004120	Toms River Chemical Corp	2040301015 Toms River				5.2			1
NJ0005550	Jersey Central Power & Light	2040301016 Toms River							
NJ0005746	American Smelting and Refining	2040301017 Toms River							
NJ0020583	Jackson Township MUA	2040301009 Metedconk R,N							
NJ0022942	Berkeley Township MUA	2030103025 Passaic River			Secondary	0.04			1
NJ0022951	Berkeley Township S.A.	2030103025 Passaic River							
NJ0022969	Berkeley Township S.A.	2030103025 Passaic River							
NJ0023370	Borough of Seaside Heights	2040301004 Atlantic Ocean			Primary	1.5			1
NJ0024775	Dover Sewerage Authority	2040301004 Atlantic Ocean	39 59 56	74 08 24	Secondary	5.5			2
NJ0026018	Ocean County Utilities Authority	2040301031 Little Egg Harbor	39 40 19	74 15 43	Secondary	4.46-8	yes	20	2,5
NJ0027316	Borough of Seaside Park	2040301004 Atlantic Ocean	39 58 00	74 08 00	Primary	1.01			2
NJ0028142	Ocean County Sewerage Authority	2040301015 Toms River	40 02 37	74 04 51	Secondary	5.75			2
NJ0029408	Ocean County Sewerage Authority	2040301004 Atlantic Ocean	39 54 12	74 03 41	Secondary	2.96			2
NJ0033341	W.R. Grosser Subdivision	2040301033 Little Egg Harbor							
NJ0034622	Borough of Point Pleasant	2040301003 Atlantic Ocean			Primary	1.18			1

1) Mueller and Anderson, 1978. Industrial Wastes.
2) NOAA. 1986. National Coastal Pollutant Discharge Inventory: Discharge Summaries for New Jersey
3) 208 Plan for Cape May County. 1980 Data.
4) POTW Trip Reports for Pretreatment Program. 1984.
5) Telephone Conversation 7/86.
6) Conversation with NJDEP Municipal Permits 7/86.
7) 208 Plan for Atlantic County.

(Table 3.1) was compiled from these data sources for each coastal county. The inventory provides the following information:

- o NPDES permit number
- o Facility name
- o USGS hydrologic code/receiving water
- o Latitude/Longitude of discharge
- o Level of treatment
- o Average flow rate
- o Availability/range of nutrient data for effluent
- o Existing permit limits

Based on discussions with personnel in the NJDEP Municipal Permits Division, only Ocean County UA, Cape May County, Lower Township, and Atlantic County SA are required to monitor for nitrogen and phosphorus. Ocean County is required to report nutrient data on Discharge Monitoring Reports. Therefore, to obtain effluent nutrient levels it would be necessary to contact all POTWs to find out if any data exists.

It is important to note that a NOAA (1986) report indicates the Avalon Sewage Treatment Plant is listed as an ocean discharge. According to NJDEP Municipal Permits (C. Hoffman, personal communication), only North Wildwood, Cape May County, Atlantic County, and Ocean County have ocean outfalls -- Avalon was not reported as discharging to the ocean. In plotting the discharge locations for "non-ocean" outfalls, it is apparent that there is a potential discrepancy for Atlantic City Electric (27) and Atlantic County SA (24), both listed in the PCS file as discharging to "Atlantic City 15".

The inventory of NPDES permitted dischargers for Atlantic County and Cape May County summarizes two items that are directly relevant to the occurrence of 1) the green tides of 1984 and 1985, and 2) recurrent phytoplankton blooms in southern New Jersey inshore waters.

Of the 11 POTW's discharging directly, or indirectly, into the Atlantic Ocean, at least six POTWs (total of 5-13 mgd) are reported as having primary treatment. The Clean Water Act (1972 and 1977 amendments) requires a minimum of secondary treatment for municipal dischargers unless they have 301h waivers. Based on the data presented in Table 3.2 (Mueller *et al.*, 1976) there is a negligible difference in effluent nitrogen levels between primary and secondary treatment.

Table 3.2. Typical POTW discharge characteristics. (Source: Mueller *et al.*, 1976).

Parameter	Concentration, mg/l, for N.Y.C. raw sewage[a]	N.J. primary effluent[b]	N.Y.C. secondary effluent[c]
SS	139	93	43
ALK[d]	190	190	170[e]
BOD_5	131	158	36
COD	$2.5\times BOD_5$[k]	$2.5 BOD_5$[k]	$4.7 BOD_5$[k]
TOC	83	0.68 BOD_5	0.94 BOD_5
MBAS[d]	10	10	1.0[f]
O & G	36	23	15
NH_3-N	10.6	0.58 Tot.N	0.64 Tot.N
Org-N	10.4	0.69 NH_3-N	0.53 NH_3-N
NO_2+NO_3-N	0.68	0.02 Tot.N[g]	0.02 Tot.N[g]
Total N	21.7	22[g]	22[g]
Ortho P	3.27	0.7 Tot.P	0.7 Tot.P
Total P	4.70	6.14	3.30
Cd	0.018	0.012[g]	0.012[g]
Cr	0.15	0.057[g]	0.057[g]
Cu	0.23	0.105[g]	0.105[g]
Fe	2.5	0.70[g]	0.70[g]
Hg	0.033	0.025[g]	0.025[g]
Pb	0.26	0.190[g]	0.190[g]
Zn	0.39	0.185[g]	0.185[g]
F.Coli[h]	0.44 T.Coli	0.44 T.Coli	0.44 T.Coli
T.Coli[i]	50×10^6	15×10^6	2.5×10^6
T.Coli-after Chlor.[j]		357	357

a. New York City treatment plant 1972 average influent concentrations, appendix 6.
b. New Jersey primary treatment plant average effluent concentrations, appendix 6.
c. New York City average secondary (intermediate) effluent concentrations, appendix 6.
d. Bay Park Plant, Nassau Co. data, Beckman (1973).
e. Average to two values, appendix 13.
f. Range = 0.3 - 1.4 mg/l.
g. Average primary + secondary effluent concentrations.
h. Based on Chambers (1971) and Silvey (1974).
i. Lake Tahoe, Calif., data, Culp and Culp (1971); org/100 ml.
j. From New York City secondary effluent F.Coli data; org/100 ml., appendix 6.
k. From Eckenfelder (1970).

Under the current round of NPDES permits for all the POTW's in Atlantic County and Cape May County, none are effluent limited for nutrients. Given the recurrent water quality problems of hypoxia and algal blooms in the southern New Jersey coastal zone, reduction of nutrient loading from the POTWs would be a reasonable management policy for EPA.

3.4 INDUSTRIAL DISCHARGERS

Several industrial dischargers were identified in the PCS database and in State Pretreatment Program files for the New Jersey Coastal Zone counties. With the exception of American Smelting and Refining and Jersey Central Power and Light discharging to Toms River; Ceiba-Geigy discharging to the Atlantic Ocean via Toms River and the Atlantic City Electric Public Service Electric and Gas power plants discharging to "Atlantic City Island," the remainder of industrial sources discharge to inland tributaries. In the evaluation of the green tide problem, these dischargers were judged to be insignificant sources of nutrient loading within the drainage basin. A listing of all NPDES dischargers in the coastal zone counties is available from the EPA/PCS database and the unpublished 1986 NJDEP report on permitted dischargers in the state.

3.5 SUMMARY OF POINT SOURCE INPUTS

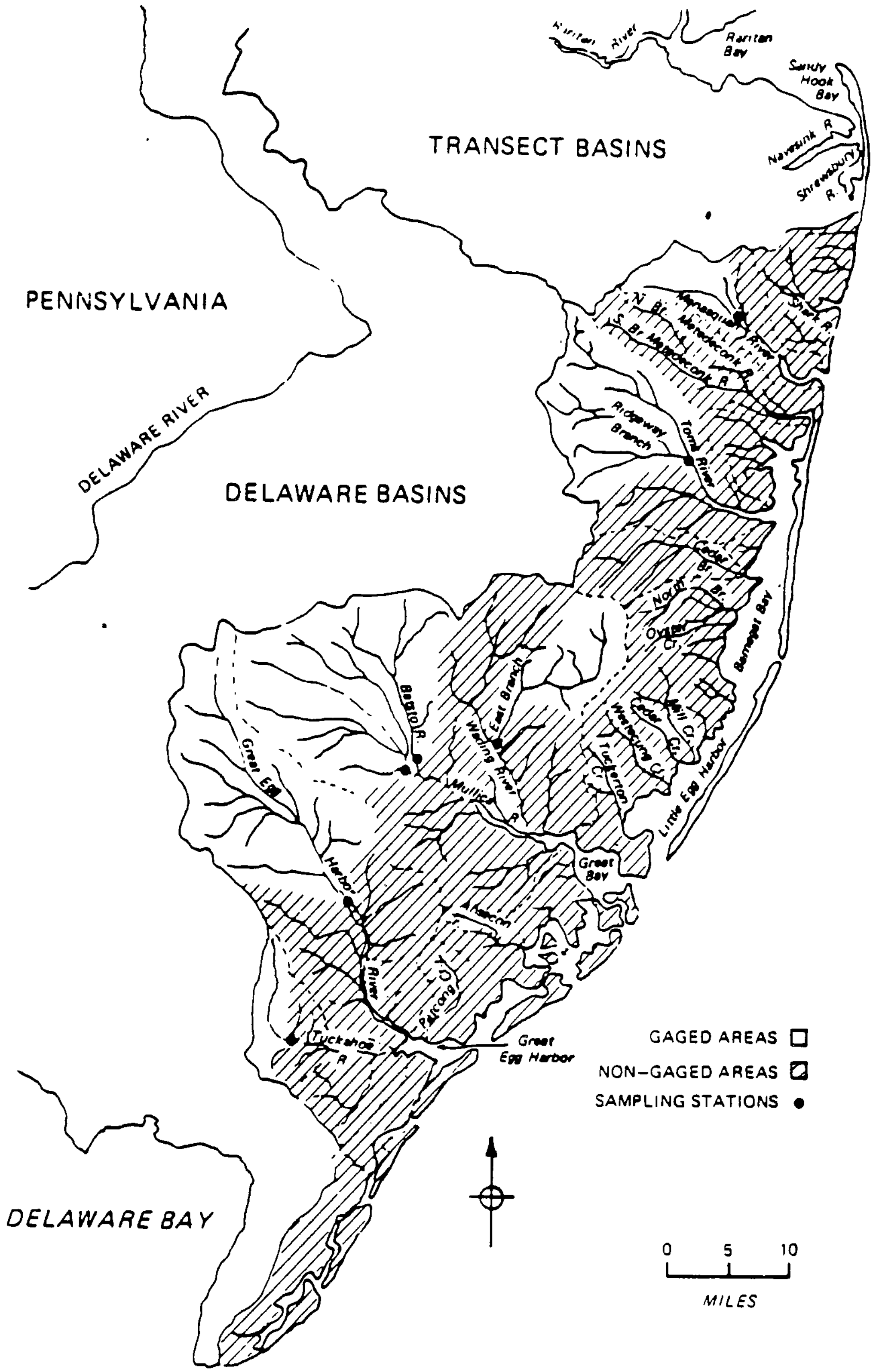
An estimate of total mass loading of nitrogen from point source dischargers is based on data from Mueller _et al._ (1976) and NOAA (1986). For the municipal loading estimates, actual effluent data for nitrogen were not available. Mueller _et al._ (1976) used typical concentrations of wastewater effluent for primary and secondary treatment plants (Table 3.2)

3.6 NON-POINT SOURCE RUNOFF

Mueller _et al._ (1976) and NOAA (1986) present estimates of non-point nitrogen source loading from the New Jersey coastal zone drainage area. Surface runoff mass loads from tributaries were estimated by Mueller _et al._ (1976) for the total area of 2,000 square miles. Most of the drainage basin is not covered by USGS streamflow and water quality monitoring stations (Figure 3.4).

To illustrate the type of data available to characterize surface runoff, streamflow and water quality data were obtained from EPA/STORET for USGS Station No. 01409815 for the West Branch of the Wading River at Maxwell, NJ,

Figure 3.4. Stream flow monitoring stations in coastal New Jersey. (Source: Mueller et al., 1976).



1974 through 1985 (Figure 3.5) and for 1983 through 1985 (Figure 3.6). It is apparent from the data that peak discharge in 1984 (ca. 625 cfs) was considerably greater than peak flows between 1980 and 1983 (250 cfs). In contrast, peak discharge in 1985 (ca. 100 cfs) reflected the driest conditions for the previous seven years of record. Historical low-flow (7Q10) is 22 cfs (nine years of record).

Long-term water quality data are presented for ammonia (Figure 3.7), nitrate and nitrite (Figure 3.8) and total Kjeldahl nitrogen (Figure 3.9). The number of observations for ammonia and nitrates in 1983 through 1985 is insufficient to relate to interannual variability in surface runoff. Total Kjeldahl nitrogen (TKN) (organic-N + ammonia), however, does reflect peak concentrations during the summer of 1984. Using data such as these for other USGS ambient monitoring stations, Mueller et al. (1976) estimated the total mass loading from surface runoff for the New Jersey coastal zone. Table 3.3 summarizes the total mass loading for flow and nitrogen estimated by Mueller et al. (1976) and NOAA (1986).

Although the data presented are highly aggregated and based on best estimates of a limited database, the data are useful to evaluate the mass loading of nitrogen from non-point source runoff in relation to the total loading from point sources. A summary of total mass loading of nitrogen from non-point and point sources is presented in Table 3.4. Non-point source runoff accounts for about 50-70% of the total nitrogen loading in the New Jersey coastal zone.

Figure 3.5. Mean Monthly Streamflow for West Branch of the Wading River, 1977-1985
(Source: EPA STORET)

01409815 | | STORET System
39 40 30.0 074 32 28.0 2
WB WADING R AT MAXWELL NJ
34005 NEW JERSEY BURLINGTON

112WRD 02040301 /TYPA/AMBNT/STREAM
760730 DEPTH 0
INDEX 0134063 000160
MILES 8.00 11.80

	PARAMETER			NOBS	AVE	MAX	MIN	BEG-DATE	END-DATE
61	STREAM	FLOW,	INST-CFS	68	168	868	34	77/10/19	86/01/14

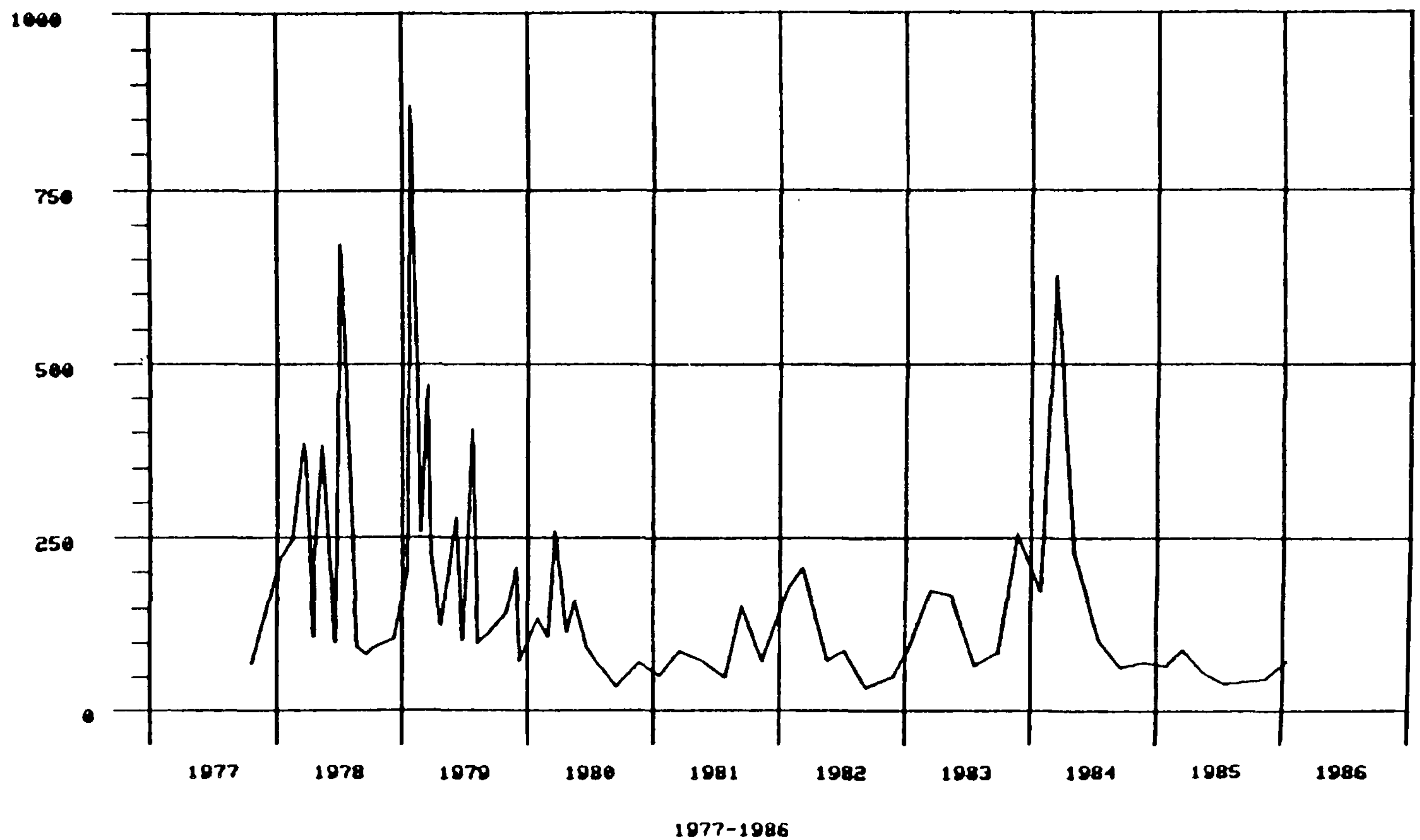


Figure 3.6. *Mean monthly stream flow for the Wading River, 1983-1985.*

(Sources: EPA STORET)

```
 01409815                                                                                     STORET System
39 40 30.0 074 32 28.0  2
WB WADING R AT MAXWELL NJ
34005 NEW JERSEY       BURLINGTON

112WRD   02040301                 /TYPA/AMBNT/STREAM
        760730      DEPTH     0
 INDEX 0134063  000160
 MILES    8.00    11.80
                   PARAMETER                         NOBS       AVE        MAX        MIN  BEG-DATE   END-DATE
             61  STREAM     FLOW,    INST-CFS         17        141        625         39  83/01/10   85/11/13
```

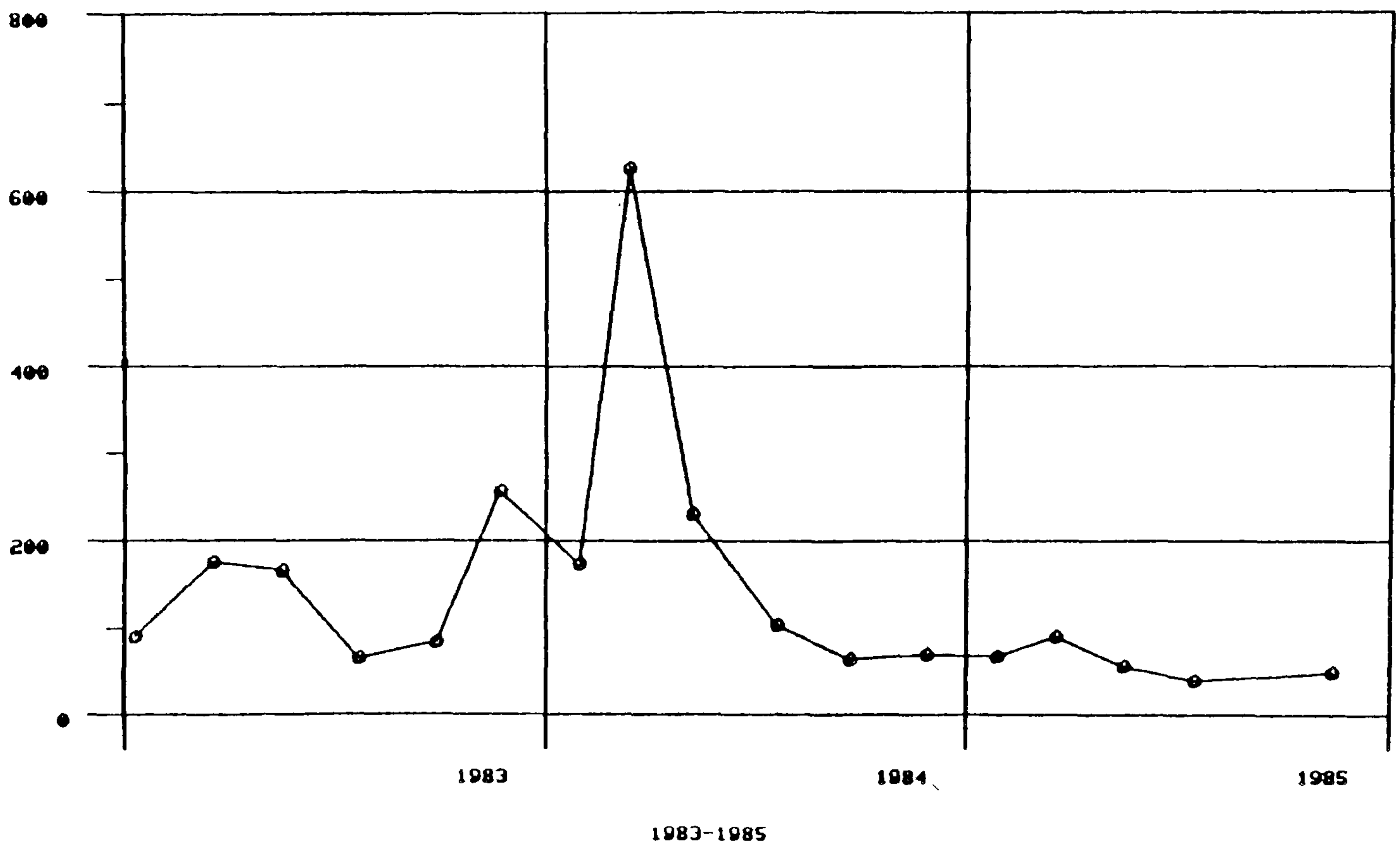


Figure 3.7. Ammonia in the Wading River, 1973 - 1985. (Source: EPA STORET)

```
 01409815                                                                        STORET System
39 40 30.0 074 32 28.0  2
WB WADING R AT MAXWELL NJ
34005 NEW JERSEY        BURLINGTON

112WRD   02040301                /TYPA/AMBNT/STREAM
      760730      DEPTH     0
 INDEX 0134063   000160
 MILES    8.00    11.80
```

PARAMETER		NOBS	AVE	MAX	MIN	BEG-DATE	END-DATE
610 NH3+NH4- N TOTAL	MG/L	47	0.031	0.260	0.000	76/05/12	86/01/14

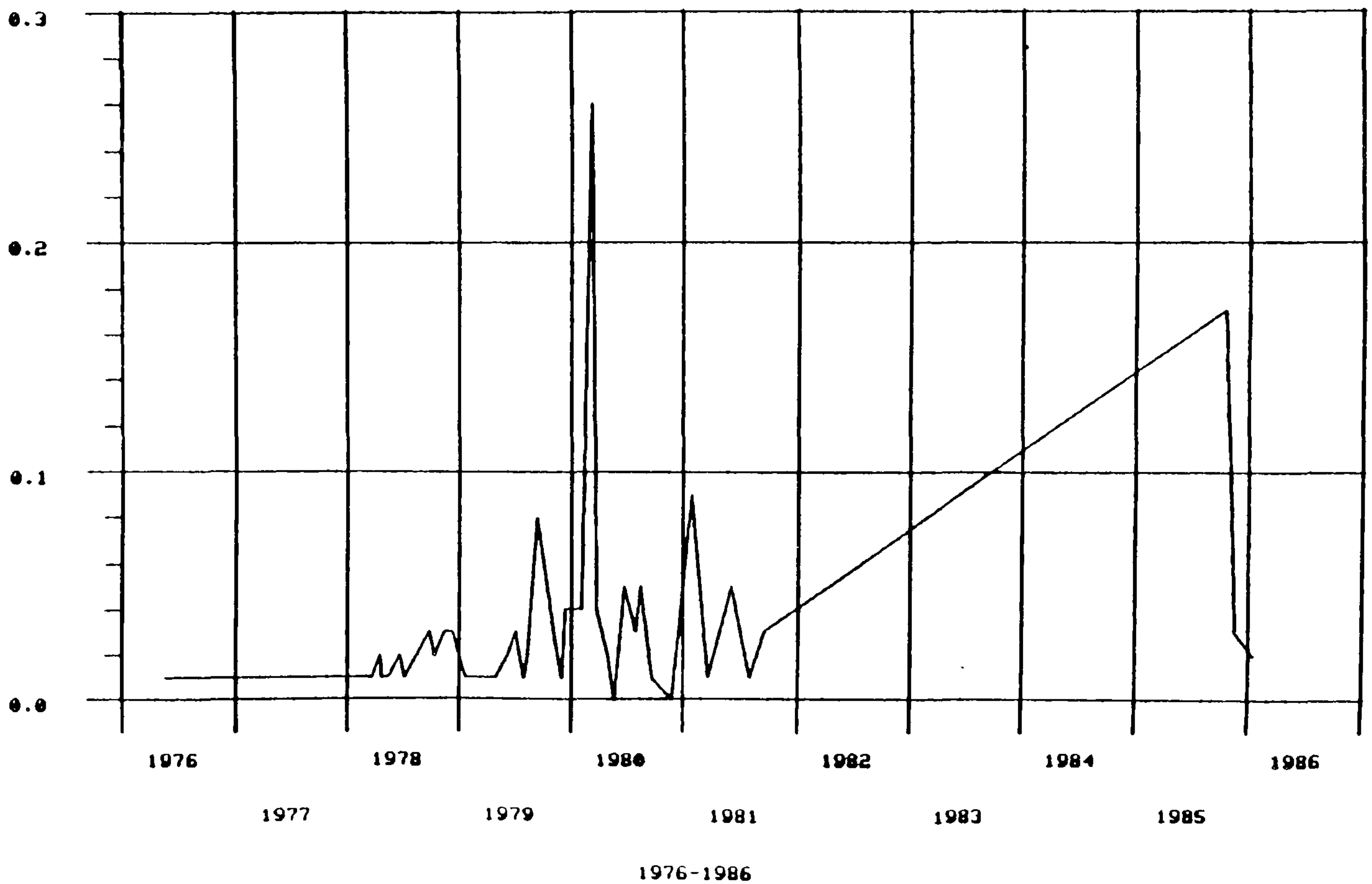


Figure 3.8. Nitrate and Nitrite in the Wading River, 1973 - 1985

(Source: EPA STORET)

01409815 STORET System
39 40 30.0 074 32 28.0 2
WB WADING R AT MAXWELL NJ
34005 NEW JERSEY BURLINGTON

112WRD 02040301 /TYPA/AMBNT/STREAM
760730 DEPTH 0
INDEX 0134063 000160
MILES 8.00 11.80

PARAMETER				NOBS	AVE	MAX	MIN	BEG-DATE	END-DATE
630	NO2&NO3	N-TOTAL	MG/L	45	0.07	0.85	0.01	76/05/12	85/10/15

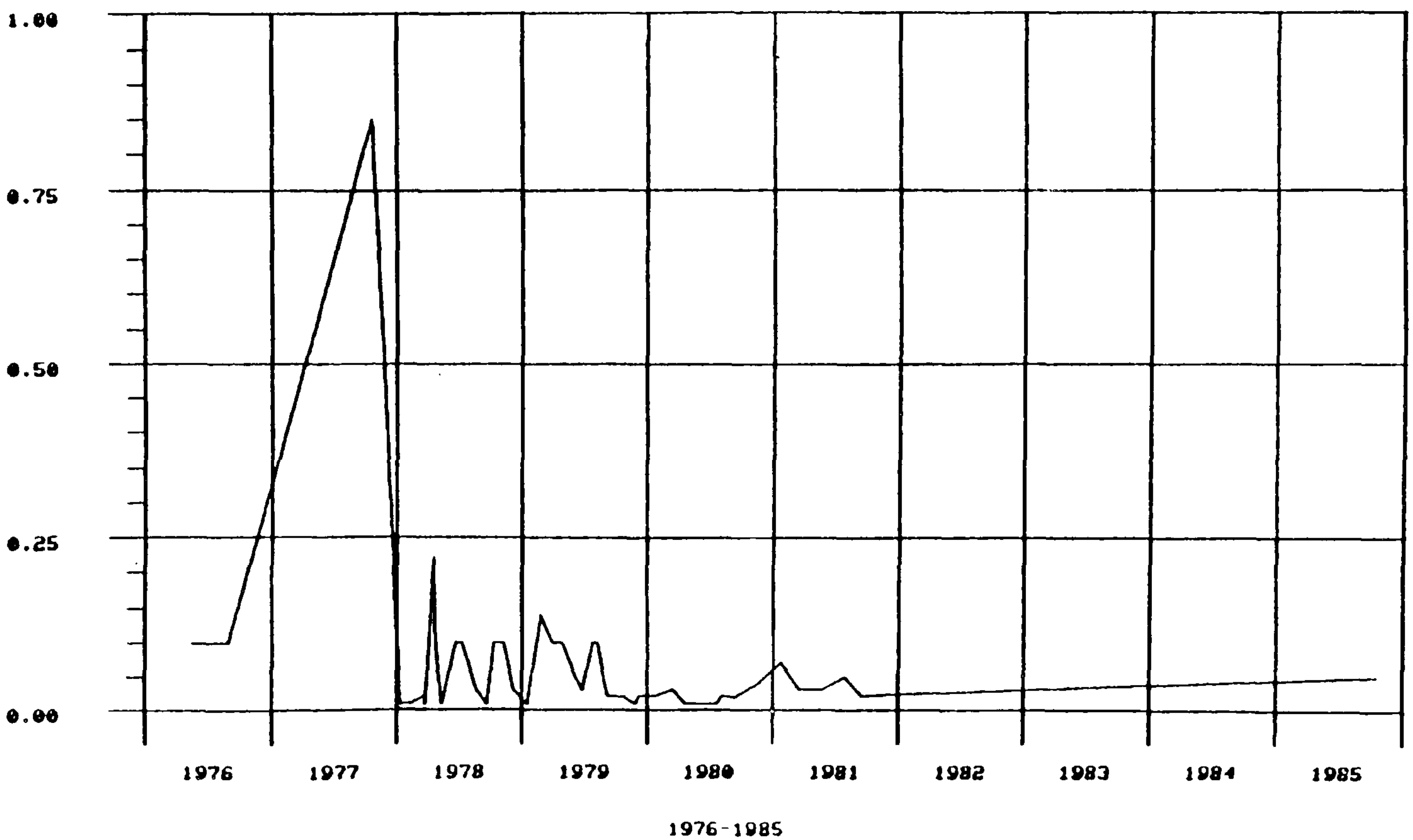


Figure 3.9. Total Kjeldahl nitrogen in the Wading River, 1973 - 1975.

(Source: EPA STORET)

STORET System

01409815
39 40 30.0 074 32 28.0 2
WB WADING R AT MAXWELL NJ
34006 NEW JERSEY BURLINGTON

112WRD 02040301 /TYPA/AMBNT/STREAM
760730 DEPTH 0
INDEX 0134063 000160
MILES 0.00 11.80

PARAMETER			NOBS	AVE	MAX	MIN	BEG-DATE	END-DATE
625 TOT KJEL	N	MG/L	73	0.484	2.500	0.100	76/06/12	86/01/14

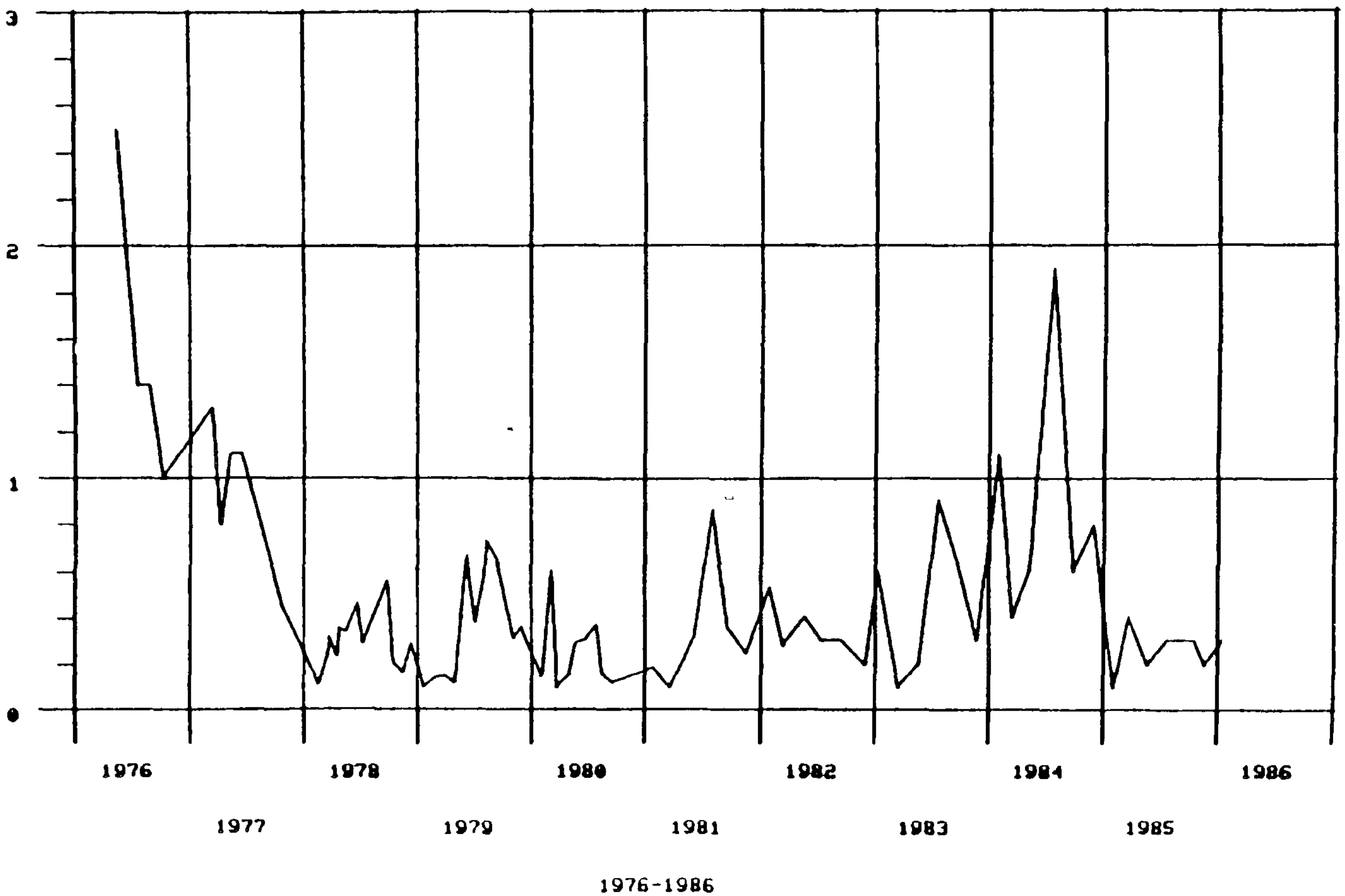


Table 3.3. New Jersey Coastal Zone Runoff Mass Loads (Source: Mueller *et al*. 1982).

	Gaged Runoff Weighted Average Concentration (mg/l)	Total Runoff Load (metric tons/day)
Drainage area (mi^2) (gauged)	727	2,000
Flow (cfs)	1,200	3,300
(cfs/mi^2)	165	--
Ammonia-N	0.2	1.6
organic-N	0.25	2.0
TKN	0.45	3.6
nitrite and nitrate	1.6	12.9
Total-N	2.05	16.5

Average survey flow = 1650 cfs

Data Source: Mueller et al. (1976).

Table 3.4. Summary of pollutant discharges to the Atlantic Ocean from New Jersey. (Source: NOAA, 1986).

Coastal County	Facility Type [b]	All Plants in County (100t/y): # of Plants	All Plants in County (100t/y): Flow (100mgy)	All Plants in County (100t/y): BOD_5	All Plants in County (100t/y): TN	All Plants in County (100t/y): TP	Plants with Ocean Outfalls (100t/y): # of Plants	Plants with Ocean Outfalls (100t/y): Flow (100mgy)	Plants with Ocean Outfalls (100t/y): BOD_5	Plants with Ocean Outfalls (100t/y): TN	Plants with Ocean Outfalls (100t/y): TP
1. Bergen	Major	4	209.0	62.5	9.9	6.1	-	-	-	-	-
	Minor	23	119.0	10.1	5.5	3.5					
	Total	27	328.0	72.6	15.4	9.6					
2. Essex	Major	2	779.0	1370.0	36.3	22.8	-	-	-	-	-
	Minor	11	42.0	0.0	2.2	1.2					
	Total	13	821.0	1370.0	38.5	24.0					
3. Union	Major	2	228.0	45.1	10.7	6.6	-	-	-	-	-
	Minor	9	12.0	1.4	0.6	0.4					
	Total	11	240.0	46.5	11.3	7.0					
4. Hudson	Major	6	332.0	188.0	15.6	9.7	-	-	-	-	-
	Minor	17	39.0	18.0	1.8	1.1					
	Total	23	371.0	206.0	17.4	10.8					
5. Middlesex	Major	4	427.0	128.0	20.0	12.5	-	-	-	-	-
	Minor	19	39.0	9.0	1.9	1.2					
	Total	23	466.0	137.0	21.9	13.7					
6. Monmouth	Major	9	143.0	16.6	6.7	4.2	8	137.5	15.8	6.5	4.0
	Minor	30	34.0	5.0	1.6	1.1	2	3.4	2.3	0.2	0.2
	Total	39	177.0	21.6	8.3	5.3	10	140.9	18.1	6.7	4.2
7. Ocean	Major	5	72.1	4.2	3.4	2.1	4	68.5	3.9	3.3	2.0
	Minor	10	6.9	1.0	0.3	0.2	1	0.4	0.3	0.0	0.0
	Total	15	79.0	5.2	3.7	2.3	5	68.9	4.2	3.3	2.0
8. Burlington	Major	9	51.8	5.9	2.4	1.5	-	-	-	-	-
	Minor	34	46.9	5.7	2.3	1.5					
	Total	43	98.7	11.6	4.7	3.0					
9. Camden	Major	7	155.6	104.1	7.2	4.4	-	-	-	-	-
	Minor	40	90.0	14.0	4.1	2.7					
	Total	47	245.6	118.1	11.3	7.1					
10. Gloucester	Major	1	47.4	3.4	2.2	1.4	-	-	-	-	-
	Minor	5	4.6	0.5	0.3	0.2					
	Total	6	52.0	3.9	2.5	1.6					
11. Atlantic	Major	1	67.1	4.5	3.1	2.0	1	67.1	4.5	3.1	2.0
	Minor	10	9.2	1.8	0.5	0.4	0	0.0	0.0	0.0	0.0
	Total	11	76.3	6.3	3.6	2.4	1	67.1	4.5	3.1	2.0
12. Salem	Major	0	0.0	0.0	0.0	0.0	-	-	-	-	-
	Minor	9	11.1	5.7	0.5	0.3					
	Total	9	11.1	5.7	0.5	0.3					
13. Cumberland	Major	2	21.4	2.7	1.0	0.6	-	-	-	-	-
	Minor	2	3.9	0.6	0.2	0.1					
	Total	4	25.3	3.3	1.2	0.7					
14. Cape May	Major	4	46.2	7.3	2.2	1.4	3	38.1	7.0	1.7	1.1
	Minor	14	16.3	5.3	0.8	0.5	2	3.8	2.5	0.2	0.2
	Total	18	62.5	12.6	3.0	1.9	5	41.9	9.5	1.9	1.3
Total	Major	56	2579.6	1935.5	120.7	75.3	16	311.2	31.2	14.7	9.1
	Minor	233	473.9	78.1	22.6	14.4	5	7.6	5.1	0.4	0.4
	Total	289	3053.5	2013.6	143.3	89.7	21	318.8	36.3	15.1	9.5

Abbreviations: t/y, tons per year; mgy, million gallons per year; BOD_5, 5-Day Biochemical Oxygen Demand; TN, Total Nitrogen; TP, Total Phosphorus.

a/ Pollutant discharges can also be disaggregated by season.

b/ Plants that discharge more than 1 million gallons/day are defined as "major". For a detailed specification of major wastewater treatment plants see Table 2.

4. WATER QUALITY DATA SOURCES

4.1 INTRODUCTION

Public concern that water quality problems such as oxygen depletion and nuisance phytoplankton blooms may be partially related to ocean disposal of waste in the New York Bight has resulted in a lengthy history of research programs (e.g., Mayer, 1982) and intense public debate (NACOA, 1981; Squires, 1983). Major oceanographic programs include those funded by the National Academy of Sciences, 1948-1949; the U.S. Atomic Energy Commission, 1954-1961; the U.S. Army Corps of Engineers, 1964-1970; the National Oceanic and Atmospheric Administration (NOAA) MESA New York Bight Project, 1973-1980; the Northeast Monitoring Program (NEMP), 1980-1985; and the MARMAP Program, 1974-present; the National Science Foundation; the U.S. Department of Interior (BLM) Outer Continental Shelf (OCS) Program, the U.S. Department of Energy, 1974-present, and the New Jersey Department of Environmental Protection. As a result of these oceanographic programs over the past 30-40 years, a large historical database exists for the New York Bight.

4.2 NOAA/NMFS HISTORICAL DATABASE

These and other historical data have been collected from academic investigators, NOAA/National Oceanographic Data Center (NODC) and other agencies, subjected to rigorous QA/QC procedures, and compiled as part of ongoing NOAA/NMFS investigations in a relational database management system of over 200,000 records. The database represents a diverse array of data originally collected for a variety of research and monitoring objectives. The databases include measurements of temperature, salinity, oxygen, nutrients, chlorophyll, primary production and phytoplankton species abundance data. The databases are developed, maintained and kept current through extensive interaction with local scientists by NMFS at Sandy Hook, NJ, using System 1032, a commercial relational database management system (Software House, Cambridge, MA) on a VAX 11/785 minicomputer located at Woods Hole, MA.

Table 4.1 presents a summary inventory of data files prepared by NOAA/NMFS (P. Fournier, personal communication) for the number of hydrographic (HYD), nutrient (NUT), and chlorophyll (CLB) observations in the System 1032 database. The inventory summarizes observations recorded between July and

Table 4.1. Data Sources for Water Quality Data for the New York Bight [b]
July-September, 1983-1985

Filename	PI	Data Source	New York Bight (# observed)			N.J. Nearshore (# observed)		
			1983	1984	1985	1983	1984	1985
NEPCLB.DMS	Zetlin	NOAA/NMFS-Sandy Hook	551	0[a]	0[a]	17	0[a]	0[a]
NEPNUT			436	0[a]	0[a]	0[a c]	0[a]	0[a]
LBTHYD	O'Reilly, Draxler	NOAA/NMFS-Sandy Hook	2066	1788	1106	0[c]	0[a]	0[a]
NEPHYD			531	31	0[c]	21	6	6
EPAHYD	Hammett, Braun	EPA-II	1202	380	0[c]			
BNLHYD	Whitledge, Stoddard	BNL	0	0	0	0	0	0
MARHYD	Mountain, Pantanjo	NOAA/NMFS-Woods Hole	0	0	282	0	0	64
WARHYD3	Warsh, Gottholm	NOAA/OAD-Rockville	4079	1949	1396	632	666	367
LDGOHYD	Akiman, Haines	Columbia U/LKDO	0	0	0	0	0	0

[a]Data currently being processed.

[b]Inventory compiled by Pat Fournier, NOAA/NMFS - Sandy Hook, NJ.

[c]Status uncertain.

September, 1983-1985, within the following two geographical regions: 1) New York Bight 38°50' - 41°00'N; 71°30 - 75°00'W; and 2) New Jersey nearshore (38°50' - 39°50'N; 73°00' - 75°00'W). The compilation of the NOAA/NMFS - Sandy Hook database for the New York Bight is an ongoing activity of the laboratory. Although numerous data are in final form in the database (e.g., NOAA/NEMP hydrographic data, 1980-1985), other data sources are currently being processed for QA/QC and compatibility with the database (e.g., chlorophyll and nutrient data from Brookhaven National Laboratory for NOAA/NEMP cruises, 1980-1985). An illustration of the spatial coverage of observations in the New York Bight is shown in Figure 4.1 for bottom oxygen, 1977-1985.

4.3 EPA/STORET HISTORICAL DATABASE

Tables 4.2 a and b present a summary inventory of data sets prepared by SAIC for a number of water quality parameters in the EPA/STORET database identified as ocean and non-ocean observation. The inventory summarizes the available data for July through September, 1983 through 1985, within a single geographical region bounded by: 38°30' - 40°30'N and 73°30' - 75°00'W. Figure 4.2 illustrates all EPA/STORET database monitoring station locations (n=1592) present in the geographical region. Many of the inland stations shown on the map, however, would not be relevant to the analysis of the green tide problem. A number of monitoring stations do, however, appear to be available for the southern coastal bays and inlets in addition to the inshore EPA and NJDEP beach surveys along the coast.

4.4 NEW YORK BIGHT HISTORICAL DATABASE

Data sets available for the New York Bight and the New Jersey nearshore region between 1983 and 1985 are summarized in Table 4.1 covering the time period of immediate interest for the green tide environmental inventory. Large historcal oceanographic data sets in the NOAA/NMFS database include hydrographic data files from Brookhaven National Laboratory (BNLHYD; data from about 1930-1981), Lamont-Doherty Geological Observatory (LDGOHYD) and the NOAA/MARMAP cruises (MARHYD). A large historical database for chlorophyll and nutrient data is available from BNL (Stoddard, 1983; Whitledge, personal communication) for the same period of record as the historical data (BNL NHYD). These historical data could be readily reformatted and compiled for

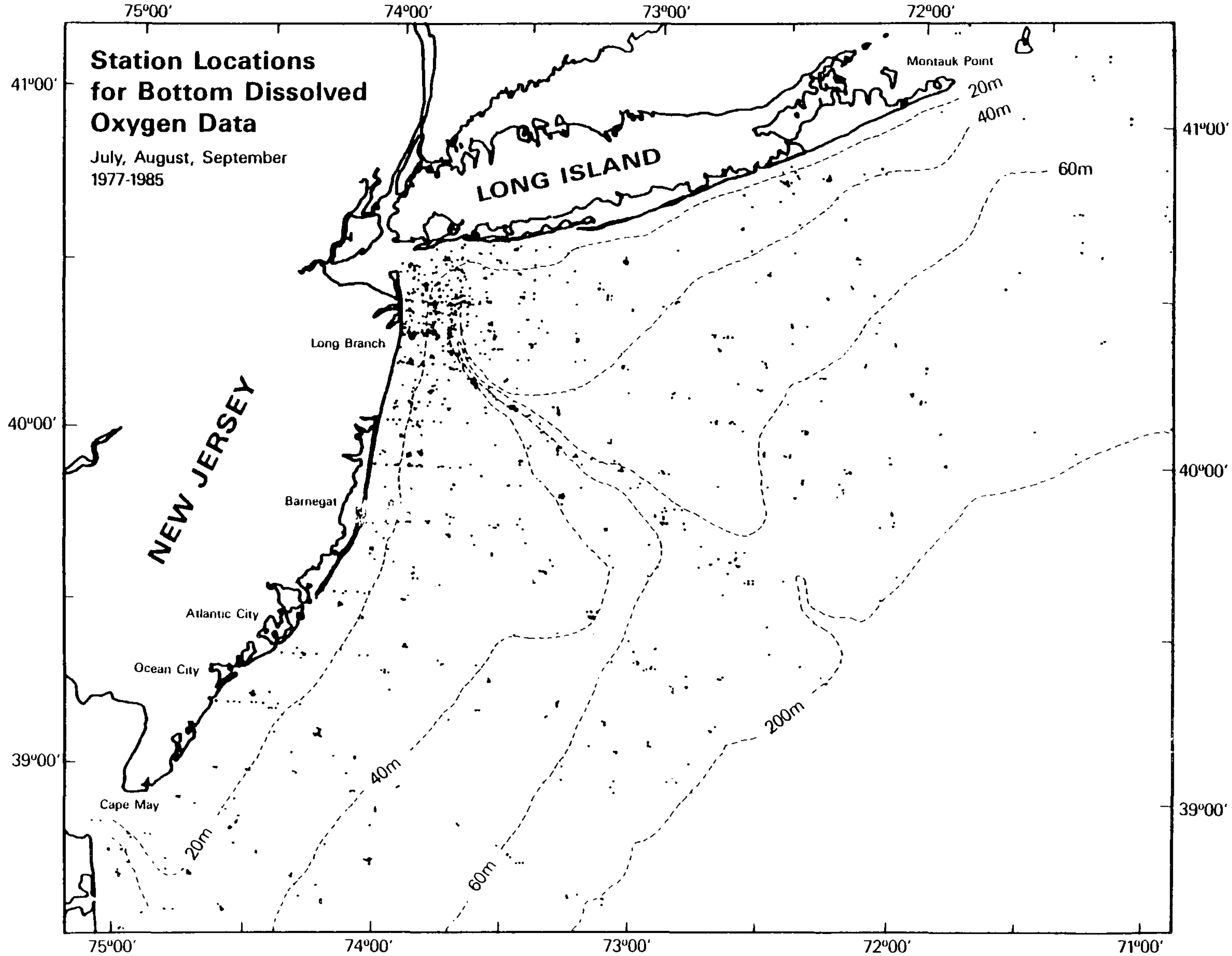


Figure 4.1. Station locations for dissolved oxygen samplings in the New York Bight indicating spatial coverage. (Source: Stoddard et al. 1986)

Table 4.2a. Inventory of EPA/STORET Observations for July-September (Ocean)

Parameter	Storet Code	1983	1984	1985
# Stations		210	198	260
Temperature	(010)	1651	1038	1880
Salinity	(480)	550	366	570
Oxygen	(300)	1104	346	1085
Organic-N	(605)	0	0	109
Ammonia	(608)	0	0	109
Nitrite	(615)	0	0	109
Nitrate	(620)	0	0	108
TKN	(625)	0	0	0
Chl-a	(32230)	0	0	0
	(32211)			
Total P	(71886)	0	0	0
Total Algae	(60050)	0	0	0

Lat/Lon Coordinates for Retrieval

(3830,7500)	(4030,7330)
(3830,7330)	(4030,7500)

Table 4.2b. Inventory of EPA/STORET Observations for July-September (Estuary, Lake, Stream)

Parameter	Storet Code	1983	1984	1985
# Stations		1063	907	928
Temperature	(010)	3726	4406	5206
Salinity	(480)	404	397	470
Oxygen	(300)	159	153	201
Organic-N	(605)	18	21	15
Ammonia	(608)	5	8	38
Nitrite	(615)	321	193	159
Nitrate	(620)	36	40	74
TKN	(625)	201	206	154
Chl-a	(32230)	27	22	17
	(32211)			
Total P	(71886)	4	0	5
Total Algae	(60050)	0	0	0

Lat/Lon Coordinates for Retrieval

(3830,7500) (4030,7330)
(3830,7330) (4030,7500)

Figure 4.2. Station locations in Southern New Jersey for data in EPA's STORET system.

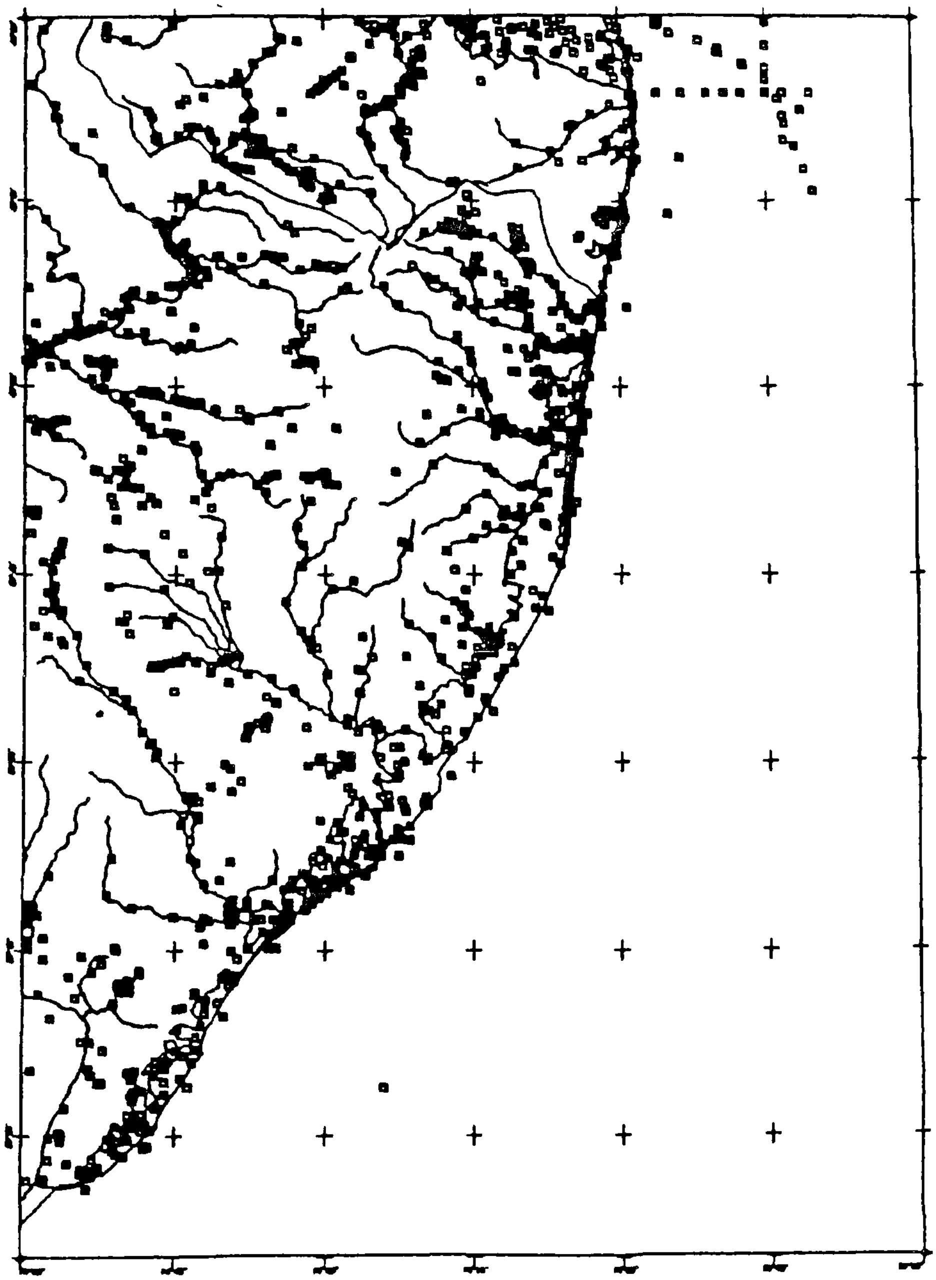


Table 4.3a. A Summary of the Brookhaven National Laboratory Cruises Taken in the New York Bight

Cruise Name/Ship	Cruise Date	Hydro	Prod.	Zoop
ACE-0 DELAWARE	July 74	X		X
ACE-0 DELAWARE	Aug 74	X		X
ACE-0 DELAWARE	Sept 74	X		X
ACE-0 DELAWARE	Oct 74	X		X
ACE-0 DELAWARE	Nov 74	X		X
ACE-0 DELAWARE	Feb 75	X		X
ACE-0 COMMONWEALTH	March 75	X		X
ACE-0 ALBATROSS	April 75	X		X
ACE-0 DELAWARE	May 75	X		X
ACE-0 DELAWARE	June 75	X	X	X
ACE-0 ATLANTIC TWIN	July 75	X	X	X
ACE-0 ATLANTIC TWIN	Aug 75	X	X	X
ACE-0 DELAWARE	Sept 75	X	X	X
ACE-I KNORR	Jan 75	X	X	
ACE-I ATLANTIS II	March-April 75	X	X	X

Table 4.3a. A Summary of the Brookhaven National Laboratory Cruises Taken in the New York Bight (Continued)

Cruise Name/Ship	Cruise Date	Hydro	Prod.	Zoop
ACE-II EASTWARD	April-May 76	X	X	X
ACE-II KELEZ	March 76	X	X	
ACE-II ONRUST	April 76	X		X
ACE-II PALUMBO	April 76	X	X	X
ACE-II EASTWARD	May 76	X		
ACE-II KELEZ	June 76	X		
ACE-II ONRUST	June 76	X		
ACE-II RESEARCHER	Sept 76	X	X	
ACE-II DELAWARE	May 76	X		
ACE-II DELAWARE	June 76	X		
ACE-III KELEZ	March 77	X		
ACE-III DELAWARE	May 77	X		
ACE-III ONRUST	June 77	X	X	
ACE-III KNORR	Aug 77	X	X	X
ACE-III ALBATROSS	Aug 77	X		
ACE-III CAPE HENLOPEN	Nov 77	X	X	

Table 4.3a. A Summary of the Brookhaven National Laboratory Cruises Taken in the New York Bight (Continued)

Cruise Name/Ship	Cruise Date	Hydro	Prod.	Zoop
ACE-IV ATLANTIS II	April 78	X	X	X
ACE-IV ARGUS	April 78	X	X	X
ACE-IV ARGUS	May 78	X	X	X
ACE-IV DELAWARE	June-July 78	X	X	
ACE-IV ONRUST	Aug 78	X	X	
ACE-IV ATLANTIS II	Oct 78	X	X	X
ACE-IV EDGERTON	June 78	X		
ACE-IV EDGERTON	Sept 78	X		

Table 4.3b. Listing of surveys, dates, cruises, and numbers of stations in the Southern New England and Mid-Atlantic Bight areas falling within potentially influenced areas of DWD 106 and adjacent waters, 1977-1981 (Data Source: Pearce *et al*., 1983).

(Source: Pearce et. al. 1983)

Year	Season	Date	Vessel	Cruise	No. Stations
1977	Late Winter	3-Mar-7 Apr	Gorlitz	77-01	12
		13 Feb-24 Feb	Mount Mitchell	77-01	10
	Early Spring	13 Apr-27 Apr	Albatross IV	77-02	3
		9 Mar-7 Apr	Delaware II	77-03	11
	Late Spring	4 May-24 May	Delaware II	77-05	72
		22 May-6 Jun	Nogliki	77-02	3
	Late Summer	19 Aug-29 Aug	Yubileinly	77-02	60
	Early Autumn	19 Oct-29 Oct	Argus	77-01	30
	Late Auumn	2 Dec-9 Dec	Kelez	77-11	14
1978	Late Winter	16 Feb-14 Mar	Delaware II	78-02	52
		19 Apr-12 May	Argus	78-04	52
	Early Summer	24 Jun-12 Jul	Albatross IV	78-07	56
	Late Summer	12 Aug-3 Sep	Belogorsk	78-01	56
	Early Autumn	19 Oct-27 Oct	Belogorsk	78-03	40
		16 Nov	Anton Dohrn	78-03	1
		14 Oct-1 Nov	Wieczno	78-04	6
	Late Autumn	16 Nov-29 Oct	Belogorsk	78-04	8
1979	Late Winter	23 Feb-4 Mar	Delaware II	79-03	82
	Early Spring	13 Apr-14 Apr	Delaware II	79-04	22
	Late Spring	17 Jun-8 Jul	Albatross IV	79-06	49
		6 May-18 May	Delaware II	79-05	55
	Early Summer	17 Jun-8 Jul	Albatross IV	79-06	37
	Late Summer	12 Aug-22 Aug	Belogorsk	79-01	76

Table 4.3b. (Continued)

Year	Season	Date	Vessel	Cruise	No. Stations
	Early Autumn	4 Oct-18 Oct	Albatross IV	79-11	63
	Late Autumn	12 Dec-19 Dec 13 Nov-21 Nov	Albatross IV Wieczno	79-13 79-03	17 1
1980	Late Winter	29 Feb-19 Mar 18 Feb-11 Mar	Albatross IV Wieczno	80-02 80-02	84 17
	Early Spring	7 Apr-27 Apr	Evrika	80-01	83
	Late Spring	24 May-6 Jun	Delaware II	80-03	84
	Early Summer	14 Jul-11 Aug	Evrika	80-06	46
	Late Summer	14 Jul-11 Aug	Evrika	80-06	31
	Early Autumn	27 Sep-9 Oct	Albatross IV	80-10	81
	Late Autumn	20 Nov-7 Dec	Albatross IV	80-12	76
1981	Late Winter	17 Feb-26 Mar	Albatross IV	81-01	62
	Early Spring	6 Jan-16 Jan	Delaware II	81-02	80
	Late Spring	I:17 Mar-3 Apr II:6 Apr-17 Apr III:20 Apr-29 Apr IV:5 May-14 May	Delaware II	81-03	50
	Early Summer	I:27 Jun-2 Jul II:7 Jul-24 Jul	Delaware II	81-04	44
	Late Summer	I:3 Aug-21 Aug II:24 Aug-11 Sep	Delaware II	81-05	71
	Early Autumn	I:15 Sep-2 Oct II:5 Oct-16 Oct III:19 Oct-30 Oct IV:2 Nov-13 Nov	Delaware II	81-06	74

Table 4.3c. Summary of NOAA/OAD Northeast Monitoring Program Cruises in the New York Bight (Source: Cathy Warsh NOAA/OAD Rockville MD).

Year	Old Cruise Numbers	Date	Ship	Area of Operation	New Cruise Numbers
1980	NEMP 80-06	Apr 21-25	KELEZ	New York Bight	KE-08-01
	80-08	June 2-6	KELEZ	"	KE-80-02
	80-12	Jul 14-18	KELEZ	"	KE-80-03
		Aug 80	KNORR	Mid Atlantic	BNL
	80-16	Sep 2-6	KELEZ	New York Bight	KE-80-04
1981	NEMP 81-03	Apr 15-20	KELEZ	Mid Atlantic Bight	KE-81-05
	81-07	Jun 3-9	KELEZ	"	KE-81-06
	81-08	Aug 1-7	ALBATROSS IV	"	AL-81-07
	81-17	Sep 9-15	MT MITCHELL	"	MN-81-08
1982	NEMP 82-03	Apr 19-26	CAPE HENLOPEN	"	CH-82-09
	82-05	May 28-Jun 4	CAPE HENLOPEN	"	CH-82-10
	82-09	Jul 26-Aug 2	CAPE HENLOPEN	"	CH-82-11
	82-11	Sep 8-15	MT MITCHELL	"	MM-82-12
1983	NEMP 83-01	Feb 8-Feb 9	PIERCE	Ches. Bay Mouth	PI-83-13
	83-03	Apr 8-15	CAPE HENLOPEN	Mid-Atlantic Bgt	CH-83-14
	83-06	May 31-Jun7	CAPE HENLOPEN	"	CH-83-15
	83-09	Jul 30-Aug 6	CAPE HENLOPEN	'	CH-83-16
	83-12	SEP 15-22	MT MITCHELL	"	MM-83-17
1984	NEMP 84-01	Feb. 1-2	WHITING	Ches. Bay Mouth	WI-84-18
	84-04	April 16-24	CAPE HENLOPEN	Mid Atlantic Bgt.	CH-84-19
	84-06	June 2-9	CAPE HENLOPEN	"	CH-84-20
	DB-84-10-1	July 25-26	CAPE HENLOPEN	Delaware Shelf	CH-84-21
	84-10	Aug 14-22	CAPE HENLOPEN	Mid-Atlantic Bgt.	CH-84-22
	84-13	Oct. 22-31	MT MITCHELL	"	CH-84-23
1985	NEMP 85-01	Feb. 28-29	PEIRCE	Ches. Bay Mouth	PI-85-24
	85-02	Mar.29-Apr.4	PEIRCE	Mid-Atlantic Bgt.	PI-85-25
	85-03	June 11-22	ALBATROS	"	AL-85-26
	85-04	August 8-14	PEIRCE	"	PI-85-27
	85-05	August		Hudson Plume	VMD

TABLE 4.3d. WATER QUALITY MONITORING CRUISES IN THE NEW YORK BIGHT[a]

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
FE01	27-29 AUG 73	25	NOAA/MESA
FE02	16-20 SEP 73	25	NOAA/MESA
FE03	1-4 OCT 73	25	NOAA/MESA
FE04	5-9 NOV 73	25	NOAA/MESA
FE05	26-29 NOV 73	25	NOAA/MESA
FE06	16-20 APR 74	25	NOAA/MESA
FE07	6-9 MAY 74	25	NOAA/MESA
FE08	10-13 JUN 74	25	NOAA/MESA
FE09	16-19 JUL 74	25	NOAA/MESA
FE10	21-24 AUG 74	25	NOAA/MESA
FE11	29 SEP - 2 OCT	26	NOAA/MESA
FE12	4-7 NOV 74	26	NOAA/MESA
RE02	8-15 MAR 74	28	NOAA/MESA
RE05	6-13 MAY 74	30	NOAA/MESA
RE15	23 FEB - 3 MAR 75	62	NOAA/MESA
WCC-1-5	AUG-NOV 73		Hazelworth
WCC-6-8	APR-JUN 74		Hazelworth
WCC-9-12	JUL-NOV 74		Hazelworth
XWCC-1	JAN 75		Starr
XWCC-2	22 FEB - 5 MAR 75		Hazelworth
XWCC-3	9-12 APR 75		Hazelworth
XWCC-4-5	MAY-JUNE 75		Kolitz
XWCC-6	29 SEP - 4 OCT 75		Starr
XWCC-7	DEC 75		Kolitz
XWCC-8	12-16 APR 76		Hazelworth
XWCC-9	17-24 MAY 76		Hazelworth
XWCC-10	28 JUN - 1 JUL 76		Starr

(a) Modified from O'Connor et al. 1977.

TABLE 4.3d(CONT.)

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
XWCC-11	8-27 SEP 76		Hazelworth
XWCC-12	28 APR - 6 MAY 77		Hazelworth
XWCC-13	31 MAY - 7 JUN 77		Hazelworth
XWCC-14	27 JUN - 1 JUL 77		Hazelworth
XWCC-15	1-9 AUG 77		Hazelworth
XWCC-16	11-19 OCT 77		Hazelworth
XWCC-17	APR 78		Hazelworth
XWCC-18	JUN 78		Hazelworth
XWCC-19	JUL 78		Hazelworth
XWCC-20	JUL - AUG 78		Hazelworth
XWCC-21	APR 79		Hazelworth
XWCC-22	MAY - JUN 79		Hazelworth
XWCC-23	JUL 79		Hazelworth
XWCC-24	AUG 79		Hazelworth
EP01	17-18 APR 74	22	Environmental Protection Agency
EP02	14, 16, 21 MAY 1974	22	Environmental Protection Agency
EP03	14 JUN 9 JUL 74	22	Environmental Protection Agency
LIC01	1 MAY 74	11	Environmental Protection Agency
LIC02	6 JUN 74	11	Environmental Protection Agency
LIC03	11 JUL 74	11	Environmental Protection Agency
NJC01	6 APR 74	10	Environmental Protection Agency
NJC02	30 APR 74	10	Environmental Protection Agency
NJC03	10 JUL 74	10	Environmental Protection Agency
Summer of 1977	15 MAY - 30 SEP 77	195	Environmental Protection Agency
Summer of 1978	1 MAY - 30 SEP 78	143	Environmental Protection Agency
Summer of 1979	1 MAY - 30 SEP 79	149	Environmental Protection Agency
Summer of 1980	1 MAY - 30 SEP 80	149	Environmental Protection Agency
Summer of 1981	1 MAY - 30 SEP 81		Not yet published
Summer of 1982			Not yet published

TABLE 4.3d (CONT.)

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
CA12	16-23 AUG 49	64	Woods Hole Oceanographic Institute
A227	10-15 SEP 56	25	Woods Hole Oceanographic Institute
CR08	28 NOV - 3 DEC 56	25	Woods Hole Oceanographic Institute
B159	12-17 FEB 57	24	Woods Hole Oceanographic Institute
B162	21-25 MAR 57	25	Woods Hole Oceanographic Institute
B165	29 APR - 3 MAY 57	25	Woods Hole Oceanographic Institute
CR13	10-20 JUL 57	25	Woods Hole Oceanographic Institute
B174	16-20 SEP 57	25	Woods Hole Oceanographic Institute
B179	18-23 NOV 57	21	Woods Hole Oceanographic Institute
B181	21-27 JAN 58	17	Woods Hole Oceanographic Institute
B183	6-10 MAR 58	15	Woods Hole Oceanographic Institute
B185	12-16 MAY 58	21	Woods Hole Oceanographic Institute
B195	5-8 SEP 58	8	Woods Hole Oceanographic Institute
B200	25 JUL 11-12 AUG 15 SEP 58	25	Woods Hole Oceanographic Institute
C112	16-21 JUL 64	32	Woods Hole Oceanographic Institute
AA52	6-28 SEP 69	19	Woods Hole Oceanographic Institute
CE04	28 JAN 69	7	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE06	16 FEB 69	10	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE07	5 MAR 69	10	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE08	13 MAR 69	10	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE09	27 MAR 69	4	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE10	15-16 APR 69	16	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE12	12-13 MAY 69	16	U.S. Army Corps of Engineers and National Marine Fisheries Service

TABLE 4.3d (CONT.)

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
CE13	28 MAY 69	7	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE15	8-9 JUL 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE16	23 JUL 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE17	6-7 AUG 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE18	20 AUG 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE19	2-4 SEP 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE20	17 SEP 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE21	29 SEP - 1 OCT 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE22	16 OCT 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE23	27-28 OCT 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE24	12 NOV 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE25	24-25 NOV 69	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE26	9 DEC 69	6	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE27	27 JAN 70	7	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE28	25 FEB 70	13	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE29	17-18 MAR 70	11	U.S. Army Corps of Engineers and National Marine Fisheries Service

TABLE 4.3d (CONT.)

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
CE30	13 APR 70	9	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE31	11 MAY 70	15	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE32	10 JUN 70	11	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE33	29 JUN 70	13	U.S. Army Corps of Engineers and National Marine Fisheries Service
CE34	13 AUG 70	16	U.S. Army Corps of Engineers and National Marine Fisheries Service
Apex Monitoring	AUG 78 FEB 79 APR 79 JUN 79 AUG 79 FEB 80 MAR 80 APR 80 MAY 80 JUN 80 JUL 80 AUG 80 SEP 80 OCT 80 NOV 80 DEC 80 MAR 81 APR 81 MAY 81 JUN 81 JUL 81 AUG 81	23	City of New York, in compliance with their ocean dumping permits has conducted the monitoring cruises and sample analyses on behalf of the metropolitan area sewage sludge dumpers.

TABLE 4.3d (CONT.)

Cruise	Sampling Dates	Number of Stations	Organization/Principal Investigator
Apex Monitoring	SEP 81 OCT 81 NOV 81 DEC 81 JAN 82 FEB 82 MAR 82 APR 82 MAY 82 JUN 82 JUL 82 AUG 82	23	City of New York, in compliance with their own dumping permits has conducted the monitoring cruises and sample analyses on behalf of the metropolitan area sewage sludge dumpers.

the System 1032 database. To provide further detail than is available from the summary inventory tables, listings of the numerous cruises in the New York Bight are presented in Table 4.3 as taken from O'Connor et al. (1977), Ecological Analysts and SEAMOcean (1983), Pearce et al. (1983) and working documents from Brookhaven National Laboratory (Whitledge, personal communication).

5. WATER QUALITY OF THE NEW YORK BIGHT

5.1 INTRODUCTION

During the past three decades, anthropogenic nitrogen inputs to the New York Bight, and other coastal ecosystems are estimated to have increased by an order of magnitude as a consequence of deforestation, sewage disposal and the use of agricultural fertilizers (Walsh et al., 1981). Because of the proximity to the New York metropolitan area, distributions of ecological indicators (e.g., eutrophication and oxygen depletion) in the New York Bight reflect complex interactions of both natural processes and anthropogenic inputs.

Water quality distributions in the New York Bight vary spatially, seasonally, and vertically. Concentration distributions of water quality parameters are influenced by loading from anthropogenic and natural sources. Mass loading of contaminant inputs from the Hudson-Raritan estuary, coastal runoff from New Jersey and Long Island, and atmospheric deposition has been summarized by Mueller et al. (1976, 1982). Naturally occurring chemical, biological and physical processes influence the assimilation, biochemical reactions, dispersion, dilution and transport of contaminant inputs to the New York Bight. In relation to the occurrence of coastal phytoplankton blooms in general, and the green tides of 1984 and 1985 in particular, the parameters of concern for the environmental inventory include the following:

- temperature
- salinity
- density
- dissolved oxygen
- nutrients
- chlorophyll-a.

Data sources and representative distributions of these water quality parameters are presented in the hydrographic processes section (temperature, salinity, density) and in the following discussions (oxygen, nutrients, chlorophyll).

Applications of the New York Bight database have included evaluations of water quality (Alexander and Alexander, 1977; O'Connor et al., 1977), nutrient enrichment (Matte et al., 1983); phytoplankton abundance and primary production (Malone, 1982; Walsh et al., 1978; Malone et al., 1983; Malone, 1984; O'Reilly et al., in press; Zetlin and O'Reilly, 1983); oxygen depletion (Swanson and Sindermann, 1979; Segar and Berberian, 1976; Stoddard, 1983; Stoddard et al., 1986; Whitledge and Warsh, submitted, 1986) and the fate of carbon production on the shelf (Walsh et al., 1981; Walsh, 1980). In this section, portions of the historical database are presented to summarize seasonal and spatial patterns of nutrient enrichment, phytoplankton abundance, and oxygen depletion.

5.2 NUTRIENTS AND PHYTOPLANKTON PRODUCTION

Depending on the loading of new nutrients imported to the coastal system relative to water column recycling of nutrients, phytoplankton production can be partitioned into new and regenerated production. When regenerated production is high relative to new production, phytoplankton production as a whole is typically low and nitrogen limited. Such systems develop when phytoplankton production, heterotrophic consumption and nitrogen regeneration are closely coupled in time and space.

As the proportion of new production increases in response to new nitrogen supplies (including anthropogenic inputs), the magnitude and variance of phytoplankton production also increases. The increased nitrogen load and the development of time or space lags between variations in phytoplankton production and heterotrophic consumption uncouples production and consumption, resulting in accumulation of phytoplankton biomass with its associated oxygen demand and an increase in the susceptibility of the ecosystem to episodes of oxygen depletion.

The analysis summarized below combines data generated from measurements of nitrogen, chlorophyll and primary production from 1973 to 1981 for 3,186 stations in the New York Bight. The analysis documents the seasonal cycle of phytoplankton production in relation to seasonal variability of ammonia, nitrate and phytoplankton biomass expressed as chlorophyll within isobath defined hydrographic regions (Figure 5.1).

Dissolved nitrate concentrations exhibit an annual cycle characterized by a winter maximum and a summer minimum, the amplitude of which decreases

Figure 5.1. Stations for depth-averaged water quality of the New York Bight. (Source: Stoddard et al., 1986).

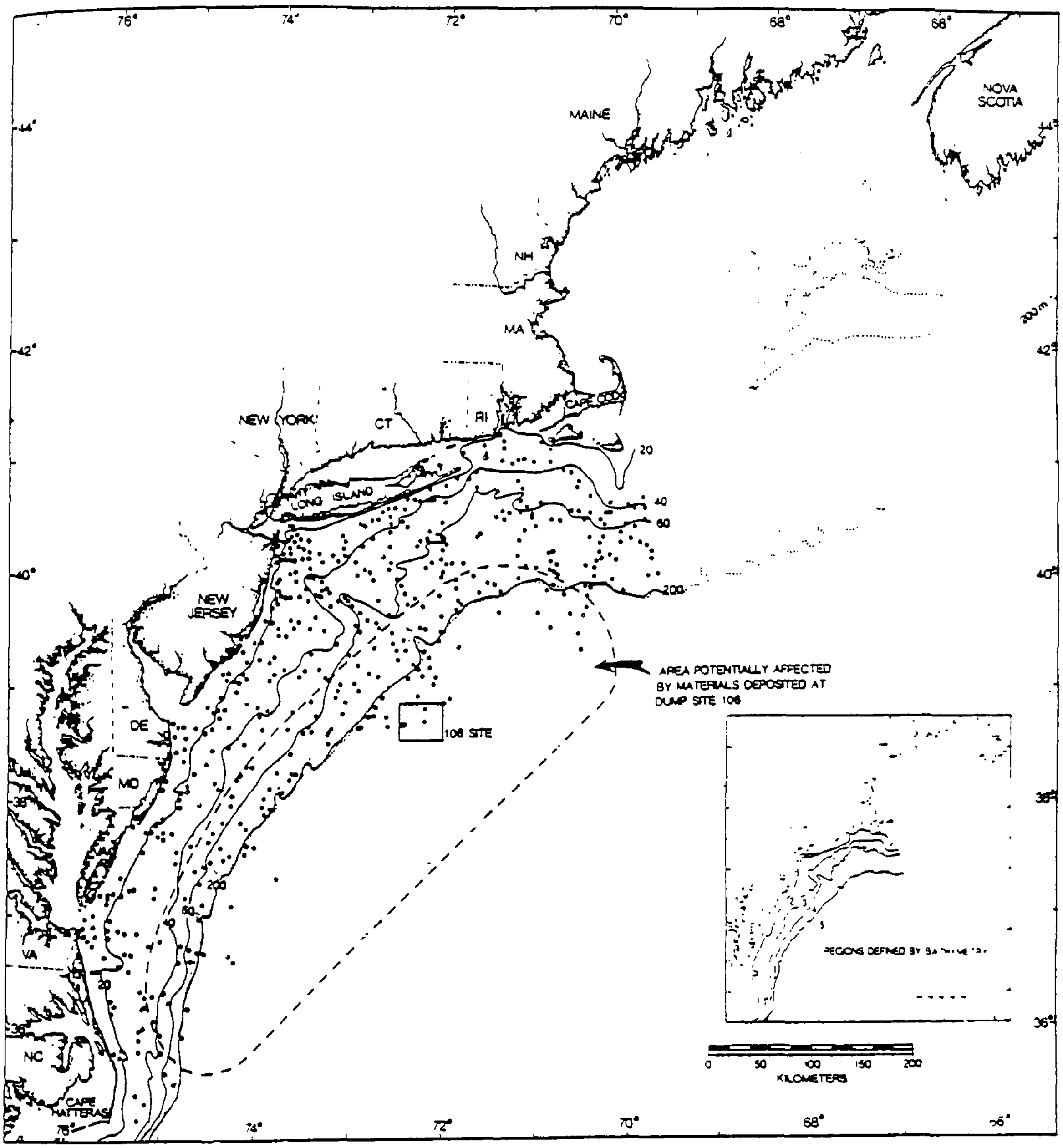
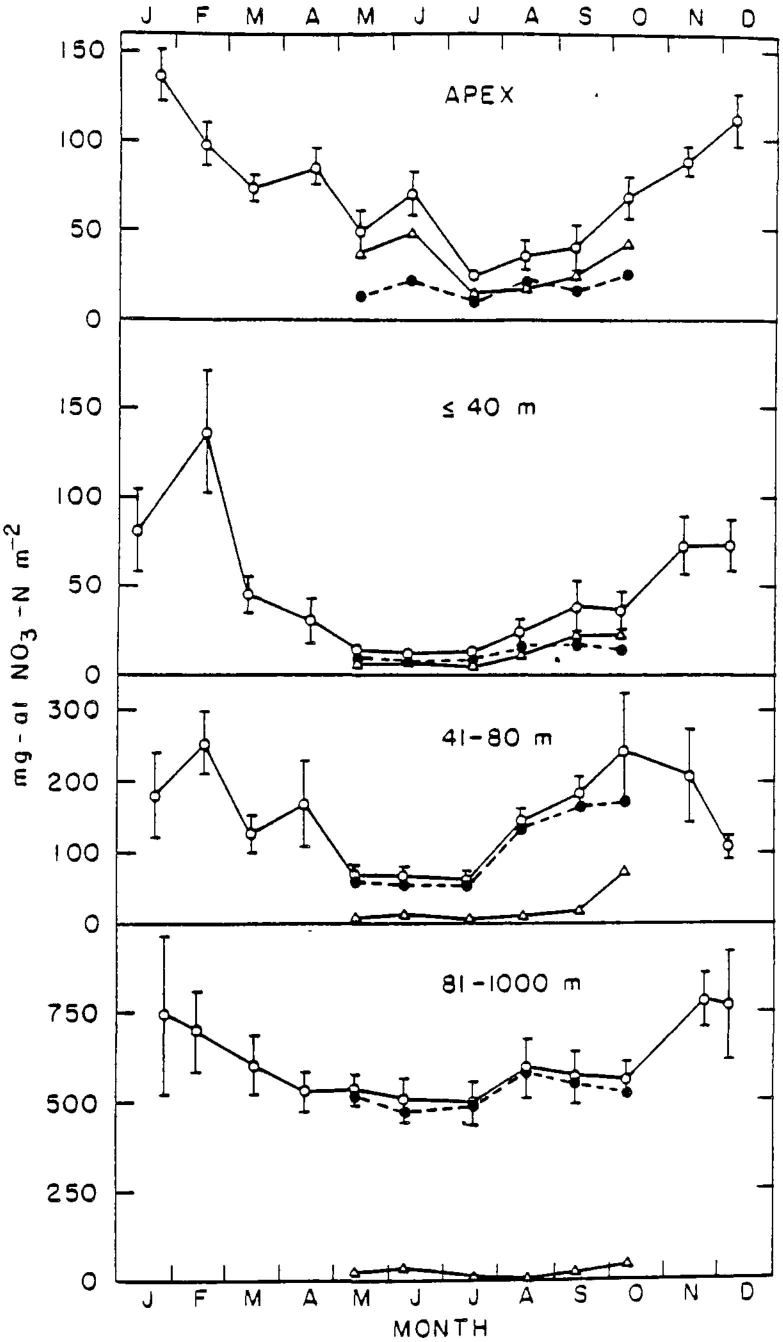


Figure 5.2. Seasonal variation of nitrate across the New York Bight. (Source: Malone et al., 1983).



0: Mean ± 2 SE
Δ: Surface layer
●: Bottom layer

seaward across the shelf (Figure 5.2). This seasonal trend reflects variations in the balance between inputs of new nitrate from the Gulf of Maine and offshore slope water and uptake by phytoplankton. In contrast, ammonium is typically highest during the summer or fall reflecting variations in the balance between generation and uptake. The exception to this generalization occurs in the Apex where new nitrogen inputs from waste water sources are significant (Figure 5.2).

The annual distribution of chlorophyll is most closely related to that of ammonium. The ammonium distribution is characterized by a winter-spring maximum, a summer minimum, and a secondary maximum in the fall. Such a seasonal cycle of phytoplankton abundance is characteristic of temperate continental shelf environments. Phytoplankton production (monthly mean) varies from less than 0.3 g C/m^2day during winter to greater than 1.0 g C/m^2day during the spring (Figure 5.4). Chlorophyll specific production (an index of growth rate) also exhibits a winter minimum and a summer maximum and is most closely related to incident solar radiation observed in the nearshore zone of the New Jersey coast.

Although the seasonal cycle is similar, the magnitude of peak August to September chlorophyll concentrations (4 ug/l) in the nearshore region (0-20 m) (Figure 5.5) of the Middle Atlantic Bight are considerably higher than over the midshelf region (20 to 40 m, 40 to 60 m) where peak levels in August-September are less than 2 ug/l. Maximum chlorophyll levels in the nearshore zone (0-20 m) reflect the very high annual rate of primary production (505 g C/m^2yr). (O'Reilly et al. in press.)

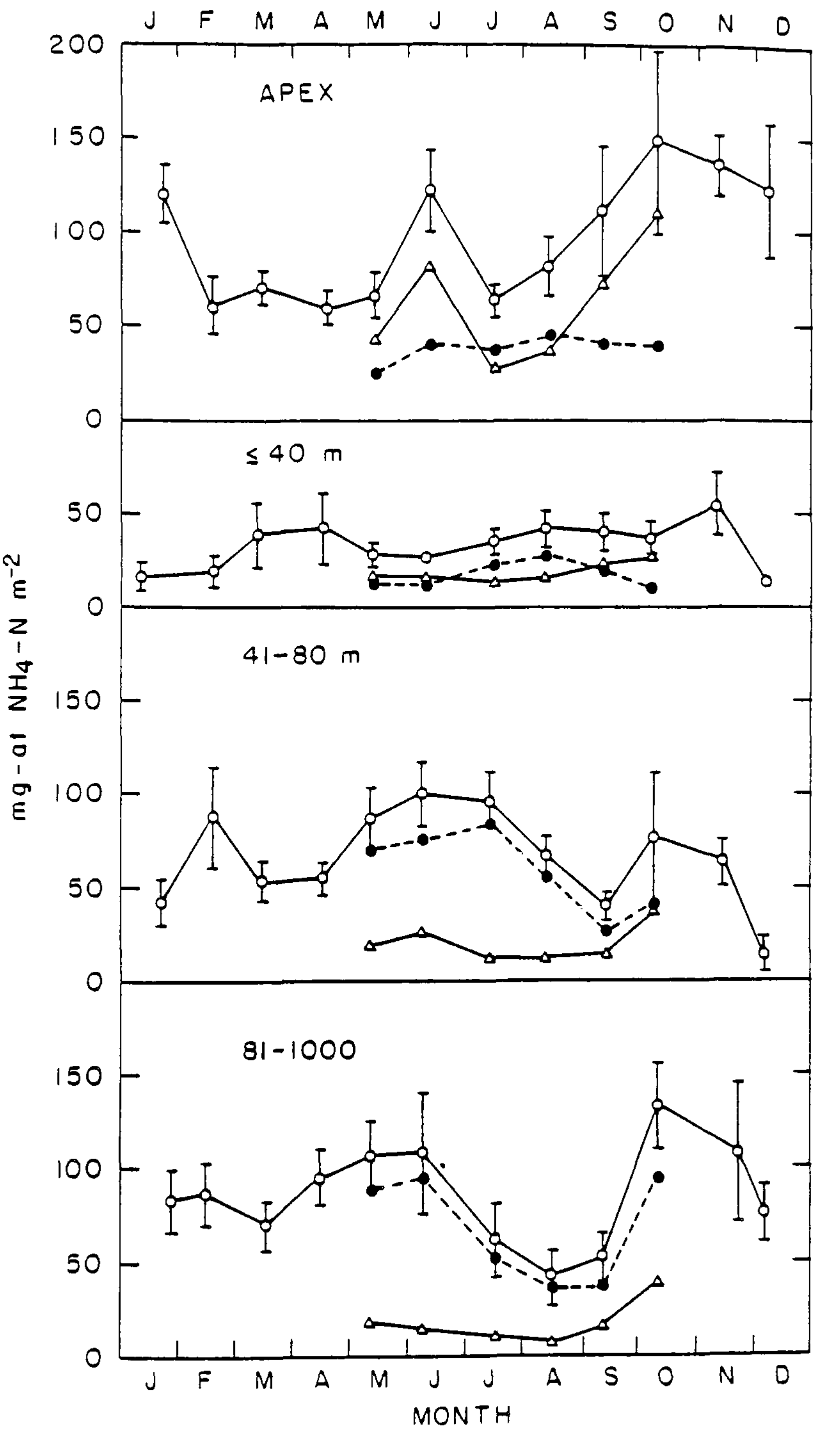
These, and other related observations (Malone, 1982, 1984; Malone et al., 1983) have been used to reach the following conclusions with respect to the effects of various nutrient sources on eutrophication in the New York Bight:

1. The biomass specific growth rate of phytoplankton is light limited on a seasonal time scale while the production of biomass is nitrogen limited on the scale of the residence time of water on the shelf;

2. Anthropogenic nitrogen loading, assimilated within the Apex and the Hudson plume along the northern New Jersey coast has resulted in an increase in annual phytoplankton production of approximately 30%.

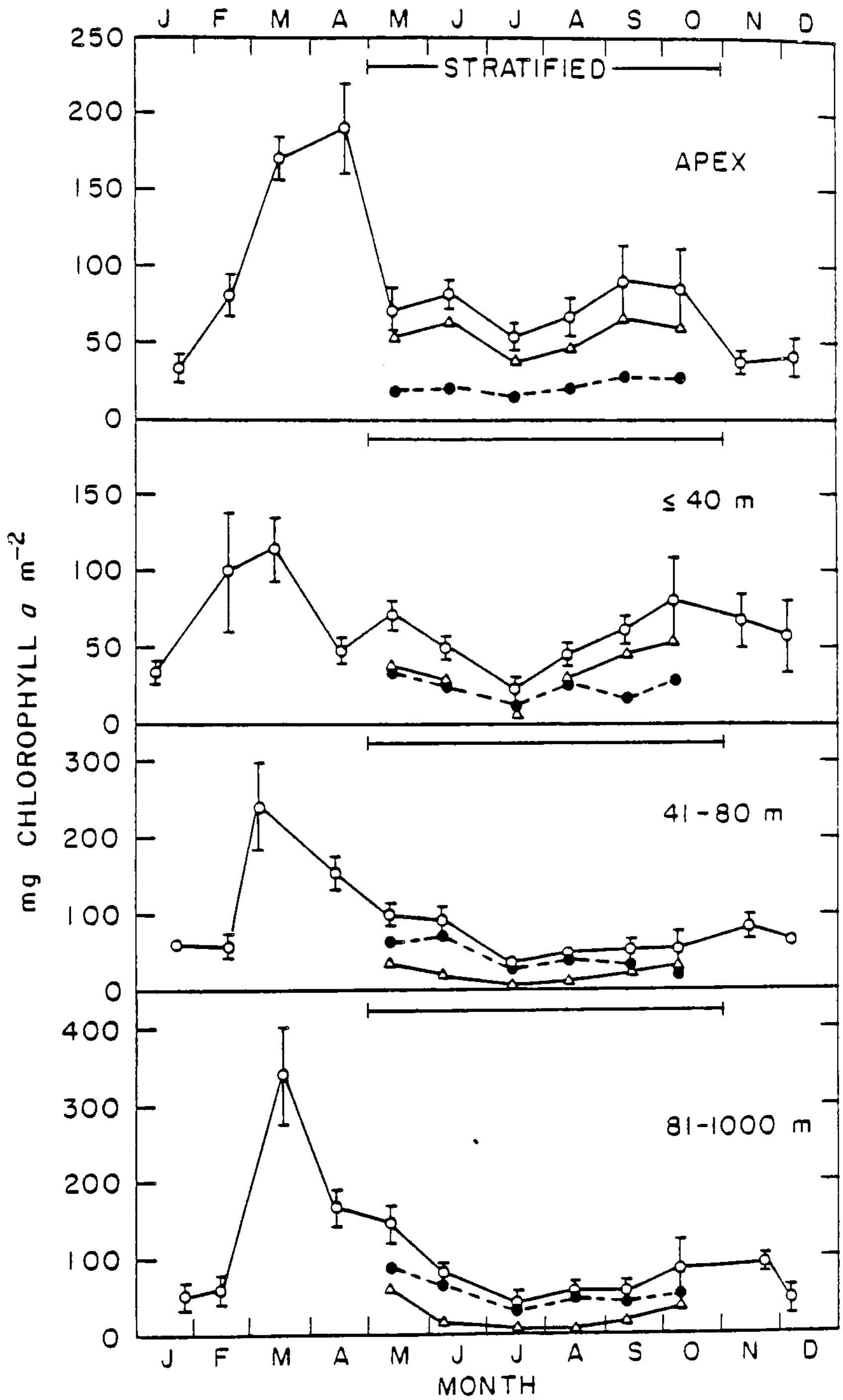
3. Further increases in urban nitrogen loading may increase phytoplankton production within the Apex during spring-summer and increase the area over which production is elevated during fall-winter.

Figure 5.3. Seasonal variation of ammonium across the New York Bight Shelf. (Source: Malone et al., 1983).



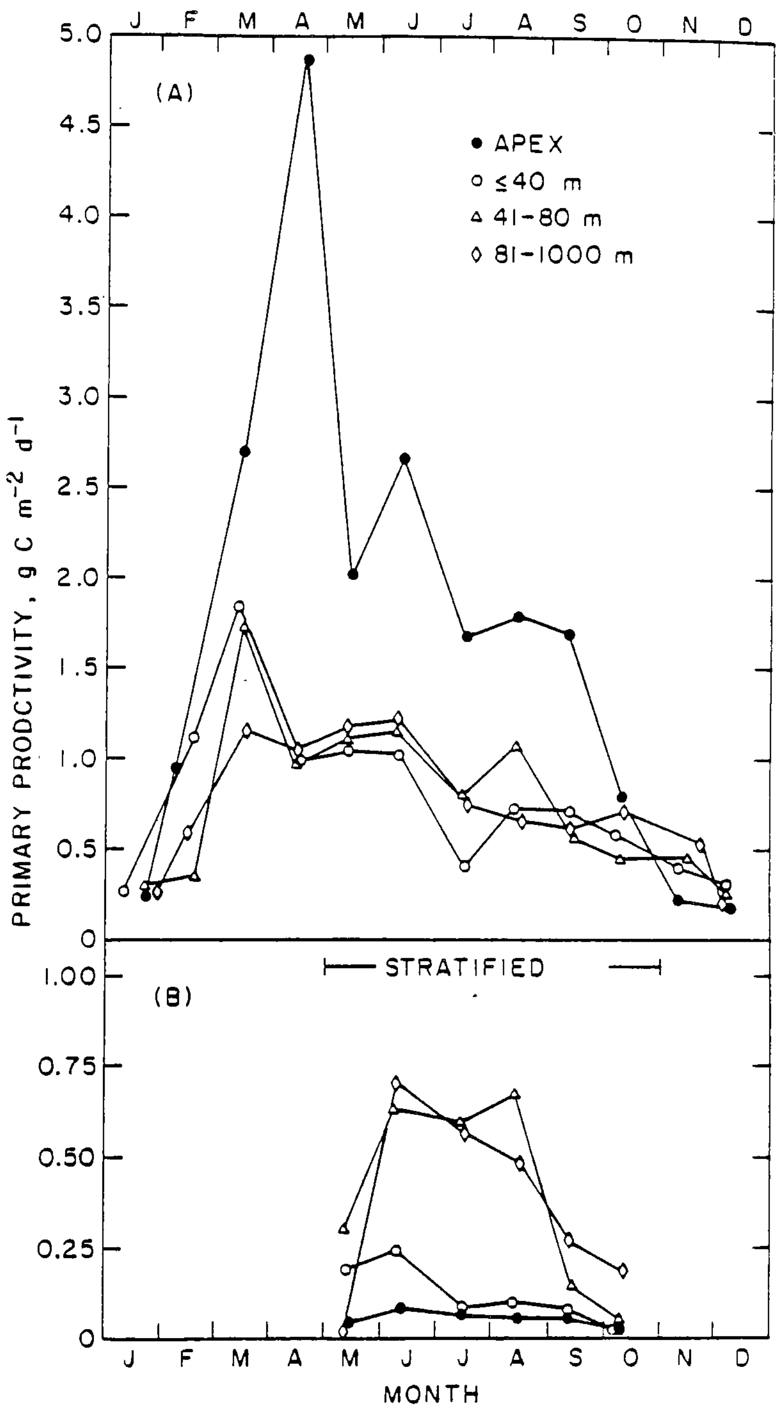
O: Mean ± 2 SE
Δ: Surface layer
●: Bottom layer

Figure 5.4. Seasonal variation of chlorophyll across the New York Bight Shelf. (Source: Malone et al., 1983).



O: Mean ± 2 SE
▲: Surface layer
●: Bottom layer

Figure 5.5. Seasonal variation of primary production across the New York Bight. (Source: Malone et al., 1983).



4. The effect of anthropogenic nutrient inputs on phytoplankton production in the New York Bight as a whole, however, is small and will remain small since current waste loading is on the order of 1-3% of new nitrogen inputs from natural sources and;

5. The quantitative effects of anthropogenic loading on phytoplankton production and other related impacts on water quality and fisheries cannot be determined with any degree of certainty until the rates and pathways by which nutrients are assimilated and recycled within the New York Bight are known in terms of biotic and abiotic factors.

Data from the nearshore region off Atlantic City, NJ (Figure 5.6) for nitrate and ammonia (Figure 5.7 and Figure 5.8) display seasonal patterns generally similar to the composite data for the New York Bight region shallower than 40 m (Figure 5.2 and 5.3). A trend of increase in ammonia concentrations is observed in late summer (July, August) in the composite data. A related increase of nitrate during August and September from nitrification is also apparent. For the monitoring stations off Atlantic City, NJ (Station 2,3, and 6) in shallow water, there is a definite increase in water column ammonia during August and September, 1974 (Figures 5.7 and 5.8). Benthic generation of ammonia could account for the observed increase over the shallow, well-mixed water column. Increasing phytoplankton production (Figure 5.6, 0-20 m) during September in the shallow nearshore zone (0-20 m) of the Middle Atlantic Bight could account for the decline of nitrate and ammonia observed during September and October at the inshore EG&G stations 2, 3, 6 off Atlantic City during 1974.

As suggested by Whitledge (personal communication), benthic generation of ammonia in the shallow, vertically mixed nearshore zone could be a significant nutrient source for phytoplankton production, including the occurrence of the green tides in 1984 and 1985 off Ocean City-Atlantic City, NJ. Anthropogenic sources of nitrogen from the local sewage outfalls combined with "naturally" occurring benthic generation of ammonia could provide sufficient nitrogen loading to sustain an algal bloom. Compilation of the nearshore monitoring data into a compatible computer database would greatly facilitate data analysis and construction of nutrient budgets for the nearshore region. Nutrient budgets are needed to evaluate the significance of anthropogenic sources of nitrogen in relation to natural processes.

Figure 5.6. Temperature, salinity and marine chemistry stations in the nearshore southern New Jersey coast. (Source: EG&G, 1975).

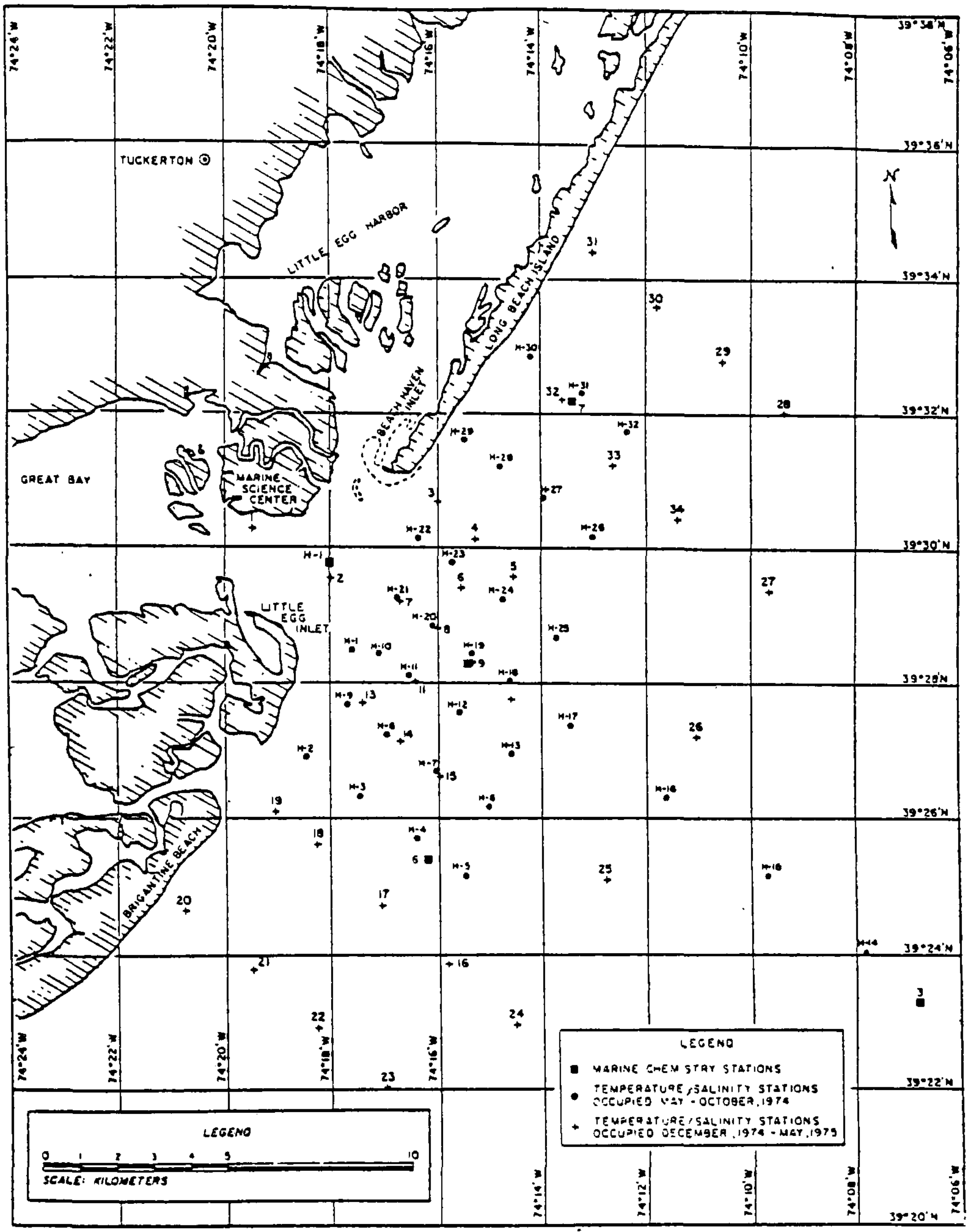
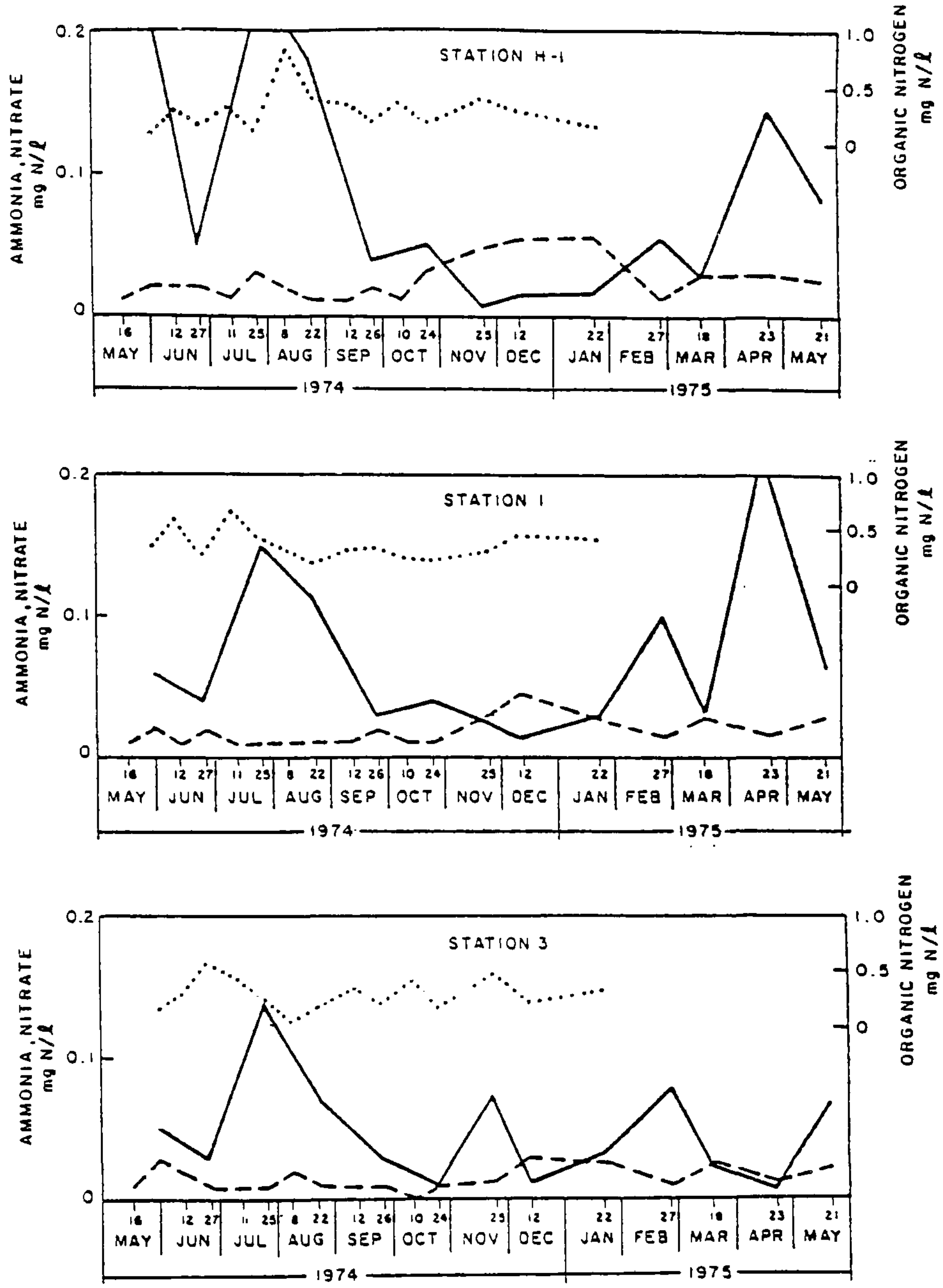


Figure 5.7. Seasonal variation of nitrogen in a transect running 20 km southeast from Little Egg Inlet. (EG&G, 1975).

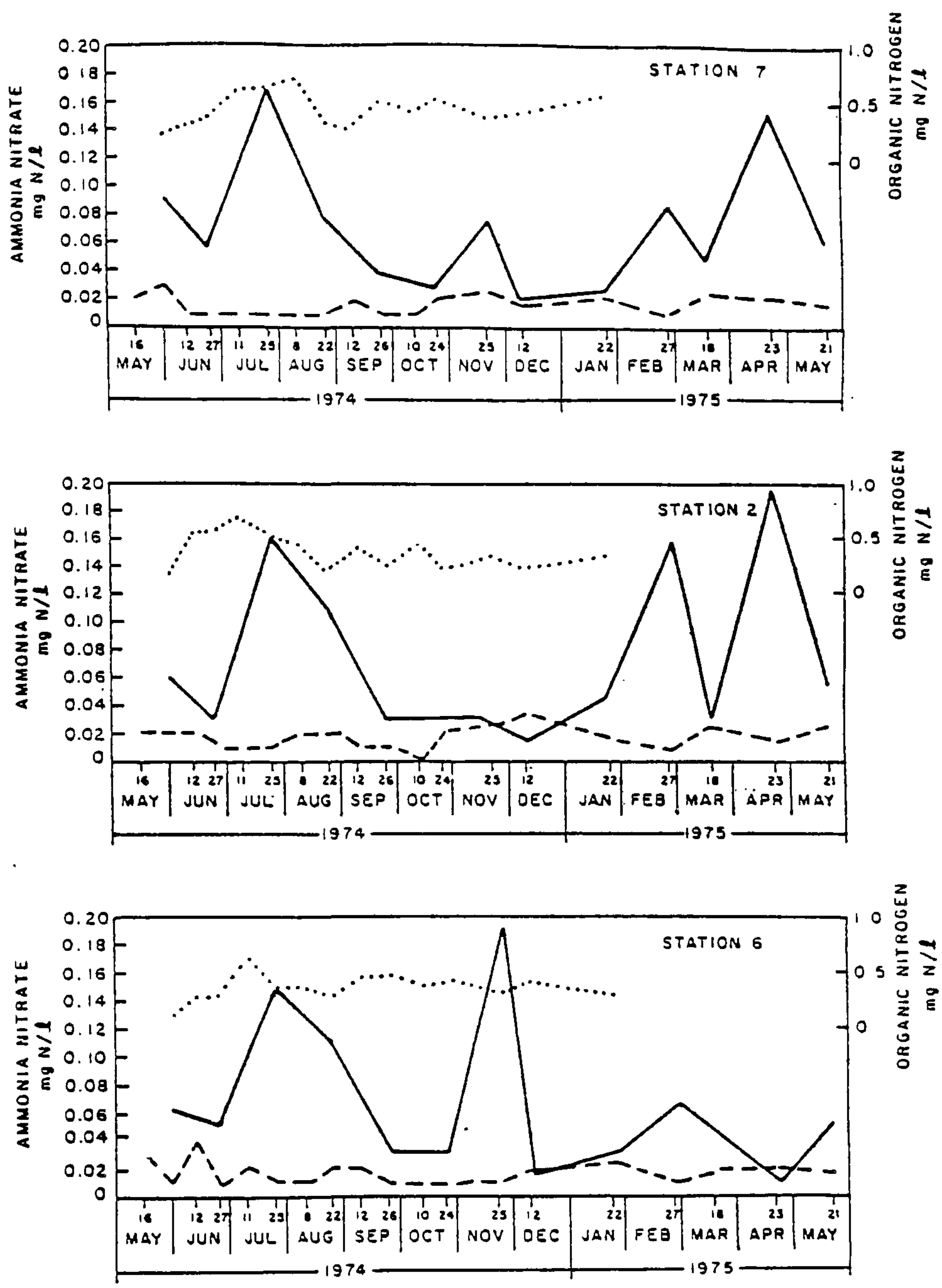


.......organic nitrogen

-------ammonia

_______nitrate

Figure 5.8. Seasonal variation of nitrogen in a north-south transect along the southern New Jersey Coast. (Source: EG&G, 1975).



.......organic nitrogen

-------ammonia

_______nitrate

5.3 NUTRIENT VARIATION RELATED TO LOW OXYGEN EVENTS

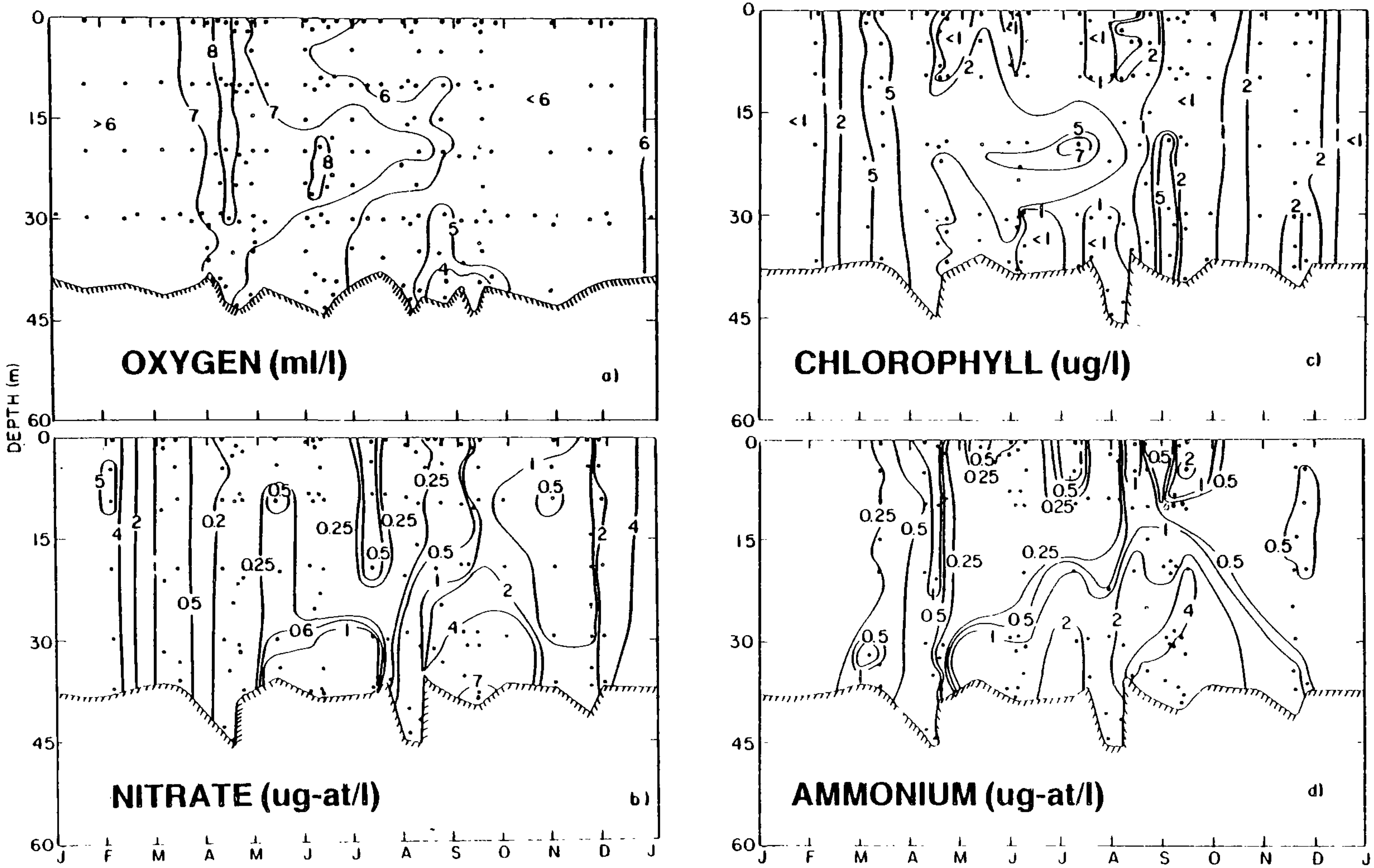
Data for nitrate, ammonium, chlorophyll and oxygen, collected within the nearshore New Jersey hypoxic region, were aggregated from 1977 to 1985 to characterize their distribution at the 40 m isobath in relation to seasonal stratification of the water column (Figure 5.9 a-d) (Whitledge and Warsh, submitted). Combining the data presented in this analysis for a single station was the only way to obtain enough data to derive reliable generalizations and conclusions.

Ammonium (Figure 5.9d) in the upper water column is reduced during July and August as nitrate concentrations within the bottom layer of the water column increase (Figure 5.10b). Approximately 50% of the nitrate accumulation may result from nitrification (oxidation of ammonium to nitrate) in the bottom layer with cross-shelf advection of nitrate rich slope water onto the shelf accounting for the remainder (Riley, 1967). High near-bottom nitrate (7-9 ug-at/l) during August-September (Figure 5.9b) is then vertically mixed throughout the water column with the erosion of stratification in October-November. Seasonal oxygen distributions (Figure 5.9a) are related to the decomposition of detrital organic material (including phytoplankton biomass produced during the March-April spring bloom, Figure 5.9c) in the bottom layer and the seasonal establishment of the pycnocline which reduces vertical oxygen flux.

The analysis of the combined data demonstrates that the distributions and dynamics of nutrients in the New York Bight are only partially related to oxygen distributions in a direct way. The bulk of nutrients are incorporated into particulate or dissolved organic matter via primary production. Oxygen production from photosynthesis occurs in the near surface layer while the organic matter produced during photosynthesis sinks below the pycnocline where oxygen demands are exerted by decomposition.

Large fluxes of nitrogen, phosphorus, and silicon, released by mineralization of detrital organic matter, are not biologically assimilated in the bottom layer. As a result, high concentrations of the materials accumulate in the late summer (e.g., Figure 5.9d). The transition from a dissolved inorganic nutrient pool to photosynthetically produced particulate organic matter and subsequent decomposition typically imposes a time-lag in oxygen-

Figure 5.9. Seasonal variation in a) oxygen, b) NO_3, c) chlorophyll and d) NH_4 in the New York Bight (Source: Whitledge and Warsh, submitted).



nutrient relationships. However, in the relatively quiescent near-bottom layer off New Jersey, oxygen depletion is correlated with the accumulation of ammonium released by decomposition from July to September (Figure 5.10).

In summary, oxygen production in the euphotic zone is related to the uptake of new nutrients by phytoplankton in the spring through early summer while oxygen depletion is related to near-bottom decomposition processes that produce ammonium with subsequent oxidation to nitrate. The extent that these processes lead to serious environmental perturbations is related to nutrient loading, the duration and degree of stratification, the frequency of storm events that vertically mix the water column, and the frequency of upwelling events which can replace nearshore water with cooler, oxygen rich water from offshore.

5.4 CHARACTERIZATION OF BOTTOM OXYGEN DISTRIBUTION IN THE NEW YORK BIGHT

Hydrographic data collected in the New York Bight from 1977 to 1985, were aggregated to characterize the near-bottom distribution of dissolved oxygen during the summer (July, September). The compilation and selection of the data represents a significant effort with 5,782 near-bottom oxygen measurements obtained from a number of data sources (Table 5.1). Station distributions of the combined data reflect high spatial resolution in the Apex and the nearshore regions, where environmental gradients are most pronounced.

On a seasonal basis, lowest mean value oxygen levels are observed within the near-bottom layer from July-September (see Figure 2.21) with nearshore areas (<20 m) of the New Jersey coast characterized by localized hypoxia (i.e., dissolved oxygen <2.5 ml/l). Recurrent low oxygen in the New Jersey nearshore region is attributed to nutrient enrichment, high rates of primary production, and settling and decay of algal biomass in the shallow, and perhaps poorly flushed nearshore region.

In 1976, however, an unusual sequence of events resulted in anoxic conditions over a 8600 km^2 area off New Jersey (Figure 5.11) and mass mortalities of shellfish valued at around $600 million. Anoxia in 1976 has been attributed to 1) early stratification of the water column and a deep thermocline 2) persistent southwest summer winds leading to 3) reversal of the subsurface

Table 5.1. Data sources for bottom oxygen in the New York Bight, July-September, 1977-1985. (Source: Stoddard *et al*., 1986).

Survey Area	PI	Data Source	No. Obs.	Reference
NJ/LI Coast and apex	Hammett, Braun	EPA-II	3,993	EPA 1985
NYB	O'Reilly, Steimle, Waldhauer	NOAA/NMFS	447	Unpublished
NYB	Warsh, Gottholm, Whitledge	NOAA/NOS BLN	428	Warsh *et al*. 1985
NYB	Han, Stoddard	NOAA/NODC	388	NOAA/MESA cruise reports
Long Branch	Draxler, O'Reilly	NOAA/NMFS	236	Unpublished
NYB	Mountain, Patanjo	NOAA/NMFS	127	Sibunka and Silverman 1984
Shinnecock	Walsh, Whitledge	BLN	89	Wold 1979
Apex	Malone, Garside	BLN	14	Malone *et al*. 1985
NYB	Aikman, Haines	Columbia U.	30	Wold 1979

Figure 5.10. Relationship between bottom oxygen and bottom ammonium in the New York Bight. (Source: Whitledge and Warsh, submitted)

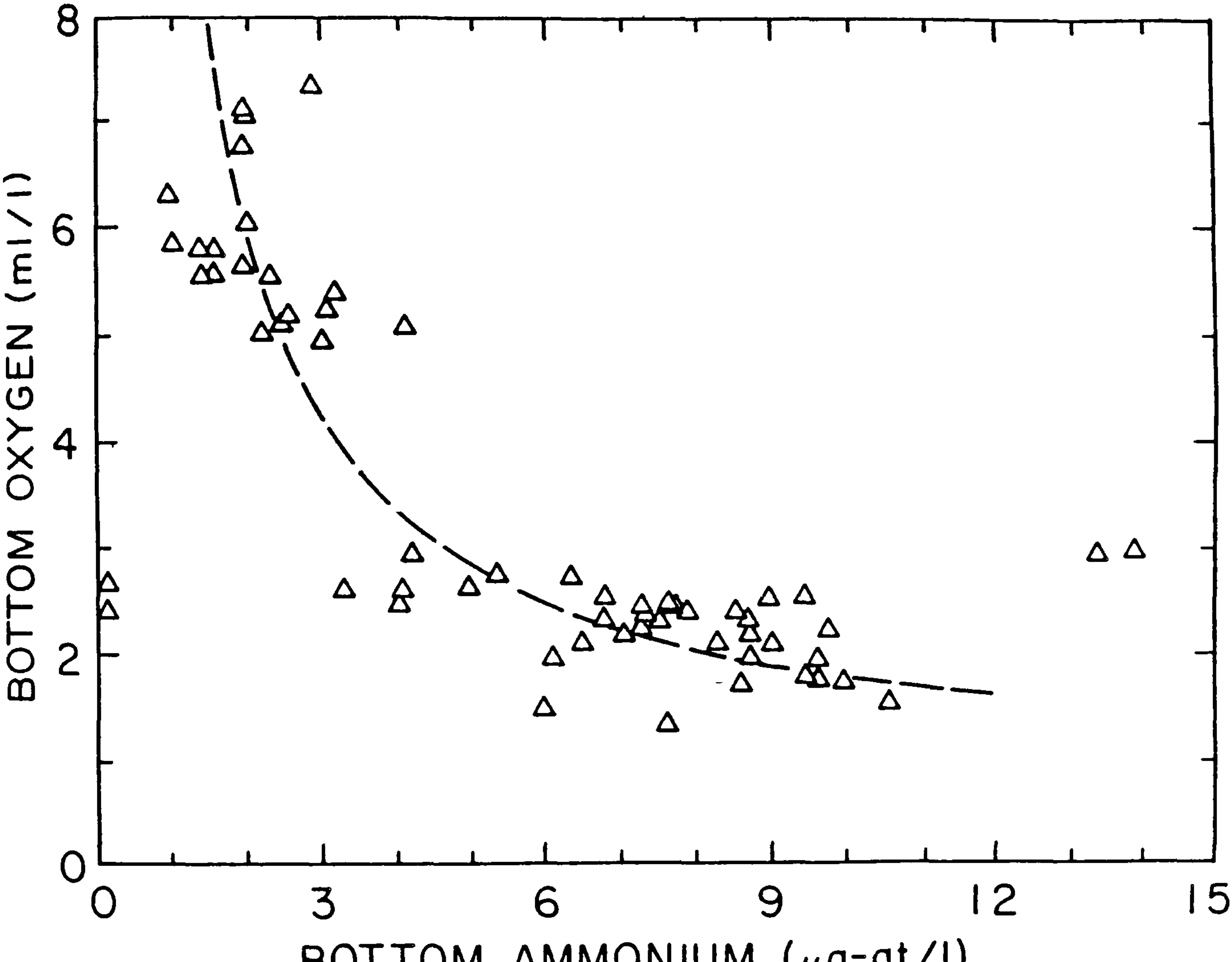
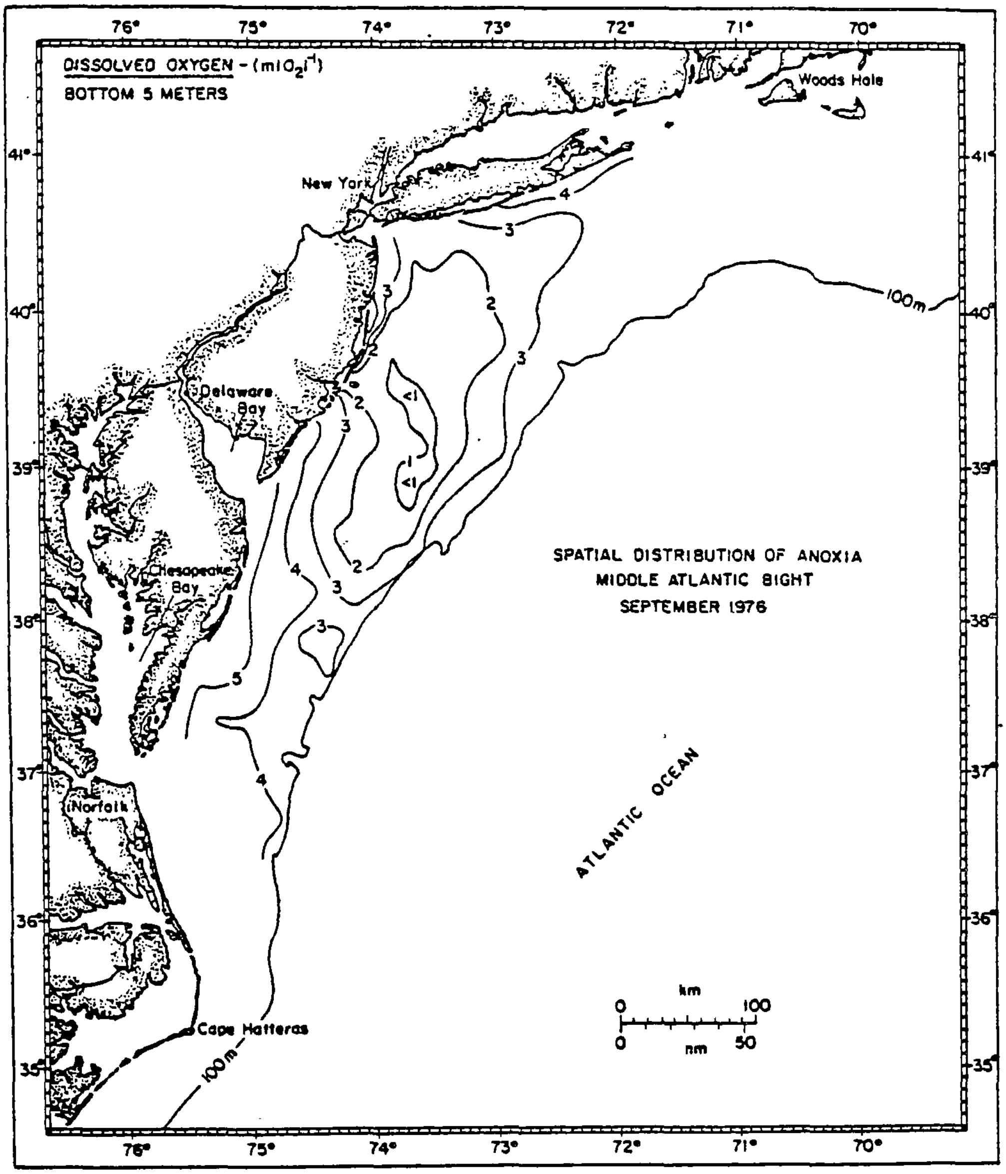


Figure 5.11. Distribution of anoxia in New York Bight, September 1976. (Source: Stoddard 1983).

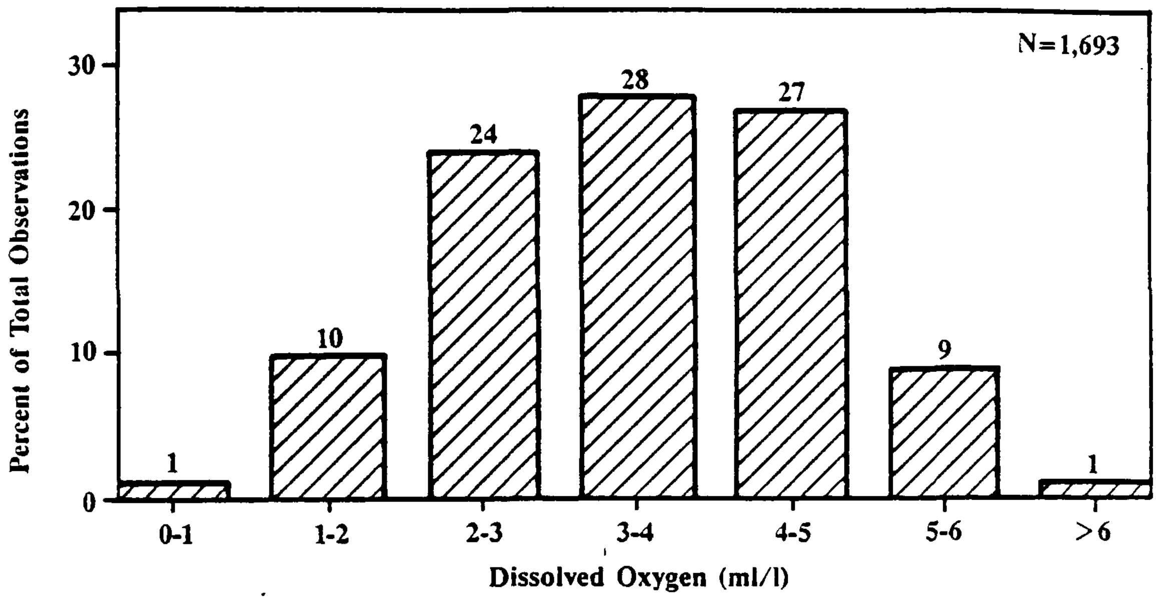


circulation regime off New Jersey 4) estuarine cross-shelf circulation with onshore convergence resulting in 5) a massive subsurface bloom of *Ceratium tripos*, and 6) respiration and decomposition of the bloom below the seasonal pycnocline (Swanson and Sindermann, 1979; Malone *et al.*, 1979; Falkowski *et al.*, 1980; Stoddard, 1983).

Generally, the mean bottom oxygen distribution within the 20-40 m isobath on the nearshore New Jersey side for the Hudson Shelf Valley is 0.7 ml/l lower than the comparable 20-40 m isobath region off the Long Island coast (Figure 2.21). The northern New Jersey nearshore is more likely to be influenced by inorganic and organic loading from the Hudson-Raritan estuary than is the Long Island coast. Based on the distribution of salinity and suspended solids (Young and Hillard, 1984) and analyses of turbidity from remotely sensed images (Munday and Fedosh, 1982), the Hudson plume is typically confined along the New Jersey coast as it flows southward mixing with shelf water. This systematic difference between the Long Island and New Jersey sides of the Hudson Shelf Valley and the differences in volume of water beneath the seasonal thermocline (Armstrong, 1979) may be important factors that predispose the New Jersey coast to anoxic conditions during major phytoplankton blooms such as occurred in 1976.

The shallow (<20 m), nearshore waters off New Jersey between Long Branch and Atlantic City are characterized by high rates of primary production and near-bottom hypoxia with summer oxygen levels less than 3 ml/l observed in 35% of the 1,693 observations between 1977 and 1985 (Figure 5.12). The New Jersey nearshore region, enriched by coastal upwelling of high nitrate subpycnocline water, coastal sewage outfalls, and anthropogenic and non-point source loading from the Hudson-Raritan estuary and numerous smaller bays and inlets along the New Jersey coast, is characterized by frequent summer phytoplankton blooms (EPA, 1985) that may be a significant factor in the recurrent coastal hypoxia. Using the data from 1977 to 1985, the minimum values of all the summer near-bottom observations within each grid segment were plotted as contour distributions (see Figure 2.22). The data show the effect of the Hudson plume with a nearshore band of low oxygen (<1 ml/l) water south of Long Branch, NJ. The Christiansen Basin, a depositional area in the Apex that receives particulate organic loading from the adjacent 12-mile sewage sludge dumpsite, dredge spoil site, and the Hudson-Raritan estuary, is characterized

Figure 5.12. Frequency distribution of bottom dissolved oxygen, July-September, 1977-1985, in the New Jersey nearshore (0-20m) area. (Source: Stoddard *et al.*, 1986).



by 1) organically enriched sediments, 2) high rates of seabed oxygen consumption (Thomas et al., 1976), 3) steep vertical gradients of dissolved oxygen near the seabed (Draxler, personal communication), and 4) low bottom oxygen during the summer. The depositional area of the Christiansen Basin in the Apex is also reflected in the distribution of minimum values (<1 ml/l).

Although previous data for specific years have identified hypoxic regions along the southern New Jersey coast (e.g., Pearce et al., 1983), the composite data from 1977 to 1985 clearly documents a large area of recurrent hypoxia in the vicinity of Ocean City-Atlantic City, NJ that extends out to approximately the 20-30 m isobath region. In the shallower inshore waters (<10 m), tidal mixing, winds and waves result in a mixed water column even during the summer when the water column is strongly stratified further offshore. Consequently, restricted vertical exchange of oxygen from the surface layer to the lower layer could not be a dominant factor in accounting for the observed widespread hypoxia in the inshore region. The remaining physical process that could account for such extensive oxygen depletion is horizontal and lateral advective processes that determine the overall residence time of water masses in the nearshore region. If high rates of organic loading (from estuarine outflow, sewage outfalls, and decaying phytoplankton blooms) were coupled with sluggish circulation patterns characterized by long residence times of water masses in the area, and low rates of replenishment of dissolved oxygen from advection and dispersion, then oxygen demands could exceed the supply rate of oxygen and hypoxic conditions could then result. Historical evidence (e.g., Bumpus, 1973) and numerical circulation models (e.g., Hopkins and Dieterle, 1983) indicate that persistent southwest winds during late summer (i.e., August) can frequently result in upwelling (Ingham and Eberwine, 1984) and alongshore flow in the nearshore region parallel to the coast near the northern coast of New Jersey. This pattern, in fact, is to be expected in shallow, nearshore coastal zones where circulation is strongly influenced by wind forcing (Scott and Csanady, 1976; Hopkins and Swoboda, 1986). The effect then of such a reversal of the "typical" net drift towards the southwest along the New Jersey coast is to increase the residence time of water masses and set up the nearshore ecosystem for 1) high rates of primary production, and 2) hypoxia. The occurrence of persistent southwest winds during the summer is a factor in a contingency table for anoxia in the New York Bight suggested by Falkowski et al. (1980).

In summary, low oxygen below the summer thermocline is the net result of a complex interaction of physical and biological factors. These factors include organic and nutrient loadings, chemical and biological oxidation rates, flushing rate and near-bottom circulation, aperiodic renewal of oxygen from storm mixing and lateral transport, stratification, and turbidity. Turbidity affects light penetration and determines the extent of vertical separation of photosynthetic oxygen production from oxygen consumption in the water column. Partial insight into the interactions of these factors was gained from the studies of the 1976 anoxic episode (e.g., Swanson and Sindermann, 1979). Additional retrospective analyses of the historical database will provide 1) further insight into the factors and processes that establish and maintain hypoxic conditions, and 2) a basis for generating and testing hypothesis on the interactions of nutrient enrichment, coastal eutrophication and oxygen depletion.

6. PLANKTON OF THE NEW YORK BIGHT

6.1 PHYTOPLANKTON

Fairly distinct communities of phytoplankton are characterized by seasonal and spatial patterns that are typical of temperate, continental shelf ecosystems. Phytoplankton distributions have been investigated for the New York Bight (Malone, 1976; Hurlburt, 1966 1970; Mandelli *et al*., 1970; Ryther and Yentsch, 1958), Georges Bank (Riley, 1946; Riley and Bumpus, 1946), Block Island Sound (Riley, 1952), Vineyard Sound (Lillick, 1940; Fish, 1925), and other adjacent regions. Summary discussions of these seasonal and spatial observations in the Middle Atlantic Bight are presented in Malone (1977), Yentsch (1977) and Smayda (1973). Historical references to the occurrence of *Gyrodinium aureolum* in the New York Bight include Hurlburt (1957) and Martin (1929).

Phytoplankton populations in the Hudson-Raritan estuary, the Bight Apex and coastal waters off Long Island and New Jersey are typically dominated by netplankton diatoms (e.g., *Skeletonema costatum*) during the unstratified winter-spring months (November-April) and by nanoplankton chlorophytes (e.g., *Nanochloris atomus*) during the stratified summer/fall months (May-October). (Figures 6.1, 6.2). Diatoms typically dominate at all times in the offshore waters of the New York Bight although during the summer of 1985, an unusually large bloom of the small green chlorophyte (*Nanochloris atomus*) persisted over the New Jersey shelf (NJDEP, 1985).

Within the nearshore region of Long Island and New Jersey, summer phytoplankton populations are typically dominated by diatoms (*Rhizosolenia* sp.; *Nitzschia* sp.) dinoflagellates (*Prorocentrum* sp.; *Peridinium*; *Ceratium* sp.) and chlorophytes (*Nannochloris atomus*). Dominance between alternating cycles of diatoms and dinoflagellates appear to be characteristic of shallow coastal waters during stratified conditions off Long Island (Mandelli *et al*., 1970) and New Jersey (NJDEP undated report). Dinoflagellate blooms off New Jersey are recurrent events during the summer. Since 1968, red tides have been associated with *Olisthodiscus luteus* (1976, 1984) and *Prorocentrum micans* (1968, 1972 and 1983) (NJDEP, undated).

Transient perturbations of characteristic phytoplankton species dominance in the Middle Atlantic Bight are becoming increasingly common summer events. The following anomalous episodes have been observed in the past two years:

Figure 6.1. Surface phytoplankton cell densities for July and December. (Source: Malone, 1977)

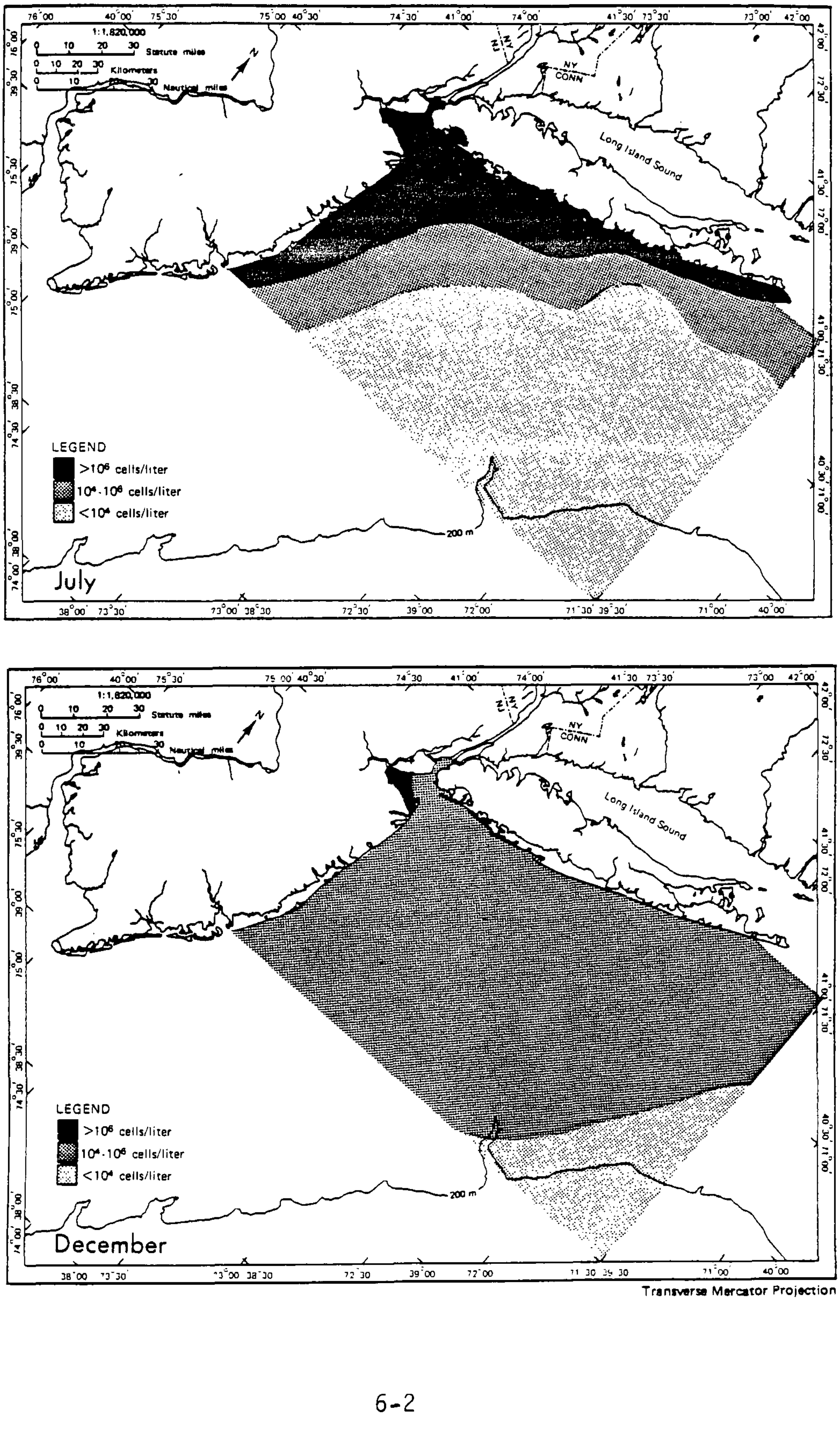
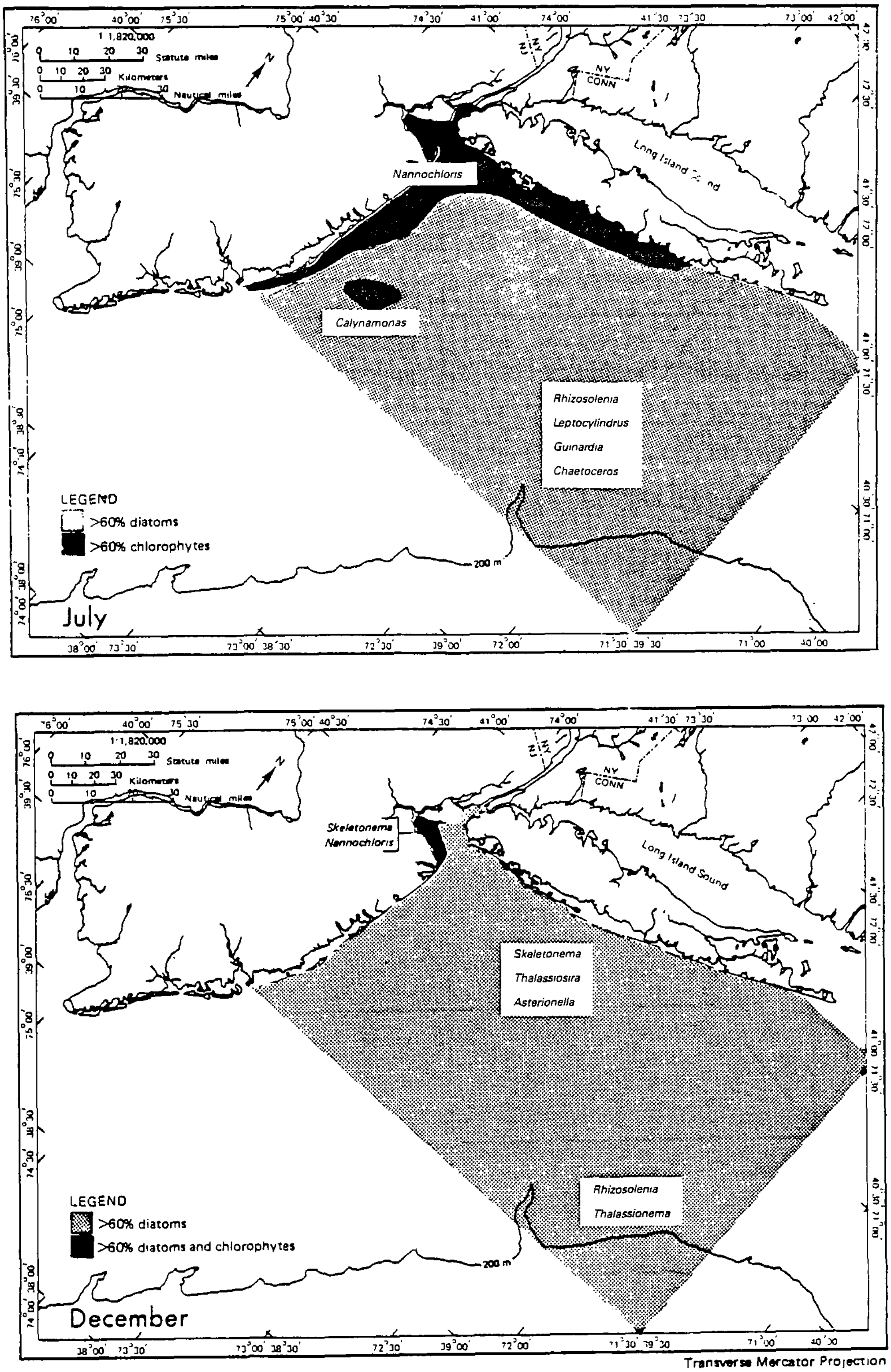


Figure 6.2. Relative surface abundance of diatoms and chlorophytes for July and December. (Source: Malone, 1977).



- August-September 1984-Green tide at Carmens River estuary in southern Long Island and off Atlantic City - Ocean City, NJ. Tentatively identified as Gyrodinium aureolum for New Jersey bloom.

- July-August 1985-Green tide off Atlantic City - Ocean City, NJ.

- August 1985-Brown tide in Narragansett Bay, RI, Peconic Bay and off Shinnecock, Long Island, NY. Widespread shellfish mortality resulted from their failure to consume available phytoplankton. There were reports of greenish water offshore of New Jersey out to 75 miles.

- July 1986-Brown tides observed in Barnegat Bay, NJ, and in Peconic Bay, LI. Viable sediment spores of toxic red tide organism (Gonyaulax tamarensis) identified in Peconic Bay, LI, and off south shore of Long Island near Shinnecock.

Summary documentation of phytoplankton observations off New Jersey during the summers of 1984 and 1985, including observations of the green tide, is presented by NJDEP (undated reports). Mahoney and Olsen (1986) have prepared a literature review on the occurrence, distribution, abundance and physiological characteristics of Gyrodinium aureolum, the dinoflagellate tentatively identified as the green tide organism. Tables 6.1 and 6.2 presents the spatial and temporal chronology of green tide observations in 1984 and 1985 as reported by NJDEP (unpublished). The various data sources for phytoplankton observations in the New York Bight and the nearshore New Jersey coastal zone are summarized in Table 6.3.

Phytoplankton production in temperate shelf ecosystems such as the New York Bight is dependent on temperature, light level and nutrient concentration in the water column. A large body of literature beginning with Riley (1946) exists for marine phytoplankton ecology. More recently Yentsch (1977) has summarized the factors related to phytoplankton production in the New York Bight. Eppley (1972) and Malone and Neale (1981) have summarized the temperature dependence of phytoplankton growth rates for diatoms (Figure 6.3). Investigations of light dependence of algal photosynthesis in the Middle Atlantic Bight include studies by Ryther (1956), Ryther and Yentsch (1958), Malone (1977), Malone and Neale (1981), and Falkowski (1981) (Figure 6.4). The regulation of phytoplankton growth by levels of nutrients in the water column is described by Dugdale (1967, 1975, 1976) (Figure 6.5) and Conway and Whitledge (1979) for the New York Bight. A summary of nitrogen kinetics theory and data is presented by McCarthy (1980). Nutrients for phytoplankton growth include nitrogen, phosphorus, silicon and assorted trace

Table 6.1 History of bloom events in 1984.

DATE	LOCATION	OBSERVATION	NOTE
April			
19	Seaside Heights	stringy, greenish-brown floating material in surf, resembling sewage	followed northeast storm
June			
A rapid but brief warming trend occurred early in the month.			
21	Raritan and Sandy Hook Bay, ocean to Sea Bright	red tide (seen from EPA Helicopter)	phytoflagellate and diatom bloom
July			
2	Long Branch	patches of murky water in surf	mixture of flagella and diatoms
5	Belmar to Sea Girt	patches of murky water in surf	mixture of flagella and diatoms
Water temperatures erratic (mostly cool) the past month; much rainfall.			
17	Sandy Hook to Long Branch	water cloudy	detritus & *Nannochloris* sp. (moderate bloom)
19	Keansburg (Raritan Bay)	red tide	unconfirmed
20	Sandy Hook Bay	sea cabbage (*Ulva*) washed up on shore	*Ulva* killed by heat and sunlight at low tide
23	Horseshoe Cove (Sandy Hook Bay)	dead bunker in bay and cove	dead fish from pound nets
23	Sea Bright	brown foam in surf	brought in by on-shore winds at high tide
20-26	Harvey Cedars	seaweed ("smelly") at sea wall	unconfirmed
31	Seaside Park	junk on beach throughout	cleaned up by beach patrol
August			
1	Long Branch	brown, green and white foamy substance in surf	phytoflagellate bloom
2	Long Branch	yellowish water to ½ mile out	*Olisthodiscus* sp + diatoms abundant in sample

istory of Bloom events in 1984 (continued).

DATE	LOCATION	OBSERVATION	NOTE
August			
4-9	Belmar and Manasquan	oily and foamy solid substance on beach; "unaesthetic" conditions come and go	Belmar beaches temporarily closec
15	Asbury Park	oily condition in surf	bloom remnants
16	Shark River Inlet	possible red tide over several square miles to one mile out	unconfirmed
15-16	Harvey Cedars	"green water" in surf, dead mussels on beach	green floc settlin out in samples
16-17	Harvey Cedars to Surf City, Atlantic City-Absecon Island Ocean City - 5th to 12th Sts.	green tide densest in these areas to one-half mile out	*Gymnodinium* sp. bloom(s); cells settle out in slim mass, shrivel up wi preserved (ocean o falls in each area
18-20	Beach Haven, Sea Isle City to Avalon	green tide along shore	same species as ab dissipated somewha after storm on 8/1
19	Manasquan (two miles off)	subsurface slime found by a diver	remnants of *O. lute* diatom bloom
22	Bay Head (two miles off)	dissolved O_2 low on bottom (0.46 ppm at 22 meters)	same vicinity as at bloom
23	Long Branch to Allenhurst	"green slime" covering 5-mile stretch (seen by a party boat)	same (*Gymnodinium*) species as in south area
25-26	Belmar to Sea Girt (to 2 miles off)	intermittent patches (20x50 yds of brilliant green water	seen by fishermen in a boat
26	Little Egg Inlet	small patch of "pink water"	ctenophores (½ mile out)
27	Lavalette to Beach Haven	patches of green water along beach (EPA helicopter)	densest off Ship Bottom, smaller patches north of Lavalette.
29	Mantoloking to Island Beach	brown water in surf	bloom remnants + diatoms in sample
Inshore water temperatures quite warm ($\leq 75^oF$) during this period.			
Sept			
1	Vicinity of Little Egg Inlet	water brownish in morning, bright green in afternoon (½ mile off Little Beach)	sky clear, bright su (greenish color extended into Great Bay)
3	Rehobeth, Delaware and Belmar, NJ	green tide (beginning around Labor Day)	caused irritation tc at least one bather

Table 6.1 History of bloom events in 1984 (continued).

DATE	LOCATION	OBSERVATION	NOTE
Sept.			
6	Southern Monmouth County to Long Beach Island	green tide (seen from EPA helicopter)	not as dense as last week
10	Shark River	some green water off inlet (EPA helicopter)	other areas clear
13	Beach Haven to Atlantic City	green tide (seen by fishermen)	densest off Brigantine (to 3 miles ou
18	Long Island (Nassau County)	green tide continuing in this area	same species as in N.J.
Oct.			
12-14	Manasquan to Belmar	green slime washing in	bloom remnants; roug seas caused by Hurricane Josephine

Table 6.2. History of Bloom Events in 1985

DATE	
May 21,28	Late spring diatom flowering with highest cell densities in Sandy Hook Bay; dissolved oxygen readings as low as 2.0 ppm on bottom of Sandy Hook Bay.
June 12	Phytoflagellate bloom in Raritan and Sandy Hook Bay.
20,25	Diatoms abundant in ocean south of Spring Lake.
July 2	Blooms extend southward in patches along the Monmouth ocean front to Spring Lake.
4	Diatoms in Long Branch to Asbury Park sector apparently associated with masses of decomposing cells.
9	Yellowish brown water reported in portions of Barnegat Bay, probably *Nannochloris atomus*, normally dominant at Sandy Hook in late summer.
18	Murky water, sometimes greenish, also reported in ocean at Island Beach and Long Beach Island. Gaps in phytoplankton data for northern stations beginning in late July and continuing through August; low DO south (to Beach Haven) and farther offshore than usual.
30	Bloom of *Nannochloris* sp. (to 300,000 cells/ml) within three miles of shore from Beach Haven to Brigantine; conspicuous abundance of jellyfish, primarily *Cyanea* sp. (roughly one individual per square yard of ocean surface) to ten miles off Beach Haven.
July 21	Bright green water along the beaches of southern New Jersey, first in the vicinity of Hereford Inlet and, subsequently, at Ocean City.
24	Water temperatures up to 24°C within the latter area.
29-31	Brilliant green water most apparent in Ocean City from 20th Street to the south end; also seen at points southward to Hereford Inlet.
August 7	Dinoflagellate counts as high as 30,000 cells/ml at Ocean City; lifeguards experienced nausea, sore throat & sinuses, eye irritation, fatigue, dizziness, fever and lung congestion; most persons on the beach apparently unaffected.

Table 6.2. History of Bloom Events in 1985 (Continued)

<u>August</u> (cont.)	
10	Northward drift of green tide. On August 10, beach from 29th to 37th Streets were closed due to the presence and odor of the algae.
12,13,14	Complaints from the Atlantic City area. On the 13th, algae much more abundant from the north end of Ocean City near 9th Street, around Great Egg Inlet, and along Absecon Island to Absecon Inlet, generally in patches within a half-mile of the surf zone extending out one to two miles in the estuarine plume. Yellow-green color most vivid around mid-day after greenish brown in early morning.
9 to 29	Bloom of <u>Gymnodinium</u> sp. peaked about this time. North of Atlantic City, the green tide was not as evident as in 1984. Murky greenish coloration, earlier evident north of Atlantic City, expanded throughout coastal waters in shades varying from light green to yellowish-brown. Apparent from Sandy Hook to Cape May County, with similar conditions in the intra-coastal area from Great Bay to upper Barnegat Bay. In late summer, several potential red-tide species including <u>Katodinium rotundatum</u> and <u>Prorocentrum redfieldi</u>, as well as <u>Gymnodinium</u> sp. also abundant in northern coastal waters.
28	Turbid green water as far out as the Hudson Canyon. Bottom dissolved oxygen remained low between Manasquan and Beach Haven transects; few minor fishkills were reported in the area one to two miles off Manasquan Inlet.
29	Material resembling sewage washed ashore at Sea Girt and adjacent sections of Monmouth County; scattered reports of bathers becoming ill, but no direct associations could be made.
<u>September</u>	
5	Murky greenish water remained through most of September.
9	<u>Nannochloris</u> remained moderately high while diatoms increased in abundance in the second week of September at northern shore and lower Cape May County.
11	Strong northeast storm resulted in increase in bottom dissolved oxygen levels to 6.0 ppm or better at all stations. Waters still somewhat murky as <u>Nannochloris</u> gradually diminished and diatoms gained in prominence. Hurricane Gloria, in September, resulted in heavy suspension of organic matter and a few scattered red tides off Ocean County. Waters remained turbid until late October.

Table 6.3. Summary of phytoplankton data sources for the New York Bight

Survey Area	Years	PI	Agency/Institution
NYB	1980-85	Mahoney, Cohn Marshall Falkowski Cosper	NOAA/NMFS-Sandy Hook Old Dominion U. BNL SUNY-Stony Brook
Hudson Plume	Aug. 1985	Malone	U. Maryland, Horn Point
NJ Coast	1974-Present	Olsen	NJDEP
NJ Embayments	1974-Present	Runyon	NJDEP

Figure 6.3. Temperature dependence of phytoplankton growth rates for a) Nanoplankton and b) Ceratium tripos. (Source: Stoddard, 1983).

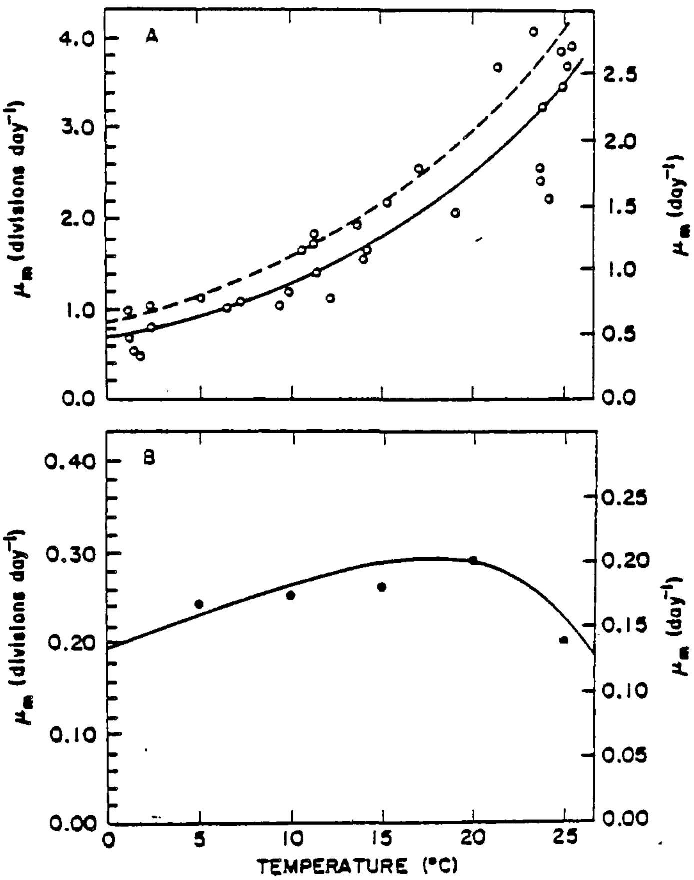


Figure 6.4. Uptake of nitrate and ammonia as a function of light, following Michaelis-Menten kinetics. (Source: Dugdale, 1976).

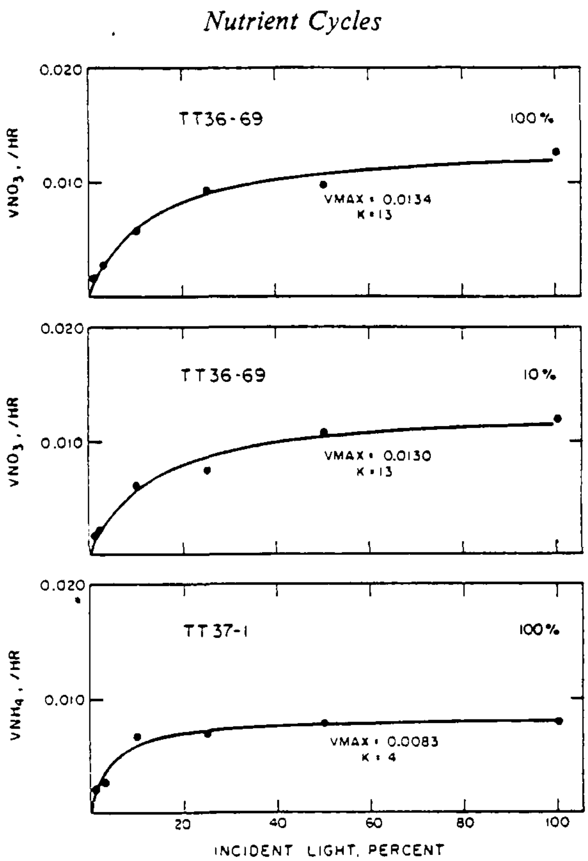
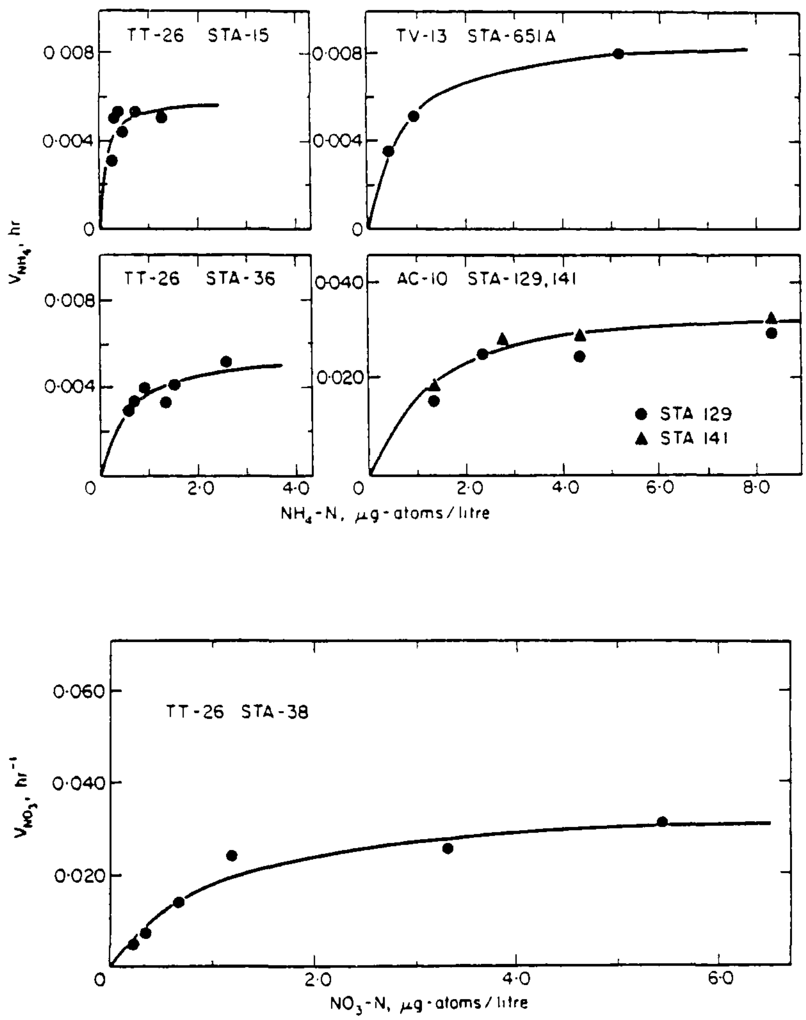


Figure 6.5. Nitrogen uptake as a function of nitrogen concentration. (Source: Dugdale, 1976).



elements and vitamins. Nitrogen and phosphorus are required by all phytoplankton species groups; silicon is required only by diatoms. In contrast to freshwater systems where phosphorus is usually the nutrient limiting phytoplankton growth, nitrogen is generally the limiting nutrient in marine ecosystems (Ryther and Dunstan, 1971).

In addition to regulation of the growth rate, the abundance and distribution of phytoplankton is controlled by lateral and vertical transport and mixing, respiration, excretion, settling, natural mortality, and grazing by herbivorous zooplankton and shellfish in shallow waters. Although biological and chemical processes are important factors, physical transport processes and hydrographic characteristics are critical factors in determining phytoplankton abundance and distributions. A summary of physiological, kinetic and stoichiometric data is presented for nanoplankton (Table 6.4) and netplankton diatoms (Table 6.5).

6.2 ZOOPLANKTON AND ZOOPLANKTON GRAZING

Zooplankton distributions in the estuarine, nearshore and coastal shelf regions of the New York bight are summarized in Grice and Hart (1962), Jeffries and Johnson (1973), Malone (1977), and Judkins *et al.* (1980) (Figure 6.6). Summary investigations of zooplankton grazing rates in the New York Bight and Georges Bank are presented in Dagg and Turner (1982).

Grazing by coastal copepods in the New York Bight (e.g., *Acartia tonsa*; *Centropages typicus* (Judkins *et al.*, 1980) is the major loss mechanism for summer nanoplankton (chlorophytes) dominated phytoplankton communities. In contrast, the major loss mechanisms for the spring diatom bloom is sinking out of the water column and cross-shelf transport off the continental shelf (Malone and Chervin, 1979; Walsh *et al.*, 1978). Significant reductions in zooplankton predation have been reported for both small red tide dinoflagellates (*Gymnodinium splendens*) in a bloom off La Jolla, California (Fiedler and Huntley, 1981) and large non-red tide dinoflagellates (e.g., *Ceratium tripos*) in the New York Bight (Dagg and Grill, 1980). These, and other similar observations, strongly suggest that a reduction in grazing mortality can provide a significant competitive advantage to dinoflagellate populations over fast-growing nanoplankton or diatoms. These observations for other dinoflagellates

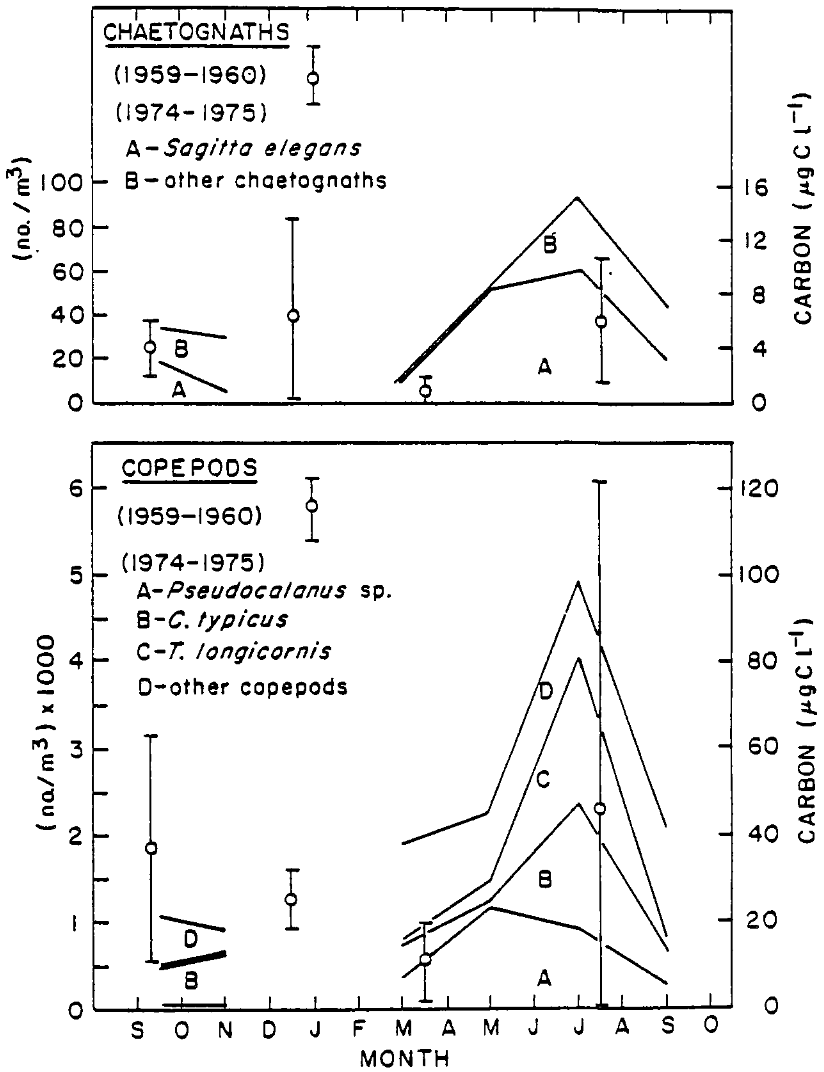
Table 6.4. Nanoplankton parameter values. (Source: Stoddard, 1983).

Notation	Parameter	Range	Value	Units	Reference
$(C/Chl)_1$	carbon/chlorophyll	69–72	80	$\mu g\ C\ \mu g\ Chl^{-1}$	Malone and Chervin (1979) Chervin et al. (1981)
$(N/Chl)_1$	nitrogen/chlorophyll	10–14	12	$\mu g\ N\ \mu g\ Chl^{-1}$	Chervin et al. (1981)
$(C/N)_1$	carbon/nitrogen	5–7	6.67	$\mu g\ C\ \mu g\ N^{-1}$	Chervin et al. (1981)
$(O_2/Chl)_1$	oxygen/chlorophyll	—	0.148	$m\ell\ O_2\ \mu g\ Chl^{-1}$	
$(Si/CHL)_1$	silica/chlorophyll	—	0	μg at $Si\ \mu g\ Chl^{-1}$	Malone (pers. comm.)
$(K_n)_1$	half saturation constant nitrogen		1.0	μg at $N\ \ell^{-1}$	
$(K_s)_1$	half saturation constant silica		0	μg at $Si\ \ell^{-1}$	Thomas et al. (1979)
$(W_p)_1$	sinking velocity	0.1–0.3	0.1	$m\ day^{-1}$	Bienfang (1979) Burns and Rosa (1980)
$(O_2/C)_1$	oxygen/carbon	—	1.84	$m\ell\ O_2\ mg\ C^{-1}$	
W_1	herbivore selectivity coefficient	—	1.0		Scavia (1980)
$(K_{rp})_1$	respiration rate at 20°C		0.1	day^{-1}	
θ	temperature coefficient for respiration		1.08		
$(\mu_m)_1$	maximum growth rate at 20°C		2.1	day^{-1}	Eppley (1972) Yentsch and Lee (1966)
$(I_s)_1$	optimal light intensity	—	300	$ly\ day^{-1}$	Parsons and Takahashi (1973)
$(K_{ep})_1$	DOC excretion as fraction of net production	0.07–0.34	0.20	—	Thomas et al. (1979) Eppley and Sloan (1965) Berman and Holm-Hansen (1974)

Table 6.5. Netplankton parameter values. (Source: Stoddard, 1983).

Notation	Parameter	Range	Value	Units	Reference
$(C/Chl)_3$	carbon/chlorophyll	—	50	μg C μg Chl^{-1}	Malone and Chervin (1979)
$(N/Chl)_3$	nitrogen/chlorophyll	5.7-9.7	7.7	μg N μg Chl^{-1}	Malone and Chervin (1979)
$(C/N)_3$	carbon/nitrogen	5.1-8.7	6.5	μg C μg N^{-1}	Malone and Chervin (1979)
$(O_2/Chl)_3$	oxygen/chlorophyll	—	0.092	$m\ell$ O_2 μg Chl^{-1}	
$(Si/Chl)_3$	silica/chlorophyll	—	0.825	μg at Si μg Chl^{-1}	Malone (pers. comm.)
$(K_n)_3$	half saturation constant nitrogen		1.0	μg at N ℓ^{-1}	Dugdale (1976) Eppley et al. (1979) Eppley and Thomas (1969) Falkowski (1975)
$(K_s)_3$	half saturation constant silica	0.7-3.4	1.5	μg at Si ℓ^{-1}	Paasche (1980)
$(W_p)_3$	sinking velocity	1-10	1.0	m day^{-1}	Smayda (1970)
$(O_2/C)_3$	oxygen/carbon	—	1.84	$m\ell$ O_2 mg C^{-1}	
W_3	herbivore selectivity coefficient	—	1.0		Scavia (1980)
$(K_{rp})_3$	respiration rate at 20°C		0.1	day^{-1}	DiToro et al. (1977) Steeman-Nielsen and Hansen (1959)
θ	temperature coefficient for respiration		1.045		
$(\mu_m)_3$	maximum growth rate at 20°C		2.5	day^{-1}	DiToro et al. (1977)
θ	temperature coefficient for growth		1.066		
$(I_s)_3$	optimal light intensity	—	300	ly day^{-1}	DiToro et al. (1977)
$(K_{ep})_3$	DOC excretion as fraction of net production		0		

Figure 6.6. Seasonal variation of zooplankton in the New York Bight. (Source: Stoddard, 1983).



species are potentially significant in explaining the persistence of the green tide of Gyrodinium aureolum in 1984 and 1985 off the New Jersey coast.

The fate of phytoplankton carbon production within the nearshore and shelf ecosystem varies considerably on a seasonal basis. Because of low grazing stress and a relatively fast sinking rate (Smayda, 1970) about 90% of the winter-spring diatom bloom (35% of annual production of 300 g C/m^2day) is exported across the shelf to the continental slope (Malone et al., 1983). By contrast, summer production of the nanoplankton dominated phytoplankton community is nitrogen limited, controlled by grazing, and phytoplankton carbon is retained within the shelf food web of the water column and benthos. During summer stratification, only about 9% of phytoplankton biomass produced from May to October (5% of annual production) is exported off the shelf to the slope (Malone et al., 1983). Interannual variations in the magnitude of cross-shelf export of phytoplankton carbon produced during summer stratified conditions may be coupled to the strength and persistence of south-southwesterly wind forcing and the resultant occurrence of flow reversals along the New Jersey coast (i.e., transport towards the northeast parallel to the coast) (Hopkins and Dieterle, 1983). Recurrent, but intermittent hypoxic episodes during late summer in the nearshore New Jersey region most likely reflect this interannual variability of cross-shelf export of phytoplankton biomass. The low frequency of widespread anoxic events, such as the 1976 episode, may reflect the annual cross-shelf export of about 10% of phytoplankton biomass produced during stratified conditions (Malone et al., 1983).

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APPENDIX A

Summary of Quantitative Current and Nutrient Data Available for The Southern New Jersey Shore, Off-Shore and Estuaries, Not Included in the References

The following reports were reviewed to determine if they contain any data that could be used to quantify currents and/or nutrient levels in the study area. Many of the reports have been described as having "no data". These reports may have other useful information but did not contain the quantitative data of principal interest.

Ref. 1: Beach and Offshore Seafloor Stability of the Coastal Waters Offshore Cape May County New Jersey, Supplement No. 2, Diamond Beach Site. Prepared for Cape May County Municipal Utilities Authority by Pandullo Quirk Associates, December 1977.

This report does not present any information needed for this study. It provides topographic data for an area off-shore of Diamond Beach in Lower Township, NJ.

Ref. 2: Physical Oceanography Of The Coastal Waters Offshore Cape May County, New Jersey, Supplement No. 1, Stone Harbor Site, December 1977.

This report presents an evaluation of the currents found off Stone Harbor. Two months of in-situ current data were obtained and five drogue studies were conducted at the site. A current meter collected data between April 11 and May 16, 1977 and again between June 29, 1977 and July 31, 1977. Drogue trackings were conducted on April 12, 13, 19, May 16 and August 2, 1977. These trackings consisted of following the movement of drogues over a time period of about one-half of a tidal cycle. Three drogues were used; one set at 3 feet below water surface, one at 6 feet and one at 9 feet. Histograms, summarizing the in-situ current data for each instrument and time period, were produced, and a harmonic analysis was performed on the current data to extract the tidal current component. The drogue trajectories were plotted for analysis.

Ref. 3-5: Comparison of Natural and Altered Estuarine Systems: The Field Data - Volumes I and II.

This study consisted of several parts which are referenced separately below. The study area which is basically the same in each part is little Egg harbor, slightly north of the principal area of concern for this study. However, it does contain a considerable amount of temporal nutrient data that might be useful.

Ref. 3: Part 1. Estuarine Evaluation Study: Primary Aquatic Production and Nitrogen. Four Year Report 1973 - 1977.

This report deals with studies of primary productivity and nitrogen in the salt marshes and lagoons adjacent to Beach Haven West near Manahawkin, NJ. Nutrient data is provided for stations in creeks and lagoons draining into Little Egg Harbor. The term of study was from June 1973 through June 1977. Nitrogen, dissolved oxygen, water temperature, salinity, chlorophyll and run-off data are reported. Monthly variation in most of these parameters and horizontal statification are also reported.

Ref. 4: Estuarine Evaluation Study: Benthic Invertebrates. Four Year Report, 1973 - 1977.

This report provides data from portions of the western side of Manahawkin Bay and Little Egg harbor in Ocean County, NM. The waterways were sampled between July 1973 and March 1975. Seasonal values are provided for temperature, salinity and dissolved oxygen at the water surface and bottom. Data was provided for six and seven seasons (i.e., summer '73 to winter '75) at 18 sites.

Ref. 5: Studies of the Manahawkin Bay - Little Egg Harbor System: 1. Finfish Study: John F. McClain, 2. Physical - Chemical Study: John Makai, and 3. Use Study: Peter J. Himchak.

The second portion of this study "Physical - Chemical Study" provides data that may be useful. This part of the study maps and describes the physical and chemical attributes of the Manahawkin Bay-Little Egg Harbor system. Thirty-four water quality stations were selected and sampled bimonthly, monthly, and/or seasonally from July 1973 until February 1974 and from June 1974 until May 1975. The parameters measured were temperature, dissolved oxygen, salinity, pH, carbon dioxide, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, detergent, B.O.D., orthophosphate, and total and fecal coliforms. Monthly values and standard deviations are reported for temperature at three sites. Monthly values at several sites are reported for salinity, nitrogen, phosphates, and B.O.D. There are some breaks in the monthly data over the study period, but values for June through November 1974 are complete.

Ref. 6-9: Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of the Proposed Site for the Atlantic Generating Station, New Jersey.

The results of this study are presented in several progress reports, each of which is referenced separately below. The study area is a site in the ocean roughly two miles off Little Egg Inlet which is in our area of interest and Little Egg Harbor which is slightly north of our area of interest.

Ref. 6: Progress Report for the Period January - December 1972, Part One.

This report presents the results of a sampling program which began in January, 1972 for fishes and invertebrates from Manahawkin Causeway at Long Beach Island to Atlantic City, New Jersey. Physicochemical parameters that were recorded with each biological collection were water temperature, dissolved oxygen and salinity, usually at the surface and bottom. Physicochemical data are summarized by month. Nutrient analyses of water samples collected in the vicinity of the ocean site during the period May 1 - July 6, 1972 and Little Egg Inlet during the period May 19 - July 25, 1972 are provided with values for nitrate, nitrite, ammonia, silicate and phosphate.

Ref. 7: Progress Report for the Period January - December 1973. Volume Three: Protoplankton and Periphyton; Zooplankton, and Terrestrial Study.

This report presents same data as the previous reference for a year later. Data is provided for temperature, salinity, dissolved oxygen, nitrate, silicate and phosphate for the period beginning May 1972 and ending June 1973. Samples were taken at many sites in the ocean and around Little Egg Inlet, Great Bay and the Mullica River at different depths and tides.

Ref. 8: Progress Report for the Period January - December 1974, Volume One: Fishes, Experimental Studies.

This report provides oxygen, salinity, and temperature data in the ocean off Long Beach Island, in Little Egg and Brigantine Inlets and in Great Bay. Data was generally collected for the surface and the bottom at different phases of the tide. Bimonthly means and ranges for all of 1974 are presented for several sites. Measurements made on individual samples collected on 60 different days over the years at various sites are also provided.

Ref. 9: Progress Report for the Period January - December 1975

This report provides the same data as the previous reference except the time period in January 1975 through December 1975.

Ref. 10: Ecological Studies for the Oyster Creek Generating Station Progress Report for the Period September 1975 - August 1976, Volume One, Fin- and Shellfish.

Water temperature, salinity, pH, dissolved oxygen, and water clarity were measured in Barnegat Bay, Forked River and Oyster Creek. The region studied in this report is 20 to 30 miles north of the area of interest. The study period was September 1975 through August 1976. Only salinity and temperature data is presented in detail. Their presentation is limited to monthly, mean surface and bottom values.

Ref. 11: Summary of Oceanographic Observations in New Jersey Coastal Waters Near 39° 28' N Latitude and 74° 15' W Longitude During The Period May 1973 Through April 1974. A report to Public Service Electric and Gas Company, Newark, NJ by EG&G, Environmental Consultants, Waltham, MA, February 1975.

This report contains data and analyses of data collected to support an environmental site assessment off Little Egg Inlet, NJ. Both current and nutrient data was collected from May 1973 to April 1974 at stations located in the ocean off Little Egg Inlet, off Brigantine Inlet, in the ocean off Beach Haven, in Little Egg Inlet and in the mouth of Great Bay. Monthly average windspeeds and directions are provided. Monthly off-shore current statistics at several stations are provided including along and off-shore mean velocities, the standard deviations of the previous velocity components, the mean speed, the standard deviation of the mean speed and the maximum speed. Current statistics by octants oriented to coastline for each station and by season are also presented. Monthly levels of nitrate, ammonia, ortho-phosphate and total phosphorus are presented for each station at surface, mid-depth and bottom. The average concentration of chloride at each station is presented by season, and depth. Measured values are also presented for 28 metals. Monthly temperature and salinity data are also presented.

Ref.12-16: New Jersey Sea Grant, Annual Report 1984-1985, New Jersey Marine Sciences Consortium.

New Jersey Sea Grant, Annual Report 1983-1984, New Jersey Marine Sciences Consortium.

New Jersey Sea Grant, Annual Report 1982-1983, New Jersey Marine Sciences Consortium.

New Jersey Sea Grant, Annual Report 1981-1982, New Jersey Marine Sciences Consortium.

New Jersey Sea Grant, Annual Report 1980-1981, New Jersey Marine Sciences Consortium.

These annual reports were reviewed and not found to contain any information relevant to our study.

Ref. 13: Review of the Ocean County Sewerage Authority Outfall Design, for The Ocean County Sewerage Authority by Pritchard - Carpenter, Consultants, May 1973.

The data in this report is North of the principal study area. The report describes a review of the design of an outfall near Island Beach State Park. The report contains a table that provides the results of a dye study. The table contains the date, dye concentration, wind direction and speed. The dye study was conducted June 26 through September 12.

Ref.14-24: The following reports were reviewed but contained no data.

Ref. 14: Anoxia on the Middle Atlantic Shelf During the Summer of 1976, Report on a workshop held in Washington, D.C., October 15 and 16, 1976. Report prepared at the University of Delaware, November 1976.

Ref. 15: Three-Dimensional Numerical Models for Hindcasting or Forecasting Estuarine Tides, Currents and Salinities, Applications of Real-Time Oceanographic Circulation Modeling, Symposium Proceedings.

Ref. 16: Landsat Analysis of the Dynamics of the Chesapeake Bay Plume on the Continental Shelf, Final Report, National Marine Fisheries Service, Northeast Fisheries Center, Sandy Hook Laboratory, Highlands, New Jersey, April 30, 1981.

Ref. 17: Mixing Processes on the Atlantic Continental Shelf, Cape Cod to Cape Hatteras, Limnol. and Oceanogr., 25(1): 114-125.

Ref. 18: Environmental Assessment Report on the Proposed Sewerage Facilities of the Ocean County Sewerage Authority, Volume I, Prepared by Environmental Assessment Council, May 15, 1973.

Ref. 19: Satellite Analysis of Estuarine Plume Behavior, Remote Sensing Center, School of Marine Science, Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, Virginia.

Ref. 20: Mixing Zone Definition for the Proposed Central Plant Outfall Off Island Beach State Part. Prepared for the Ocean County Sewerage Authority, Ocean County, New Jersey by Stevens Institute of Technology, Hoboken, New Jersey.

Ref. 21: Evaluation of Proposed Sewage Sludge Dumpsite Areas in the New York Bight, NOAA Technical Memorandum ERL MESA-11, February 1976.

Ref. 22: The Ocean County Sewerage Authority Ocean County, New Jersey, North Central and Southern Outfall Diffusion Studies. Prepared by Woodward-Envicon, Inc. June 5, 1974.

Table A-1

Summary of Readily Available Quantitative Current and Nutrient Data

			Currents	Nutrients
Ref.	1:	Beach and Offshore Seafloor Stability of the Coastal Waters Offshore Cape May County, New Jersey, Supplement No. 2. Diamond Beach Site. Prepared for Cape May County Municipal Utilities Authority by Pandullo Quirk Associates, December 1977.	No Data	No Data
Ref.	2:	Physical Oceanography Of The Coastal Waters Offshore Cape May County, New Jersey. Supplement No. 1, Stone Harbor Site, December 1977.	Drogue Current Meter	No Data
Ref.	3:	Comparison of Natural and Altered Estuarine Systems: The Field - Volumes I and II Part 1. Estuarine Evaluation Study: Primary Aquatic Production and Nitrogen. Four Year Report 1973 - 1977.	No Data	Nitrogen D.O., Temp. Salinity Chlorophyll Runoff (monthly)
Ref.	4:	Comparison of Natural and Altered Estuarine Systems: The Field Data - Volumes I and II, Estuarine Evaluation Study: Benthic Invertebrates. Four Year Report, 1973 - 1977.	No Data	D.O., Temp. Salinity (seasonal)
Ref.	5:	Comparison of Natural and Altered Estuarine Systems: The Field Data - Volumes I and II, Studies of the Manahawkin Bay - Little Egg Harbor System: 1. Finfish Study: John F. McClain, 2. Physical - Chemical Study: John Makai and 3. Use Study: Peter J. Himchak.	No Data	Nitrogen B.O.D. Temperature Phosphates Salinity (monthly)
Ref.	6:.	Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of the Proposed Site for the Atlantic Generating Station, New Jersey, Progress Report for the Period January - December 1972, Part One	No Data	D.O., Temp. Salinity (monthly) Nitrogen, Phosphate, & Silicate. (spec.days)

Ref. 7:	Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of the Proposed Site for the Atlantic Generating Station, New Jersey, Progress Report for the Period January-December 1973, Volume Three: Protoplankton and Periphyton, Zooplankton, and Terrestrial Study.	No Data	Temperature Salinity,Oxygen, Nitrate, Silicate,Phosphate (spec. days 5/72-5/73) Ocean, Great Bay, Mullica R. & L. Egg Inlet
Ref. 8:	Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of The Proposed Site for the Atlantic Generating Station, New Jersey, Progress Report for the Period January-December 1974, Volume One: Fishes, Experimental Studies.	No Data	Temp., Salinity, Oxygen, (spec. days & bimonthly avg. 1-12/74) Ocean, Great Bay, & Little Egg Inlet
Ref. 9:	Ecological Studies in the Bays and Other Waterways Near Little Egg Inlet and in the Ocean in the Vicinity of the Proposed Site for the Atlantic Generating Station, New Jersey, Progress Report for the Period January-December 1975.	No Data	Same as previous (bimonthly only) all 1975
Ref. 10:	Ecological Studies for the Oyster Creek Generating Station Progress Report for the Perion September 1975 - August 1976, Volume One, Fin- and Shellfish.	No Data	Minimal 75-76 nutrient, related data but collected too far north
ƚef. 11:	Summary of Oceanographic Observations in New Jersey Coastal Waters Near 39° 28' N Latitude and 74°15'W Longitude During The Period May 1973 Through April 1974. A report to Public Service Electric and Gas Company Newark, NJ by EG&G, Environmental Consultants, Waltham, MA, February 1975.	Current Meter (wind data) also Little Egg Inlet Area off-shore 7 the mouth of Great Bay	Nitrate, Ammonia, orthophosphate, & total phosphorus. Chloride, metals Salinity, Temp. (monthly avg.) Mainly Ocean
ǝf.12-16:	New Jersey Sea Grant, Annual Reports (four reports) 1980-1985, New Jersey Marine Sciences Consortium.	No Data	No Data
·f. 13:	Review of the Ocean County Sewerage Authority Outfall Design, for the Ocean County Sewerage Authority by Pritchard - Carpenter, Consultants May 1973.	Dye Study (North of principal area of interest)	No Data