The Impact of Improved Sewage Treatment in the East River on Western Long Island Sound

by

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THE IMPACT OF IMPROVED SEWAGE TREATMENT IN THE EAST RIVER ON WESTERN LONG ISLAND SOUND

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by

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INTRODUCTION

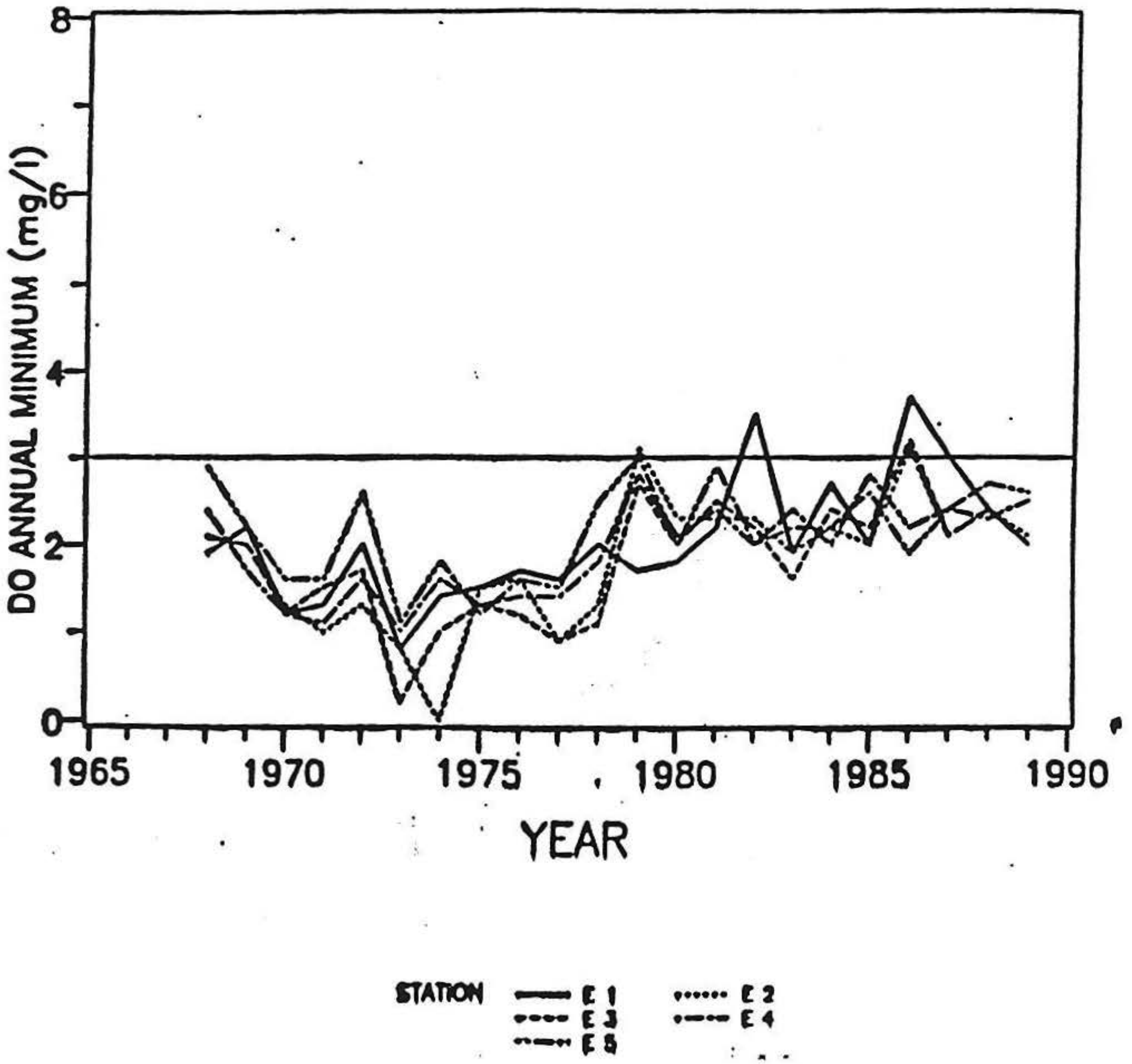
Since the 1960s there have been many changes taking place along the shores of the East River and western Long Island Sound (WLIS). Foremost are the following:

- reductions in industrial port and harbor usage along the East River,
- development along the shores and watersheds of western Long Island Sound,
- increase in and upgrading of sewage treatment emptying into these waters, and
- population changes.

Along with these changes, there has been an apparent increase in the summer minimum bottom dissolved oxygen concentration [DO] in the main stem of the East River (Figure 1), a more or less stable summer minimum bottom [DO] in the upper East River (Figure 2) and an apparent, rather disturbing decrease in the summer minimum bottom [DO] in WLIS (Figure 3) (Parker and O'Reilly, 1991). In the latter case, hypoxic conditions have been observed (Long Island Sound Study, 1990) to varying degrees since 1986, reaching anoxia ([DO] = 0 mg/L) levels in the summer of 1987.

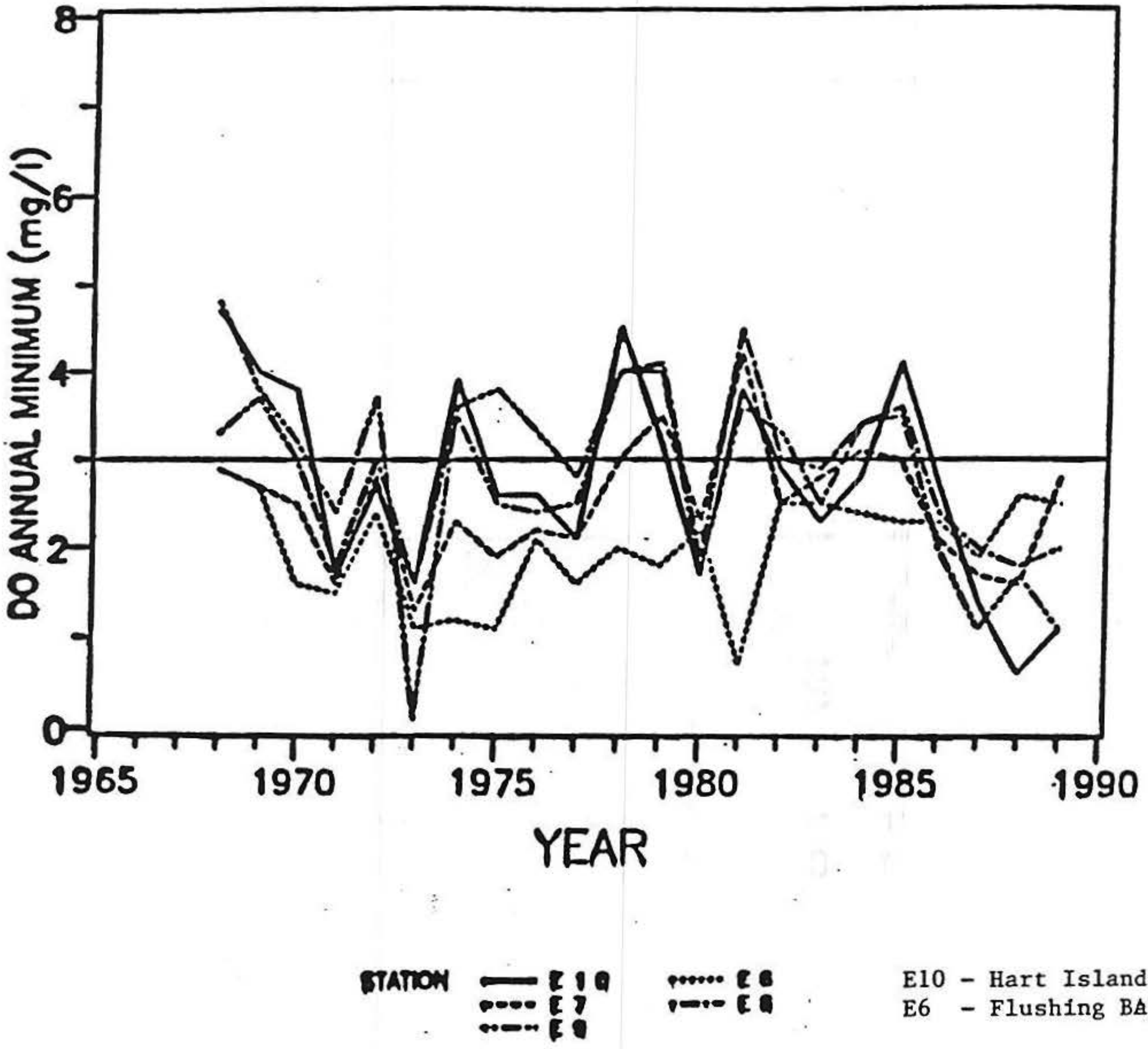
This white paper identifies, for the purpose of a possible more in-depth analysis, some of the major changes in sewage treatment that have taken place along the East River and WLIS over the last three decades; how these changes may have had an effect on the marine environment and particularly [DO]; and, suggests possible means to alleviate the apparent DO stress that may be occurring in WLIS.

It is disturbing that the frequency and the geographic and



(E1 station is at **The Battery, E5** station is at Brother Island)

Figure 1 - Summer minimum bottom dissolved oxygen concentration in the lower East River, 1968 - 1989. From Parker and O'Reilly (1991)



E10 - Hart Island
E6 - Flushing BAy

Figure 2 - Summer minimum bottom dissolved oxygen concentration in the upper East River and western narrows of Long Island Sound, 1968 - 1989.
From Parker and O'Reilly (1991)

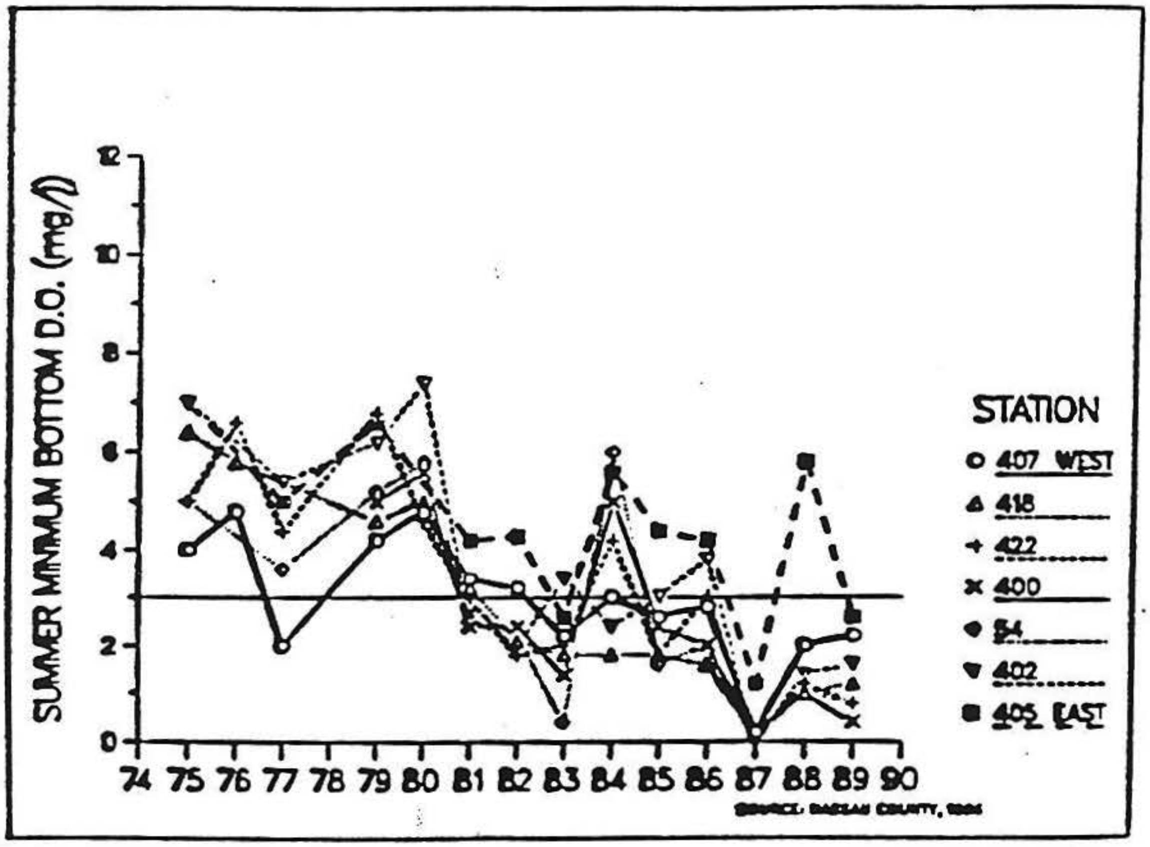


Figure 3 - Summer minimum bottom dissolved oxygen concentrations off north shore of Nassau County in Long Island Sound, 1975 - 1989. From Parker and O'Reilly (1991)

temporal extent of hypoxic events may be increasing in recent years despite the fact that sewage treatment has, in general, been upgraded from raw and primary treatment in the 1960s to almost 100% secondary treatment in the 1990s. While secondary treatment is not necessarily designed to alleviate hypoxic problems in coastal waters, there are theoretical removals of 85% of both suspended solids and biological oxygen demand (BOD_5) and 10-20% of nitrogen. Primary treatment removes approximately 35% of both suspended solids and biological oxygen demand (BOD_5) and approximately 5% nitrogen.

There are potentially numerous reasons for the apparent recent decrease in summer bottom minimum [DO]. Prior to making decisions with regard to expending more on costly technologically-based fixes for nutrient removal, it is incumbent that the causes of the apparent decrease are thoroughly explored.

According to the fine and extensive review of the oxygen depletion problem by Parker and O'Reilly (1991), Welsh and Eller (1991), and Keller _et al_. (1991), it is still not clear whether the apparent recent declines are a sampling artifact due to a sparsity of information in earlier years. Koppelman _et al_. (1976) stated that summer [DO] in WLIS was below standards in the early 1970s, NYC DEP (1990) found this also but as far back as 1920, and Squires (1971) suggested that biostimulation of the WLIS was a problem nearly two decades ago. Has the Long Island Sound Study (LISS Annual Report, 1990) confirmed what may have existed for some period of time?

There may be, however, many other causes that could contribute to an actual decline in [DO].

1. Oceanographic and meteorologic conditions in recent years may have been such that they reduced gravitational circulation, or increased the duration or degree of stratification. Valle-Levinson et al. (in press) have shown that enhanced gravitational circulation is important for advecting DO into the bottom waters of WLIS -- thus low flow or drought years could contribute to an oxygen depletion problem. An increase in thermal stratification could have reduced the flux of oxygen to bottom waters, perhaps during warm years (as the 1980s have been characterized) by increasing the strength or duration of stratification. Mild winters may have reduced the spring freshet from the Hudson River, thus redistributing the river-borne sediment and nutrient loads that eventually affect WLIS.

2. It is also possible that the sediments in WLIS are a source of the increasing oxygen demand. This would be caused by decomposition or respiration processes. A long-term change in the character of the sediments may have occurred in association with solids introduced by the treatment plants and transported to WLIS, or as a consequence of detritus accumulating from eutrophication processes.

3. Increased loads of nutrients from non-point sources and may also contribute to the problem of low DO. Perhaps also the decrease in toxicity of sewage effluent associated with increased levels of treatment, pretreatment programs, and regulatory reductions have led to a proliferation of biomass in the waters

of concern.

4. With the improvement in sewage treatment over the past 30 years, the organic carbon load and the oxygen demand of plant effluents have been reduced. With the removal of suspended solids and an attendant improvement in water clarity, the depth of the photic zone in the receiving water may have increased -- possibly leading to an increase in phytoplankton biomass. The resulting increased biomass, whether generated in the East River or WLIS, could exacerbate the tendency toward eutrophication in the less flushed WLIS.

This paper will focus on the latter. However, much of the information accumulated to date will undoubtedly be beneficial in examining several of the other issues or combinations thereof as well.

PHYSICAL CHARACTERISTICS OF THE EAST RIVER AND WESTERN LONG ISLAND SOUND

The East River is a tidal strait 25.8 km in length connecting the Upper Bay of New York Harbor at The Battery with WLIS (Figure 4) at a transect between Throgs Neck and Willets Point (Swanson et al., 1983). It has a volume of approximately 273 x 10^6 m^3 below mean low water (Jay and Bowman, 1975). The main channel depths are about 10.7 m in the northern section and 12.2 m at the southern end (Swanson et al., 1983).

Jay and Bowman (1975) summarize the circulation in the East River as being estuarine with the long-term net flow of water and salt toward the Upper Bay, the long-term net flow of fresh water

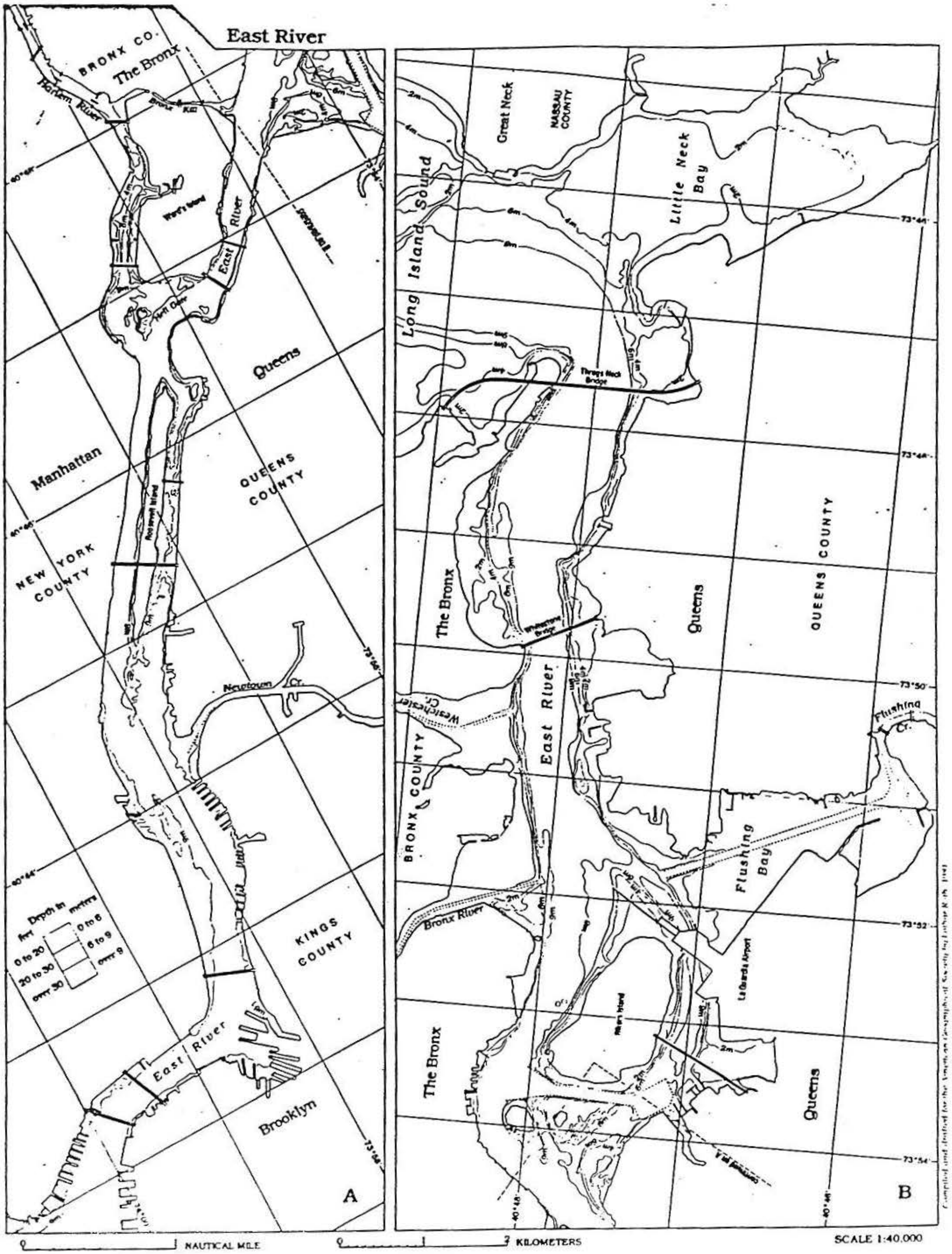


Figure 4 - Map of the East River

toward Long Island Sound (LIS). The net long-term flux of water is directed out of LIS and toward New York Harbor. The total rate was found to be approximately 100 m^3s^{-1} (Hydroqual, 1991). During low flow (drought periods), sewage treatment plant effluent can be a significant source of fresh water to the East River.

The tidal excursion of the East River is less than the length of the River -- between 16-21 km. The residence time, which is the ratio of the volume of the River to the average of flood and ebb flow through Hell Gate, is 2.4 tidal cycles (30 hours) (Jay and Bowman, 1975).

RECENT CHANGES IN NEW YORK CITY WATER POLLUTION CONTROL PLANTS

In 1960, there were five New York City water pollution control plants (Table 1) along the East River discharging approximately 477 MGD of effluent, a considerable quantity of which was probably transported toward WLIS. The level of treatment at these facilities was generally classified as activated sludge or extended aeration (US EPA, 1971) and was somewhere between what is generally accepted as primary and secondary. Based on Mueller et al. (1976) and New York City Department of Environmental Protection (NYC DEP) treatment plant information, it is estimated that approximately 300 MGD of raw sewage emptied into the East River in the early 1960s. The Newtown Creek plant was added in 1967 and by the time it was fully on-line it was discharging 173 MGD and serving an additional population of some 2 million.

TABLE 1

East River Water Pollution Control Plants

Plant	1990 Rated Capacity (MGD)	1990 Flow[†] (MGD)
*Wards Island	250	263
*Hunts Point	200	162
Newtown Creek (on line 1968)	310	329
Red Hook (on line 1987)	60	43
*Tallman Island	80	63
*Bowery Bay	150	161
*Hart-City Island	1	

*Plants operating in 1960
In the mid-1970s, the Hart-City Island Plant was linked to the Hunts Point Plant
[†] Total flows include wet weather flow.

During the 1970s, with the exception of the Newtown Creek Plant, the water pollution control plants were gradually upgraded to full secondary treatment. During that period there was a considerable amount of raw sewage discharged as a consequence of construction. The remaining raw discharges, following upgrading, along the East River were eliminated in 1987 when the Red Hook Plant went on-line. By 1990, there was an average of 1021 MGD of treated sewage effluent discharged by six New York City plants[1] to the East River (NYC DEP, 1991) from a population of some 4.8 million. The Newtown Creek Plant (329 MGD) remains

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[1] The Hart-City Island Plant now discharges through Hunts Point.

operating at advanced primary treatment but plans to convert to secondary treatment are underway. The total effluent discharges to the East River represent approximately 62% of the entire sewage effluent of the five boroughs of the City, serving nearly 68% of their population.

As part of New York City's efforts to implement the Ocean Dumping Ban Act of 1988 (P.L. 100-688), NYC DEP is installing sewage sludge dewatering facilities at eight locations around the City. Five of these dewatering facilities will be co-located with water pollution control plants on the East River -- at Red Hook, Hunts Point, Wards Island, Bowery Bay, and Tallman Island. In addition to their own sludge, the Hunts Point dewatering facility will receive sludge from the Newtown Creek Plant, and Wards Island will receive sludge from the North River plant. These dewatering facilities will produce sludge cake amounting to 499 dry tons per day, which will then be appropriately processed for various forms of land application (NYC DEP, unpubl.).

However according to NYC DEP, the dewatering process will also produce a considerable volume of filtrate or centrate that must be treated. The centrate will possibly be rich in nitrogen (perhaps 15% to 40% of existing loads) and could significantly add to the existing effluent nitrogen mass loads.

SEWAGE TREATMENT PLANT LOADINGS

New York City, Nassau County, and Westchester County, New York are the major direct sources of sewage effluent to WLIS.

The NYC DEP has provided detailed information on flows, total suspended solids, and BOD_5 for the water pollution control plants on the East River for the period 1960-1990. Annual summaries of these are plotted in Figures 5, 6 and 7. The total treated effluent released to the East River has increased from 477 MGD in 1960 to 1021 MGD in 1990. It is estimated that over the same period, raw discharge to the East River has decreased from about 400 MGD in 1960 to only that associated with treatment plant breakdowns and combined sewer overflow (CSO) discharge in 1990 -- a very small amount compared to the treated effluent. Thus, total flow to the East River has increased from 877 MGD in 1960 to 1021 MGD in 1990 (Figure 5). The latter flow is all secondary treated effluent except for 329 MGD of advanced primary treated effluent from the Newtown Creek Plant.

Total suspended solids (TSS) concentrations from the relevant water pollution control plants gradually increased from 1960 to the mid-1970s and then decreased to near 1960 concentrations by 1990. TSS concentrations of 110 mg/L from raw discharges have been assumed (Mueller et al., 1982).

The TSS mass loads (Figure 6) contributed by New York City East River sewage treatment plants and raw discharges decreased from about 276 metric tons per day (tonnes/day) in 1974 to 71 tonnes/day in 1990.

An estimate of the BOD_5 mass loads for raw discharges into the River was made assuming concentrations of 104 mg/L (Mueller et al., 1982). Using this estimate and the measured concentrations at the plants, the total mass loads were calculated and plotted in Figure 7.

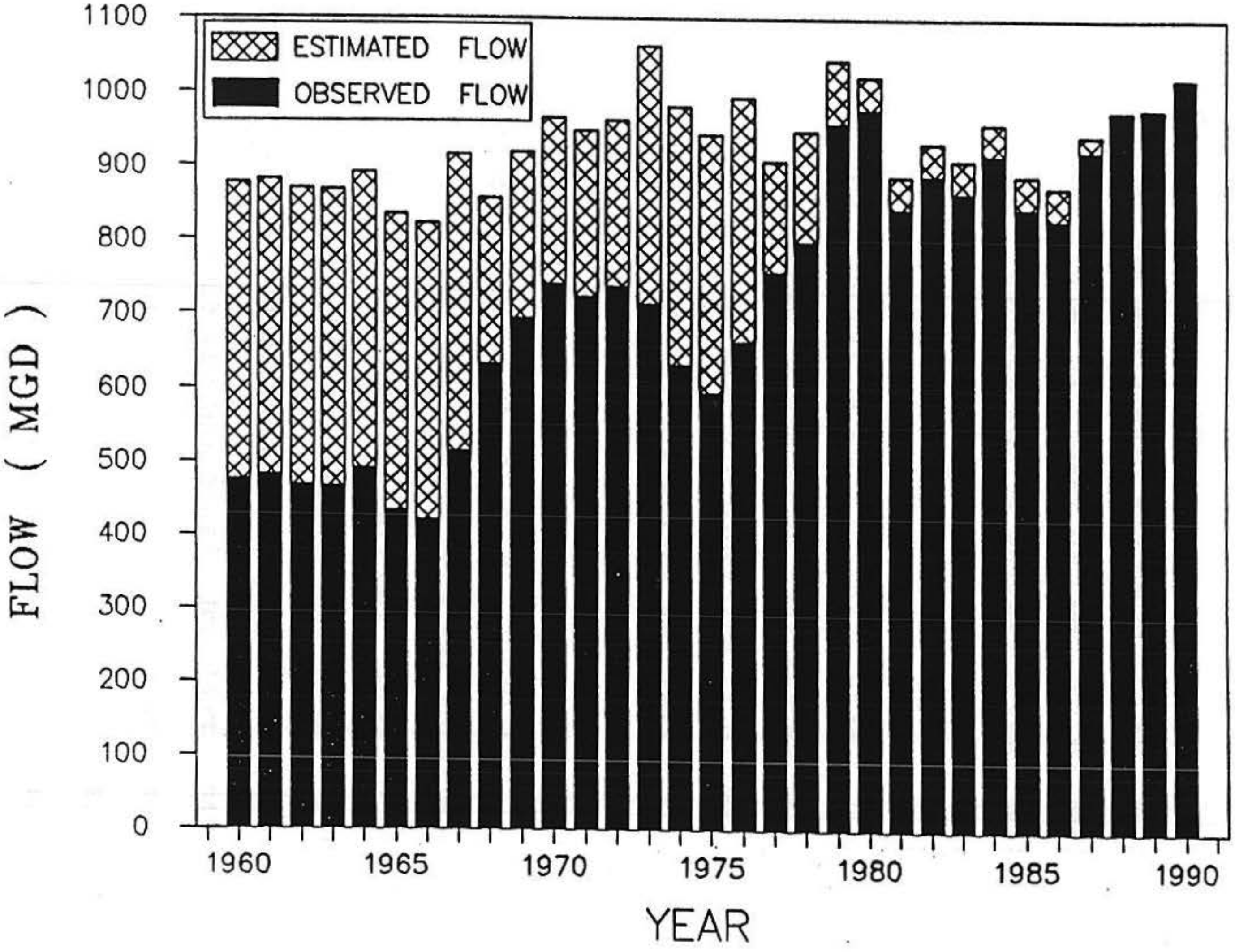


Figure 5 - Estimated (untreated) and observed (treated) effluent from East River water pollution control plants.

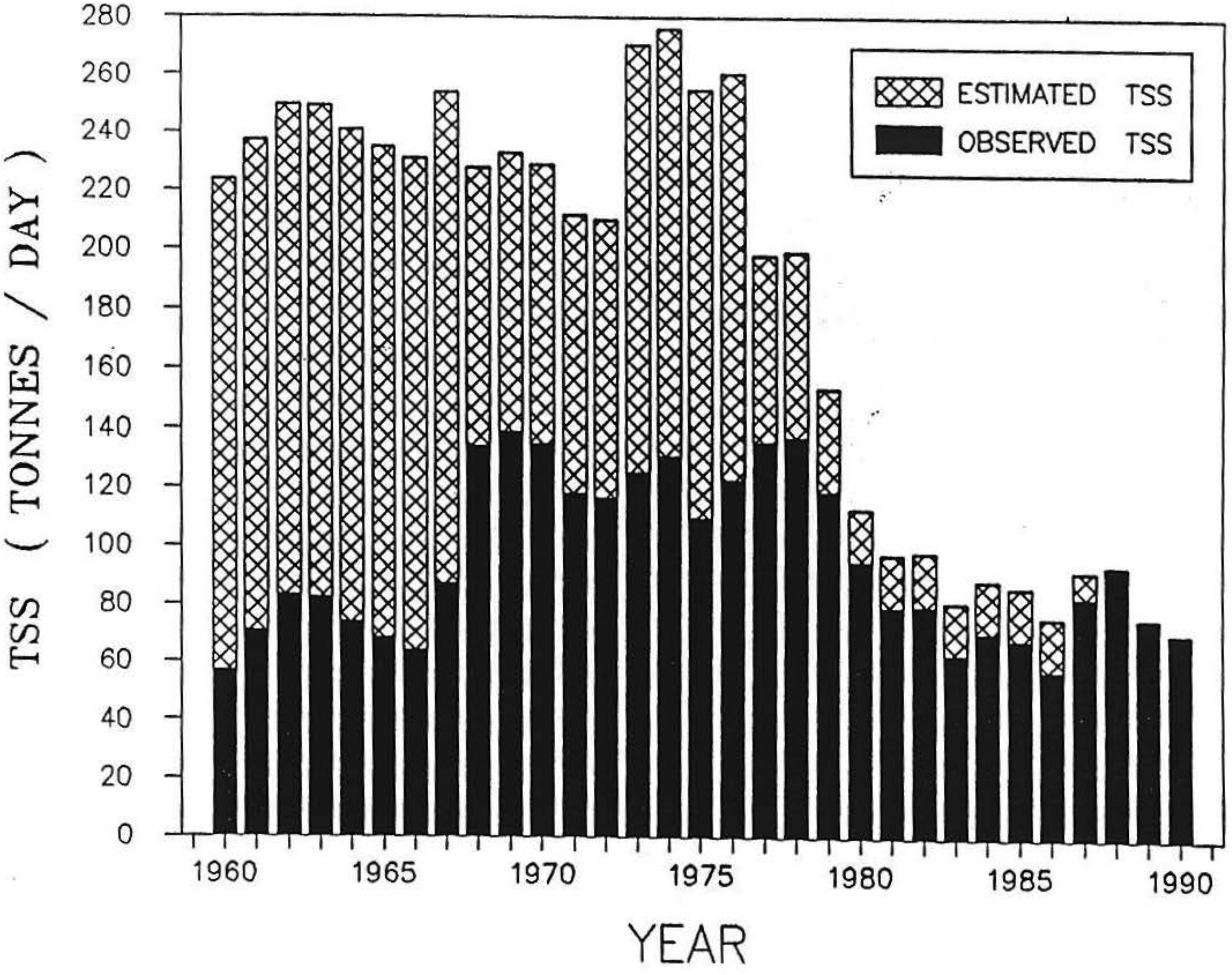


Figure 6 - Total Suspended Solids (TSS) from estimated (untreated) and observed (treated) East River water pollution control effluent.

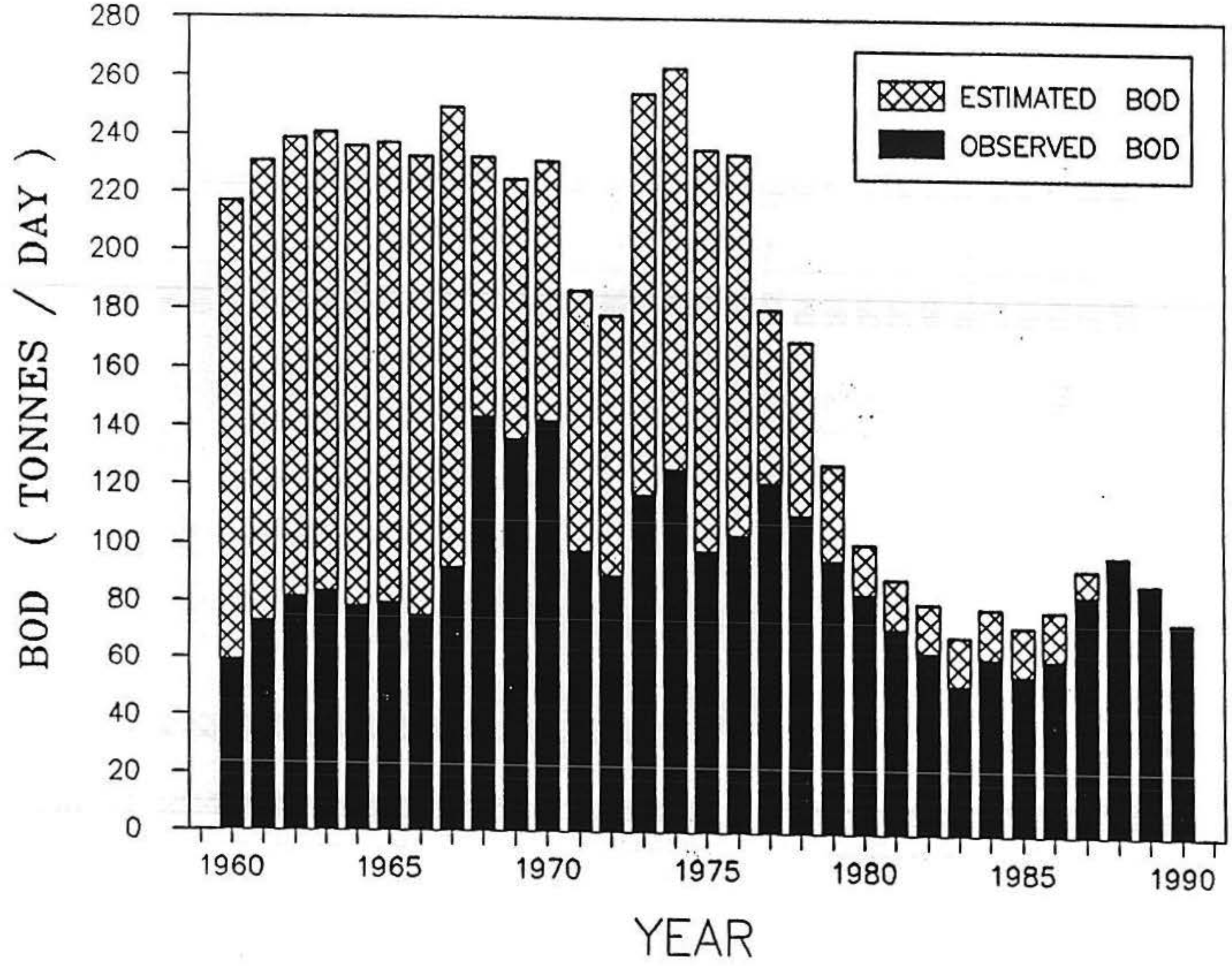


Figure 7 - Biological Oxygen Demand (BOD) from estimated (untreated) and observed (treated) East River water pollution control plant effluent.

The mass loads of BOD_5 introduced into East River receiving waters by treatment plants and raw discharges have varied between 217 tonnes/day in 1960 peaking in 1974 at approximately 263 tonnes/day. Following the completion of the Red Hook Water Pollution Control Plant, the mass loads of BOD_5 decreased to 75 tonnes/day in 1990.

Total nitrogen mass loads are plotted in Figure 8. Nutrient mass loads have been estimated using Mueller et al.'s (1982) concentration data (Table 2) and the NYC DEP flow data. More recent data indicates, however, the values from Mueller et al. (1982) for nitrogen may be low (J. Semon, per. comm.).

TABLE 2

Typical Municipal Wastewater Characteristics for Conventional Pollutants

Parameter	New York City Raw Sewage (mg/L)	New York City Secondary Effluent (mg/L)
TSS	110.00	20.00
BOD	104.00	15.00
TOC	93.00	39.00
NH_3-M	10.00	7.90
Org-N	13.00	6.10
NO_2-N	0.07	0.19
NO_3-N	0.38	1.30

from Mueller et al., 1982

Total nitrogen entering the East River raw sewage discharges and sewage treatment plants is estimated to have decreased from a peak in 1973 of 72 tonnes/day to about 60 tonnes/day in 1990. Much of this decrease would appear to be associated with a

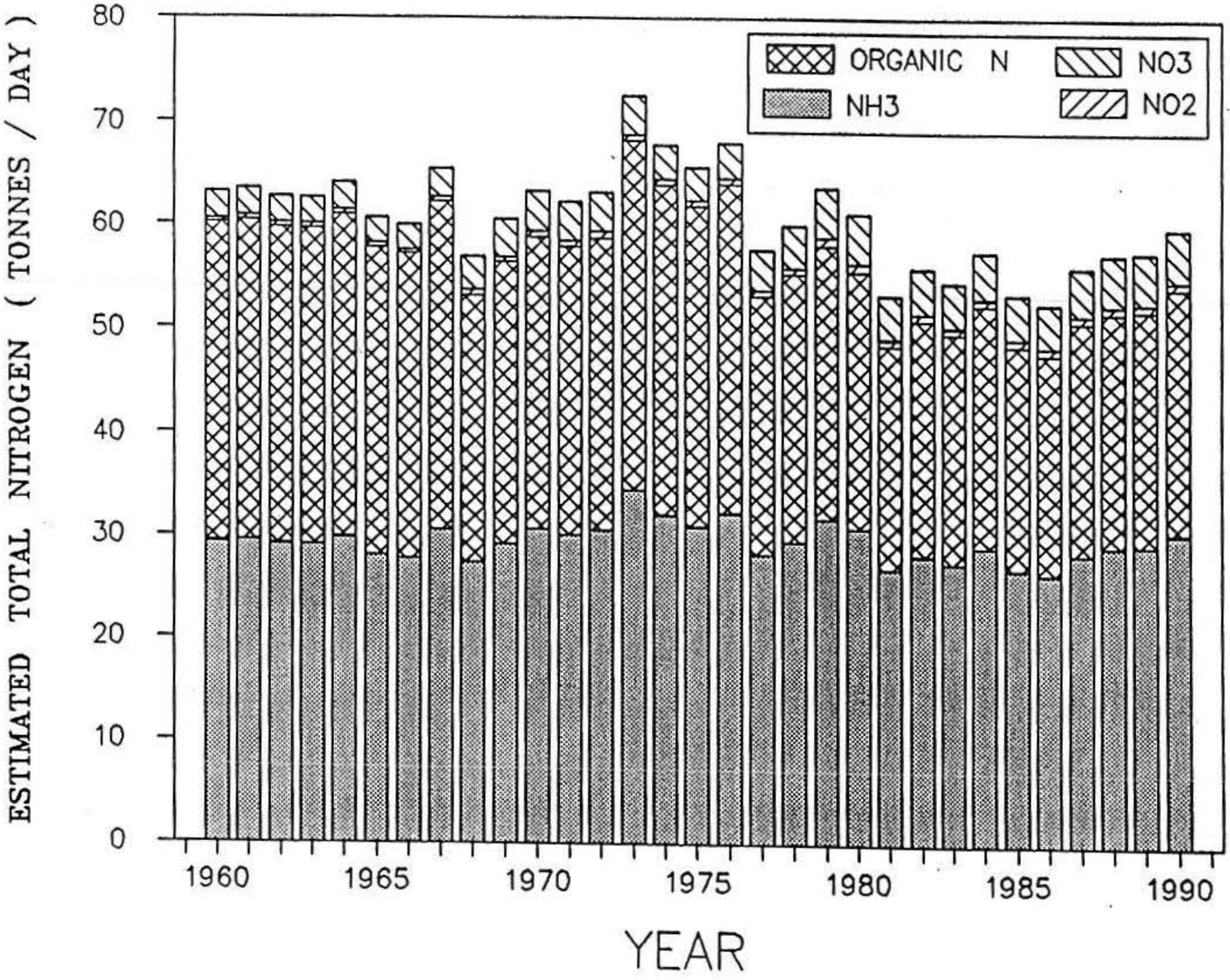


Figure 8 - Estimated Total Nitrogen from untreated and treated effluent from East River water pollution control plants.

reduction of organic nitrogen associated with the removal of the raw discharges. A considerable amount of the nutrient load in the raw discharges was probably shunted to the primary and secondary sludges. This would seemingly be supported by the large nutrient loads projected to be in the filtrate of the dewatering facilities.

From 1950 to 1960, Nassau County, NY, experienced a doubling in population; however, the County's sewage treatment plants on the north shore of Long Island did not undergo much of a change in population served or average daily flow because many of the homes had septic systems and others fed into sewage treatment plants that did not discharge into LIS (Interstate Sanitation Commission, 1963). The County's population growth peaked in 1970, decreasing thereafter. For 1990, the total population served by these sewage treatment plants was approximately 112,950 with an average daily flow equalling 14.6 MGD. This is a decrease of approximately 6,600 people served by the sewage treatment plants with a corresponding decrease of 1.5 MGD into the bays adjacent to WLIS. These plants empty into the heads of Manhasset Bay, Hempstead Bay, Oyster Bay, Little Neck Bay, and Cold Spring Harbor. According to the Interstate Sanitation Commission (ISC), all of these plants have been following secondary treatment practices since 1968.

Westchester County, NY, has four sewage treatment plants discharging effluent directly into WLIS that serve a population of approximately 207,000. In 1960, three of the four plants were discharging raw sewage. In 1966, approximately 22.4 MGD of effluent was receiving primary treatment prior to its discharge into WLIS. The amount of effluent from the County's sewage treatment plants has almost doubled to 43.5 MGD in 1990. Three of the four plants have recently been upgraded to secondary treatment and the other one still provides only primary treatment.

SECCHI DISK AND TURBIDITY MEASUREMENTS

A way of understanding the effects of upgrading effluent from primary to secondary treatment can be explored in terms of changes in water clarity and biomass. Water clarity can be examined through secchi disk and turbidity measurements. Secchi disk sampling by the Nassau County Department of Health Bureau of Water Pollution Control was carried out in WLIS from 1974 to 1990 using a black and white 8 inch diameter disk. The information available from four stations suggests no significant change in surface water clarity from 1974 to 1985 (Figures 9 & 10). The data indicate some slight variability from May to September with secchi disk depths ranging from approximately 1 to 2 meters. From 1985 to 1990, it appears that water clarity decreased by 0.5-1.0 m. Turbidity measurements also taken by Nassau County show similar results as the secchi disk readings. There is little annual change in the mean values covering the periods 1974-1979 and 1980-1985. However, for the period spanning 1980-1985 and 1985-1990, there is a decrease in water clarity indicated by an increase from mean values of 2-3 nephelometer turbidity units (ntu) to 4.5-6 ntu in turbidity. From 1985-1990, the data also exhibit a monthly decrease in water clarity from

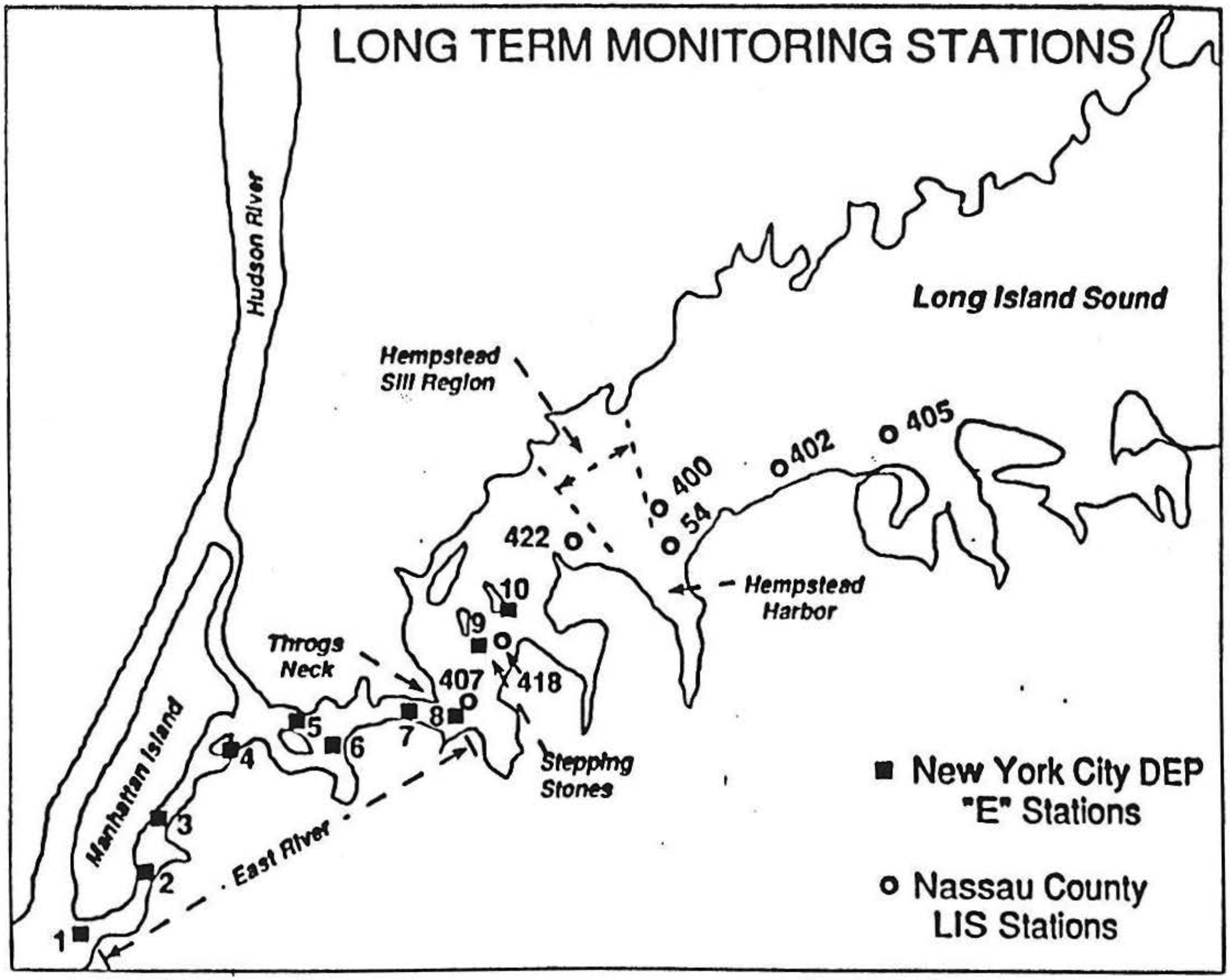


Figure 9 - Station locations from Parker and O'Reilly (1991).

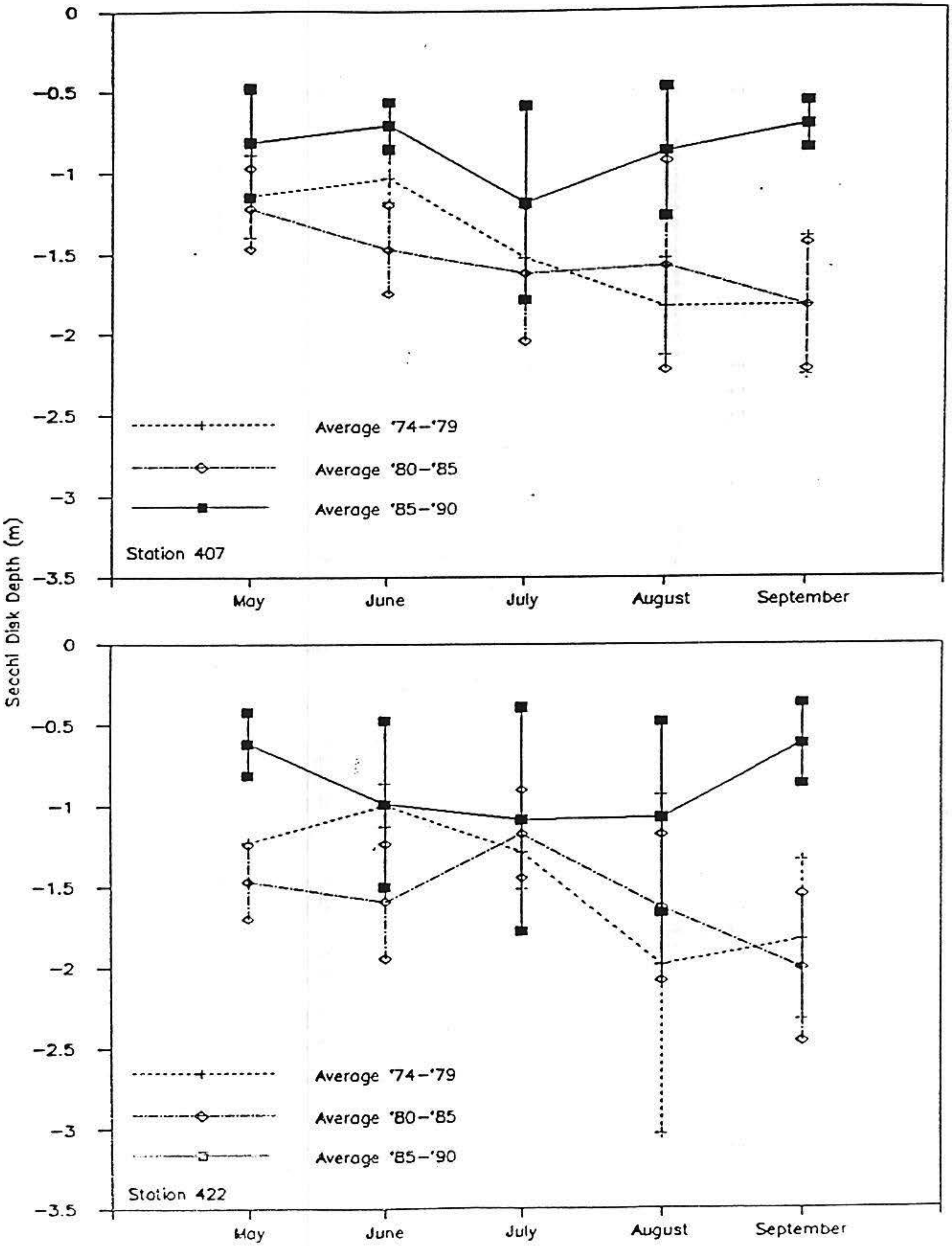


Figure 10 - Secchi Disk depths in WLIS. (± standard deviation)

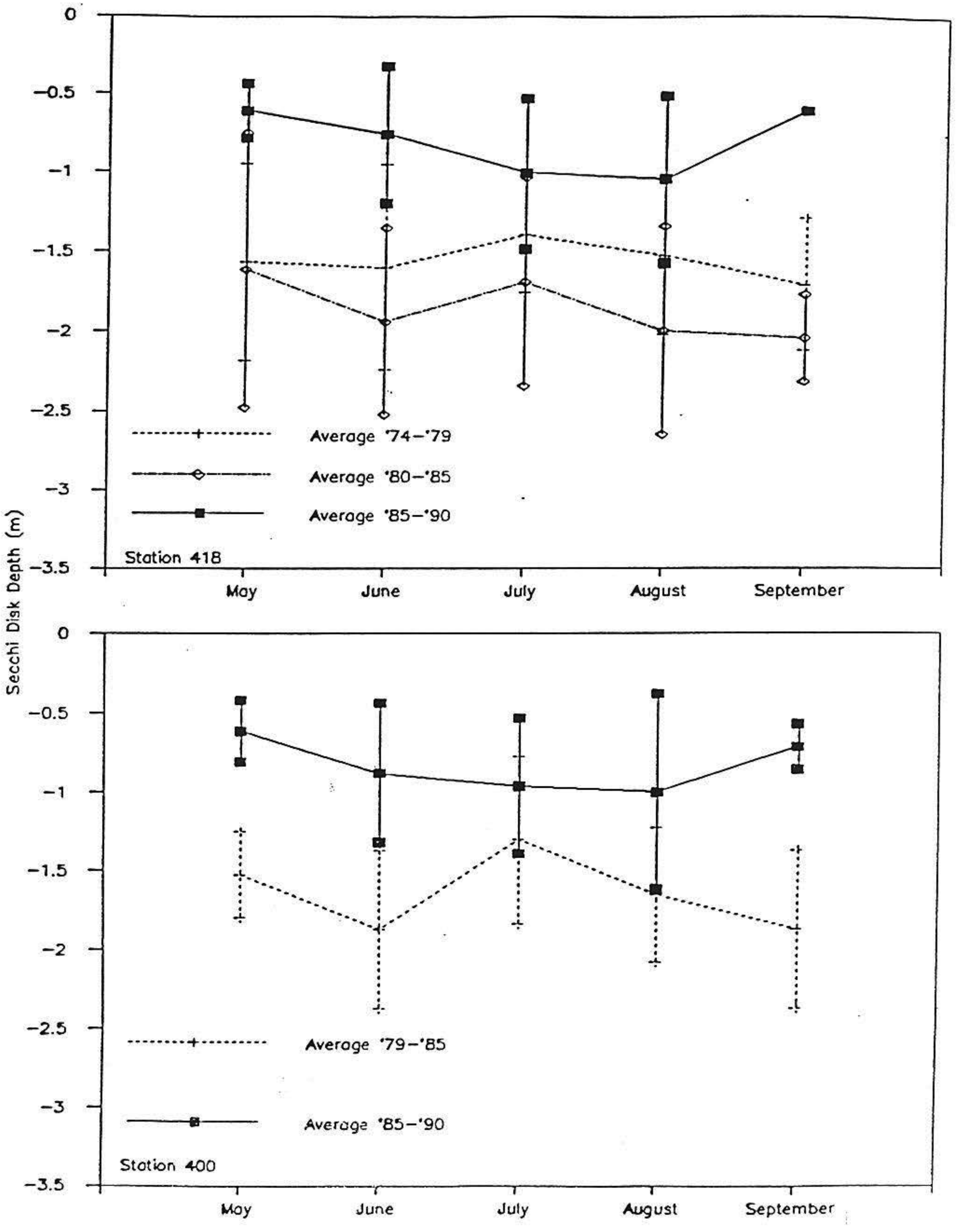


Figure 10 (cont.)

May to September (Figure 11). There is no apparent reason for the decrease in water clarity, i.e. chlorophyll a and TSS values have not increased; however, both secchi disk and turbidity measurements support this trend.

CHLOROPHYLL a AND PHYTOPLANKTON

Chlorophyll a average measurements, an estimate of phytoplankton biomass, do not appear to have substantially changed in the past 40 years with the possible exception of some evidence of a marginal increase in the vicinity of Throgs Neck. Conover (1956) measured chlorophyll a in WLIS for two years beginning in March 1952, Olson (1976) measured chlorophyll a in the western portion of LIS from October 1974 to May 1975, and Cosper et al., (unpubl.) measured chlorophyll a from The Battery to a distance 200 km east through LIS, from January to December 1989. Surface average chlorophyll a values ranged from 1.5 to 16 μg/L in 1974-1975 (Olson 1976). Conover (1956) observed a similar range of surface average chlorophyll a values from 1 to 14 μg/L. Cosper et al., (unpubl.) measured mean monthly chlorophyll a concentrations from 2-34 μg/L, with the highest values observed in the Throgs Neck region (Figure 12).

Phytoplankton species composition also does not appear to have changed appreciably since the Conover (1956) and Riley and Conover (1956) studies. Comparisons of phytoplankton species identified by Cosper et al., (unpubl.) from 1989 data, Riley and Conover (1956) from 1952, 1953, and 1954 data, and Long Island Lighting Company (1983) data from the late 1970s and early 1980s

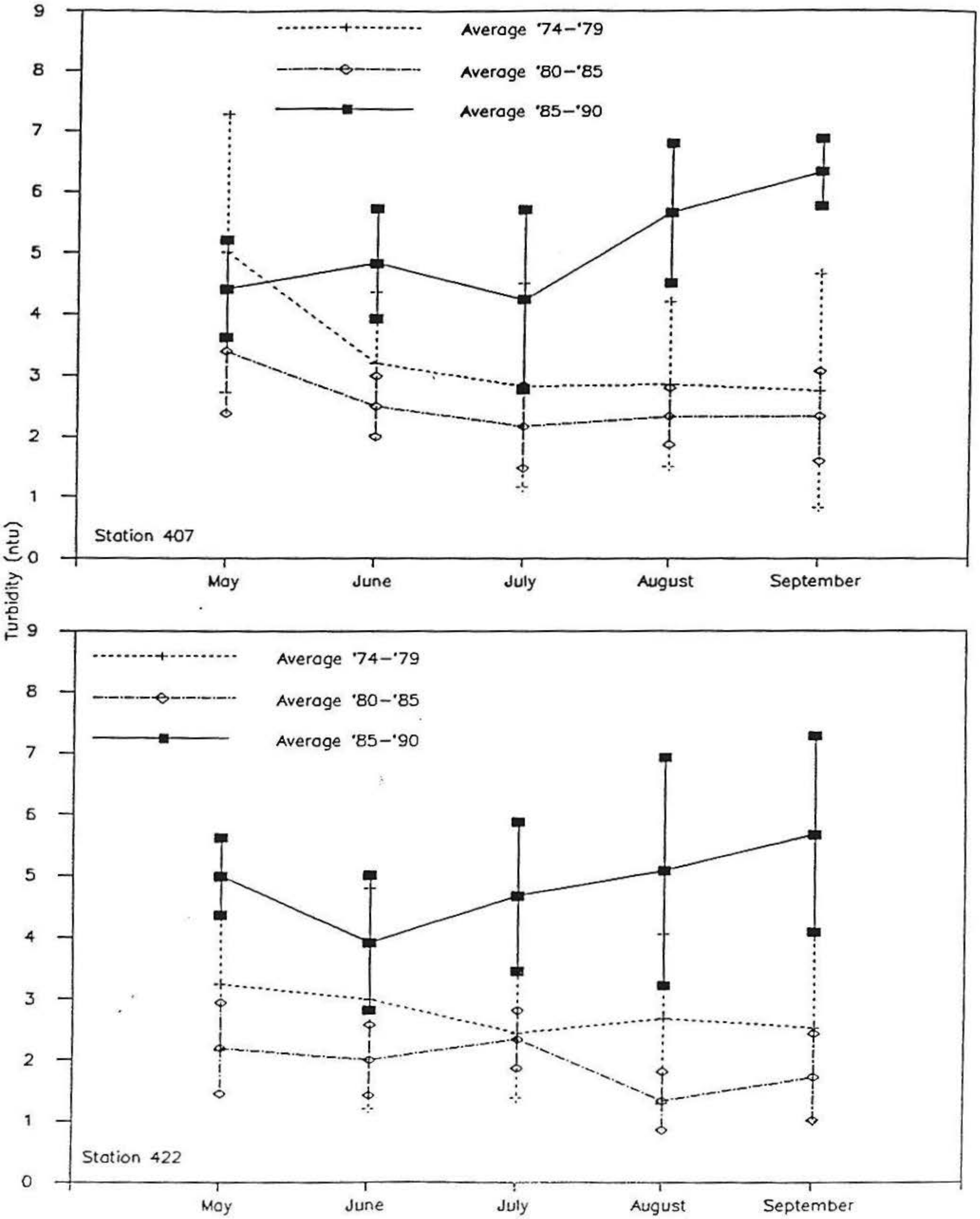
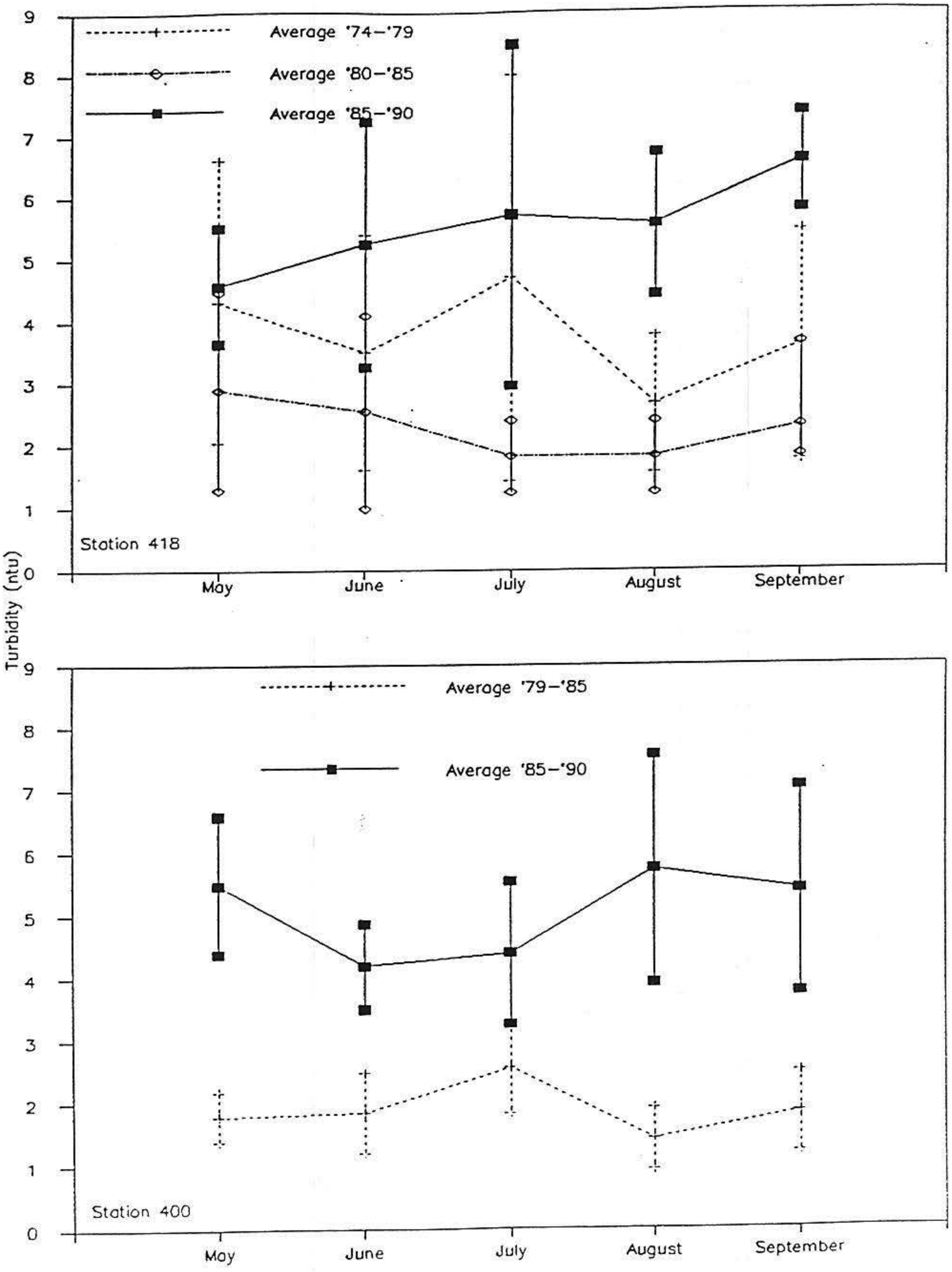


Figure 11 - Turbidity measurements in WLIS.



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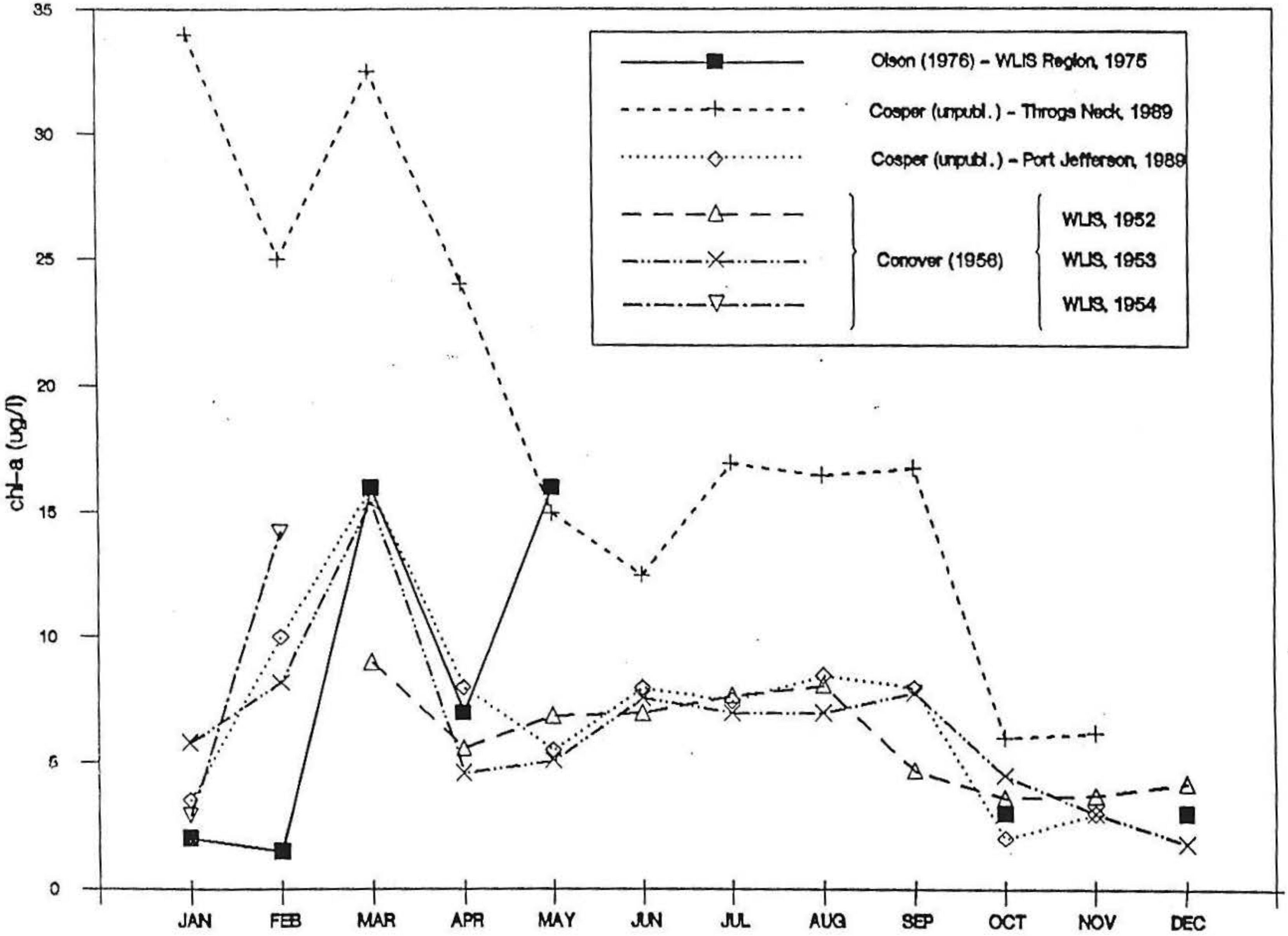

Figure 12 - Chlorophyll a measurements in Long Island Sound.

do not show great differences in species composition, although an absolute comparison is difficult to make due to differences in sampling technique (Monteleone _et al_., unpubl.).

The timing of the onset of the Winter-Spring bloom in Long Island Sound (LIS) may have changed slightly since the early 1950s. Between 1953 and 1969, blooms occurred twice in January, five times in February and four times in March. Between 1972 and 1989, blooms occurred eight times in March, and only twice in February. Could this mean that the onset of the phytoplankton blooms has been sufficiently delayed resulting in a shift, prolonging, or delay of the decay of phytoplankton biomass thereby enhancing low [DO]?

Phytoplankton are not nutrient limited in the New York Harbor and East River, but blooms do not generally occur in this area due mainly to the turbidity of the water column (Malone, 1982). Turbidity is considerably reduced in the Throgs Neck area, relative to the East River, and Cosper _et al_., (unpubl.) found in 1989 that mean chlorophyll _a_ measurements in that region of WLIS were substantially higher than measurements in other areas of LIS and the East River (Figure 13). These high measurements of chlorophyll _a_ in the Throgs Neck region may be a result of excess nutrients.

There also may be hydrographic conditions in WLIS that allow phytoplankton to achieve greater biomass. Olha (1990) found that of the 180 blooms in the New York-New Jersey area from the 1950s to the 1980s, only fifty were generated by increased nutrient input or runoff, with the remainder a result of a variety of

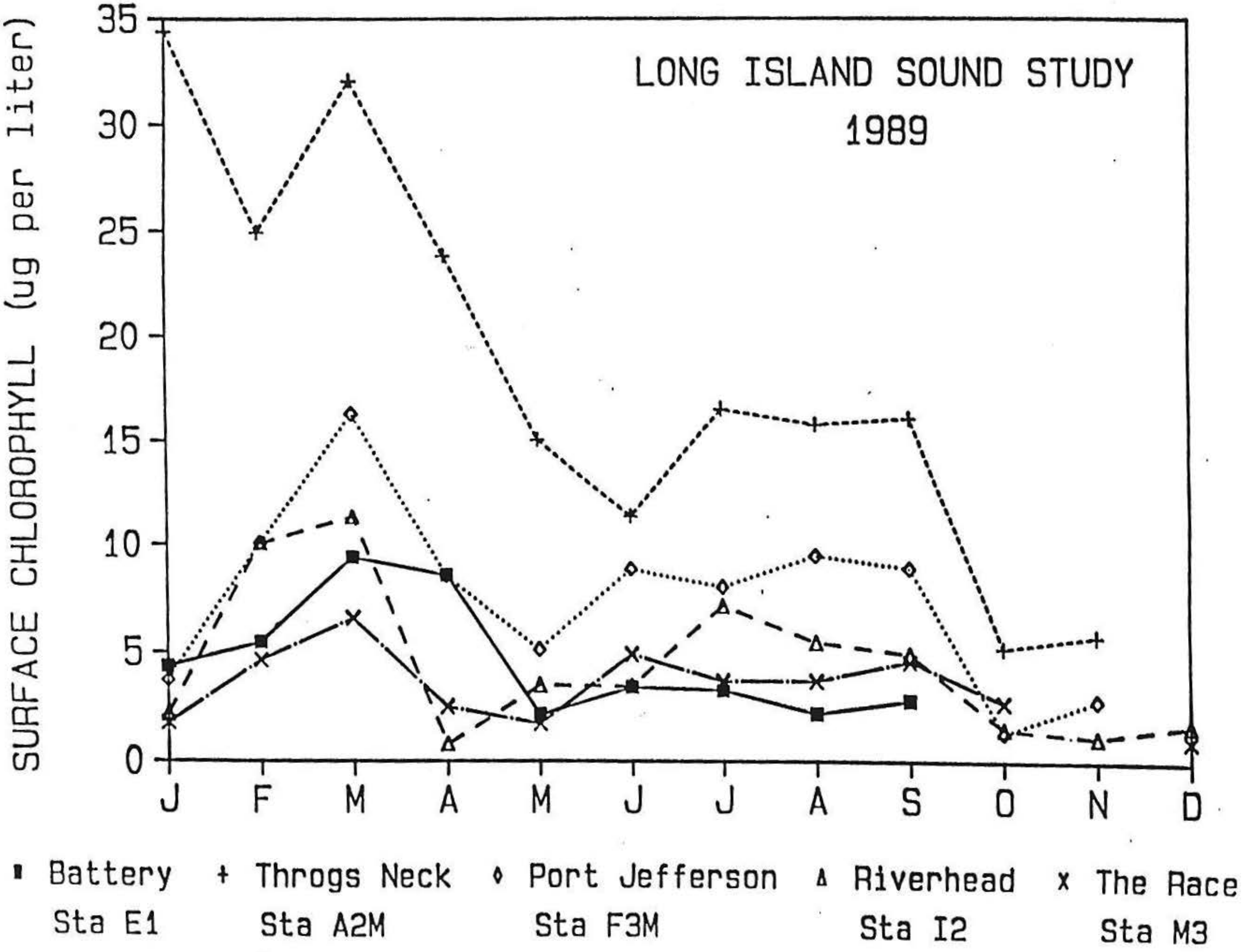

Fig. 1.3 - Mean monthly chlorophyll a concentrations from 1989 at selected stations in Long Island Sound. Data are from Cosper et al. (unpubl.).

hydrographic conditions, i.e., winds, salinity, stratification, oceanic transport.

Available chlorophyll a and species data make it difficult to determine whether or not blooms in WLIS have increased in recent years.

NITRATE VS AMMONIUM

There has been approximately a **12 tonne/day** reduction in total nitrogen released to the East River from elimination of raw discharges and upgrading of treatment plants since the mid-1970s. Despite this reduction there is still concern about the significance of nitrogen with regard to the hypoxia problem. Much debate has focused on what species of nitrogen, ammonium (NH_4^+), or nitrate (NO_3^-) is more likely to be utilized by phytoplankton (Morris, 1974; Carpenter and Dunham, 1985). A determination of whether ammonium or nitrate is preferred is important in understanding the hypoxia problem in WLIS for the following reasons: ammonium is the main form of nitrogen released in sewage effluent; ammonium is toxic to many marine organisms; and most importantly, nitrification of ammonium by organisms is an oxygen demanding reaction that can further exacerbate the problem of hypoxia. Previous work had found phytoplankton to preferentially utilize ammonium over nitrate (Eppley et al., 1969).

Ammonium and nitrate are both readily taken up by phytoplankton. The species of nitrogen that will be utilized by phytoplankton depends on a number of factors including water temperature, salinity, family of phytoplankton (diatom or dinoflagellate), and the concentrations of NH_4^+ and NO_3^- in the water column (Carpenter and Dunham, 1985). Therefore, it cannot be assumed that converting ammonium to nitrate makes the nitrogen less available to phytoplankton, and blooms less likely to occur.

The Stamford Water Pollution Control Facility in Stamford, CT, is using biological nutrient removal techniques to nitrify NH_4^+ to NO_3^- and denitrification to convert NO_3^- to nitrogen gas. This is being undertaken to reduce the amount of NH_4^+ in sewage effluent and thereby reduce BOD in the water column. The Stamford facility is able to remove 97% of the ammonium in the effluent with nitrification (LISS Fact Sheet #11, 1990) and an average of 70% total nitrogen removal. Nitrification is achieved mainly through increased cell retention time, or increased aeration in the secondary settling tanks (J. Semon, per. comm.). Denitrification is achieved by creating an anoxic zone within the aeration system. These processes can be achieved without any major change in the operation of the plant (J. Semon, per. comm.).

FISHERIES

The principal fisheries of Long Island Sound have had boom and bust years since the 1960s, and the State of Connecticut, Department of Environmental Protection (CT DEP) as part of the LISS, provides a comprehensive review of the information for the years 1961-1985 (CT DEP, 1989). The overall catches of finfishes and shellfish have increased since the 1960s (CT DEP, 1989). However, it is difficult to determine whether the increased numbers of fishes caught and shellfish landed are due to increased effort or improvements in water quality (CT DEP, 1989).

Fish-kills in enclosed embayments of LIS, like Hempstead Harbor and Manhasset Bay, are common. Between 1970 and 1986 there were 48 fish-kills in Hempstead Harbor, many of them attributed to low [DO]. Fish-kills in open areas of LIS are uncommon. This can be because fishes in these areas can more easily move from low [DO] regions to more oxygenated regions and because low [DO] is generally less common in open areas. It could also be that in the more open areas of LIS that there is less likelihood that kills would be observed. However, given the fishing and boating traffic in the area this seems unlikely.

In 1987, there were 21 fish-kills reported for the New York side of LIS, from the Throgs Neck Bridge to Smithtown Bay, that were a result of low [DO]. The widespread low [DO] in WLIS in 1987 was caused by a bloom of a marine dinoflagellate that was unusually dense and long-lasting (Chytalo, per. com.). It has been proposed, although not proven, that nutrient inputs from sewage treatment plants and storm water runoff were responsible for maintaining the bloom at elevated levels and for an extended period of time (Chytalo, per. com.).

DISCUSSION

From 1960 to the present the population increase in the general area of the East River and WLIS has been only modest. The large changes occurred in the late 1940s and 1950s. During the last three decades however, there have been significant changes in sewage treatment. The amount of raw sewage entering the East River has, with the exception of CSO discharges and treatment plant breakdowns, decreased to near zero. The level of treatment has increased such that nearly 98% of all pertinent discharges in New York City, Nassau County, and Westchester County are secondary.

The mass loads of TSS and BOD entering the East River have each decreased over 70% since 1974. The mass load of nitrogen discharged by treatment plants has nearly doubled since 1960 as treatment plant flows increased, but with the elimination of raw discharges, there has been an overall decrease of 12 tonnes/year since 1973.

The results from limited observations in the receiving waters of the East River have been indistinguishable in terms of water clarity (secchi disk) and chlorophyll a. There has apparently been considerable measured improvement in summer bottom minimum [DO] in the lower East River. Improvement in [DO] in the upper East River is not as apparent.

The following is a synopsis of issues related to the apparent recent decline in bottom [DO] in the WLIS.

1. WLIS has probably experienced hypoxic conditions in the past. However, they were largely unobserved because they were not severe enough to have caused large scale benthic mortalities. There is certainly evidence of measured low [DO] in the early 1970s.

2. There is a suggestion of decreased water clarity in WLIS (based on Nassau County water quality monitoring data) in the

late 1980s. There is no apparent increase in phytoplankton biomass, however, as measured by chlorophyll a over the period of the 1950s to the present. The cause of the change in turbidity is curious and its relationship to phytoplankton biomass and hypoxia should be explored.

3. Surface water temperatures seemingly have been warmer in the 1980s compared to the 1970s (Figure 14). This may have hastened the onset of stratification and intensified it as well. However, when specifying these conditions for use in the model described by Valle-Levinson *et al*. (in press), there is not a dramatic reduction in bottom [DO].

4. Total suspended solids from sewage treatment plants have decreased over 70% since 1974 yet there has not been an increase in chlorophyll a, which would be expected with increased light penetration. This may mean that sewage treatment plant loadings of suspended solids are insignificant when compared to river-borne suspended solids. Another scenario might be that chlorophyll a has not increased because the total mass load of nitrogen from sewage treatment plants has been reduced somewhat thereby limiting phytoplankton growth. The role of silica, found in constant amounts in sewage effluent and a necessary element for diatom growth, has not been well defined in producing or sustaining Winter-Spring diatom blooms (McLaughlin *et al*., 1982).

5. It is also possible that the warmer winters of the past several years, [7 of the past 10 years have had an average annual temperature at Central Park of 1° C above the long-term mean with

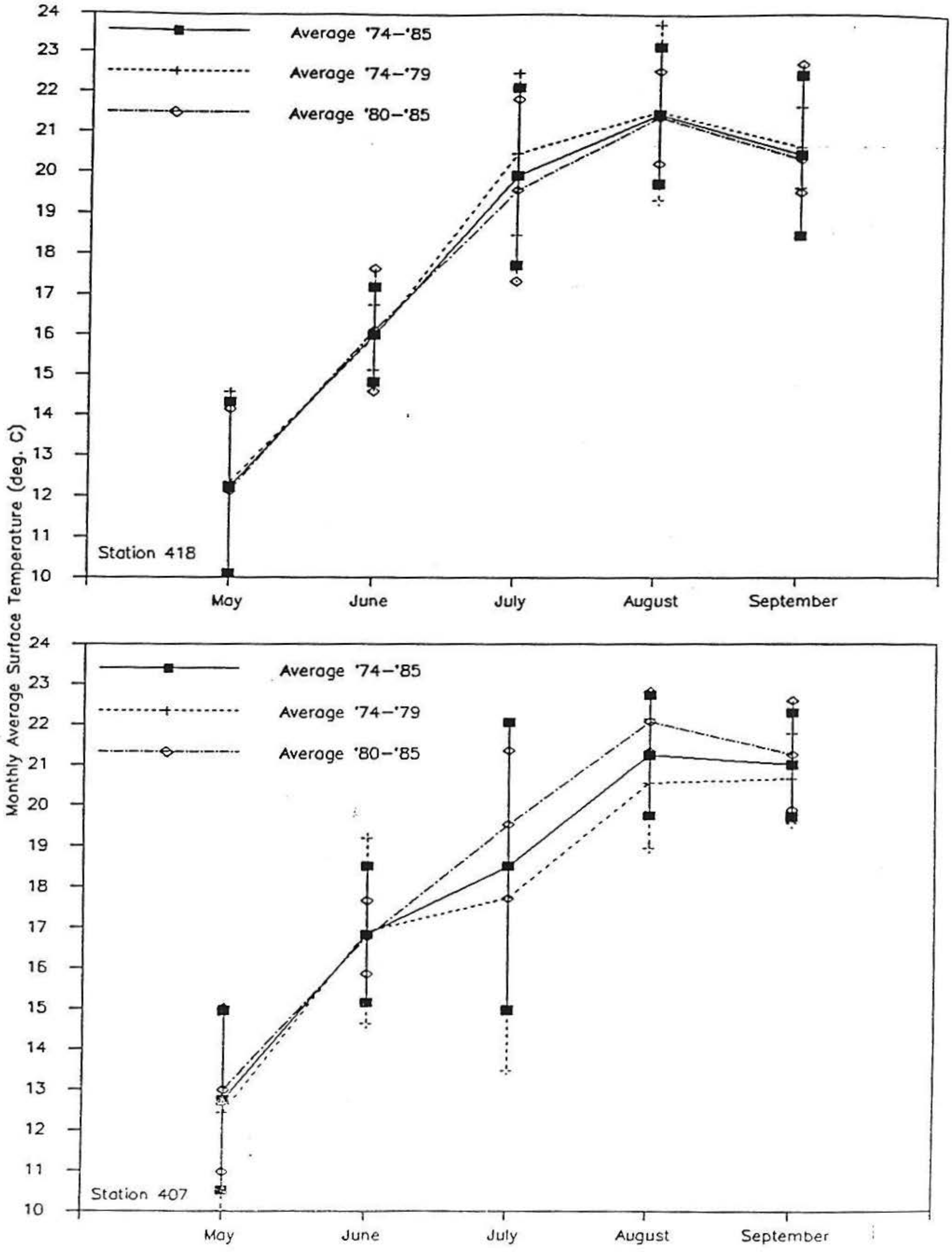

Figure 1 4 - Monthly average surface temperature in WLIS for 1974-1985.

1990 being the warmest since records have been kept (New York Times, 1990)], have caused the spring freshet of the Hudson River to occur earlier and prolonged the impact of it by adding nutrients to the system for a longer period of time thereby enhancing phytoplankton blooms. This process could possibly increase the severity of oxygen depletion or broaden the width of the low-DO trough, by sustaining blooms for an extended period of time. In fact, a brief review of the available information does suggest that over the last twenty years, the time of bloom initiation has occurred later in the year, perhaps more directly impacting the summer DO decline.

In summary, it would appear that the recent hypoxic events may not be as out of the ordinary as recent data collection efforts would lead one to believe. A quick examination of some of the available monitoring data suggest no obvious linkage of changing sewage treatment processes with the apparent decline in DO in WLIS. There are a number of nearly independent activities and natural events that have mutually contributed to increasing the likelihood of a hypoxic event. Among these are the continued burden of the sewage treatment plant effluents from New York City, Nassau County and Westchester County, changed water clarity and perhaps increased biomass production in the Sound, milder winters, hotter summers, and reduced flows in the Hudson River. The role of climate on the WLIS hypoxia problem should be better understood.

RECOMMENDATIONS

* Further examination of historical data, particularly climatological data as it relates to the causes of hypoxia in WLIS is warranted prior to investing in costly high-tech tertiary treatment programs.

* A study of the apparent recent changes in turbidity in WLIS and its relationship with oxygen demand is warranted.

* In some sewage treatment plants, inexpensive nitrification and denitrification is possible to varying degrees and should be implemented.

* Water conservation measures (see White Paper on that topic) in New York City could potentially reduce or stabilize the quantity of sewage requiring treatment. This could have many benefits; but, with regard to the hypoxia problem, it could allow increased detention times that would reduce the quantity of NH_4^+ released to the receiving waters.

* Alternative approaches, other than through existing New York City water pollution control plants, for using or disposing of nutrient-rich dewatered sludge centrate should be found.

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APPENDIX D

*Aquaculture Methods For Use in Managing Eutrophicated Waters**

by

John Merrill
John Kilar
Xiaohang Huang
Charles Yarish

**This white paper was not commissioned but was distributed at the Workshop.*

Submission to:

Long Island Sound Study:
Alternative Technologies Workshop.

TITLE:

Aquaculture methods for use in managing eutrophicated waters.

AUTHORS:

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ABSTRACT:

Excessive growths or blooms of macroalgae ("green tides") resulting from eutrophication are increasingly common in nearshore marine habitats. In the worst cases, the resulting algal biomass eventually dies and decays through anaerobic processes leading to release of high concentrations of hydrogen sulfide and resultant foul smells. Along the Brittany coast of France, and in the lagoon of Venice, Italy, such conditions have seriously impacted the tourism industries and therefore, are being intensively studied. At this time the principal remedial effort being applied is the physical removal and disposal of the algal biomass prior to the onset of anaerobic decay. This is achieved at great expense to the local government authorities, since algae typically associated with these blooms (e.g. <u>*Ulva*</u> *sp.) have little or nor current value as* *marketable products. It is proposed that the introduction of valuable species to such areas through the application of mariculture techniques could help to reduce the problems at no or little incurred cost. Since excessive algal growth is often a "threshold" type function, the removal of even a portion of the total nutrient load could greatly alleviate the most damaging phenomena. Simple mariculture techniques will be discussed and their potential impacts will be considered relative to nutrient removal models.*

INTRODUCTION:

In temperate Atlantic estuaries, the primary producers define several critical communities consisting of: (1) benthic seaweeds (macroalgae); (2) seagrasses; (3) salt marsh grasses; (4) phytoplankton; and (5) benthic microalgae (Kremer & Nixon 1978, Pomeroy & Weigert 1981, Welsh et al. 1982). Of these primary producers, the seaweeds are underutilized resource where intervention into eutrophication is possible.

One of the most widespread and easily recognized effects of eutrophication in coastal marine ecosystems is the proliferous growth of macroalgae. Such blooms often occur to such a degree that the algal biomass becomes a significant problem, either through its direct fouling effects or as a result of hypoxia (and associated release of noxious products such as hydrogen sulfide) produced from its eventual death and decay (Briand 1987). In some locations, for example along the coast of Brittany in France, and in Puget Sound, U.S.A, the problem is characterized by the accumulation of the green alga Ulva in wind-rows along the beaches. In such cases the descriptive term "Green Tide": has been applied. This name has subsequently been applied to other excess macroalgae situations in order to bring attention to their similarities, although such phenomena are not always the result of green algae, nor are they always associated with tidal events (a model adapted from the concept of "red tides" associated with dinoflagellate blooms; Fletcher 1990).

The conditions which lead to green tides typically include: 1) high inorganic nutrient levels and 2) relatively shallow water without strong currents or waves (Sfrisco et al. 1987). These conditions are found throughout the world wherever bays or lagoons with suitable physical characters are impacted by the eutrophicating affects of agricultural runoff or human sewage discharge.

The most common macroalgae leading to green tides are species of the green alga Ulva, although significant additional biomass may come from other green algae such as Enteromorpha or Monostroma. It is a somewhat unique characteristic of Ulva that it can thrive without any attachment to the substratum whatsoever. This is a particularly important point since the types of locations where green tides are most significant tend to have mud, silt, or sand bottoms as a result of the relative lack of water movement. The ability to thrive un-attached, coupled with a strong ability for nitrogen uptake from the seawater, contribute to its domination of these habitats.

In many places direct action has been necessary to reduce or eliminate the damaging impacts of green tides. Such action typically consists of harvesting or otherwise removing the offending algal mass. This type of harvesting has reached major proportions in some places, for example, Venice Lagoon where amounts in excess of 200 tons per day are removed over extended periods through Spring, Summer, and Fall seasons (Sfrisco et al. 1987). Intervention on such a massive scale is achieved only at tremendous expense. For example, 46,000 mt of Ulva were harvested from Venice Lagoon during the 1989 removal project at a cost exceeding U.S. $5.6 million (Fletcher 1990). It is thus imperative that ways be found to reduce the costs associated with the treatment of green tides.

It is unfortunate that the algae typically associated with macroalgal blooms are ones for which there exists little market potential, for if these seaweeds had intrinsic value, their removal and disposal could be the basis of a viable maritime industry. Nevertheless, in Israeli fish ponds Ulva lactuca and Gracilaria conferta, are now used to strip these marine fishponds of effluents (Cohen & Nori submitted, Nori & Cohen submitted). The Ulva is even harvested and used as a filler in sausage meats. In the People's Republic of China, Gracilaria tenuistipitata is grown in pond culture on Hainan Island. This alga is used in part to strip nitrogenous effluents from adjacent housing developments prior to release of these waters into the sea (Yarish pers obs). The removal cost of macroalgae may also be mitigated by useful disposal of the harvested seaweed for fertilizers, animal food, or biomass substrates for methanogenic bacteria (Chapman & Chapman 1980, Bird & Benson 1987). Fortunately it is possible to introduce more valuable species into problem areas through aquaculture methods.

On a worldwide basis, many different species of macroalgae are cultivated (Waaland 1981). Most of the types cultivated successfully on a commercial scale are those used for human food, particularly in Asia (Abbott 1988). The best known examples include the red alga Porphyra ("nori"), and the brown algae Undaria ("Wakame") and Laminaria ("kombu") (Arasaki & Arasaki 1983, Waaland 1981, Miura 1980). Other species have been cultivated as sources for valuable extractive products, e.g. the red algae Eucheuma for caraageenan and Gracilaria for agar (Jansen 1979, Bird & Benson 1987, Hanisak & Ryther 1984, Lewis et al. 1988). A key consideration in every example of seaweed farming is the selection and optimization of a suitable substrate. The sea farm grounds are most often in areas where the same species would not otherwise occur because of the lack of suitable substrate materials at the *appropriate water depth.*

If we consider the conditions present in a typical bay or lagoon that is subject to repeated green tide occurrences, we usually find that the overall nutrient status of the water is excellent for support of algal growth. These nutrients come either form current sources of runoff and discharge or from mineral cycling processes within the sediments (cf. Bianchi et al. 1988). In many cases, by providing a suitable substratum, and by providing adequate inoculum, we can cause desirable species of seaweed to dominate. As with any agricultural crop whether it is rice, wheat, or seaweed, it is essential to understand the particular biological requirements of the target species in order to successfully manage it under cultivation.

Some examples will serve to demonstrate typical methods of seaweed cultivation and how these might be applied in eutrophicated bays and lagoons.

Porphyra ("nori") Cultivation

The most valuable cultivated seaweed on a worldwide basis is Porphyra (Chapman & Chapman 1980). Selected strains of P. yezoenis and P. tenera are farmed on a very large scale in Japan as well as in Korea and China for the production of the edible product "nori" (Mumford & Miura 1988, Miura 1975). Nori is a key ingredient in the japanese dish called "sushi", in which nori is used as a flavorful wrapper around a filling of vinegared rice and various vegetables or fish (Arasaki & Arasaki 1983).

Nori is grown on nets that are suspended just at the water surface (Merrill 1989, Mumford & Miura 1988, Miura 1975). These nets can be supported on poles driven into shallow mud or sand bottoms, or in floating gridworks of rope in deeper sites. Key *environmental requirements for the cultivation of currently valuable strains include temperatures in the range of 6-16°C and salinities slightly below full-strength seawater, 25-32 ppt. An essential aspect of these techniques is the need to provide periodic drying to the juvenile plants. Drying eliminates competing species and epiphytes. This is achieved either by the normal exposure during low tides in the case of pole culture, or by controlled lifting of the nets in the case of floating culture.*

Nori is a very fast growing plant, requiring only 45 days from seeding to first harvest. It has a very high protein content, hence high in nitrogen, up to 40% protein by dry weight. The productivity and nitrogen uptake of this plant are sufficiently great to make it an excellent choice for eutrophication abatement.

Kelp Species, e.g. Laminaria, Undaria

Laminaria ("kombu") and Undaria ("wakame") are kelps cultivated principally in Asian countries (Druehl 1988). These are widely recognized to be used in preparing soups and as flavoring in other dishes (Arasaki & Arasaki 1983), but are primarily utilized as raw material for extracting alginate, mannitol, and iodine in industry in China. They have markets that are almost as large as that for nori.

There have been several attempts to develop kelp farming in North America for alginate, "kombu", or bio-gas production. Perhaps the greatest potential exists with the kelp growing in Long Island Sound because of their rapid growth rates due to the availability of light during the winter and the relative abundance of nutrients throughout the growing period (Brinkhuis et al. 1987, Egan & Yarish 1990). Sporophytes of Laminaria longicruris (a variety of L. saccharina) *attain lengths up to eight meters with mean growth rates of 2.53 cm* da^{-1} *in May and early June. Maximum standing crop has been observed in May (1986: 24 kg* m^{-2}*; 1987: 47 kg* m^{-2} *fresh weight; Egan & Yarish 1990). Plants on north shore of Long Island Sound live at least two years (i.e. biennial; Egan & Yarish 1988, 1990). The microsporophyte or gametophyte may be the oversummering stage in the Sound (Egan et al. 1989). Fast growing strains with differential thermal sensitivities have also been isolated from natural populations of L. longicruris in Long Island Sound (Yarish & Egan 1987, Yarish & Egan 1989, Egan et al. 1989). Genetic crossing experiments between L. longicruris and L. saccharina performed at the University of Connecticut at Stamford and continued at the State University of New York's Flax Pond greenhouse facilities, have showed that although the plants were interfertile, there were inherited differences in growth rates (Yarish et al. 1990, Egan et al. 1990). Chinese rope culture techniques have been extended to the in situ cultivation of L. longicruris in the lab and field. Pedigree lines has been established for several of the fast growing strains. Cultivation scenarios have also been presented for kelp mariculture in Long Island Sound (Yarish & Egan 1989).*

Kelps are typically grown on large diameter (10-20 mm) rope lines which are suspended at suitable depths below the surface (Brinkhuis et al. 1987, Druehl et al. 1988, Merrill & Gillingham 1991a, Kawashima 1984). Inoculation of the long-lines is achieved by careful preparation of seedstock inoculum in on-shore facilities. Another commonly used technique places pre-inoculated substrate onto the ocean floor (25-30,000 stones ha^{-1}*; 15 kg stones). Yields of 2.5 kg f.wt of kelp per stone are typically obtained (Huang, pers. data). The production of kelps is usually 10 times greater than nori per hectare (Huang, pers. data).*

Protein content is lower in the kelps, typically in the range of 8-12% by dry weight.

Their value in pollution abatement is augmented by their value as habitat for fish and shellfish. In fact, kelps can justifiably be grown specifically for this purpose even in areas without the need for nutrient reduction (Merrill & Gillingham 1991b). The ultimate success of kelp mariculture will depend upon market factors and its total cost in the region. Farming ventures may be enhanced if nutrient removal is considered part of the farm's operational functions (Yarish et al. 1990). Careful consideration of engineering and economic principles are necessary along with the need to extend existing kelp research technology to potential aquaculturalists.

Other Potential Species: Sargassum

The brown alga, Sargassum filipendula ?, occurs throughout western Long Island Sound. Sargassum contains the commercially valuable phycocolloid, alginate (Chauhan 1970, Pillai 1954, 1956, 1957, Shah et al. 1967, Roa 1969, Varier et al. 1951). Previously, this species was recognized solely as a summer annual in Long Island Sound; however, recent investigations (Kilar unpublished data) have found shallow subtidal populations that are perennial. Perennial populations of Sargassum are reported elsewhere (e.g. S. cymosum; Kilar et. al 1991). Attempts to grow Sargassum in ponds have not been very successful, however, the plant appears ideally suited for long-line culture. While uprights portions of the plant are annual or perennial in nature, the basal holdfast and perennial stem are long-lived (2-5 yr). Upright portions could be harvested without disturbing the perennial base.

Other Options: Seeding

While the examples cited above represent cases of complete cultivation, there may be circumstances in which controlled cultivation is uneconomical, or is undesirable for other reasons. In such cases it may be possible to apply simplified techniques toward "enhancement" of desired species. For example, in some shallow lagoons where unattached populations of *Ulva* dominate, the simple addition of shell fragments or pebbles, with or without pre-inoculation with spores, may be sufficient to stimulate the development of *Gracilaria*. This species seems to prefer at least some attachment points. Similarly, standing crops of natural beds of kelp or *Sargassum* could be significantly increased. Since these species are valuable as raw material for industry, their harvest could potentially support local fishermen.

Nutrient Removal

A useful framework within which to consider the beneficial value of nutrient uptake and removal is that of "Algal Biomass Potential" (ABP; Oswald 1988). In the presence of sufficient quantities of other elements, a single nutrient may support a finite quantity of biomass production by a given species. For example, ABP can be defined for nitrogen as follows:

$$\text{ABP (mg dw algae/l)} = \frac{\text{available N (mg/l)}}{\text{algal N composition (\%)}}$$

If we consider a system supporting *Ulva* growth (approx. 3.5% N) with 20 mg/l nitrogen, we can calculate as follows:

$$\frac{\text{20mg/l N}}{\text{3.5\% N}} = \text{571 mg dw } \underline{\text{Ulva}} \text{ / l ABP}$$

Furthermore, in a shallow lagoon we can calculate the biomass per unit area as:

$$1\ ha \times 2\ m\ depth = 20{,}000{,}000\ liters$$

$$\times\ .571\ mg/l$$

$$= 11.4\ t/ha\ ABP$$

Interestingly, the Ulva biomass production of Venice Lagoon has been estimated at 18.5 t/ha (Sfrisco et al. 1987). It follows that any proportion of the ABP that can be utilized by a harvested crop will reduce that remaining for support of the growth of "problem" algae such as Ulva. To illustrate the nutrient uptake value of nori we can make the following calculations for commercial nori production:

$$\frac{450\ gdw}{m_2} \quad X \quad \frac{0.07\ g\ N}{gdw} = \frac{31.5\ g\ N}{m_2}$$

This production figure of actual 450 gdw $m^{-2}yr^{-1}$ is for a typical 5 month harvest season and is based on approximately 40% surface area coverage by the cultivation system. Again, we can compare this nitrogen uptake value to those estimated for Ulva in Venice Lagoon of 50-70 g N $m^{-2}yr^{-1}$ (Sfrisco et al. 1987).

The removal of this quantity of nutrients from the water should have the immediate beneficial result of reducing the biomass of problem species. Even when complete replacement of problem species is not feasible, partial replacement may be sufficient to reduce the total algal biomass below the threshold of hypertrophic events. Furthermore, by continued harvests in successive years, it could be expected that significant amounts of nutrients could be removed *from the sediment load.*

Nutrient Management: Natural Populations

Nearshore communities of benthic macroalgae, seagrasses, salt marsh grasses, phytoplankton, and benthic microalgae serve as buffers, absorbing, storing, and gradually releasing nutrients (Kremer & Nixon 1978, Pomeroy & Wiegert 1981, Welsh et al. 1982). Many of these estuarine habitats serve as nursery grounds for many offshore and nearshore species (Perkins 1974, Nixon 1980, Odum 1980). Nutrient additions to coastal embayments above ambient conditions bring about changes, especially among fringing benthic communities. Blooms of one or more "opportunistic algae", overgrow established plant and animal assemblages resulting in a drop in community diversity (e.g., Kautsky 1982, Hawkins & Hartnoll 1983, Littler & Murray 1975, Brown et al. 1990, Tewari & Joshi 1988). Losses of habitat in embayments therefore can be expected to affect living marine resources throughout wide geographic areas.

The ability of environmental managers to predict "bloom events" or to regulate the growth of natural beds would significantly contribute to their skills in maintaining environmental quality and species diversity. Any attempt to understand or model macroalgal populations must be based on a knowledge of abiotic or biotic parameters that regulate specific growth rates and abundance patterns. Past attempts to model the macrophyte growth in Long Island Sound have been overly simplistic (e.g. Sampson & Curtis 1987), ignoring complicated life-history patterns and growth strategies. For example, most environmental models presently utilize external supplies of nitrogen and relate them to algal growth. This approach is limited due to the simultaneous variation of many environmental factors, an unknown nitrogen requirement for growth and *reproduction in situ, the presence of a continuous supply of nitrogen due to water motion (nutrient flux or loading), and the ability of algae to store large amounts of nitrogen (Hanisak 1979, 1983). The development of monitoring protocols utilizing internal nitrogen could significantly add to our skills in managing these systems.*

The measurement of internal concentrations of nutrients has many advantages over other single-source measurements when assessing enviromental impact.

1) Tissue analysis of nutrients reflects the total nutrient environment, i.e., measuring the effects of nutrients presently being discharged, those discharged from previous years, and trapped in sediments.

2) Pulses of nutrients from runoff (short-term temporal events) are difficult to capture when sampling water and even more difficult to interpret as to their effects on macrophytes.

3) Measurements of tissue nutrients are directly pertinent to the plant metabolism.

Effective managment policies for coastal resources requires (1) identifying the cause of the problem by constructing and testing hypotheses, (2) identifying effects and the appropriate parameters to measure, and (3) taking steps to remove or reduce environmental impact (NOAA Eutrophication Workshop 3-5 January 1991). Internal tissue nitrogen are considered critical to the understanding, controlling, and mitigating the effects of opportunistic, marine macrophytes in aquaculture and could be similarly applied to natural beds (Yarish et al. 1991).

Summary

There is a widespread need for active intervention in eutrophicated marine ecosystems in order to reduce the occurrence of green tides, hypoxia and other ill effects. A significant contribution *to such efforts can be made by using aquaculture techniques to alter or manage the species composition in the target area. By cultivating species with intrinsic economic value, the great costs associated with harvest and removal of undesirable species can be reduced or eliminated. The nutrients absorbed by the cultivated algae are removed from the ecosystem through harvest. Complete countervention of nutrient flux is not required since even partial nutrient removal may bring concentrations below threshold levels. An additional side benefit of such actions is the development of a new economic base for coastal fishing communities. When coupled with efforts at long term source reduction it should be possible to recover highly eutrophicated ecosystems.*

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APPENDIX E

*Tide Gates As Means of Alleviating Hypoxia of Alleviating Hypoxia in Western Long Island Sound and Reducing Water Pollution in New York/New Jersey Harbor Waters**

by

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**This White Paper was not commissioned and was received after the Workshop.*

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PRELIMINARY ASSESSMENT OF RELOCATION OF OUTFALLS FROM SELECTED SEWAGE TREATMENT PLANTS TO ALLEVIATE HYPOXIA IN WESTERN LONG ISLAND SOUND

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FIGURES
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SUMMARY

Two groups of sewage treatment plants were selected to assess the efficacy of outfall relocation as an alternative to nitrogen removal by advanced waste treatment to alleviate hypoxia in western Long Island Sound. The treatment plant discharges to the East River and those from Westchester County were selected strictly for illustrative purposes in this preliminary concept analysis. East River loadings could be relocated toward inner New York Harbor and the ocean while discharges from Westchester County could be relocated toward central Long Island Sound. In both cases, relocation alternatives would convey effluents away from the hypoxic Western Narrows area of Long Island Sound and thus serve the purposes of this preliminary conceptual analysis.

The following results are presented based on this analysis:

- Outfall relocation of the East River loads appears to be a viable alternative to nitrogen removal by advanced treatment. Loads relocated out of the East River to harbor areas with greater assimilation capacities can substantially reduce the effect of such loads on water quality conditions in the western sound. The deep tunnel alternative which was evaluated as the means of outfall relocation appears to be cost effective in comparison to nitrogen removal. In addition, load relocation may produce multiple benefits in terms of improved water quality in the East River proper as well as in the western sound, and may facilitate the integration of facilities for control of combined sewer overflows.

- Outfall relocation of the Westchester County discharges does not appear to be a cost effective alternative to nitrogen removal. Loads relocated by submarine pipeline toward central Long Island Sound reduces the impacts of these loads in the Western Narrows. However, some fraction of the relocated load is trapped in the estuarine circulation pattern which exists in the sound, is returned toward the western sound in bottom waters, and attenuates the effectiveness of

load relocation. Consequently, extended lengths of pipeline may be required to produce water quality improvements which are equivalent to nitrogen reduction by advanced treatment. By inference, relocation of other discharges to Long Island Sound from Long Island and Connecticut is also not likely to be cost effective.

- Relocation of East River loads may have adverse impacts as well as multiple benefits. A series of technical investigations are outlined to further define the feasibility and efficacy of outfall relocation and to more rigorously assess attendant benefits and potential adverse impacts.

INTRODUCTION

The Long Island Sound Study (LISS) of the National Estuary program is in the process of preparing a Comprehensive Conservation and Management Plan (CCMP) to improve the health of the estuary and ensure compatible human uses within the sound ecosystem. During the study, much attention has been focused on the existing problem of low dissolved oxygen which occurs during the summer in bottom waters of western Long Island Sound. In order to understand the causal mechanisms producing this condition, an extensive field data collection effort was undertaken in 1988 and 1989 for the purpose of developing and calibrating hydrodynamic and water quality models of Long Island Sound. Such models would be used to determine the quantitative relationships between point and nonpoint pollutant inputs and hypoxia and would serve as a technical basis for management decisions.

Thus far, a second generation coarse grid two-dimensional, time-varying water quality model with eutrophication kinetics and interactive sediments, LIS 2.0, has been used to analyze the 1988 and 1989 data base (HydroQual 1991). The preliminary modeling results indicate that approximately 75 percent of the dissolved oxygen depression at the critical location in the western sound is due to nitrogen effects, the limiting nutrient in the summer, with the balance due to oxidizable carbon. Currently, a more refined three-dimensional coupled hydrodynamic and water quality model, LIS 3.0, is in the process of calibration and will be used to assess the effectiveness of various management alternatives for the CCMP.

LIS 2.0 has been used for a preliminary evaluation of various management options for control of hypoxia in the western sound. As summarized in a report on interim actions for hypoxia management (LISS 1990), three potential levels of management of the various point and nonpoint pollutant inputs were tested with LIS 2.0 to assess the response to the system. For municipal sewage treatment plants (STPs), the three levels of management considered reductions of 20, 50 and 72 percent of total nitrogen for illustrative purposes. It is likely that in development of the final CCMP, a similar range of potential nitrogen reductions for STPs will again be considered.

Information developed for the LISS by contract consultants, state agencies and individual municipalities indicate that advanced treatment for nitrogen removal, while technically feasible, is costly for the higher levels of reduction. As a consequence, the LISS requested the Marine Sciences Research Center of the State University of New York at Stony Brook to convene a workshop to identify and assess alternatives to enhanced nutrient removal at sewage treatment plants to alleviate hypoxia in western Long Island Sound. One alternative which may be so considered is the relocation of loads away from the critical area as a method of reducing adverse water quality impacts in lieu of advanced waste treatment. It is the purpose of this concept paper to assess the potential advantages and disadvantages of load relocation as a substitute for nitrogen removal at STPs. In the following sections, existing information is summarized, potential relocation requirements for selected discharges are developed in a very preliminary manner, the cost effectiveness of load relocation as compared to effluent nitrogen removal is addressed, other advantages and possible adverse impacts are discussed, and specific research needs to address areas of uncertainty are identified.

BACKGROUND

Existing Conditions

The Long Island Sound study area extends from the Battery in New York City to Block Island, Rhode Island. At present, 44 municipal STPs discharge an average of 1,200 million gallons/day of treated effluents either directly to the sound or into tidal waters of tributaries. The municipal discharges are located on Figure 1 and tabulated in Table 1.

The present total nitrogen loading from all municipal STPs is approximately 26,000 tons/year (140,000 pounds/day). This loading and inputs from other sources such as tributaries, atmosphere, coastal runoff, and sound boundaries together with organic carbon loads from all sources were inputs to the LIS 2.0 model (Figure 2) for calculation of the dissolved oxygen balance. The total nitrogen loading from point sources (primarily STPs) to Long Island Sound is

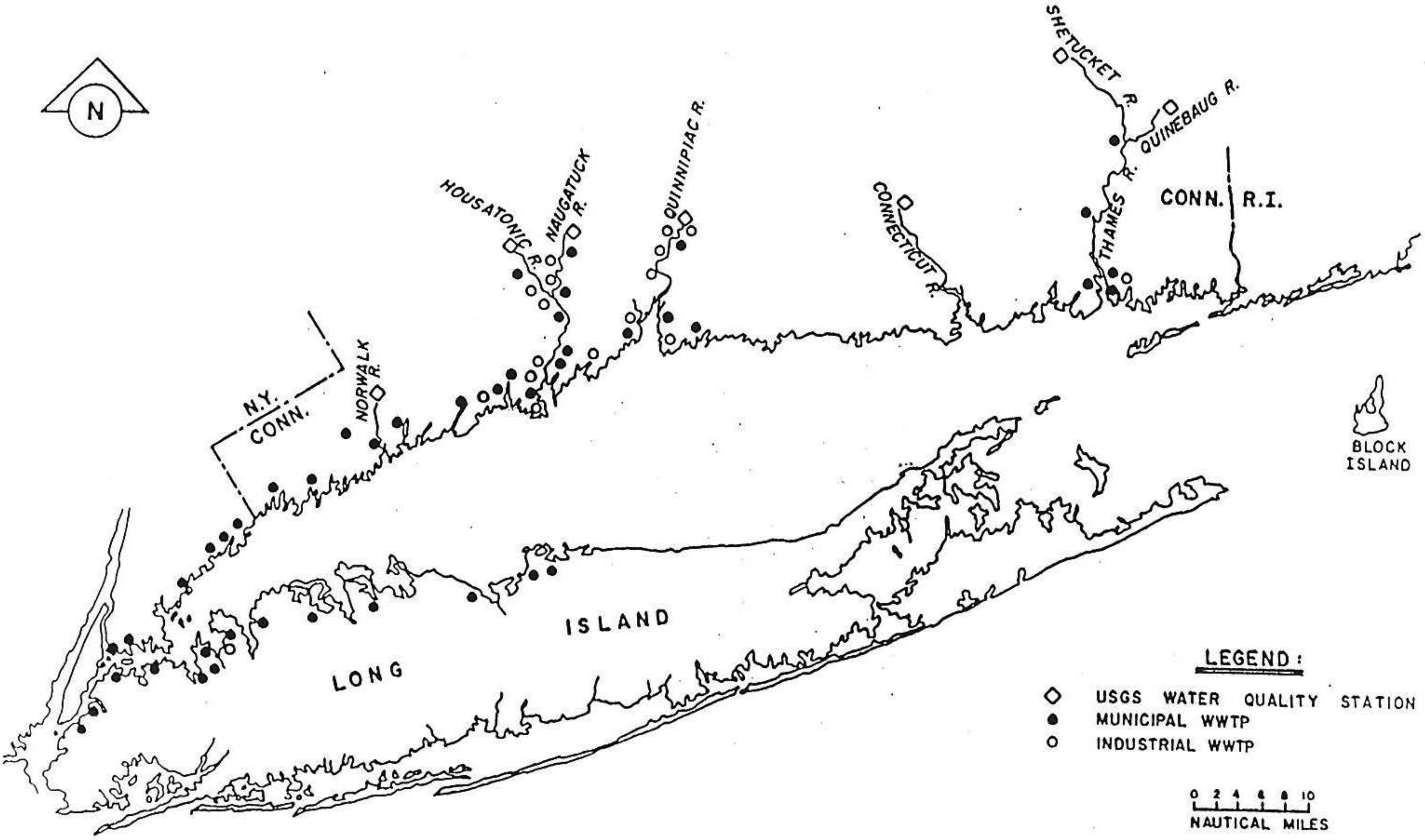


FIGURE 1 LOCATION MAP OF POINT SOURCE DISCHARGES TO LONG ISLAND SOUND

TABLE 1.. LONG ISLAND SOUND MUNICIPAL AND INDUSTRIAL WASTEWATER TREATMENT PLANT FACILITIES (WWTP), 1988

Facility Name	NPDES Number	Receiving Waters	Miles from Battery	Mean Flow (cfs)
MUNICIPAL				
Red Hook	NY0027073	East River	1.7	68.5
Newtown Creek	NY0026204	East River	4.1	529.9
Wards Island	NY0026131	East River	7.5	341.1
Bowery Bay	NY0026158	East River	10.1	224.7
Hunts Point	NY0026191	East River	11.0	217.2
Tallmans Island	NY0026239	East River	13.3	100.0
Belgrave WPCF	NY0026841	Little Neck Bay	16.5	2.5
Port Washington STP	NY0026778	Manhasset Bay	19.5	4.5
Great Neck SD STP	NY0026999	Manhasset Bay	19.5	4.2
Great Neck Village	NY0022128	Manhasset Bay	19.5	1.2
New Rochelle	NY0026697	Long Island Sound	20.9	19.2
Mamaroneck	NY0026701	Long Island Sound	24.3	19.5
Glen Cove STP	NY0026620	Glen Cove Creek	25.1	8.6
Blind Brook STP	NY0026719	Long Island Sound	27.6	3.2
Port Chester SD STP	NY0026786	Bryam River	28.9	6.1
Greenwich WPCF	CT0100234	Long Island Sound	31.1	12.5
Oyster Bay SD STP	NY0021822	Oyster Bay Harbor	33.8	2.4
Stamford WPCF	CT0101087	Stamford Harbor	34.4	22.7
Huntington STP	NY0021342	Huntingtn Harbor	39.5	2.7
New Canaan STP	CT0101273	Five Mile River	40.0	2.4
Norwalk WPCF	CT0101249	Long Island Sound	41.6	13.5
Westport WPCF	CT0100684	Saugatuck River	46.1	2.4
Fairfield Town Hall	CT0101044	Long Island Sound	48.0	11.3
Kings Park SCSD #6	NY0023311	Long Island Sound	48.1	1.1
Bridgeport Westside	CT0100056	Long Island Sound	55.1	40.8
Bridgeport Eastside	CT0101010	Long Island Sound	55.1	11.3
Stonybrook SCSD #21	NY	Port Jefferson Harbor	57.0	2.5
Port Jefferson SCSD #1	NY0021750	Port Jefferson Harbor	57.0	1.1
Stratford WPCF	CT0101036	Housatonic River	58.1	11.5
Milford-Beaver Brook	CT0100749	Housatonic River	58.1	2.6
Milford-Housatonic	CT	Housatonic River	58.1	8.5
Derby WPCF	CT0100161	Housatonic River	58.1	2.0
Shelton WPCF	CT0101303	Housatonic River	58.1	2.8
Ansonia WPCF	CT0100013	Naugatuck River	58.1	4.0
Seymour WPCF	CT0100501	Naugatuck River	58.1	2.2
West Haven SPCF	CT0101079	Long Island Sound	67.6	10.2
East Shore WPCF	CT0100366	Long Island Sound	69.5	41.0
Boulevard WPCF	CT0100340	Long Island Sound	69.5	19.1
North Haven WPCF	CT0100404	Quinnipiac River	69.5	4.2
Branford WPCF	CT0100048	Branford Harbor	72.1	4.3
New London WPCF	CT0100382	Long Island Sound	111.6	7.9
Groton City WPCF	CT0100242	Fort Hill Brook	111.6	2.7
Groton Town WPCF	CT0101231	Poquonock River	111.6	5.2
Montville WPCF	CT0100935	Thames River	111.6	1.5
Norwich WPCF	CT0100412	Thames River	111.6	7.8

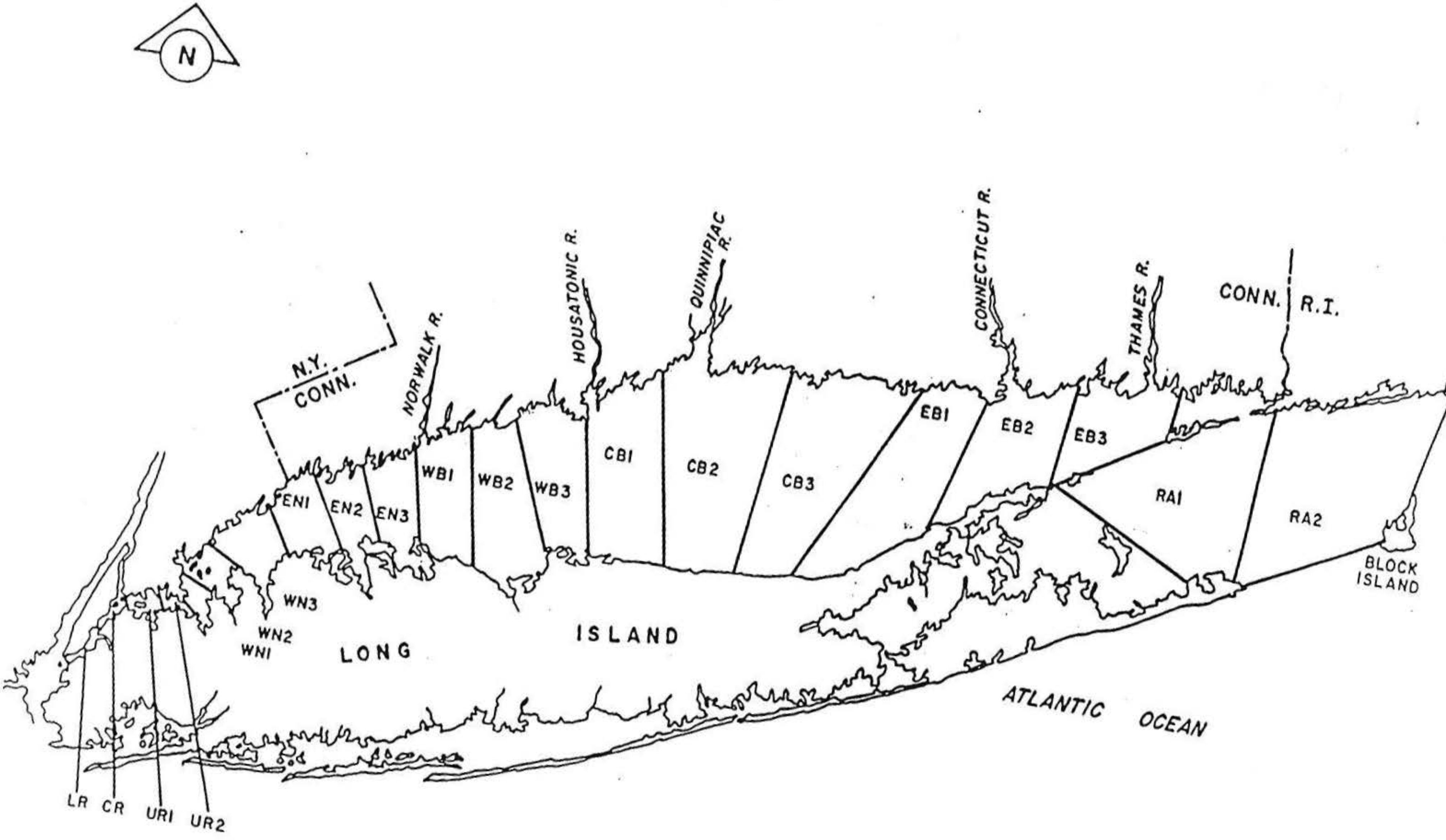


FIGURE 2. SEGMENTATION MAP FOR LONG ISLAND SOUND WATER QUALITY MODEL

compared to other inputs, natural and enriched, on Figure 3 (LISS 1990). The improvement in dissolved oxygen in the Western Narrows (critical location - model segment WN 2) of Long Island Sound resulting from removal of various enriched inputs as forecasted by LIS 2.0 is shown on Figure 4. As shown on this diagram, it is estimated that coastal point source nitrogen discharges (primarily STPs) account for approximately 1.1 mg/l of oxygen depression in bottom waters of the Western Narrows under critical conditions. Organic carbon discharges produce additional, but much less, oxygen depression.

Estimated Effects of Nitrogen Reduction

As indicated, the LIS 2.0 model was used to provide a preliminary estimate of the effectiveness of nitrogen reduction on dissolved oxygen for various potential levels of management. The three scenarios which were considered for reduction of enriched nitrogen from the various sources are shown in Table 2.

TABLE 2. PERCENT OF THE ENRICHED PORTION OF TOTAL NITROGEN REMOVED AT THREE LEVELS OF MANAGEMENT

	Level of Management		
Source	Low	Mid	High
STPs	20%	50%	72%
Tributaries			
Connecticut River	8%	25%	35%
Housatonic River	8%	25%	40%
Coastal	0%	0%	13%
Atmosphere	0%	0%	30%
Total	14%	37%	55%

The effects of the various levels of management on the dissolved oxygen distribution in Long Island Sound as calculated by LIS 2.0 are shown on Figure 5. The diagram shows the projected minimum dissolved oxygen in the bottom waters of Long Island Sound under summer conditions for the three levels of

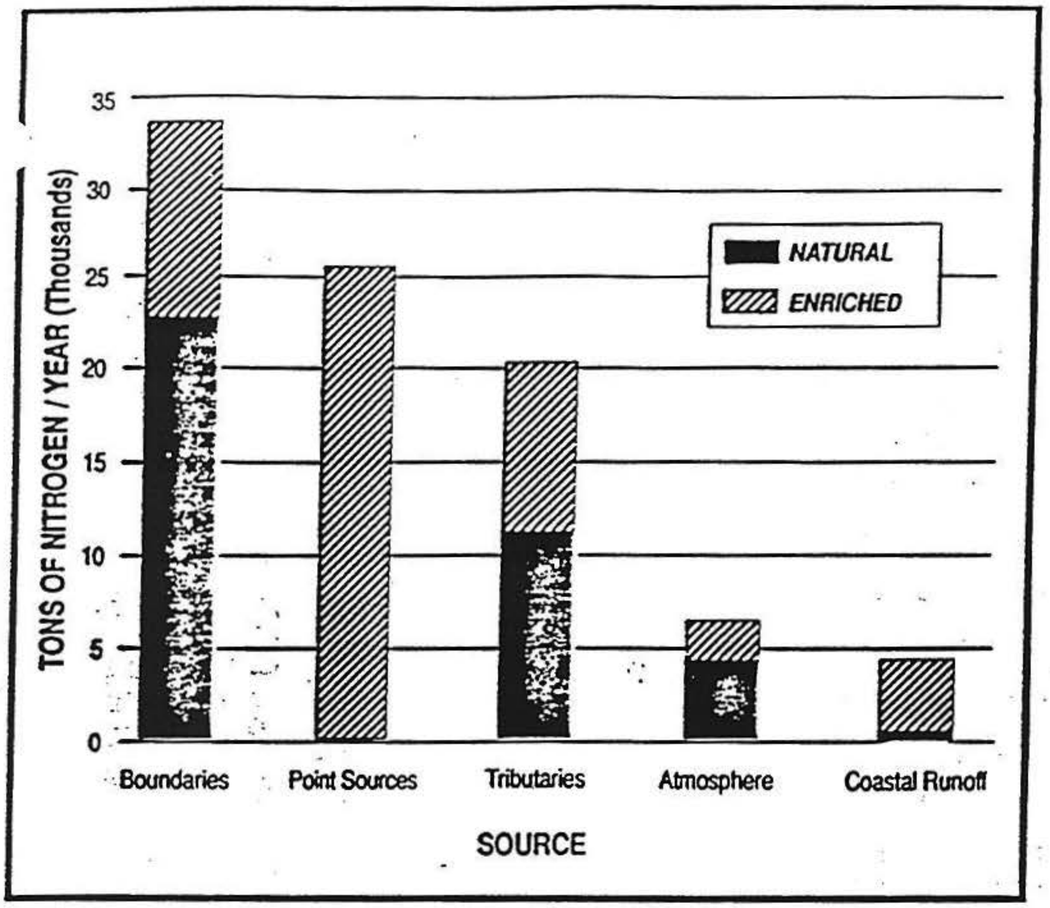


Figure 3. Natural and enriched sources of nitrogen (tons of total nitrogen per year), by source type, that enter Long Island Sound, ca. 1989. Specific loads are as defined in Table 5.

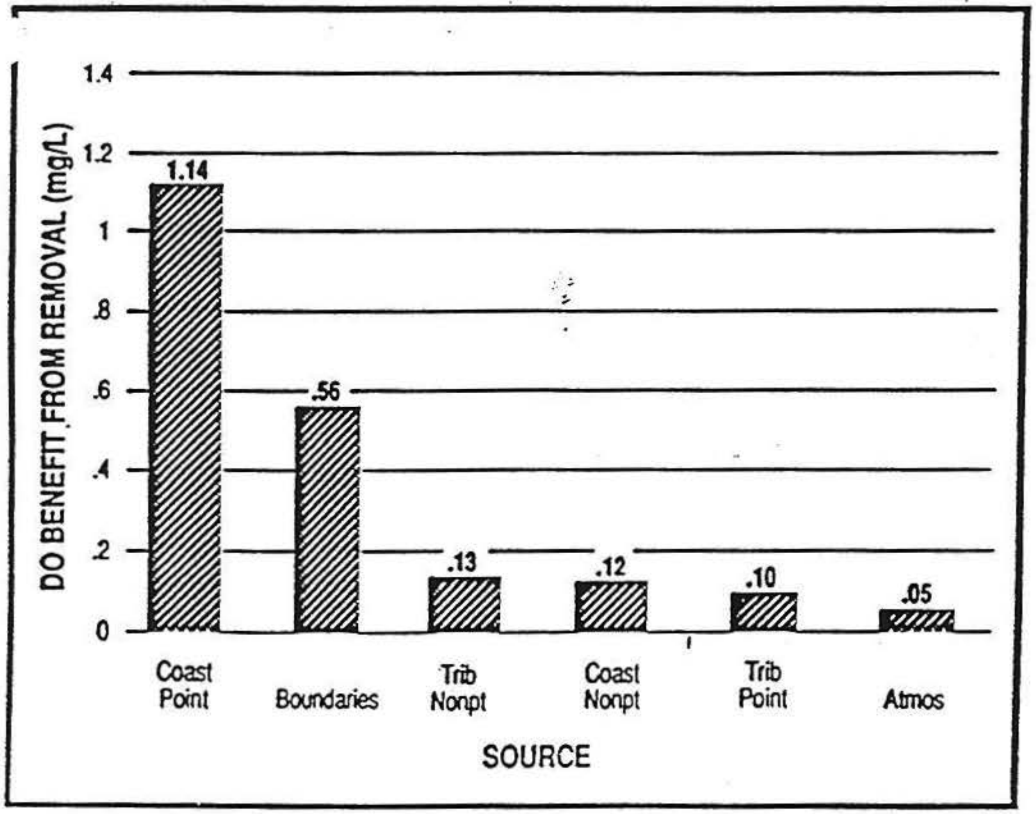


Figure 4. The improvement in dissolved oxygen levels (mg/L), by source type, forecast by LIS 2.0 to occur in the Western Narrows of Long Island Sound if the human-enriched portion of the nitrogen was removed. This response is based on the level of point and nonpoint enrichment identified in Table 5.

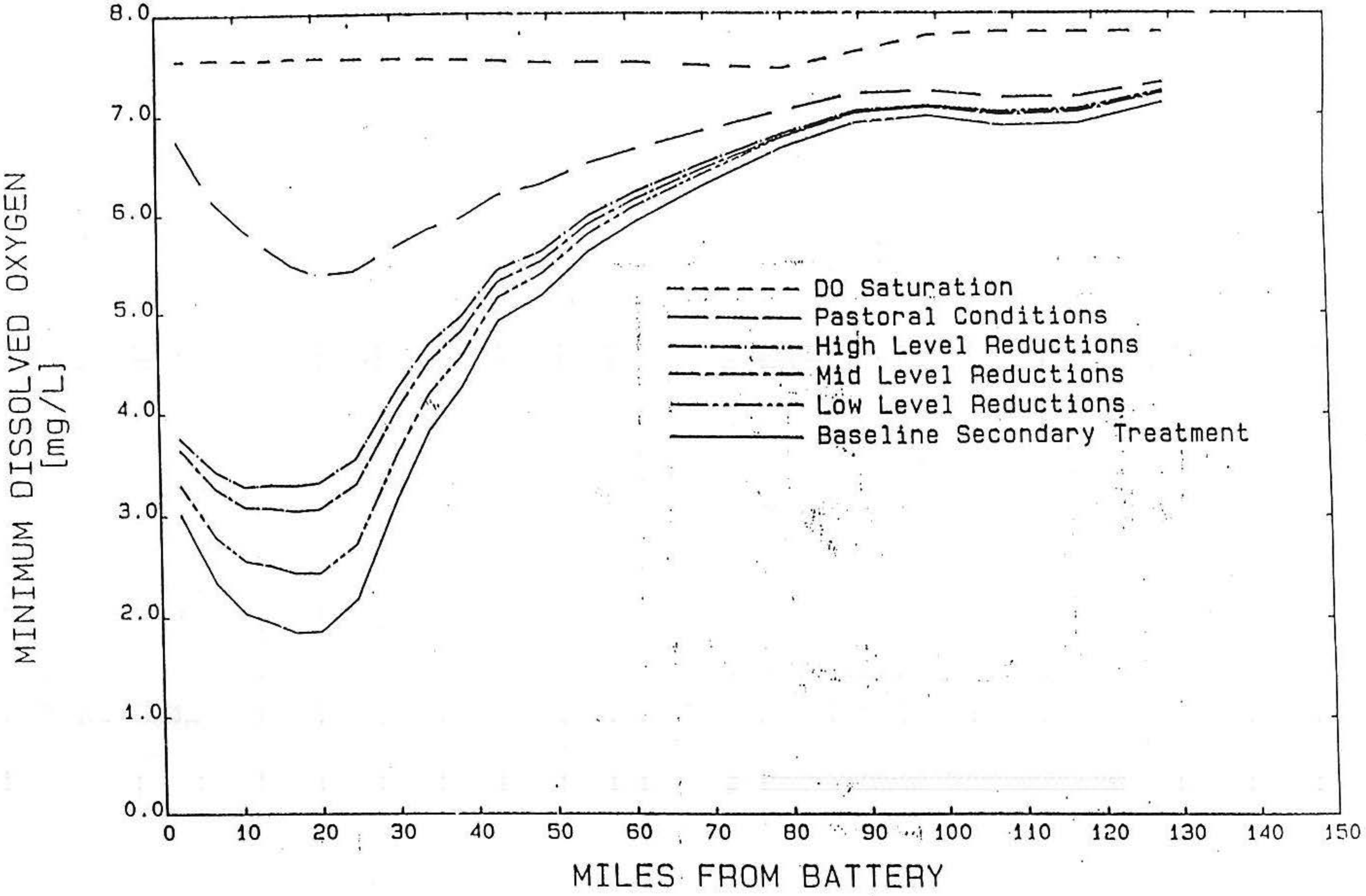


FIGURE 5. SPATIAL PROFILES OF COMPUTED MINIMUM DISSOLVED OXYGEN CONCENTRATIONS FOR THREE ACTION ALTERNATIVES

nitrogen reduction. Baseline secondary treatment with no nitrogen reduction is shown for comparison. Estimated pastoral (undeveloped) conditions are also shown.

RELOCATION OF OUTFALLS

Concept and Selection of Discharges

The purpose of reducing total nitrogen loads from any individual, or grouping of, STP discharge(s) by advanced waste treatment is to produce a corresponding reduction in that fraction of total nitrogen concentrations in the receiving water which is due to that (those) discharge(s). Such a reduction in instream total nitrogen concentration affects the eutrophication process and results in some level of improved dissolved oxygen at the critical location and other areas. The purpose of relocating any single or grouping of outfalls would also be to modify the instream total nitrogen distribution in such a manner as to improve dissolved oxygen by some level. In either case, the purpose of the procedure, nitrogen removal or relocation, is to modify the instream total nitrogen distribution in such a manner as to produce desired levels of improvement in dissolved oxygen.

In order to effectively compare nitrogen removal by treatment with load relocation, application of a water quality model with eutrophication kinetics is the method of choice. The model would first be used to assess the effect on dissolved oxygen of some specified level of nitrogen removal from any individual load or grouping of loads. Then, the model would be re-executed, assuming no nitrogen removal, but with the load(s) relocated to a series of appropriate positions until the same level of dissolved oxygen improvement is forecasted, if possible. The outfall relocation position which produces the same dissolved oxygen improvement is then the equivalent, in that particular sense, of nitrogen removal by advanced treatment. The engineering feasibility and cost of both alternatives may then be compared.

The application of a eutrophication based water quality model to assess outfall relocation(s) for purposes of this paper was both technically infeasible and beyond the scope of present effort. However, as subsequently described, preliminary modeling computations were performed to place an initial perspective on the feasibility of outfall relocation as a management option. For this purpose, simplified modeling computations were performed utilizing the following strategy:

- It was assumed for computational purposes that total nitrogen discharges behave as conservative substances in the receiving water. Eutrophication kinetics and dissolved oxygen responses were not considered.

- In the receiving water models used (as subsequently described), hypothetical loadings of a conservative substance were input for selected STPs near existing outfall locations. The receiving water response to the conservative loading was then computed throughout the study area, including the critical Western Narrows area of Long Island Sound.

- Additional model computations were performed with the conservative loadings for the selected STPs relocated to alternative discharge positions. The receiving water response to the relocated conservative loading was recomputed throughout the study area.

- From the previous step, the response of conservative substance concentration in the Western Narrows produced by the mass loading from the selected STPs could be related to discharge (outfall) location. The objective was to determine, as possible, the length of outfall relocation required to produce a 50 percent and 75 percent reduction in the concentration of conservative substance at the critical Western Narrows location as compared to the base case (existing outfall position). On a preliminary basis, it would be assumed that the relocated outfall positions which produce a 50 percent and 75 percent concentration reduction at the critical location are the technical equivalents of mid level and high level nitrogen reductions considered in the Status Report (LISS 1990).

It is emphasized that the foregoing assumption is made for preliminary assessment purposes only. Reducing the nitrogen concentrations at the critical location by a given percentage from outfall relocation may not have the same effect on dissolved oxygen as the same percentage reduction of loads by nitrogen removal. If outfall relocation appears to be a potentially effective management option, then a more detailed analysis with a eutrophication model using dissolved oxygen as the equivalence indicator is warranted.

In order to perform a preliminary assessment of the concept of outfall relocation as an alternative to nitrogen removal, two groups of loadings were selected for evaluation: loadings to the East River from New York City treatment plants, and loadings to Long Island Sound from Westchester County.

East River Discharges

The New York City Department of Environmental Protection (NYCDEP) operates six STPs which discharge treated effluents to the East River proper (Table 1): Red Hook, Newtown Creek, Wards Island, Bowery Bay, Hunts Point and Tallman Island. The total nitrogen discharges from these plants were almost 80 percent of the total of all STPs discharging to the study area (Battery to Block Island) during the 1988 and 1989 field program. This fact should not be construed to mean that the East River discharges, therefore, cause 80 percent of the dissolved oxygen depression at the critical location as caused by all STP discharges. The actual effect of any nitrogen discharge or group of loadings depends upon the mass input, but also on proximity to the problem area and the receiving water concentration distribution produced by the load(s) as affected by transport, dilution and other kinetic and transfer factors. The proportional effect of the East River discharges on dissolved oxygen in the Western Narrows as compared to that caused by all STP discharges is less than the proportional share of nitrogen mass input. Nevertheless, East River discharges have a significant share of the total STP impact on dissolved oxygen in the western sound and were selected for illustrative analysis.

As shown on Figure 1, East River discharges are distributed along the length of the waterway from the Battery to Throgs Neck. The purpose of the present analysis is not to perform a plant by plant evaluation of each of these discharges but rather to provide a broad initial overview and assessment of outfall relocation. A detailed analysis would likely consider upper East River discharges (Wards Island to Tallman Island) separately from lower East River discharges. However, for preliminary modeling purposes, it is assumed that all East River discharges enter the river at Wards Island, the approximate mid point.

Modeling Procedures. The engineering alternative which would appear practical and effective with regard to reducing the impact of East River loads on the western sound is to relocate these discharges away from the critical location and toward the ocean. The concept is to make these loadings less proximate to the western sound while perhaps affording the discharges greater transport and dilution than at present. The LIS 2.0 modeling framework is not adequate for this purpose as its western boundary is located at the Battery.

For purposes of this preliminary analysis, NYCDEP authorized application of the New York Harbor 208 Water Quality Model (HydroQual 1984, Hydroscience 1978) shown on Figure 6. Due to the extended spatial domain of the model, East River loadings could be relocated to a number of alternative positions toward the harbor entrance. The model provides seasonal steady-state computations and has two vertical layers in the East River and Hudson River above the Battery. The model has inferred circulation deduced from salinity distributions and has received extensive calibration for salinity, dissolved oxygen, coliform bacteria and other water quality variables.

As noted, the 208 Model has inferred circulation patterns estimated from salinity distributions. In this version, it has been assumed that no net tidally averaged flow exists in the East River in either direction. Recent

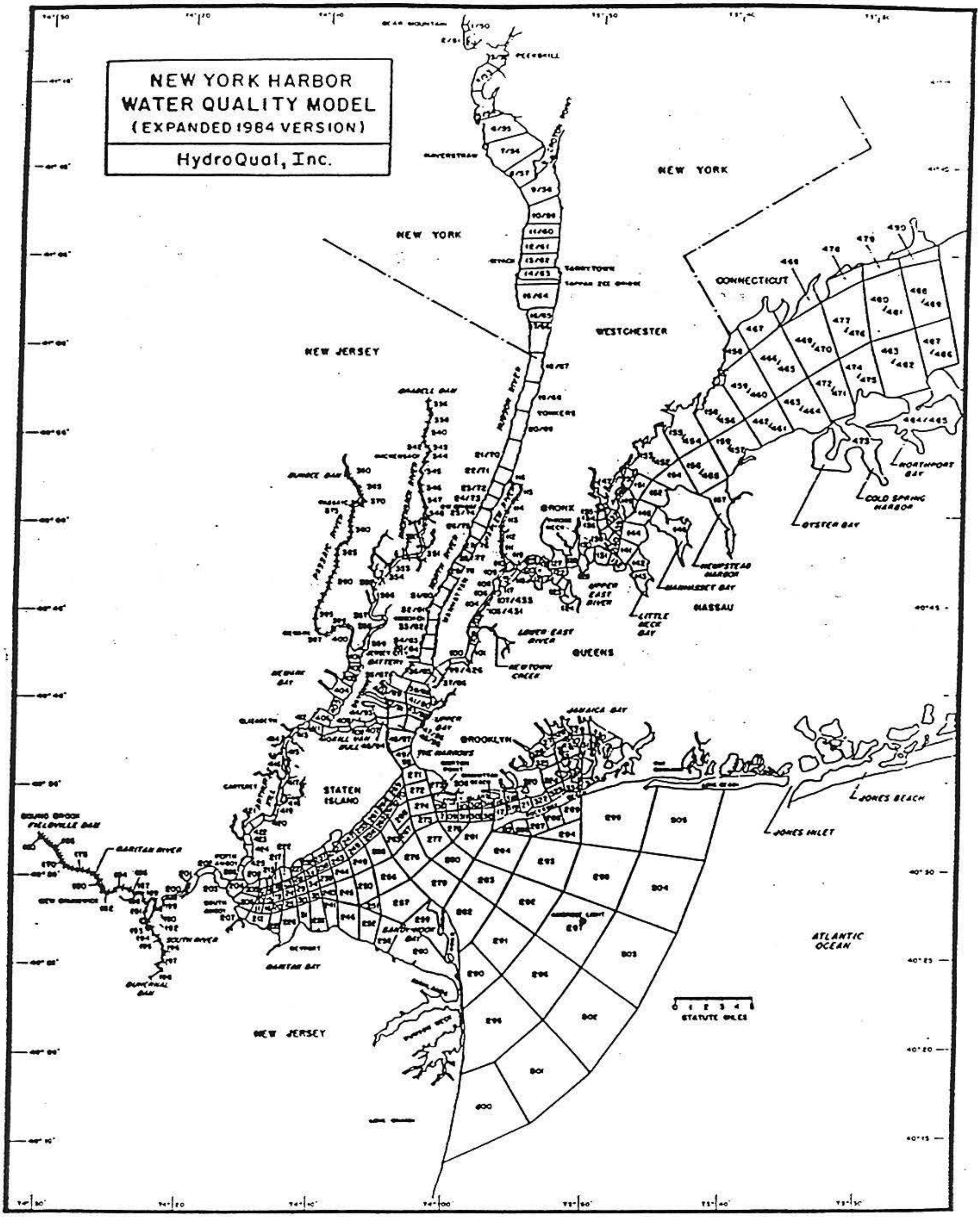


FIGURE 6. EXPANDED 490 SEGMENT HARBOR MODEL

detailed hydrodynamic calculations (HydroQual 1991) have shown that a characteristic two-layer estuarine circulation pattern (schematically shown on Figure 7) exists in the East River. It is estimated that the long term tidally averaged flow in the upper layer of the East River is directed toward the sound at a rate of 230 cubic meters/second and, in the lower layer, toward the harbor at 330 cubic meters/second. Therefore, the net long term tidally averaged flow integrated vertically in the water column at Throgs Neck is estimated to be from sound to harbor at approximately 100 cubic meters/second. Inclusion of this net flow into the 208 Model would require model recalibration, an effort beyond the present scope. The 208 Model was, therefore, applied without this net tidally averaged flow. It is expected, however, that results will still be informative for initial assessments.

Modeling Results. The 208 Model was applied as follows. Various Model inputs (freshwater inflows, rainfall, etc.) were assigned for average summer conditions. A mass of conservative substance (as a surrogate for total nitrogen) was input into the East River at Wards Island as representative of the East River discharges in general. All other loads within the model domain were assigned as zero. The mass discharge was arbitrarily assigned to produce a peak concentration of 1.0 mg/l at the discharge location. It was assumed that the concentration of conservative substance would be reduced to zero by dilutional factors at the boundaries of the model and boundaries conditions were so assigned. The model was executed for the base case and the concentration of conservative material calculated throughout the model domain. The same mass loading was then input at other locations in New York Harbor, as shown on Figure 8, and the model re-executed to calculate the system sensitivity to discharge locations. The alternative locations considered for the sensitivity calculation are: the lower East River, the Upper Bay, the Narrows and the Lower Bay near the Sandy Hook-Rockaway Transect.

Modeling results are presented on Figures 10 through 14 for the five disposal locations considered. On each diagram, spatial concentration distributions of conservative substance are plotted for various waterways on a mileage scale in accordance with transects shown on Figure 9.

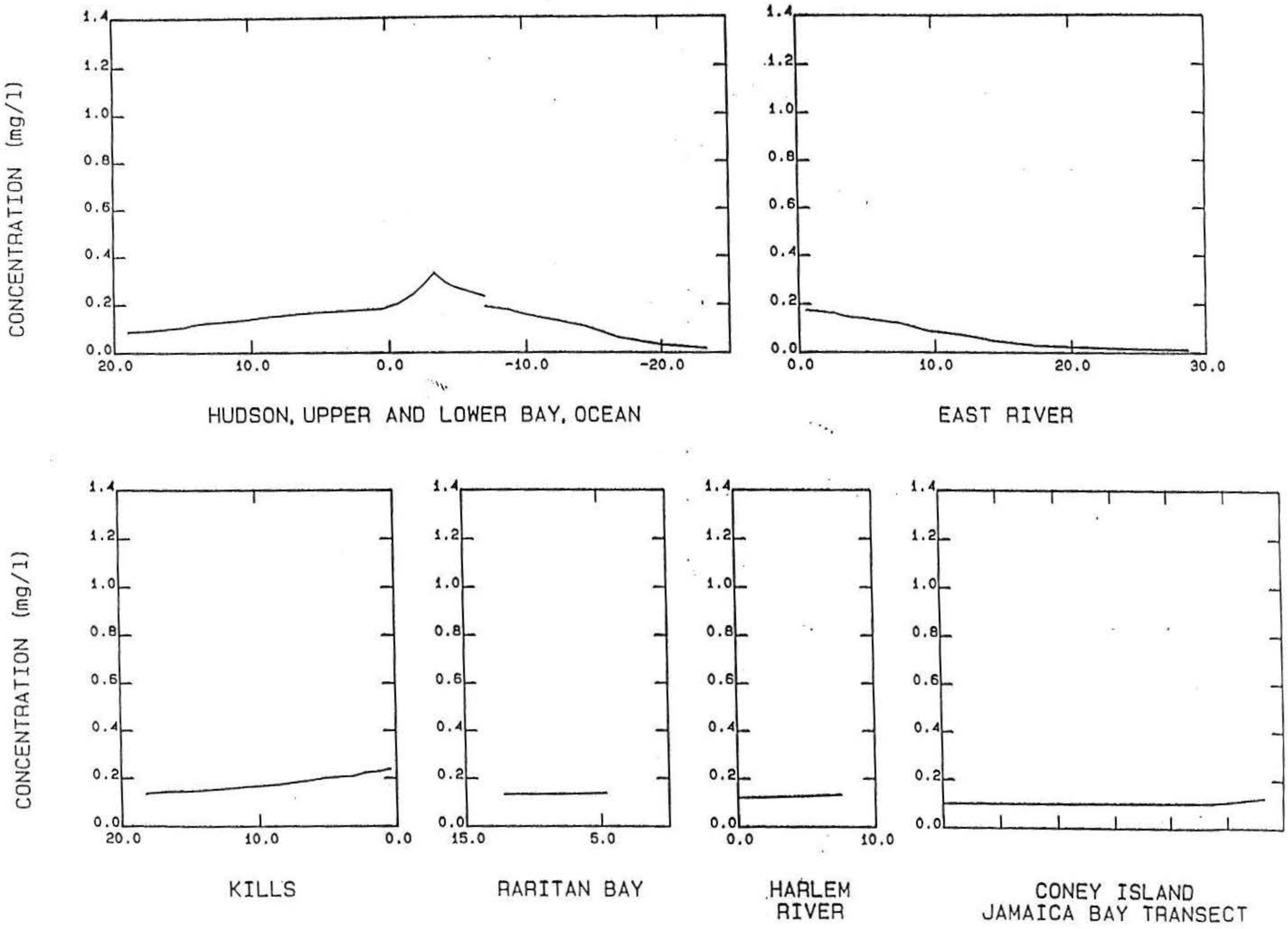


FIGURE 12. CONCENTRATION PROFILES FOR ^ CONSERVATIVE MASS INPUT TO THE UPPER BAY

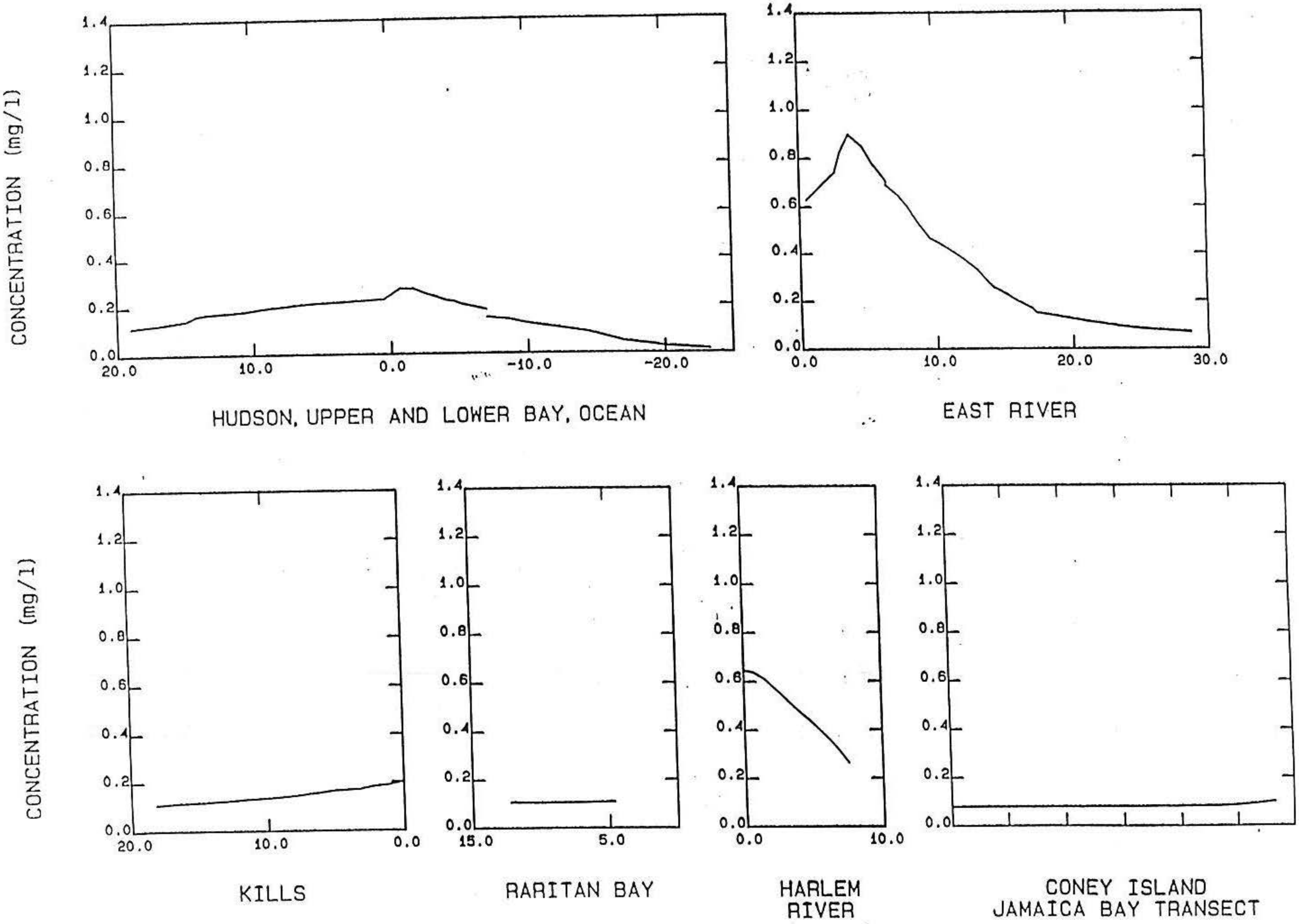


FIGURE 11. CONCENTRATION PROFILES FOR A CONSERVATIVE MASS INPUT TO THE LOWER EAST RIVER

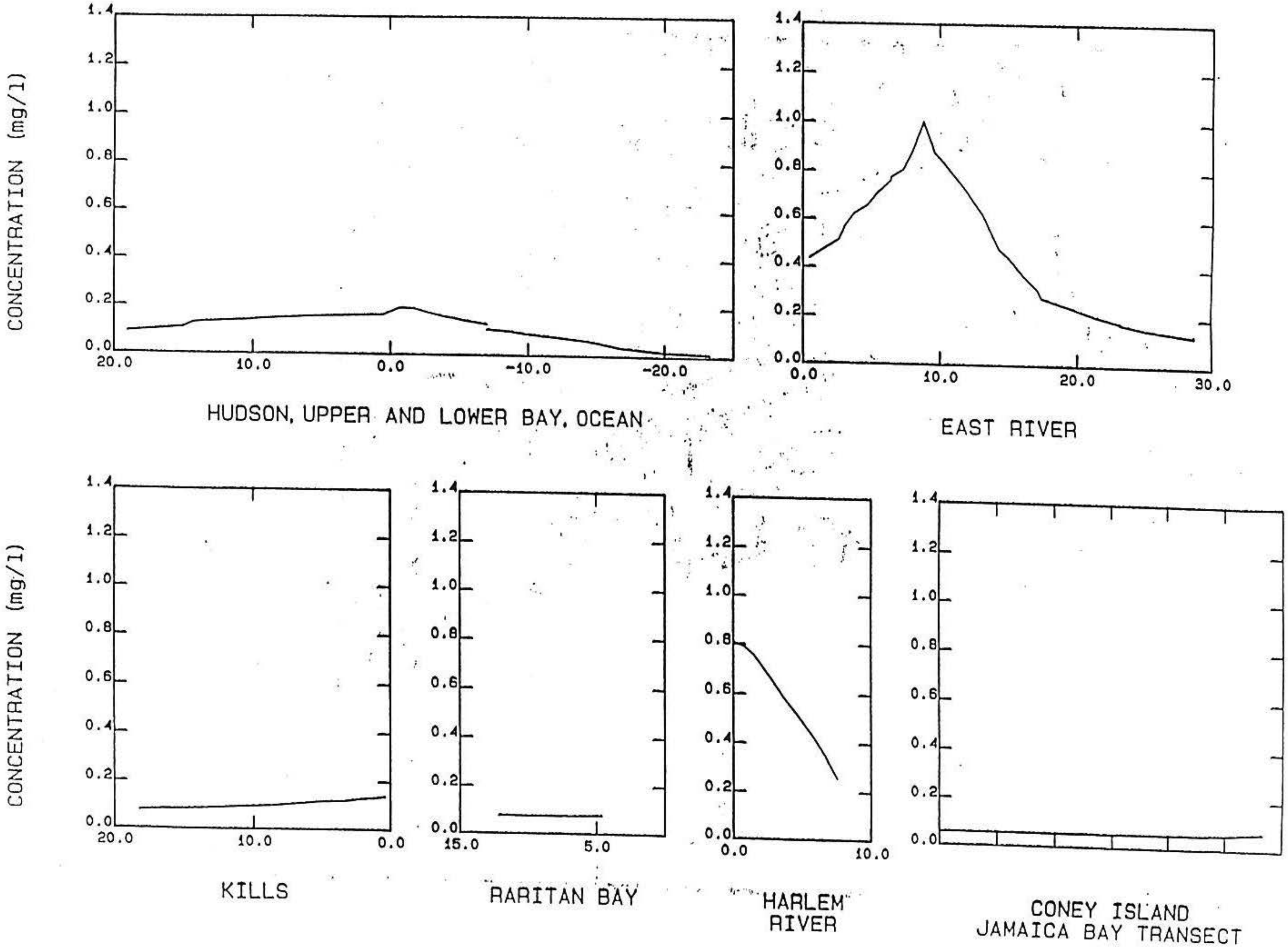


FIGURE 10. CONCENTRATION PROFILES FOR A CONSERVATIVE MASS INPUT AT WARDS ISLAND

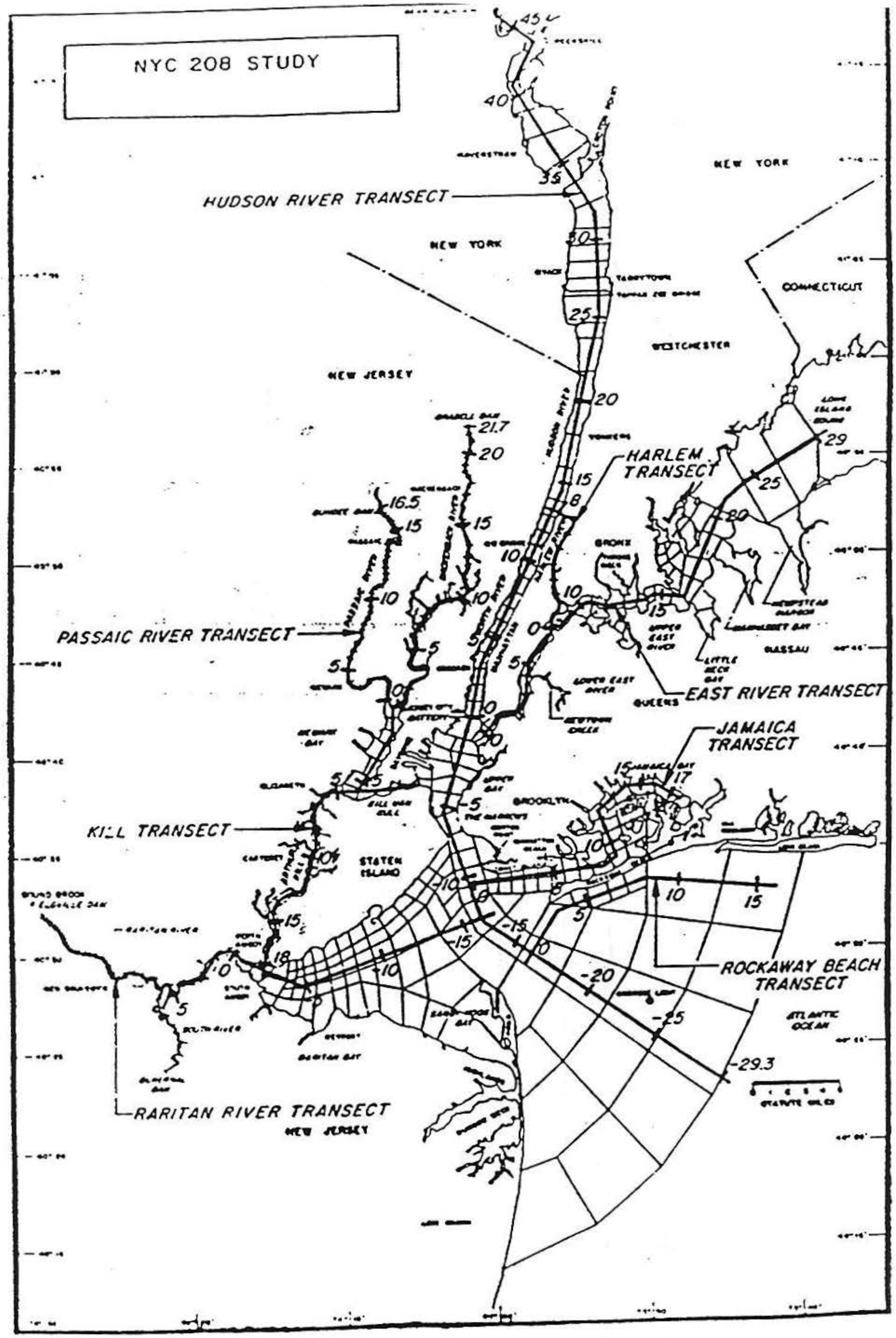


FIGURE 9. LOCATION OF CENTERLINE PLOTTING TRANSECTS

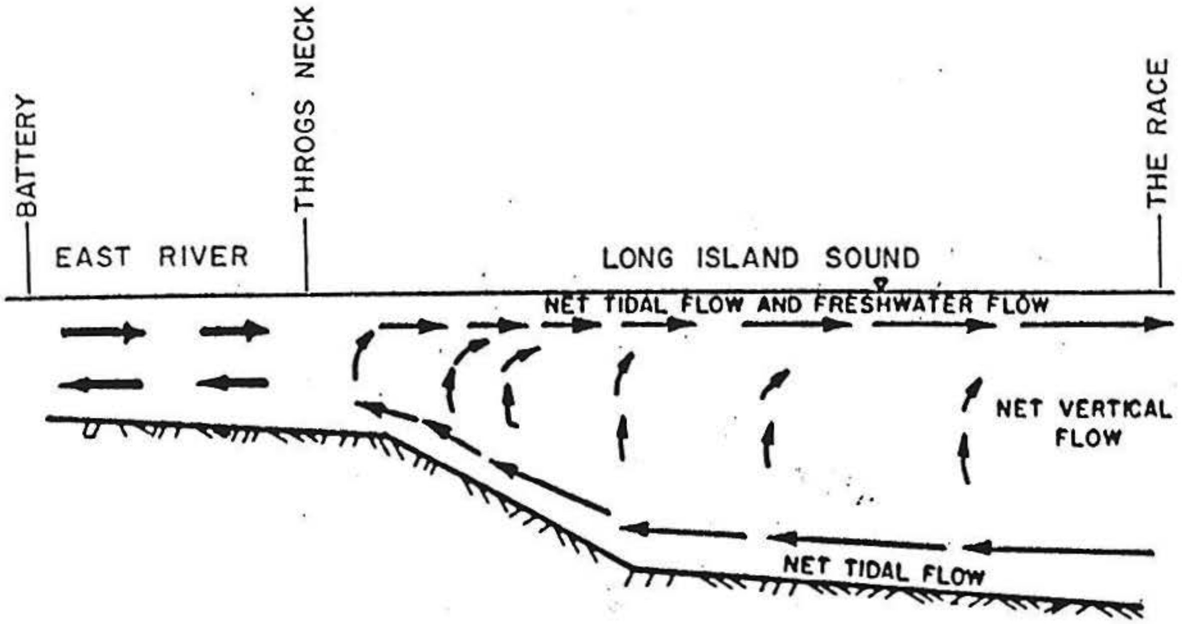


FIGURE 7. SCHEMATIC OF NET ESTUARINE CIRCULATION PATTERN

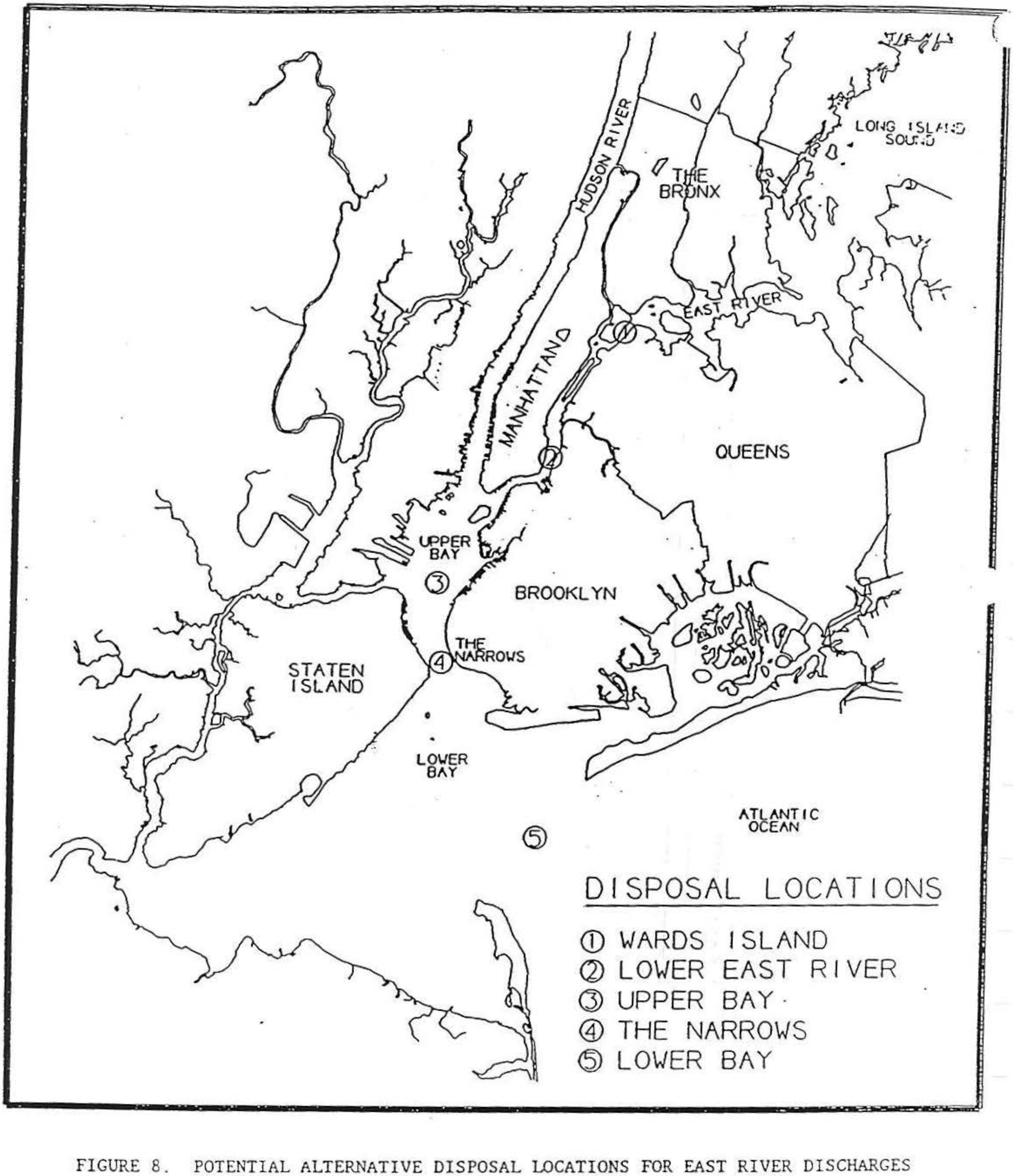


FIGURE 8. POTENTIAL ALTERNATIVE DISPOSAL LOCATIONS FOR EAST RIVER DISCHARGES

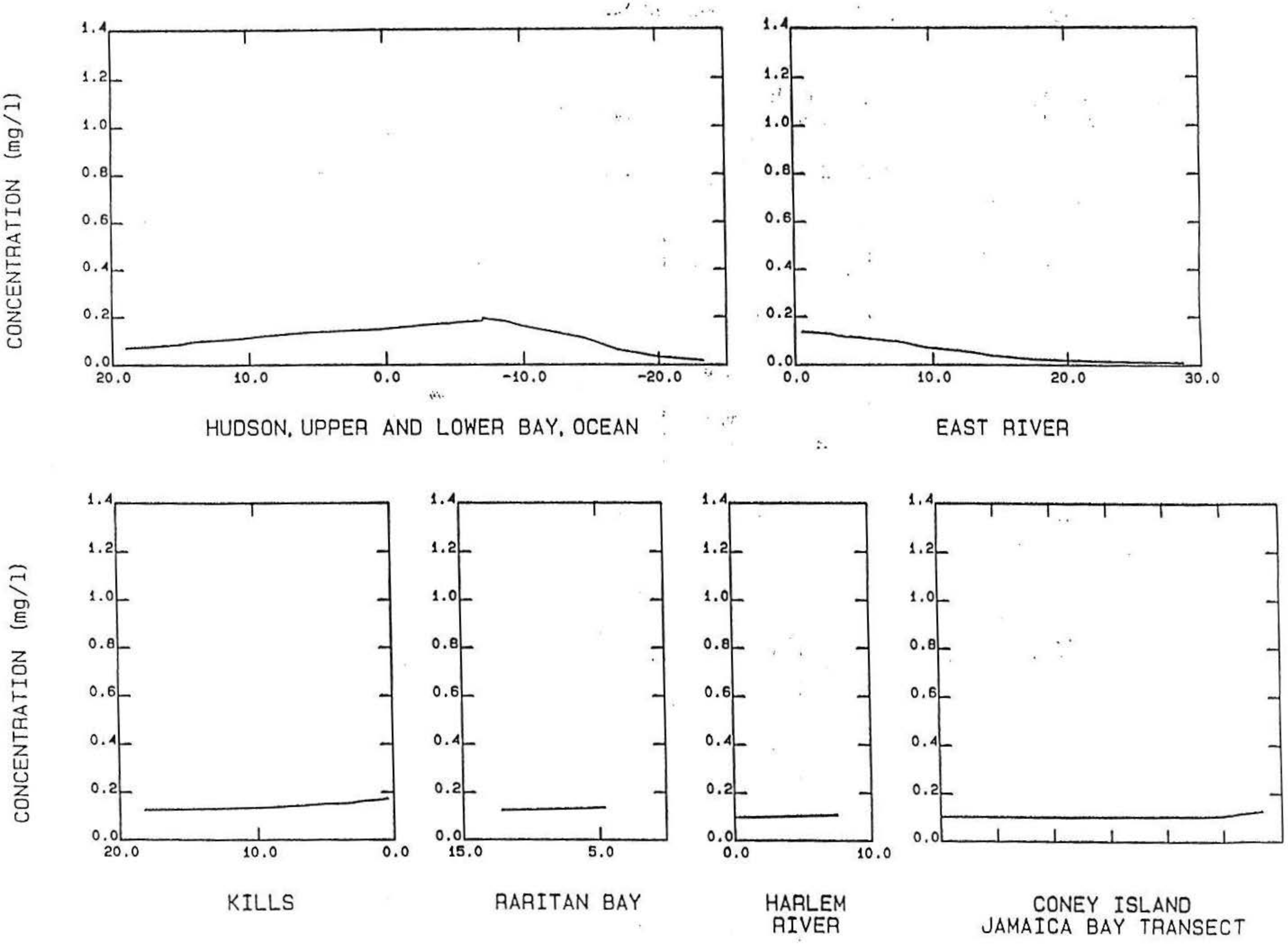


FIGURE 13. CONCENTRATION PROFILES FOR A CONSERVATIVE MASS INPUT TO THE NARROWS

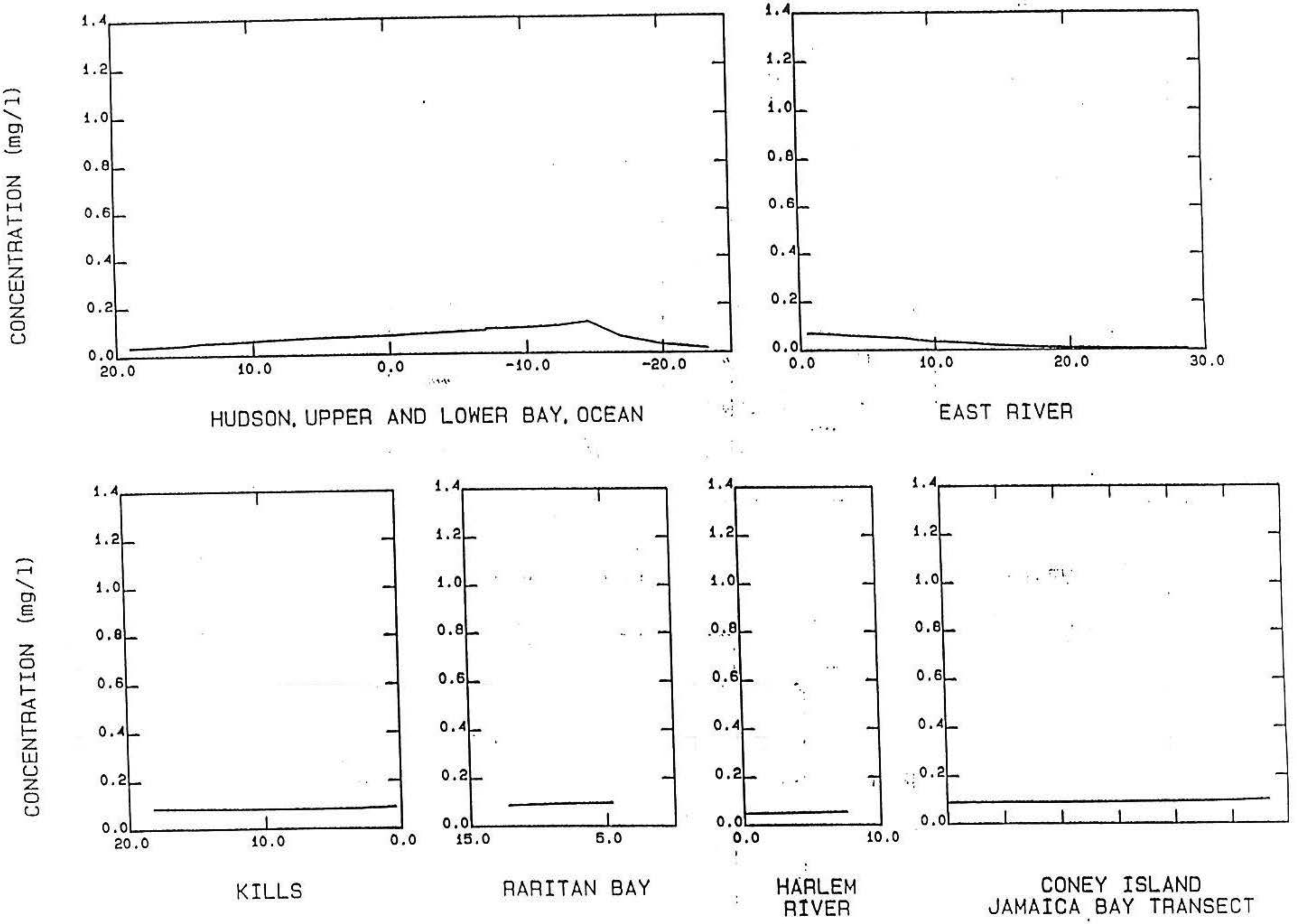


FIGURE 14. CONCENTRATION PROFILES FOR CONSERVATIVE MASS INPUT TO THE LOWER BAY

Observation of the results shown on Figures 10 through 14 indicates a progressive reduction of concentration values in the East River (milepoints 0 to 15) and western Long Island Sound (milepoints 15 to 30) as the load is successively relocated away from the sound and toward the ocean. The peak concentration in the East River for the base case of discharge at Wards Island is 1.0 mg/l (Figure 10) which is reduced to less than 0.1 mg/l for discharge to the Lower Bay (Figure 14).

Of particular interest is the sensitivity of the concentration at the critical location in the western sound (milepoint 20 - the Western Narrows) to changes in discharge location. Figure 15 is a summary of the calculated concentrations at milepoint 20 as a function of outfall location. The top panel presents actual calculated concentration values at milepoint 20 which are then normalized to the base case (Wards Island discharge) on the bottom panel. It is observed that relocation of the assumed load to the lower East River site produced a 50 percent reduction in concentration at milepoint 20 and that relocation to the Upper Bay produces a 90 percent reduction. These results suggest that relocation of load out of the East River can significantly alter the impacts of these loads on water quality in the western sound.

Examination of Figures 10 through 14 also indicates that while concentrations are sharply reduced in the East River and western sound as a result of load relocation, concentrations are increased in other portions of the harbor. For example, relocating the assumed discharge at Wards Island to the Upper Bay lowers East River concentrations by an average factor of approximately 10, lowers Harlem River concentrations by an average factor of approximately 5, but increases concentrations (due to this load) in the Upper Bay, Kills, Raritan Bay and Jamaica Bay by a factor of approximately 2. Thus, these results indicate a tenfold reduction in East River and western sound concentrations (caused by the assigned load) can be produced by outfall relocation at the expense of a twofold increase in concentration (caused by the assigned load) in other locations of the harbor.

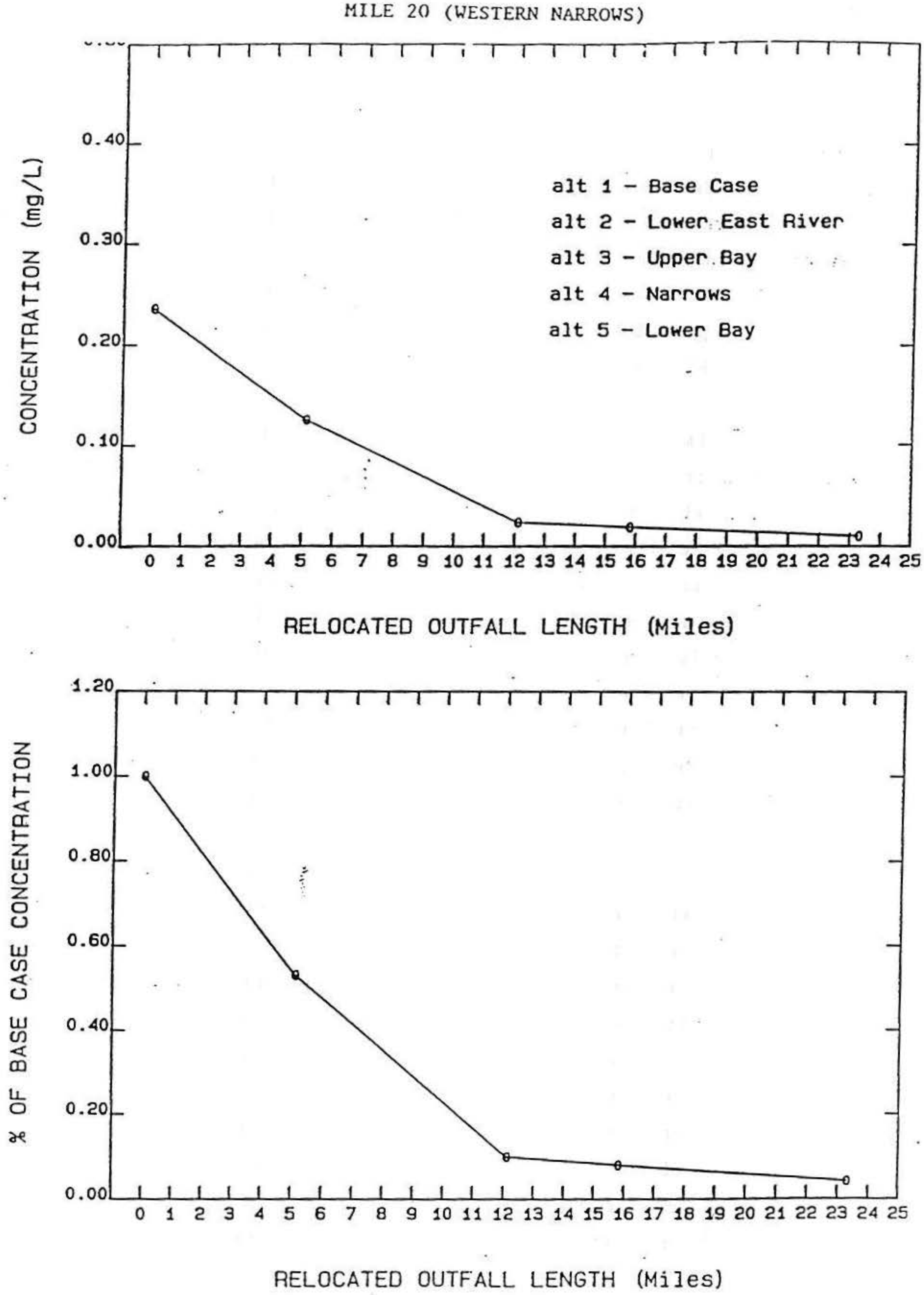


FIGURE 15. RESPONSE OF CONSERVATIVE SUBSTANCE CONCENTRATIONS
IN THE WESTERN NARROWS TO RELOCATION OF EAST RIVER LOAD

It is to be noted that the actual significance of increased concentrations in various parts of the harbor resulting from potentially relocated East River loads can only be fully assessed in a comprehensive analysis which considers all loads to the harbor. For example, although the effect of relocated East River loads could increase the fraction of a pollutant concentration due to East River loads by a factor of 2, the East River loading impact, in comparison to impacts from other harbor loads, could be relatively minor. Hence, any potential increase in pollutant concentration caused by load relocation must be compared to existing concentrations as produced by all loads.

Westchester County Discharges

The foregoing analysis indicates that relocation of loads out of the East River toward the ocean has technical merit in terms of reducing pollutant concentrations in the Western Narrows of Long Island Sound. In this section, the efficacy of relocating loads on the other side of the Western Narrows to the east toward central Long Island Sound is examined.

Four Westchester County discharges were selected for the illustrative analysis: New Rochelle, Mamaroneck, Blind Brook and Port Chester (Table 1). These plants have a combined effluent flow of approximately 30 million gallons/day and represent in excess of 3 percent of the total nitrogen loading to the sound from all STPs. Although this loading may appear to be a relatively small fraction of the total input, these discharges are in the immediate vicinity of the stressed area of the western sound and preliminary analysis indicates that discharges in this region have somewhat more of an impact on dissolved oxygen at the critical location per pound of nitrogen released than more remote discharges.

As shown on Figure 1, the four Westchester County discharges are located within a zone of approximately 8 miles on the northern shoreline of the sound immediately to the west of the Connecticut state line. For purposes of this analysis, it will be assumed that all treated effluent from these plants will be collected and conveyed on-shore to the vicinity of the Mamaroneck STP for discharge and possible relocation.

Modeling Procedure. The model of choice to evaluate, in a preliminary manner, the efficacy of relocation of the Westchester County discharges is LIS 2.0, as illustrated on Figure 2. The spatial domain of LIS 2.0 readily allows for examination of Westchester load relocation to the east, toward central Long Island Sound. For purposes of this analysis and consistency with the East River load evaluation, the Westchester County loads were considered to be conservative substances.

Modeling Results. The LIS 2.0 model was applied as follows. The various model inputs (freshwater inflows, estuarine two-layer circulation, etc.) were assigned as determined for the LIS 2.0 calibration period (April 1988 to September 1989). A mass of conservative substance (as a surrogate for total nitrogen) was input into model segment WN3 (Figure 2) as representative of the Westchester County discharges. The mass discharge was arbitrarily assigned to produce a peak concentration of 1.0 mg/l at the discharge for ease of reference. It was assumed that the concentration of conservative substance at the boundaries of the model from these loads would be reduced to zero by external dilution processes and boundary conditions were so assigned. The model was executed for the base case and the concentration of conservative material was calculated throughout the model domain. The same mass loading was then input at other locations in Long Island Sound as shown on Figure 16 and the model re-executed to calculate the system sensitivity to discharge location. The alternative discharge positions were considered to be located in model segments EN1, EN2, EN3, WB1, WB2 and WB3 (Figure 16). In all cases, it was assumed that an effectively operating diffuser manifold was in place at the terminal location of the outfall so that the effluent would reach the surface, even under conditions of high density stratification. Although effluent nutrients would thus be placed in surface waters and, therefore, immediately available for phytoplankton growth, positioning such nutrients in surface waters to the east of the critical area would take advantage of the existing estuarine circulation (Figure 7) and transport materials away from the problem area.

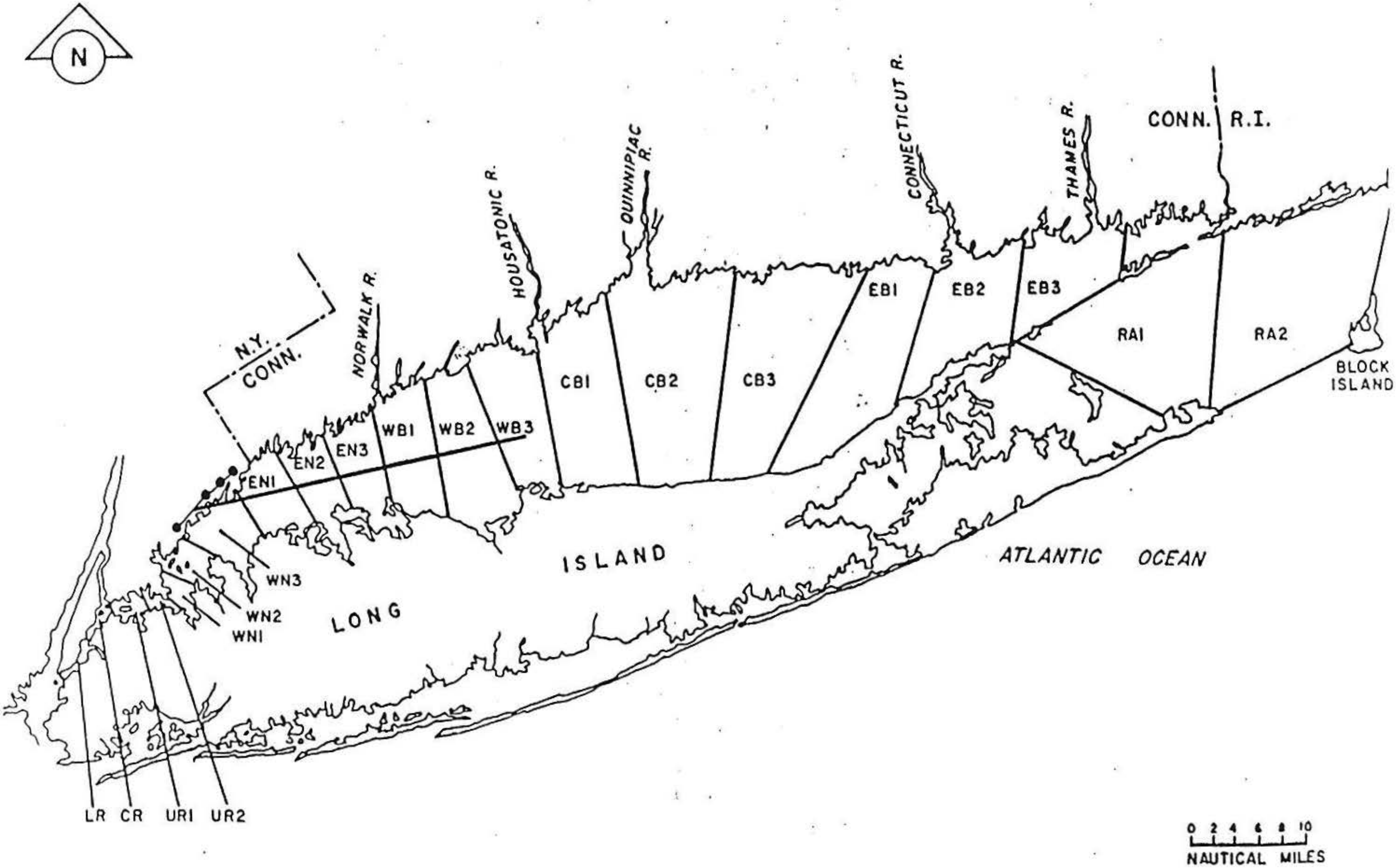


FIGURE 16. ILLUSTRATIVE DISPOSAL LOCATIONS FOR WESTCHESTER COUNTY DISCHARGES

Modeling results for three of the alternative discharge locations are compared to the base case on Figure 17. Spatial concentration distributions of conservative substance as calculated for May 1989, the beginning of the summer algal bloom, are presented on a mileage scale, distance from the Battery. Concentration distributions are presented as calculated in both the upper and lower layers of the LIS 2.0 model. The peak concentration in the upper layer for the base case of 1.0 mg/l is progressively reduced as the load is relocated eastward toward the central sound. For the maximum relocation considered, discharge to WB3 30 miles to the east, the peak concentration is reduced only to approximately 0.5 mg/l, presumably by additional dilution from the two layer estuarine circulation pattern (Figure 7).

Figure 18 shows the concentration response in model Segment WN2 (the critical Western Narrows location) for the various location alternatives. The top panel presents actual calculated concentration values in Segment WN2 for the various relocation alternatives. The top panel presents actual calculated concentration values in Segment WN2 which are then normalized to the base case (discharge to Segment WN3) on the bottom panel. It is observed that in order to reduce the Western Narrows concentration which results from this load by 50 percent, an outfall relocation of more than 15 miles to the east is required. Further, these results suggest that in order to reduce the Western Narrows concentration from this load by 75 percent, an outfall relocation of greater than 30 miles would be required.

The reductions in concentration in the Western Narrows as a result of outfall relocation toward the central sound indicate that fairly extensive distances are required to produce desired levels of response. It is considered that the estuarine circulation pattern which exists in Long Island Sound (Figure 7) is responsible for the attenuated response. Pollutant inputs to the upper layer are transported eastward away from the critical area. However, vertical dispersion processes gradually mix the surface and lower layers and some of the pollutant material is transported in the lower layer in a westerly direction back toward the discharge and the critical area. Because of this trapping and recycling of material, relocation of loads to the east toward the

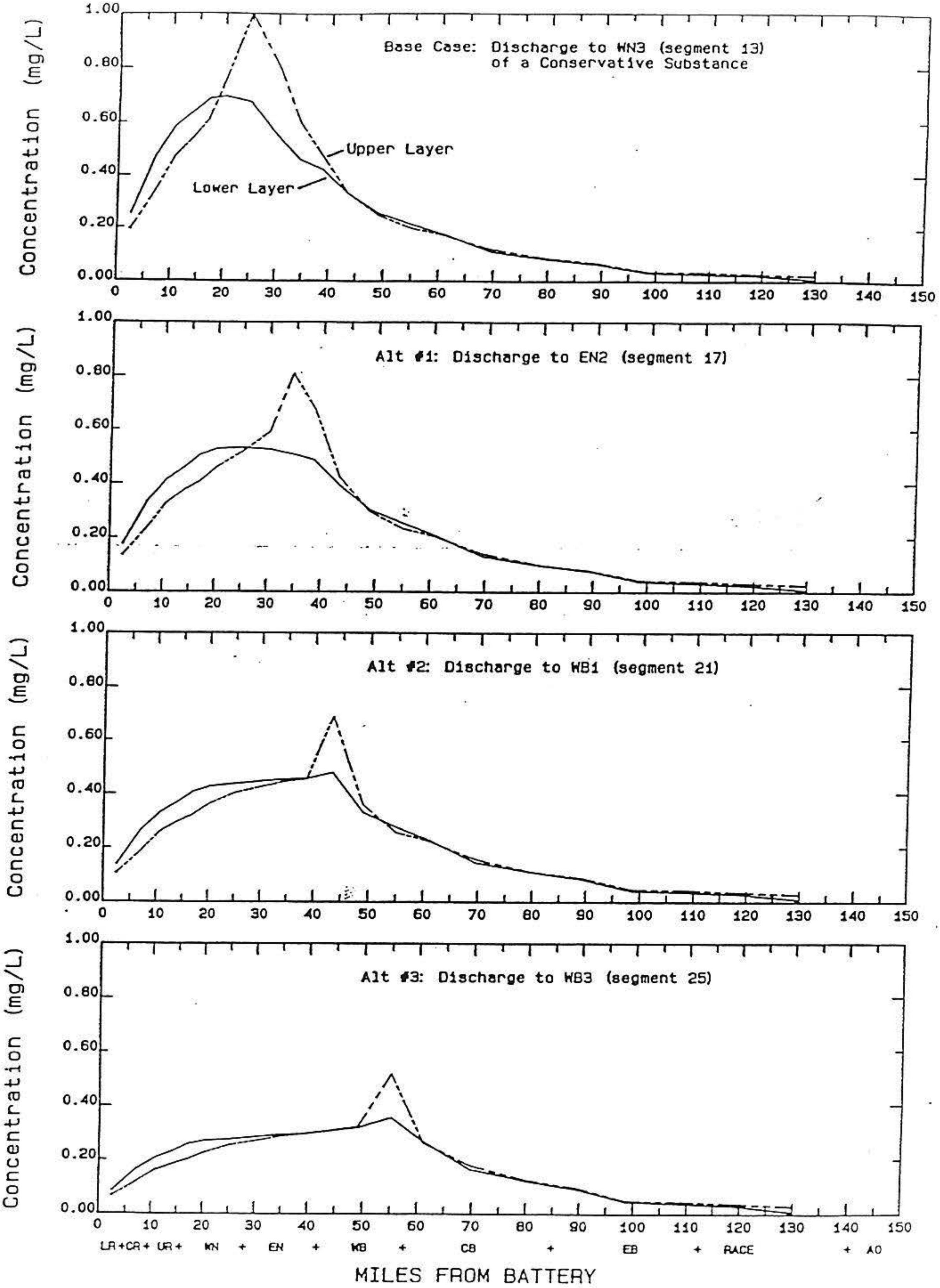


FIGURE 17. LONG ISLAND SOUND SPATIAL PROFILES
MAY 1989

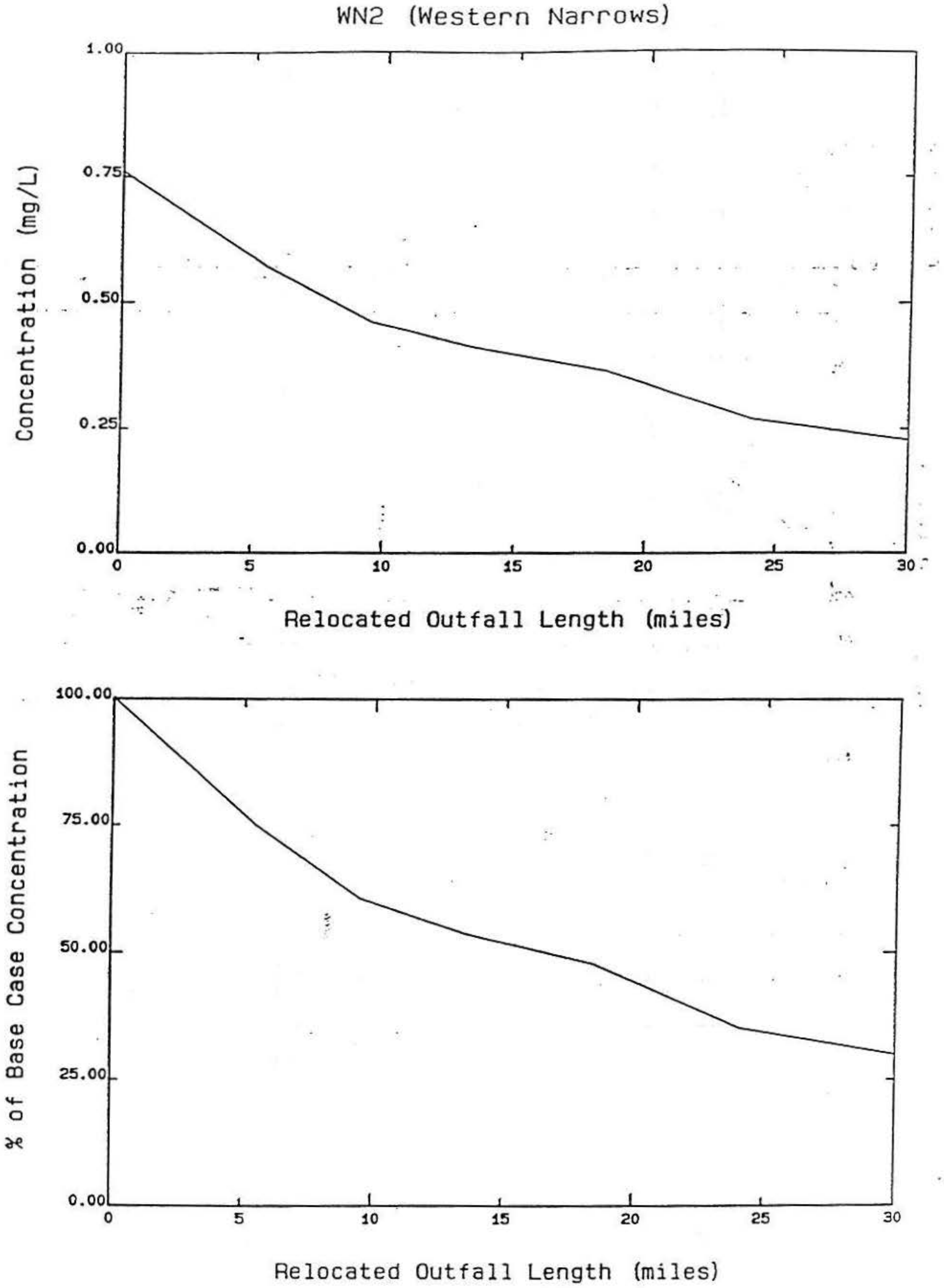


FIGURE 18. RESPONSE OF CONSERVATIVE SUBSTANCE CONCENTRATIONS IN WESTERN NARROWS TO RELOCATION OF WESTCHESTER COUNTY LOAD

central sound do not produce as pronounced a reduction in concentrations values in the Western Narrows as otherwise might be expected.

It is noted that much of the results and discussion presented here is based upon preliminary circulation patterns as established by calibration of LIS 2.0 with observed salinity and temperature date. All results should be considered tentative until final evaluation of estuarine circulation patterns with the hydrodynamic component of LIS 3.0 are completed.

ENGINEERING AND COST CONSIDERATIONS

The illustrative results of the foregoing section indicate that relocation of the East River loads (from the assumed Wards Island location) toward the harbor entrance and relocation of Westchester County loads on the order of 15 to 30 miles toward the central sound would reduce the concentration in the critical area of the western sound by 50 to 75 percent or more, the same order of reduction which may be considered for mid level and high level nitrogen removal at municipal treatment plants. However, the concept of outfall relocation to control hypoxia in western Long Island Sound is a viable alternative to nitrogen removal only to the extent that it is feasible in the engineering sense and cost competitive. The feasible engineering approaches which are considered in this analysis by which to develop first estimates of the order of magnitude of costs associated with outfall relocation are: (1) a deep tunnel for relocation of the East River loads and (2) a submarine outfall pipeline for relocation of Westchester County loads.

East River Discharges

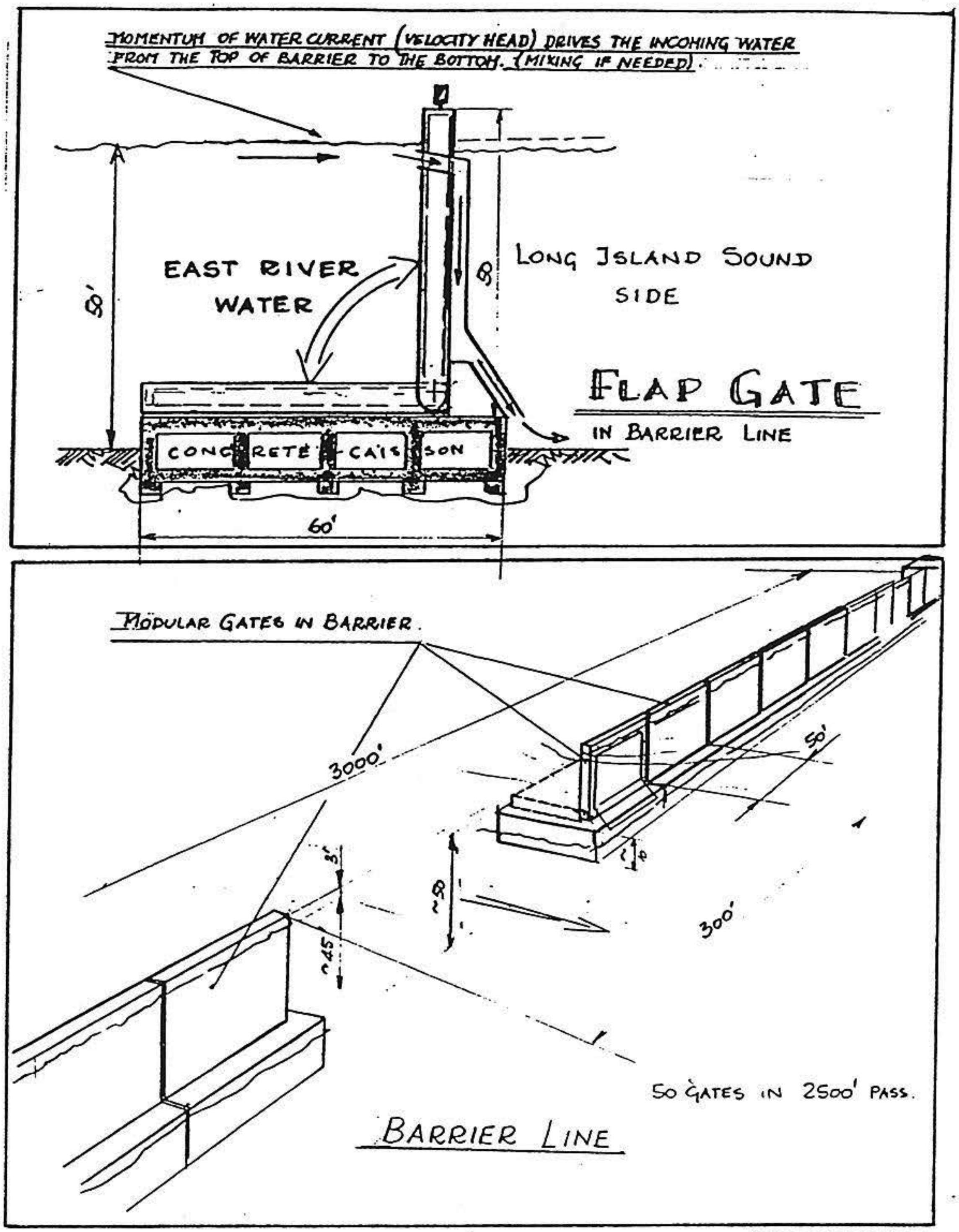
The construction of a deep tunnel to convey East River loads to new potential disposal locations was considered to have substantial merit as a relocation alternative. Tunneling technology has progressed to the point where it is quite feasible and cost competitive in comparison to other conveyance alternatives. In this potential application, tunnel construction: (1) can produce a single conduit which is sufficiently large to accommodate all East

River STP discharges, (2) takes advantage of local geotechnical features (bedrock), (3) causes minimal surface disruption on water and land, (4) may have application for other uses, e.g., retention of combined sewage, and (5) is relatively easy to accomplish with present day technology.

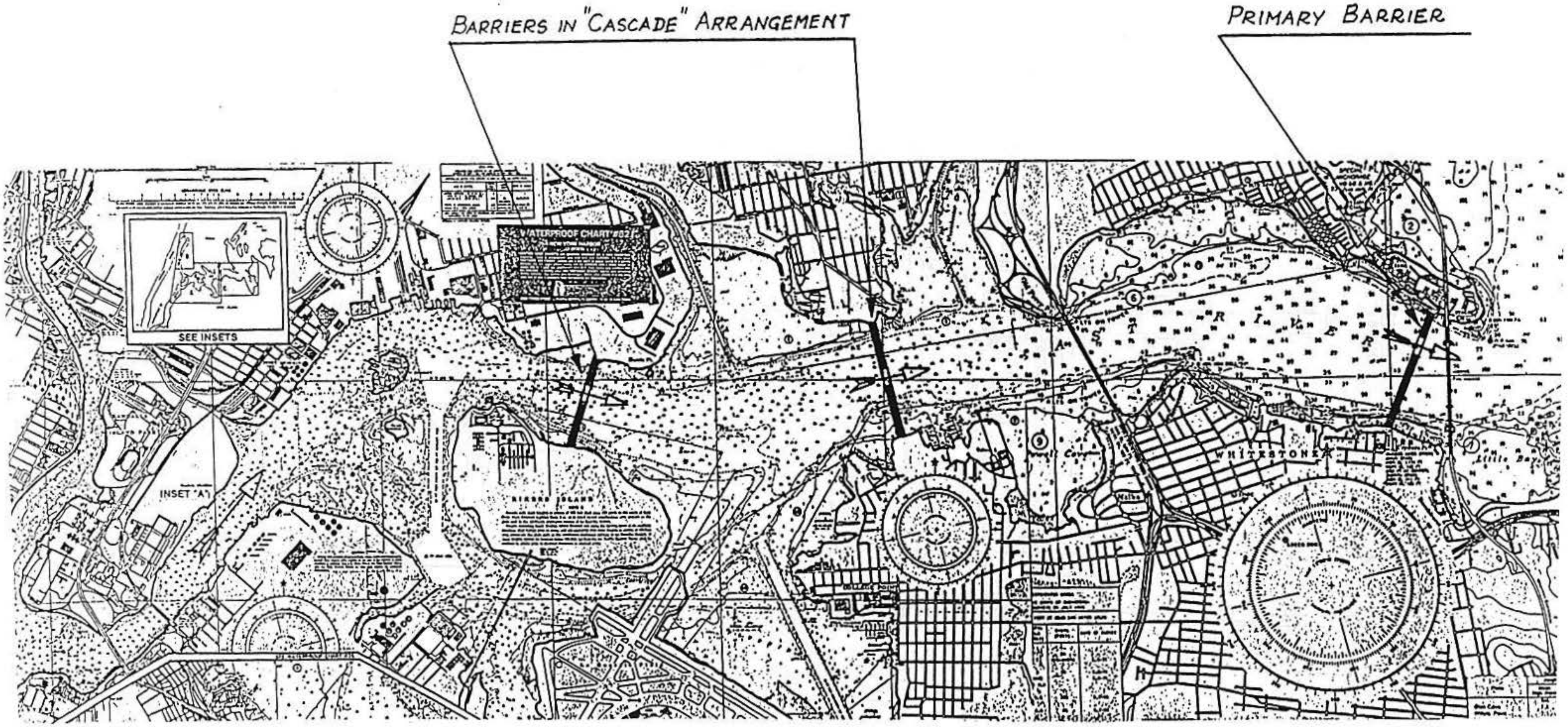
The analysis of relocation of the East River discharges (from the assumed Wards Island central disposal location) as summarized on Figure 15, indicates that Western Narrows concentrations produced by these loads can be reduced by approximately 50 percent by relocating the loading to the lower East River, a distance of approximately 5 miles. However, such a relocation is not likely to materially improve water quality conditions in the East River proper. Consequently, it is assumed that if the concept of the East River load relocation is to be considered viable, the results should be water quality improvement in the East River as well as western Long Island Sound. Consequently, the alternative relocation scenario which potential improves both East River conditions as well as Long Island Sound as compared to the base case is conveyance to the Upper Bay (Figures 10 and 12).

The preliminary modeling analysis described previously assumed that all East River loads were effectively discharging at Wards Island. However, for a preliminary order of magnitude cost analysis, the actual physical location of the East River STPs is considered. It is assumed that a deep tunnel will be constructed to collect effluent beginning at the easternmost STP in the East River, Tallman Island, and then be routed along the East River to collect other STP discharges as shown on Figure 19. The tunnel would then be extended as necessary to terminate at a selected disposal location. Three such extensions are shown schematically on the diagram. For preliminary costing estimates, the following tunnel lengths are assumed from Tallman Island to the potential terminal points: Upper Bay, 15 miles; the Narrows, 20 miles; and the harbor entrance at the Sandy Hook-Rockaway Point transect, 25 miles.

The preliminary tunnel plan and cost estimates are based on the following:


MOMENTUM OF WATER CURRENT (VELOCITY HEAD) DRIVES THE INCOMING WATER FROM THE TOP OF BARRIER TO THE BOTTOM. (MIXING IF NEEDED).
EAST RIVER WATER
LONG ISLAND SOUND SIDE
FLAP GATE
IN BARRIER LINE
CONCRETE CAISSON
80'
80'
60'
MODULAR GATES IN BARRIER.
3000'
50'
300'
3'
~45
~80
10
50 GATES IN 2500' PASS.
BARRIER LINE

Dwg. 4.



DWG. 5

EASTBOUND TIDE CURRENT – BARRIERS IN CLOSED POSITION – RESTRICTED FLOW EAST

(when tide current WESTBOUND – barriers open – UNRESTRICTED FLOW TO WEST.)

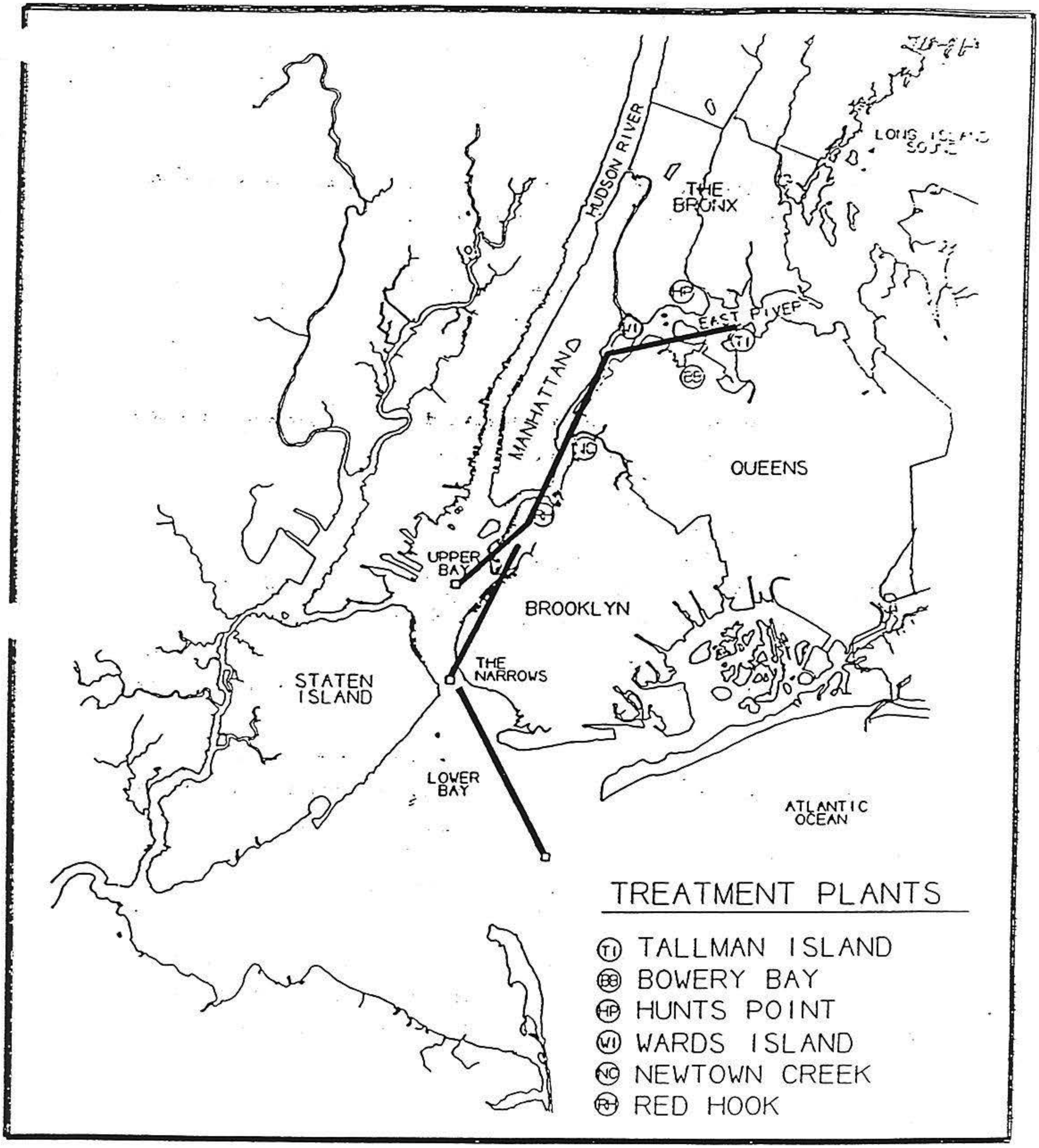


FIGURE 19. PRELIMINARY TUNNEL ROUTES TO ALTERNATIVE DISPOSAL LOCATIONS

- Collection and conveyance of all treatment plant discharges in the East River: Tallman Island, Bowery Bay, Hunts Point, Wards Island, Newtown Creek, Red Hook.

- Assumed effluent flow rates: 1,100 million gallons/day (dry weather), 2,200 million gallons/day (wet weather).

- Tunnel size: assume constant 22 foot diameter finished tunnel for entire length (actual diameter will vary as effluent is collected) constructed by tunnel boring machine.

- Tunnel depth: 300 feet to 600 feet deep in competent bedrock sloping downward toward the terminal location.

- Tunnel components:
    - 3 - 40 foot diameter workshafts
    - 8 - 10 foot diameter dropshafts with surge tanks
    - 1 - 20 foot diameter riser and header
    - 1 multi-port diffuser system
    - 6 effluent pumping stations (total of 2,200 million gallons/day).

Preliminary order of magnitude cost estimates were developed for the foregoing plan and included provision for miscellaneous equipment requirements, power during construction, contingency, engineering, administrative and legal fees.

Table 3 presents the preliminary estimated capital costs for tunnels with various terminal points and the resulting estimated concentration reduction of conservative substance in the Western Narrows. The estimated cost (New York State Department of Environmental Conservation [NYSDEC] 1991) for nitrogen removal by advanced treatment at the East River plants is presented for comparison.

TABLE 3. PRELIMINARY CAPITAL COST SUMMARY
(MILLIONS OF 1991 DOLLARS)

Outfall Tunnel			Nitrogen Removal		
Length	% Reduction(1)	Cost	Level	% Removal	Cost
15 Miles	90	\$3,000	Mid	50	\$5,800
20 Miles	92	\$3,500	High	72	\$7,000
25 Miles	95	\$4,000			

(1) of conservative material in the Western Narrows due to relocation of East River loads assumed to be located at Wards Island (Figure 15).

Table 3 indicates that the various outfall tunnel alternatives which cause a 90 to 95 percent concentration reduction in the Western Narrows appear to compare favorably on a capital costs basis with advanced nitrogen removal of 50 to 72 percent at the treatment plants. Although operations and maintenance costs for the tunnel have not be estimated, it is expected that such costs would also compare favorably with those for advanced treatment.

It must be emphasized that all estimated costs are highly preliminary in nature and are presented for first comparisons only. In addition, the following points are noted regarding the outfall tunnel alternative:

- The plan considered above assumes interception and conveyance of all East River loads. Other viable alternatives which may be considered are interception and relocation of selected East River loads only, e.g. the upper East River loads (Wards Island, Hunts Point, Bowery Bay, Tallman Island).
- An alternative which may be considered to tunnel construction is extending existing outfalls along the bottom of the East River to the various potential terminal points. This alternative, however, which involves extensive marine construction, is likely to be expensive and disruptive.

- Issues which remain to be evaluated include sediment and solids deposition in the tunnel structure, marine construction details of the river section of the tunnel, detailed tunnel hydraulics and surge tank evaluations, geology along the tunnel route, and the possibility of integrating combined sewer overflow (CSO) retention facilities into the tunnel system.

Notwithstanding the foregoing qualifications, it is considered on a preliminary basis that outfall relocation of the East River loads by tunnel is a viable alternative for control of hypoxia in western Long Island Sound.

Westchester County Discharges

The engineering alternative which was considered most viable for relocation of the Westchester County discharges was construction of a submarine outfall pipeline. The basic approach herein for relocation of these discharges consists of consolidating individual treatment plant discharges at a centralized point on-shore and then conveying these flows to various potential terminal points to the east toward central Long Island Sound. In accordance with the results shown on Figure 18, outfall lengths to 30 miles must be considered in order to produce the required response in the Western Narrows. In this illustrative plan, preliminary cost estimates are based on the following:

- Collection and conveyance of four Westchester County treatment plant discharges: New Rochelle, Mamaroneck, Blind Brook and Port Chester - total design flow approximately 45 million gallons/day.

- Construction of on-shore sewers, effluent pumping stations, and associated appurtenances as needed to convey effluent flows to a central point in the vicinity of Mamaroneck.

- Construction of a 72 inch diameter submarine pipeline from Mamaroneck to various terminal points in Long Island Sound requiring lengths from 5 miles to 30 miles (Figure 16).

- Construction of a diffuser using a design to force penetration of the pycnocline and place the effluent in the surface layer.

- Trench excavation, backfilling, rock excavation, pile bedding, concreting and pipe support foundations as needed (Figure 20).

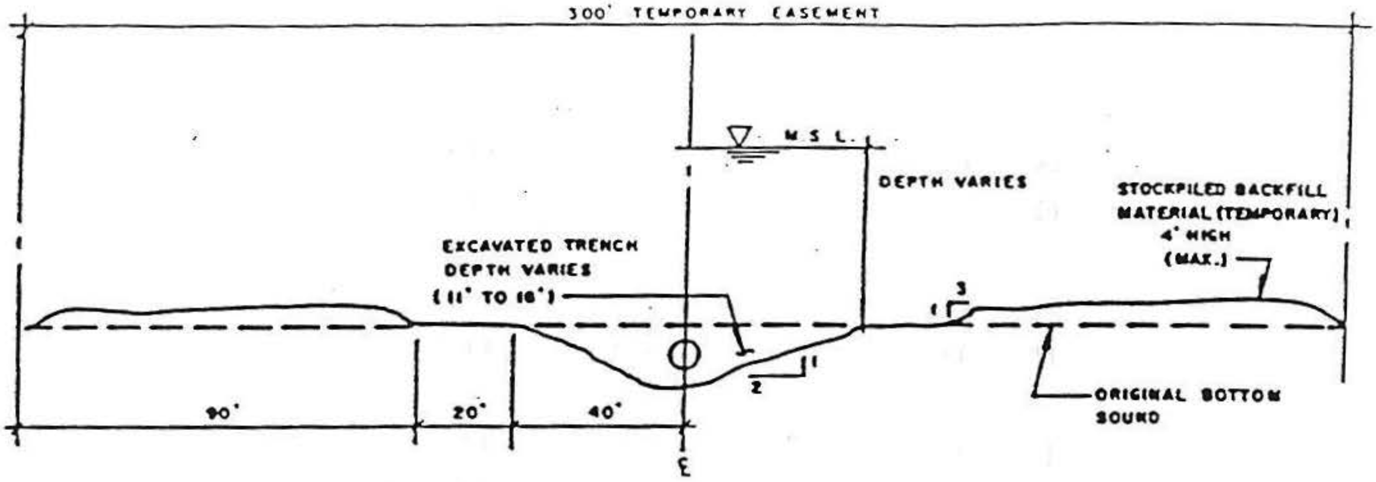
Preliminary order of magnitude cost estimates were developed for the foregoing plan including contingency, engineering, administrative and legal fees. Table 4 presents a summary of the preliminary estimated costs for outfall relocation to various terminal points and estimated concentration reductions of conservative substance in the Western Narrows. The estimated costs (NYSDEC 1991) for nitrogen removal by advanced treatment of the Westchester County plants is presented for comparison.

TABLE 4. PRELIMINARY CAPITAL COST SUMMARY
(MILLIONS OF 1991 DOLLARS)

Outfall Pipeline			Nitrogen Removal		
Length	% Reduction[1]	Cost	Level	% Removal	Cost
5 Miles	25	$158			
10 Miles	40	$277			
15 Miles	50	$395	Mid	50	$224
20 Miles	55	$514			
30 Miles	70	$751	High	72	$276

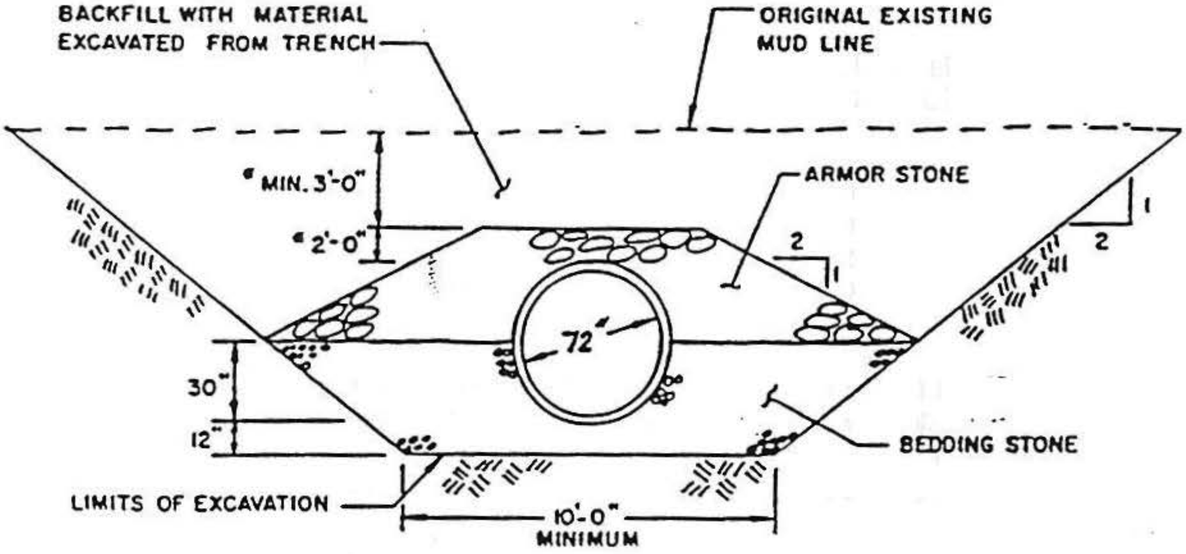
[1] of conservative material in the Western Narrows due to relocation of Westchester County loads assumed to be located in LIS 2.0 model segment (WN3) (Figure 18).

Table 4 indicates that the costs for outfall pipeline lengths of 15 miles and 30 miles which appear to be necessary to attain required concentration reductions in the Western Narrows do not compare favorably with estimated costs for nitrogen removal by advanced treatment. Operation and maintenance cost considerations could make the comparison somewhat more favorable. However, it is noted that the estimated costs for nitrogen removal by advanced treatment are on the high end of the working engineering range. Lower treatment costs would make the cost comparison even more unfavorable for outfall relocation.



TRENCH EXCAVATION
FOR OUTFALL CONSTRUCTION

(TYPICAL SECTION)



SUBAQUEOUS TRENCH DETAIL

NOT TO SCALE

FIGURE 20. OUTFALL PIPELINE DETAILS

It is emphasized that all estimated costs are highly preliminary in nature and presented for first comparisons only. In addition, the following points are noted regarding the outfall pipeline alternative:

- The preliminary plan assumed that the outfall pipeline would be constructed almost entirely off-shore. Some savings could possibly be realized by constructing the conveyance line on-shore as far as possible and then into the sound as necessary in order to minimize marine construction. However, this would involve crossing state and other jurisdictional boundaries thus limiting political acceptability.

- The cost estimate for the preliminary outfall relocation plan must be considered as uncertain due to a number of factors: lack of detailed geotechnical data on-shore and underwater; basic assumptions regarding land access, sewer routing, water depths, piling requirements; and lack of information regarding permitting restrictions, utility interferences, etc.

- The preliminary plan assumed relocation of the Westchester County discharges to the east. No consideration was given to possible relocation to the west and conveyance to a potential East River tunnel.

Notwithstanding the foregoing, the preliminary analysis conducted as described indicates that relocation of outfalls from the Westchester County discharges does not appear to be a cost effective alternative to nitrogen removal by advanced treatment.

BENEFITS OF OUTFALL RELOCATION

The analyses performed for this paper indicate, on a preliminary basis, that relocation of East River discharges to a zone between the Upper and Lower New York Bays appears to be a cost effective alternative to nitrogen removal at sewage treatment plants to alleviate hypoxia in western Long Island Sound.

Relocation of Westchester County discharges toward the central sound (and by inference other loadings on Long Island and in Connecticut) does not appear to be cost effective for this purpose. Consequently, the potential benefits associated with outfall relocation are discussed primarily for the East River load relocation alternative.

The potential benefits which may be realized by relocation of the East River outfalls are summarized as follows.

Improved Dissolved Oxygen in Western Long Island Sound

The primary objective of the outfall relocation is to improve dissolved oxygen in the western sound. The preliminary analysis would suggest that dissolved oxygen in the western sound can be improved at least to the same extent, it not a greater degree, by relocation of the East River loads as described as would result from nitrogen removal at the sewage treatment plants.

Improved Dissolved Oxygen in the East River

An attendant benefit of relocating loads out of the East River would be to improve dissolved oxygen conditions in that waterway. It is estimated that approximately 35 percent of the dissolved oxygen depression which exists at present in the East River proper is the result of instream oxidation of organic carbonaceous materials (biochemical oxygen demand [BOD]) discharged from the sewage treatment plants. Relocation of East River loads would alleviate this depression in the East River. In addition, dissolved oxygen conditions in the various East River tributaries, Newtown Creek, Flushing Bay and Creek, Bronx River, Pugsley Creek and Westchester Creek, and the Hutchinson River would be improved to the extent that water quality conditions in those areas are affected by tidal exchange with the East River proper. In addition, the effect of the planned reactivation of the Gowanus Canal flushing tunnel would be enhanced by recirculation of water (from the vicinity of the Brooklyn Navy Yard) of higher dissolved oxygen content.

Reduction of Toxics Concentrations in the East River

An investigation is presently in progress within the New York - New Jersey Harbor Estuary Program to identify problem toxic metals which exist in the harbor and adjacent waters and perform wasteload allocations as required. To the extent that any toxic metals problem is identified within the East River, outfall relocation will reduce such concentrations. Even if applicable standards are not contravened, relocation of the large volume of East River loads to other areas of greater assimilation capacity will reduce potential toxicant concentration values in the East River proper. The concentration of trace metals, problem organics and residual chlorine (from effluent disinfection) will be so reduced. Any toxic effects of East River discharges on the western sound would also be mitigated.

Potential Reduction of CSO Impacts

It is possible that construction of an East River tunnel could be designed in such a manner to permit integration of control facilities for CSOs. The NYCDEP is currently conducting city-wide studies (NYCDEP) to determine those facilities which are required for CSO control. It is possible that the concept of an East River tunnel could be integrated into the East River and Inner Harbor CSO Facility Plans currently in progress. One concept would be to oversize the tunnel to accommodate CSO flows and to use the tunnel during rainfall events exclusively for retention of CSO while discharging treatment plant effluents at current locations. The retained CSO volume would then be conveyed to a CSO treatment facility for processing. These are operational considerations requiring detailed engineering evaluations. To the extent that integration of CSO control facilities is possible with the outfall tunnel, attendant water quality benefits would include reduction of total and fecal coliform bacteria (and pathogen) concentrations in the East River and control of floatable materials. There will also be some additional beneficial effect on East River dissolved oxygen levels. Any effects of East River CSO discharges on the western sound would also be mitigated.

Improved Habitat for Living Marine Resources

As discussed, relocation of STP discharges by construction of an outfall tunnel could have multiple water quality benefits in western Long Island Sound and the East River. The general improvement in water quality in both locations in terms of improved dissolved oxygen and reduction in the concentration of potential toxicants would presumably enhance the environment for fish, shellfish and benthic communities.

Conserve Capital Resources

The preliminary analysis indicates that tunnel construction for outfall relocation compares vary favorably on a cost basis with nitrogen removal by advanced treatment. It is possible that substantial capital and operational and maintenance resources could be saved using this alternative, or perhaps redirected toward other pressing environmental matters (e.g., sludge management, STP upgrades, CSO control, toxics reduction, water supply, air quality, etc.).

POTENTIAL ADVERSE IMPACTS

The large scale relocation of loads from the East River to an alternative disposal location may result in adverse impacts which are summarized as follows.

Adverse Water Quality Impacts at New Discharge Location

While relocation of loads will improve water quality conditions in Long Island Sound and the East River, some level of degradation will occur at the selected discharge location. Dissolved oxygen will be decreased and concentrations of potential toxics will be increased by some amount. The operative question is: what is the comparison (trade-off) of improvements in the western sound and in the East River as compared to degradation at the site of relocation? It is judged from very preliminary calculations that the comparison is favorable to relocation. Tidally induced circulation, dispersion and other transport processes are much greater in the Upper and Lower Bay potential disposal zones than in the East River. It appears that changes in water quality at the alternative disposal locations could be relatively small in comparison to existing conditions. Construction of an effective large scale multi-port diffuser system would be required to minimize impacts.

Introduction of Additional Pollutant Load into Hudson River Circulation

Relocation of East River loads to the Upper or Lower Bays could introduce pollutants into the estuarine circulation of the Hudson River (similar to the Long Island Sound circulation shown on Figure 7). Any pollutants entering the lower layer would be transported up into the Hudson River with the tidally averaged flow along the bottom for some distance before being mixed with the surface layer (downstream) flow. This potential impact can be mitigated to some extent by design of the diffuser field at the terminal point of the tunnel to cause the diluted effluent to rise to the surface, even during periods of strong density stratification.

Increased Nutrient Flux to New York Bight and Raritan Bay

The New York Bight Restoration Plan (U.S. Environmental Protection Agency 1989) is currently sponsoring an investigation to assess the impact of the flux of nutrient materials from New York - New Jersey Harbor on recurrent hypoxia in New York Bight. It is possible that relocation of the East River loads to the Upper or Lower Bay will increase the total flux of nutrient materials from harbor to bight by some amount. Any potential increase in hypoxia in the bight should be compared with improved dissolved oxygen in the western sound and East River. The effect of relocated nutrient loads on eutrophic conditions in Raritan Bay should also be assessed.

Adverse Impacts at Ocean Beaches

Relocation of discharges from the East River to the inner harbor will bring such loadings closer to ocean beaches (Staten Island, Coney Island, Raritan

Bay, Rockaway and Sandy Hook). The principal concern would be potential increased pathogenic contamination. This potential impact, however, is mitigated by disinfection of treatment plant effluents which is now practiced year-round. Consequently, increases in coliform bacteria concentrations at these beaches due to STP load relocation is expected to be minor. The effectiveness of disinfection on reduction of actual pathogens as compared to coliform bacteria is an issue to be addressed. Potential bacterial increases at ocean beaches resulting from incorporation of CSOs into the tunnel plan would be mitigated by treatment and disinfection.

Disruption of Habitat near the Diffuser Field

Construction of the diffuser field at the selected terminal point will alter the habitat of the benthic community in the affected area. An additional closure zone for shellfishing may also be necessitated. However, the terminal point is not likely to be situated in waters either classified or used for shellfishing.

OTHER CONSIDERATIONS

Other factors which deserve consideration in the evaluation of the efficacy of outfall relocation include the following.

Public Acceptance

The concept of load relocation to initiate water quality impacts resulting from treatment plant discharges may not be acceptable to members of the public who believe that pollutant load reduction by treatment is the preferable procedure.

Enhancement/Reduction of Primary Productivity

Opinion has been expressed (MSRC 1991) that outfall relocation could adversely effect primary productivity and fisheries in Long Island Sound and enhance productivity in New York Bight. Regarding the sound, any outfall relocation would be designed to have approximately the same effect as nitrogen removal at treatment plants. Consequently, the issue of productivity changes is not specific to the concept of outfall relocation and, therefore, is an issue for the LISS in general. The trade-offs between possible increased hypoxia and improved productivity in the bight is an issue for the Bight Restoration Plan.

Altered Harbor Circulation

The potential relocation of large volumes of freshwater (STP flows) entering New York Harbor could alter harbor circulation patterns, particularly in the East River and in the Upper Bay - Lower Bay - Hudson River complex. Such freshwater flow added directly to the Hudson system could reduce salinity intrusion by some amount, particularly during low river flows, thus affecting habitats. Any reduced salinity intrusion, however, by this means could mitigate the impact that potential upstream withdrawals for water supply might have on advancing the salt front. Changes in East River circulation could alter the interaction of the East River and western Long Island Sound.

Intermittent Discharge

The concept of discharging treatment plant effluents only during that portion of the tidal cycle which would transport effluents away from the western sound is somewhat similar in principle to load relocation. The principal effect is to relocate the discharge(s) downstream (away) from the critical area by some portion of the tidal excursion. However, during the period of active discharge, the required effluent flow rate is twice the normal value. Storage facilities at the treatment plants would be required. Space at the East River treatment plants is generally limited. Deep tunnels could be considered. However, the effluent storage volume required for this approach is on the order of that required for the tunneling scheme.

RECOMMENDED ADDITIONAL STUDIES

On the basis of this preliminary analysis, the concept of outfall relocation appears to be a cost-effective alternative to advanced treatment at the East River sewage treatment plants with potential multiple benefits. However, the potential water quality benefits and possible adverse impacts need to be more rigorously defined and compared. If the option of outfall relocation is to be considered further, it is recommended that detailed feasibility studies be conducted for these purposes. If the efficacy of outfall relocation is confirmed and this option selected, comprehensive final engineering design studies would follow.

It is recommended that the feasibility studies contain the following elements.

Development of Integrated System-Wide Water Quality Model of the Harbor, Sound and Bight

The optimal procedure by which to define outfall relocation requirements as an alternative to nitrogen removal by advanced treatment is to use expected dissolved oxygen changes in Long Island Sound as the equivalence indicator. This requires that a eutrophication model of the system is available:

- to calculate the improvement in dissolved oxygen in Long Island Sound due to nitrogen removal at the East River plants (or selected plants), and
- to determine the relocation requirements of the subject load(s) to achieve the same results.

No system-wide model is presently available for this purpose. Models, however, are being constructed for each of the major components of the system: New York - New Jersey Harbor (Figure 21 - NYCDEP City-Wide CSO Facility Plans), Long Island Sound (Figure 22 - LISS), and New York Bight (Figure 23 - New York Bight Restoration Plan).

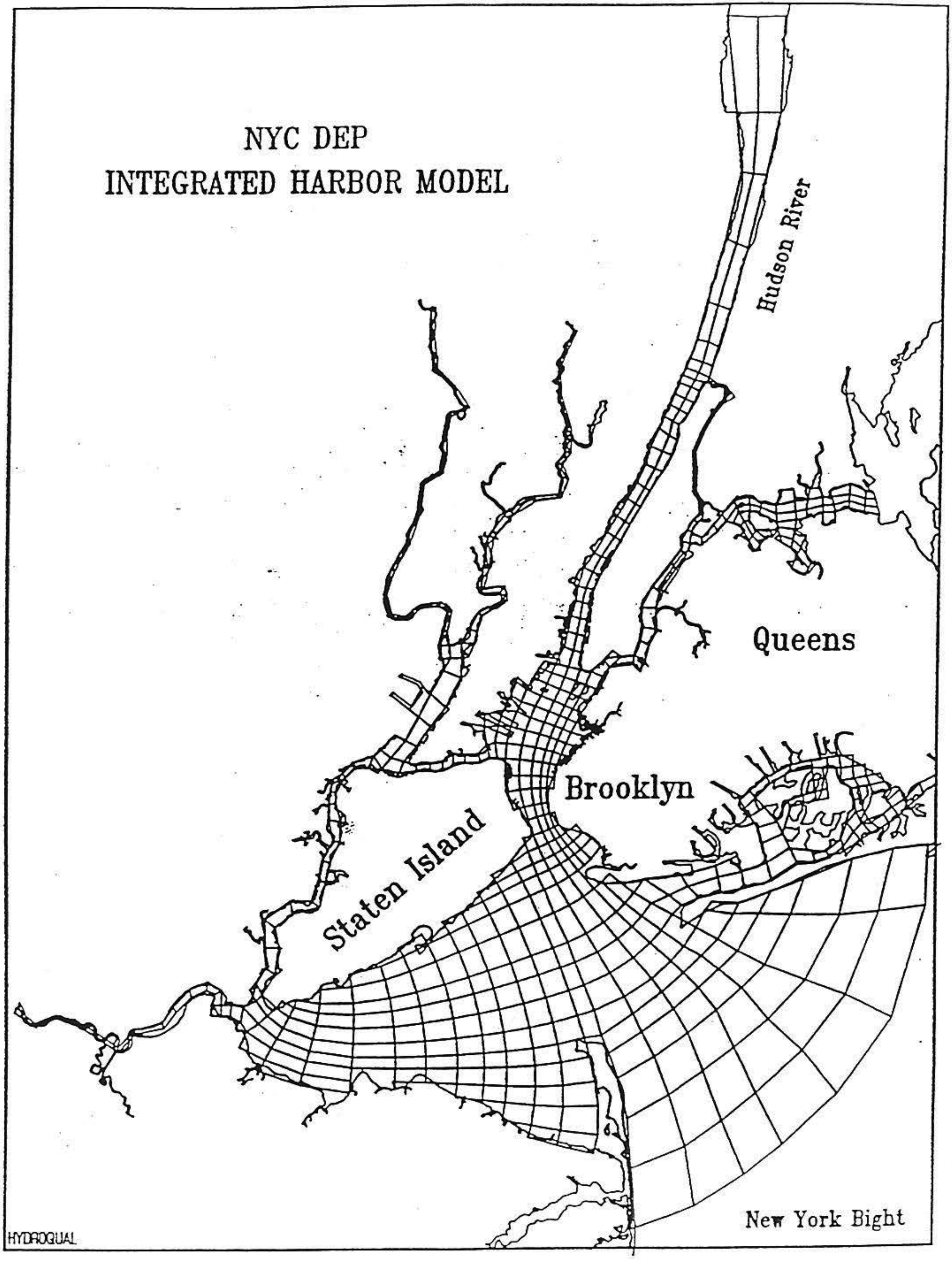


FIGURE 21. SEGMENTATION DIAGRAM FOR UPDATED NEW YORK HARBOR MODEL (1991)

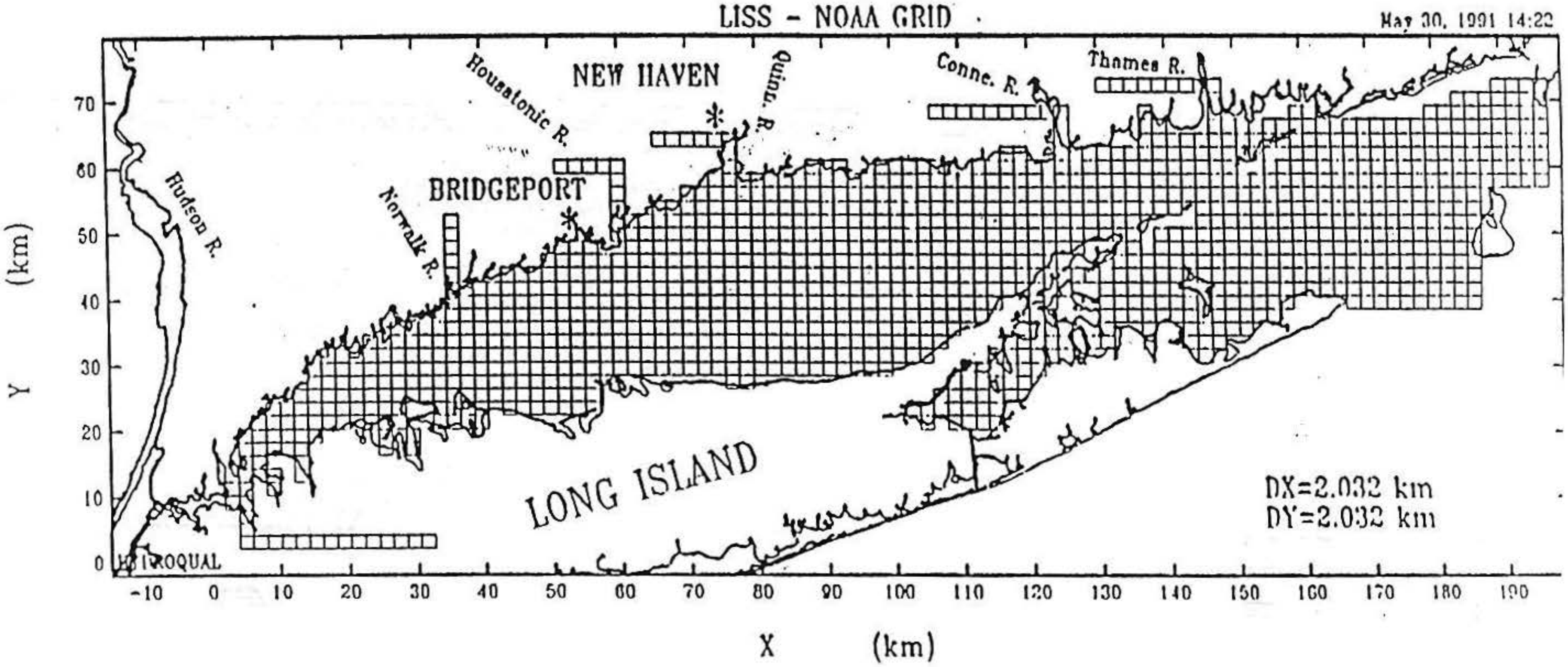


FIGURE 22. SEGMENTATION DIAGRAM FOR THE LONG ISLAND SOUND MODEL (LIS 3.0) (1991)

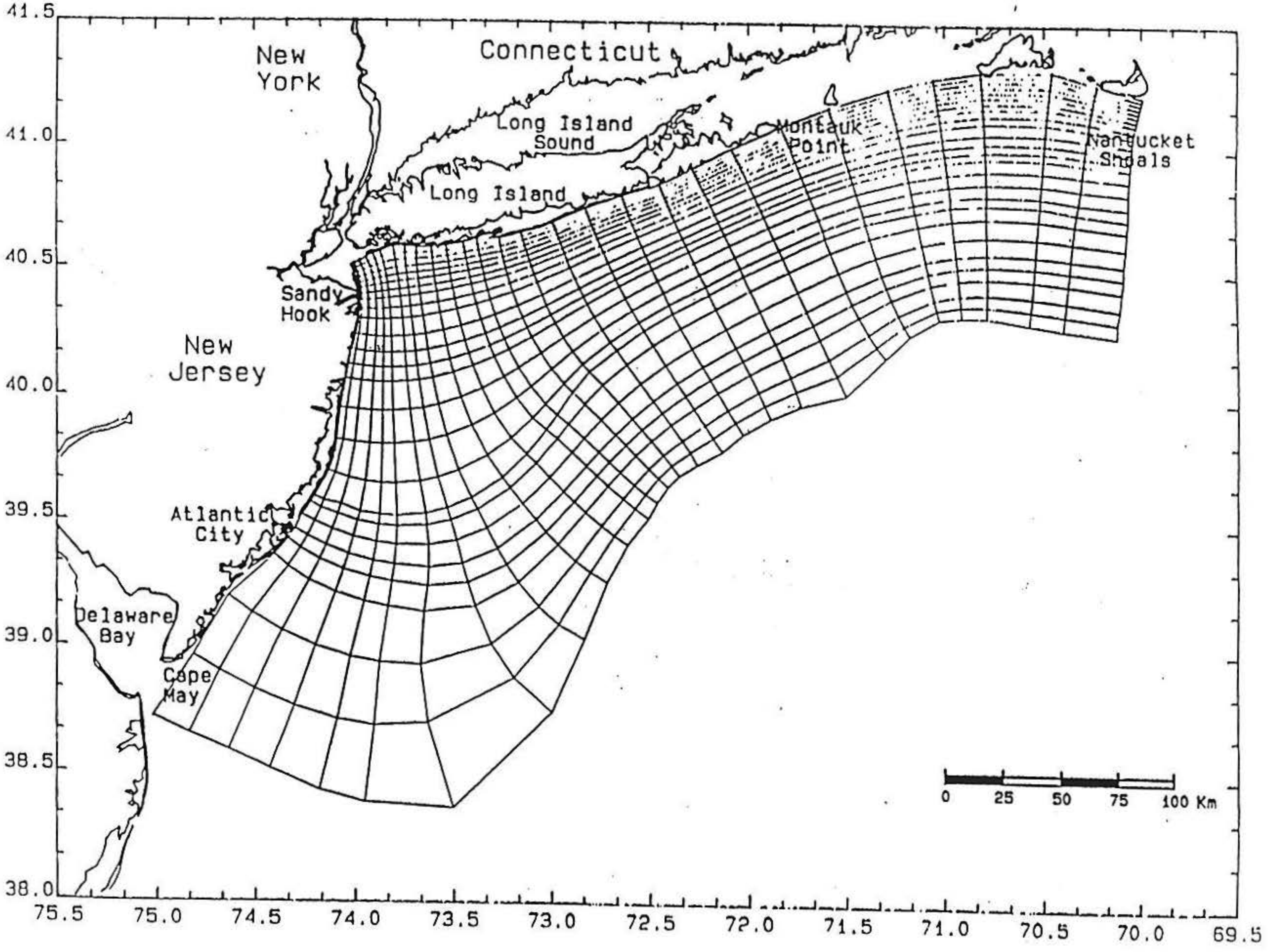


FIGURE 23. SEGMENTATION DIAGRAM FOR THE NEW YORK BIGHT MODEL (1991)

It is recommended that appropriate portions of the spatial domains of these models (all of the harbor, some/all of the sound and hypoxic area of bight) be used to construct an integrated, system-wide coupled hydrodynamic and water quality model. This model would employ the nutrient-phytoplankton-dissolved oxygen kinetics and water column - sediment interactions as in the LIS 2.0 and LIS 3.0 models and would be applied to define the effects of nutrient and organic carbon inputs on dissolved oxygen. The system-wide model would be of benefit to the LISS in general as well as for an evaluation of outfall relocation requirements in particular.

Calibrate Model with Available Data

The system-wide model would require calibration prior to application for outfall relocation requirements. The available historical data base in New York Harbor has a number of deficiencies as subsequently identified. However, preliminary calibration with existing information is recommended. It is believed that the most data-rich period for the sound and harbor is the 18 months between April 1988 and September 1989, during the LISS program and field work for NYCDEP CSO planning studies. These data would be supplemented by whatever information is available in New York Bight.

Collect Additional Field Data for Model Refinement

As noted, the existing data base in New York Harbor and New York Bight has deficiencies in information needed for eutrophication modeling. It is recommended that, at a minimum, a field program be initiated to fill data gaps as follows:

- Obtain additional nutrient data on STP discharges, tributary inputs and stormwater.
- Obtain year-round water quality measurements at selected master stations.

- Expand water column measurements to include organic nitrogen (a current deficiency) in addition to inorganic forms.
- Measure particulate and dissolved components of nutrients.
- Conduct tests to measure algal photosynthesis and respiration in the water column.
- Obtain sediment nutrient flux measurements.

Apply Models for Detailed Evaluation of Outfall Relocation Requirements and Potential Adverse Impacts

The calibrated and refined system-wide eutrophication model would be used:

- to assess outfall relocation requirements to produce the equivalent improvement in dissolved oxygen in Long Island Sound as nitrogen removal by advanced treatment at selected plants;
- to assess improvements in dissolved oxygen in the East River from relocation of organic carbon loads, and
- to evaluate the consequences of load relocation on dissolved oxygen conditions in the Upper and Lower Bays and New York Bight.

It is recommended that the water quality model now under development within the context of the New York - New Jersey Harbor Estuary Study to perform required wasteload allocations for toxic metals under Section 304 (1) of the Clean Water Act be applied in the feasibility study. The New York Harbor Toxics Model would be used to assess improvements in trace metals concentrations in the East River and western sound in response to load relocation alternatives. The model would also define impacts in those regions of the harbor affected by the relocated loadings.

It is further recommended that the harbor-wide CSO model now under development as part of the NYCDEP CSO Facility Planning Projects be applied in the feasibility study if CSO facilities are to be integrated with the tunnel concept. The New York Harbor CSO Model would be used to assess improvements in coliform bacteria concentrations in the East River and western sound in response to CSO retention and treatment and impacts at the new disposal locations and area beaches.

Assess Effects of Outfall Relocation on Living Marine Resources and Habitats

Refined estimates of the effects of various outfall relocation alternatives on living marine resources and habitats in the western sound, East River and harbor are recommended.

Conduct Engineering Feasibility Studies

Parallel engineering investigations should be conducted with the foregoing tasks for the following purposes:

- to further refine the engineering requirements and costs associated with nitrogen removal by advanced treatment at selected sewage treatment plants;

- to develop preliminary engineering plans for various outfall relocation concepts:
  - deep tunnel
  - outfall extension
  - integrated CSO facilities, and

- to prepare refined cost estimates for outfall relocation alternatives.

Analysis of Historical Data Base

Questions are asked with increasing frequency regarding the causes of long term changes and inter-annual variability in water quality in the harbor-sound-bight system. A long term data base exists in New York Harbor as developed by the NYCDEP Harbor Survey which began in 1909. It is recommended that consideration be given to an analysis of a substantial portion (20 to 40 years) of the long term record. Such an analysis would refine the understanding of cause and effect relationships between pollutant inputs and water quality by an evaluation of long term trends and year-to-year variability. The results of this procedure would provide additional credibility to the modeling analysis of the impacts of outfall relocation and identify areas of possible technical uncertainty.

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