1997
NEW YORK HARBOR
WATER QUALITY SURVEY

NEW YORK CITY
DEPARTMENT OF ENVIRONMENTAL PROTECTION

BUREAU OF WASTEWATER POLLUTION CONTROL
MARINE SCIENCES SECTION

The Harbor Survey Vessel, The Osprey

August, 1998

The New York City Department of Environmental Protection (DEP) performs an intensive, annual survey of water quality in New York Harbor. The following is a copy of the **1997 New York Harbor Water Quality Survey**. This report includes summarized data and a discussion of our monitoring results in this, the 88th year of the program.

The purpose of the Harbor Survey Program is to assess the effectiveness of New York City's various water pollution control programs, and their combined impact on water quality. Tables, graphs, and figures in the report summarize New York Harbor water quality for the Summer of 1997, assess long term trends (some dating back to 1909), and provide data for computerized water quality models.

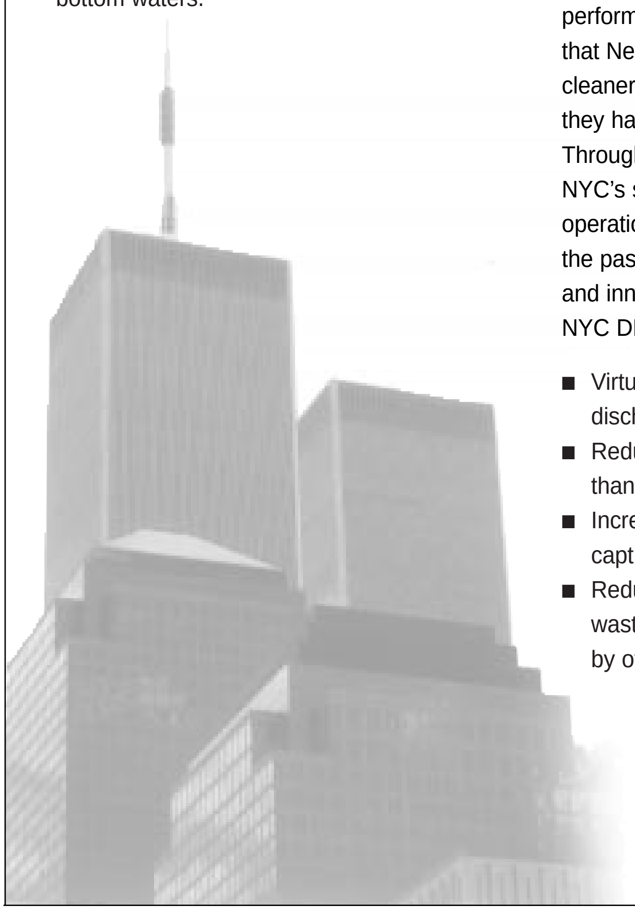
We are continuously striving to improve our performance and enhance the usefulness of this report. Consequently, your comments are encouraged. Questions or suggestions may be directed to Alan I. Stubin or Naji Yao of DEP's Marine Sciences Section at 212-860-9378. Your interest in the quality of New York City's waters is greatly appreciated.

Very truly yours,

Joel A. Miele Sr., P.E.
Commissioner

PROGRAM OVERVIEW

The New York City Department of Environmental Protection (NYC DEP) monitors the waters surrounding New York City. These estuarine waters (composed of a mix of oceanographic and riverine sources) are collectively referred to as New York Harbor. NYC DEP's current monitoring program, **The New York Harbor Water Quality Survey** has developed from an effort begun by the Metropolitan Sewerage Commission in 1909, in response to public concerns about gross pollution in the Harbor. The monitoring program has continued to expand since the early 1900's when only twelve stations were used to record the impacts of sewage pollution. At present, NYC DEP monitors 53 stations throughout the Harbor, measuring over a dozen water quality parameters for both surface and bottom waters.



NYC DEP performed its **88th Water Quality Survey of New York Harbor in 1997**. The Harbor Survey, funded primarily by NYC DEP and performed by the DEP's Marine Sciences Section, monitors the quality of the Harbor waters and identifies the impacts of pollution control programs to these waters. This program provides the longest documented assessment of human impacts on the City's water environment. Through its sampling of a number of water quality and human-health related indicators, this survey: identifies changes in the environmental health and ecosystem quality of the New York Harbor; describes long-term water quality trends; and provides a unique data base for regional scientists, educators, and private citizens.

Based on these indicators and other performance measures, there is evidence that New York Harbor's environment is cleaner, and the water quality better, than they have been since the turn of the century. Through development and upgrades to NYC's sewage treatment system, as well as operational improvements implemented over the past 10 years, and a suite of aggressive and innovative pollution control programs, NYC DEP has:

- Virtually eliminated raw sewage discharges;
- Reduced illegal discharges by more than 70%;
- Increased wet-weather related floatables capture to almost 70%;
- Reduced toxic metals loading to the wastestream from industrial sources by over 90%.

> ***...New York Harbor's environment is cleaner, and the water quality better, than they have been since the turn of the century.***

Consequential to these actions there is strong evidence of improvements to New York Harbor water quality and ecosystem health. These range from the reestablishment of breeding populations of peregrine falcons and other waterfowl (including bald eagles) in several areas of the Harbor, to improved benthic communities in the lower New York Bay, and include:

- The opening of all NYC public beaches since 1992 and the lifting of wet-weather swimming advisories for all but three of these beaches;
- The upgrading of 68,000 acres of shellfish beds since 1985 and the removal of shellfishing restrictions for 30,000 acres off of the Rockaways and in Raritan Bay;
- Signs of the reestablishment of shortnose sturgeon;
- Decreases in chemical concentrations in fish tissues and a subsequent relaxing of state advisories on human consumption of striped bass in parts of the Hudson River;
- A 50-90% reduction from peak levels of priority pollutants in fine-grained sediment in the Hudson River.

This report provides information as to how well New York Harbor waters (spanning from the Westchester-Bronx border on the Hudson and in Western Long Island Sound, to the Kills around Staten Island, to the Sandy Hook-Rockaway transect) are meeting their state-designated use classifications, such as swimming and fishing. Benefits that have resulted due to improved Harbor water quality are also documented.

Coney Island Beach

ACKNOWLEDGEMENTS

The 1997 Harbor Survey Program was made possible by the cooperative efforts of the New York City Department of Environmental Protection's Marine Sciences Section, Special Projects Laboratory, and the Marine Section. These sections are all within the Bureau of Wastewater Pollution Control. The continued development of the Harbor Survey program has been made possible by the dedication and professionalism of numerous staff from this Bureau.

This effort was jointly produced by the staff of the Marine Sciences Section, including: Jordan Adelson, Bernadette Boniecki, Michael Cacioppo, Harold Coakley, Haymankumar Lochan, Raymond Negron, Marie O'Shea, Andrew Owens, Beau Ranheim, Yin Ren, Cori Rizzo, Farzana Shaheed, Bessie Stantley, Alan Stubin, Naji Yao, Jiye Zhang and Captain of the HSV Osprey, Robert Smith.

This report benefited from the review of Robert Adamski, Phil Heckler, Robert Alpern, Mary Keating, Cathy DelliCarpini, Les Coleman, Robert LaGrotta, Arthur Ashendorff, Anne Seeley, Jerry Volgendi, Stella Rozelman, and the staff of the Marine Sciences Section. Laboratory analyses and data production were supervised by Trikam Patel and Patrick Jagessar, and performed by Lovely Chacko and Gilbert Roman. Microbiology was conducted by Lorraine Johnson, Maureen DeSouza, and Pari Malakkhani. Computer and database enhancements were made possible through the ongoing contributions of Phil Markowitz and Sarah Ho. Contractual assistance was provided by Fay Jacques and Jasen Tompkins. Design and publishing were overseen by Panero Design, Inc.

This report was written by:
The City of New York
Department of Environmental Protection
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April 10, 1998

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Survey Synopsis

NYC DEP monitors a number of common water quality indicators. These include human health indicators, such as sewage-related coliform bacteria; and environmental health indicators such as dissolved oxygen, nutrients, and chlorophyll 'a'. A summary of the summer (June through September) 1997 water quality conditions follows:

Fecal coliform bacteria, an indicator of raw or partially treated sewage, have exhibited significant long-term reductions throughout the Harbor since the early 1970s. This water quality improvement can be attributed to: continued water pollution control plant construction and upgrades throughout the Harbor area; the abatement of illegal discharges; reduced raw sewage bypassing due to improved surveillance and inspection of the sewer system; and increased capture of wet weather combined sewer overflows. In 1997, average conditions met swimmable standards at all but three locations in the Harbor.

Dissolved oxygen (DO), vital to most aquatic life, is considered low at levels less than (<) 5 mg/l and is lethal to many organisms at levels of <3 mg/l. Of 53 stations monitored over the summer, dissolved oxygen concentrations of <3.0 mg/l were recorded only a single time at four bottom stations in the Upper East River and Western Long Island Sound waters. Trend analysis reveals that DO concentrations have improved throughout the Harbor since 1968, with the exception of sites in Jamaica Bay and Western Long Island Sound. Although many sites violated standards at least once during the summer of 1997, DO compliance since 1992 remains high relative to pre-1992 results.

NYC DEP monitors a number of common water quality indicators.

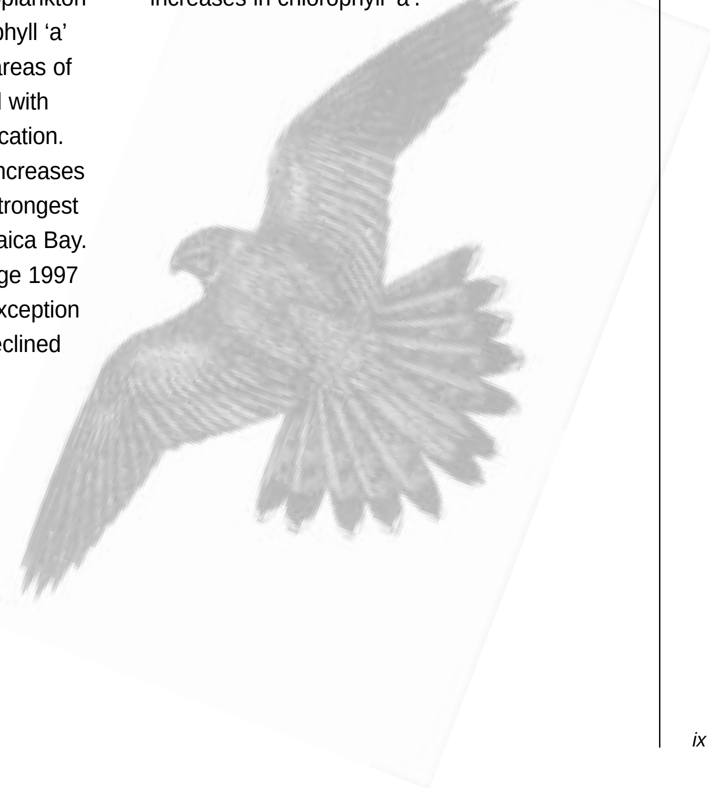
Tanker awaits daybreak in Upper Bay

Nutrients, natural life-sustaining substances, are critical to maintaining an appropriate balance for the health and productivity of aquatic systems. High levels of nutrients or *eutrophication* is considered detrimental to aquatic habitats and diminishes the recreational value of these waters. **Nitrogen and phosphorus,** used as indicators of nutrient enrichment, continue to be found in high concentrations for most Harbor waters. Highest 1997 levels were observed in Jamaica Bay, the Kills, and the East and Harlem Rivers. Trend analyses of the past 13 years demonstrate little significant change in nutrient levels for most Harbor Survey stations. This is likely due to consistent nutrient discharges from both point and nonpoint sources. NYC DEP is currently involved in a regional effort to implement aggressive actions for reducing Harbor nutrient loadings over the next 15 years.

Chlorophyll 'a' is a plant pigment, the concentration of which in water is used as an estimate of productivity or phytoplankton biomass (see below). High chlorophyll 'a' concentrations, common to some areas of the Harbor, are typically associated with conditions symptomatic of eutrophication. Trend analysis reveals significant increases in chlorophyll 'a' since 1989, with strongest increases to have occurred in Jamaica Bay. Despite this long term trend, average 1997 summer concentrations (with the exception of Jamaica Bay) appear to have declined relative to 1995 conditions.

The presence of algae or **phytoplankton** are also indicative of water quality, with certain species and higher plankton concentrations evidence of eutrophic conditions. In the Harbor, high phytoplankton concentrations or *blooms* are most common in outlying areas (Western Long Island Sound and Lower NY Bay-Raritan Bay) and embayments (Flushing Bay and Jamaica Bay). Blooms are cyclic in their intensity and appear highest in early spring and late summer, with diatoms and green algae being predominate in the Harbor.

A Secchi disk is used to estimate the transparency of surface waters. High **Secchi transparency** is indicative of clear water, while low Secchi readings are typically associated with light-limiting conditions and degraded waters. Secchi data from 1985-97 reveals a declining trend in transparency at most locations throughout the Harbor, with exceptions of the Kills. Decreases in Secchi transparency appear inversely related to increases in chlorophyll 'a'.



INTRODUCTION

The New York City Department of Environmental Protection (NYC DEP) performed its 88th Annual Water Quality Survey of New York Harbor from June through September of 1997. Additional winter, spring and fall sampling throughout the Harbor were also performed. The purpose of the Harbor Survey Program is to document the impact of NYC's various water pollution control programs on water quality in the Harbor. In addition, to support modeling and clean-up activities associated with the Long Island Sound Study, and at the bequest of USEPA and NYSDEC, the Harbor Survey Program has been expanded since 1989 to include more intensive sampling of the East River-Long Island Sound transect. The Harbor Survey Program is funded primarily by NYC DEP and performed by the NYC DEP Marine Sciences Section.

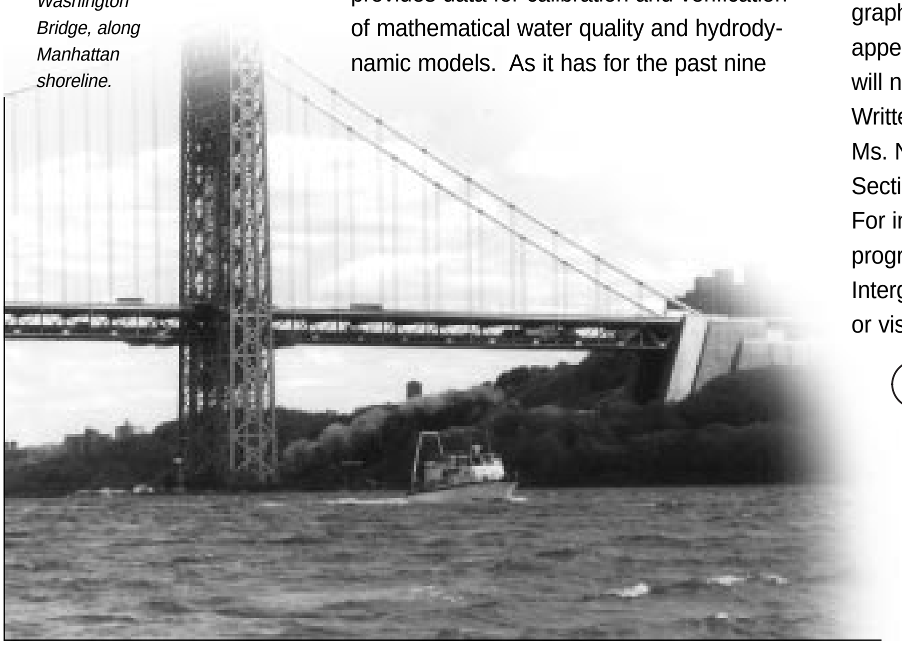
The purpose of the Survey is to document the impact of water pollution control programs...

This report describes recent patterns of ambient summer water quality in the Harbor, makes comparisons with New York State Department of Environmental Conservation (NYS DEC) water quality standards (where possible), documents long-term trends and provides data for calibration and verification of mathematical water quality and hydrodynamic models. As it has for the past nine years, the Harbor Survey Program continued in 1997 to support the Long Island Sound Study, for which it performed hypoxia and nutrient monitoring, receiving partial funding through a USEPA grant. Harbor Survey involvement in additional DEP programs includes participation in the *Shoreline Survey Sentinel Monitoring Program* and a new *Enhanced Beach Protection Program*.

Temporal and spatial variability in water quality in the Harbor is often very high, and the number of samples collected for any one parameter may or may not be sufficient to account for this variability. As a result, no one set of data in this report is fully representative of true conditions. For example, plankton blooms can form and dissipate within a few days, and therefore their existence may sometimes go undetected. Also, sampling after precipitation events has been linked to higher coliform concentrations and lower dissolved oxygen (DO) levels in some Harbor areas, and possibly affects the concentration of other parameters, as well.

Unlike past years, in which descriptive statistics and associated data tables, graphs, and figures were provided as appendices, data and additional materials will now be made available upon request. Written requests can be directed to Ms. Naji Yao, Deputy Chief, Marine Sciences Section, Wards Island, New York 10035. For information on this and other NYC DEP programs, contact the Bureau of Public and Intergovernmental Affairs at 718-595-6600 or visit our Web site:

www.ci.nyc.ny.us/dep



HSV Osprey heading south of George Washington Bridge, along Manhattan shoreline.

FACTORS AFFECTING WATER QUALITY IN NEW YORK HARBOR

Regional Hydrodynamics

The Hudson-Raritan system **(Figure 1)** is a varied and complex coastal plain estuary dominated by a drowned river valley (the Hudson). New York City's 578 miles of waterfront include a network of tidal straits (Arthur Kill, Kill Van Kull, and the Harlem and East Rivers), open and enclosed bays (Raritan, Jamaica and NY Bays), tidal mud flats, and beaches. The estuary communicates with the Atlantic Ocean through the Race at the eastern end of Long Island Sound, and through the mouth of lower NY Bay at Sandy Hook (Swanson et al., 1982). The tidal pulse is semi-diurnal throughout. The progressive tidal wave of the Harbor and the standing tidal wave in the Sound meet in the Harlem and East Rivers.

Upstate New York, and portions of New Jersey, Massachusetts and Vermont together comprise the Harbor Estuary's total watershed of approximately 16,300 mi^2 (42,217 km^2). Freshwater input into the estuary, is dominated by the Hudson River, draining 13,400 mi^2 (34,600 km^2), with the Raritan, Passaic, and Hackensack Rivers in New Jersey (NJ) draining most of the remaining area.

With an average flow at the Battery of 21,000 ft^3/s (594 m^3/s), the Hudson River constitutes approximately 87% of the total riverine flow into the system (Mueller et al., 1982). Still, the volume of water introduced from the tributaries is small compared to the amount introduced by tidal action (by about 220 times on a volumetric, annual basis), and tides dominate the density-driven estuarine circulation (NOAA, 1985).

Water residence times vary spatially and temporally. For example, residence times vary from 1.25 days in the East River, to 35 days in Jamaica Bay. Residence times for the Hudson River vary from 15 days during spring high river flows, to 45-60 days during summer low-flow conditions (Clark *et al.*, 1982).

This network of varying freshwater inflows, tides, and tidal flows produces vertical density stratification in some areas (Hudson River and upper NY Bay), with seasonal and tidal variations in stratification. Other areas are vertically homogeneous, e.g., the East River and Arthur Kill. Because the difference between surface and bottom salinities in the estuary is generally less than 10 ppt, the estuary is classified as moderately stratified and partially mixed (NOAA, 1985; Clark *et al.*, 1992). The complex circulation and mixing patterns produce high spatial and temporal variability in water quality, and make the net transport of waste materials difficult to quantify (O'Connor and Mueller, 1984). In addition, tidal current speeds are variable, with maximum speeds of five knots reached at Hells Gate in the East River.

Regional Population Growth Since The 1800s

Historic increases in regional population are directly responsible for degradation of the local aquatic resources through destruction of habitat, dredging and filling, changes in land use, over-harvesting of fisheries, inappropriate solid waste disposal, and especially the discharge of untreated municipal and industrial effluents (Suszkowski, 1990). In 1810, New York emerged as the largest city in the new nation, surpassing Boston and

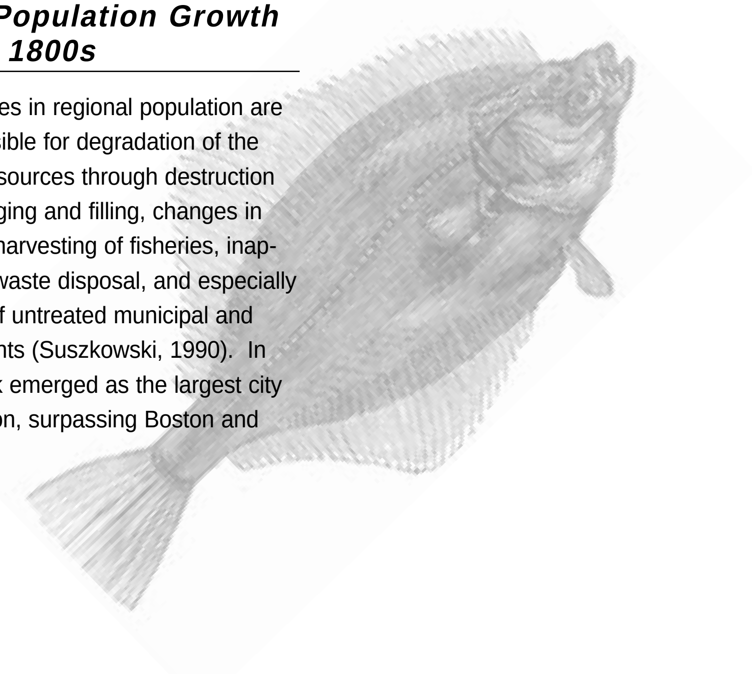
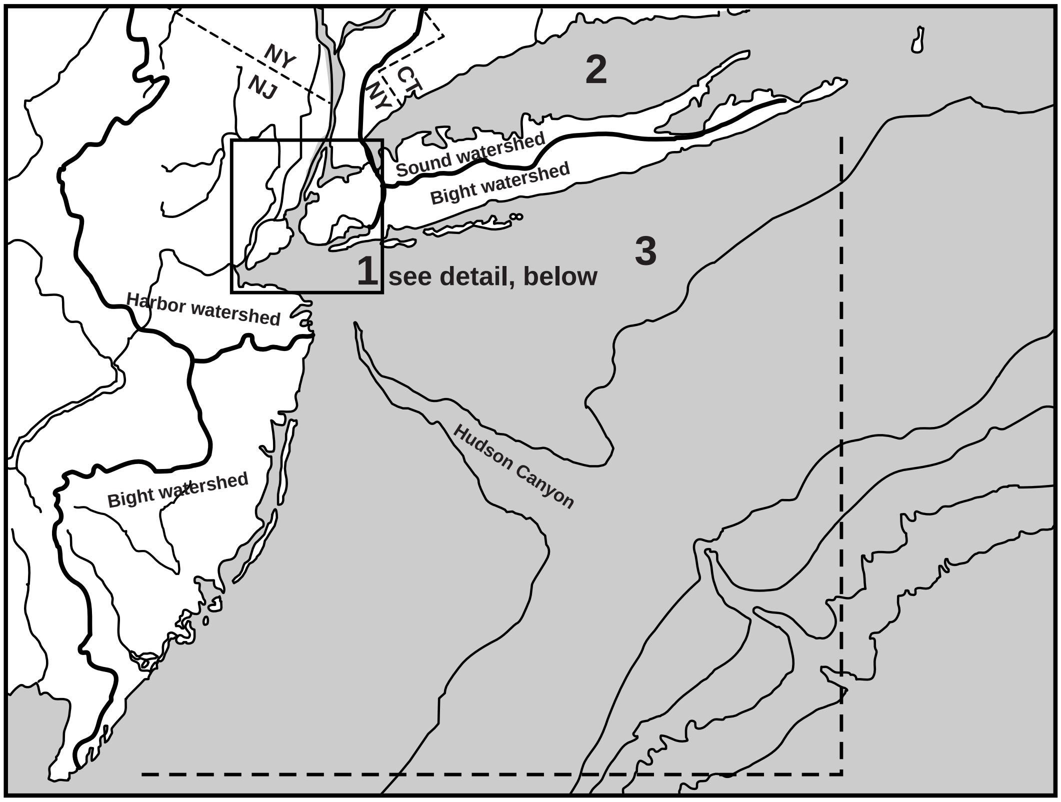
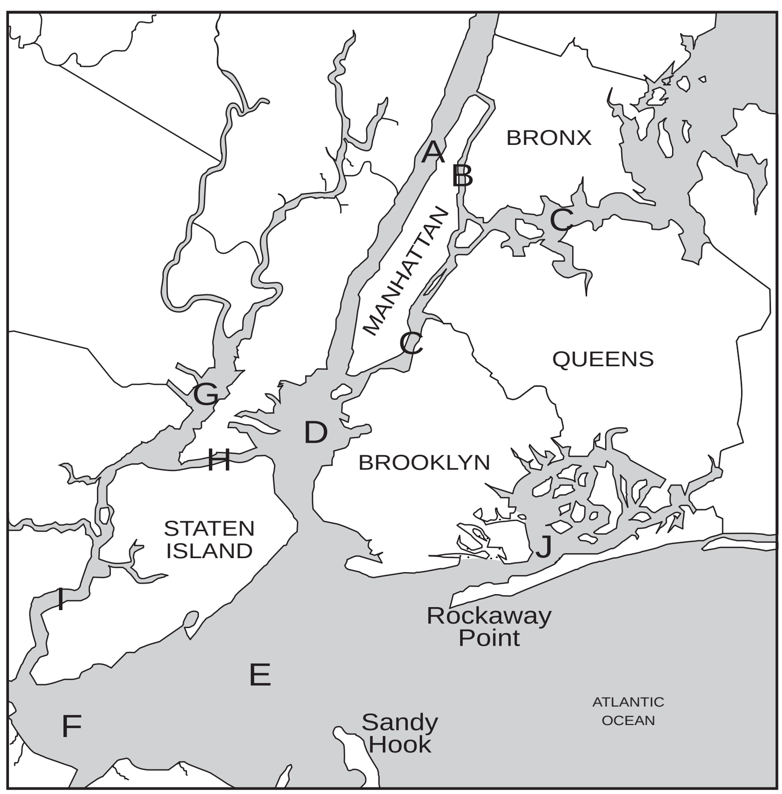


FIGURE 1 **THE HUDSON-RARITAN SYSTEM**





THE HARBOR-SOUND-BIGHT ESTUARY

1. New York Harbor
- A. Hudson River
- B. Harlem River
- C. East River
- D. Upper NY Bay
- E. Lower NY Bay
- F. Raritan Bay
- G. Newark Bay
- H. Kill Van Kull
- I. Arthur Kill
- J. Jamaica Bay

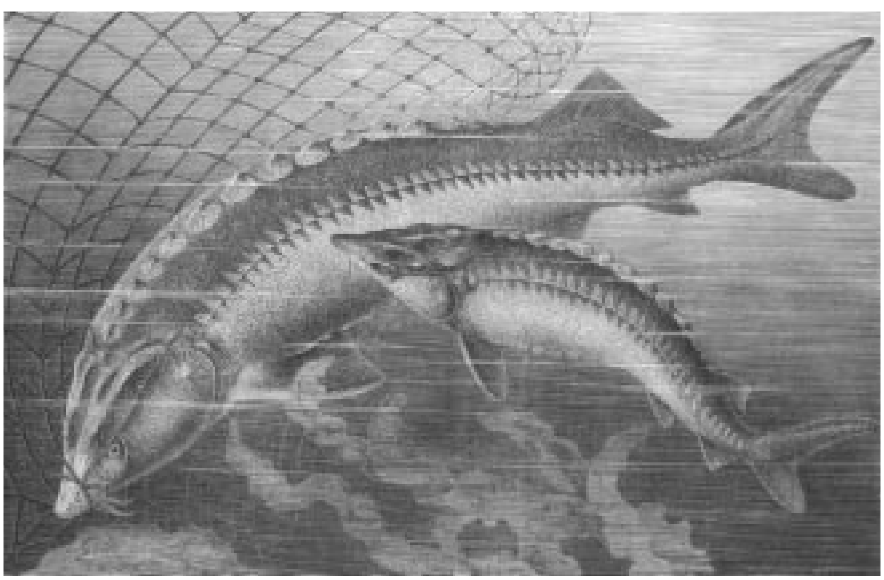
2. Long Island Sound

3. New York Bight

Philadelphia (US EPA, 1998). With most of the industrial activity of New York and New Jersey centered around the Harbor, and the proximity of shipping and other transportation routes, the Harbor Estuary became a major link in the region's industrial economy. Since the turn of the century, progressive suburban development transformed a once agricultural region into a densely populated metropolis. Population in the Harbor drainage area increased from about four million in 1880 to ~17 million in 1980. By the late 1980s, 88% of residents lived within 13% of the drainage area, including NYC's 7.5 million inhabitants (Suszkowski,1990).

Major degradations in water quality from 1890 to 1920 are attributable to increases in population and the rate of development in the late 1800s (Pearce, 1987; Studholme, 1987). In the early 1900s, the Metropolitan Sewerage Commission of NY reported evidence of gross sewage pollution within 15 miles of Manhattan (Caspe, 1990). In 1906, "seas of floating garbage" were described, exacerbated by the ocean disposal of garbage which was not banned until 1936. In addition, discharges of raw sewage and industrial effluents were associated with the decline of a major oyster fishery around Staten Island prior to 1900 (Pearce, 1987). By 1910, ~600 mgd (26 m^3/s) of untreated sewage was being discharged from NYC alone (Caspe, 1990). Typhoid outbreaks in 1904 in Jamaica Bay, and 1918 in Raritan Bay, closed the oyster industry by 1925 (Studholme, 1987). Over-fishing, loss of habitat and spawning areas from dredge/fill operations, and associated changes in salinity, currents, and siltation are blamed for the decline of several other important commercial fisheries by the 1930s. These fisheries include hard and soft clams, shad, sturgeon, menhaden, and smelt (Pearce, 1987; Studholme, 1988; Studholme, 1987).

Over-fishing, loss of habitat...are blamed for the decline of important commercial fisheries...

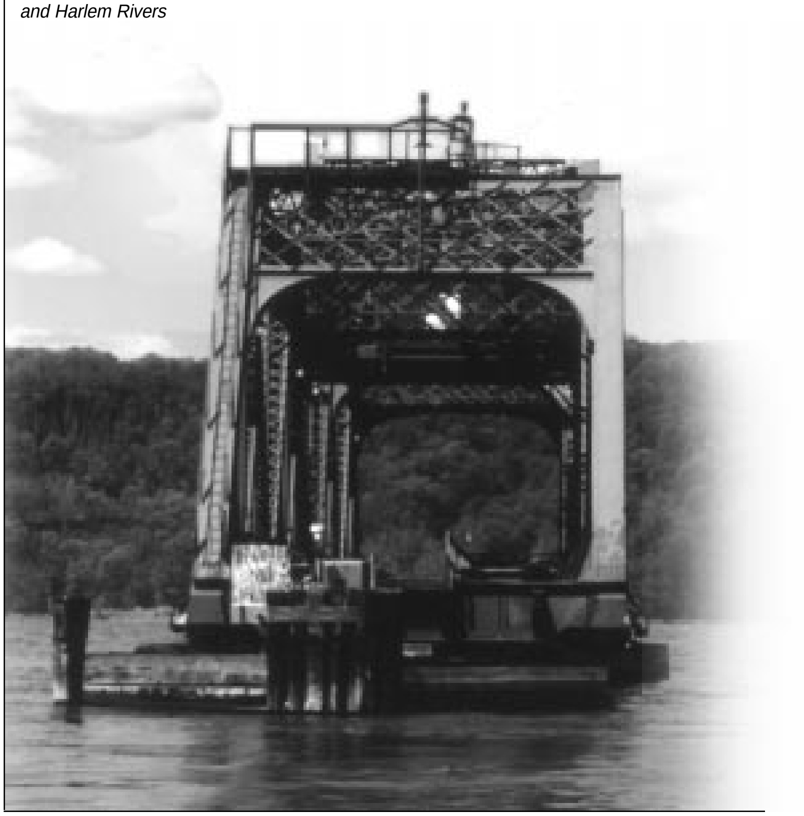


Physical Changes

Over the decades, significant physical changes have occurred throughout the Harbor including dredging of channels, blasting of reefs, filling of wetlands and streams, and bulkheading of shorelines. The net effect of these changes has been to reduce the ability of the estuary to both flush out contaminants and to absorb the effects of pollution. A number of significant changes include the following:

- Between 1609 and 1978, ~1348 acres (5.5 km^2) of Manhattan were land filled (Squires, 1990);
- By 1970, ~2200 acres of Newark Bay marsh were destroyed for the construction of Newark Airport. Newark Bay is presently 33% smaller than in 1886, and its mean depth has increased from 2 m to 3.1 m (Suszkowski, 1990);
- Between 1949 and 1979, ~4930 acres of Jamaica Bay were filled for the construction of JFK Airport (Squires 1990). By 1971, ~70.9 million m^3 had been dredged from Jamaica Bay, including 37 million m^3 taken from Grassy Bay to provide fill for the Airport (West-Valle et al., 1992); Jamaica Bay's mean depth has changed from 3 to 16 ft (Thatcher and Mendoza, 1990) and the bay's residence time has increased from 11 to 35 days (West-Valle et al., 1992);
- From 1680 to 1850, East River wetlands, stream mouths and coves were altered, filled and/or bulkheaded. This destroyed littoral zones and created rigid and even shorelines (NYC DEP, 1983). Blasting of reefs and rocks from 1850 to 1920 increased depths to 30-40 feet below mean low water, and reduced currents at Hells Gate (the confluence of the East and Harlem Rivers) from more than 10 knots to about 5 knots (Neyer, 1994);
- Between 1895 and 1938, Rikers Island grew from 60 acres to more than 400 acres from the dumping of coal, refuse and ashes;
- Prior to 1959, wetlands had been destroyed on a massive scale, with the rate of destruction peaking in the tri-state area from 1954-1964. Whereas the NYC portion of the Harbor supported ~27,600 acres of wetlands in the year 1900, by 1969, only 3,800 acres remained (Squires, 1990).

Spuyten Duyvil Railroad Bridge at Junction of Hudson and Harlem Rivers



Pollutant Sources

The Hudson-Raritan Estuary is currently subjected to loadings from numerous municipal and industrial wastewater sources, as well as, non-point runoff from its drainage area. Of the average fresh water inflow to the Harbor of ~27,000 ft^3/s (765 m^3/s), approximately 80.7% is from tributaries, 14.9% is attributed to municipal point sources, 3.7% is from more than 1,000 storm water outfalls, 1.3% is from ~650 combined sewer overflows (CSOs), and 0.3% is from ~400 direct industrial discharges (HydroQual, Inc., 1991). The non-tributary sources represent an estimated flow of 5,300 ft^3/s (150 m^3/s).

Note that 'Harbor' boundaries for this flow component analysis extend to Poughkeepsie on the Hudson River, to Throgs Neck on the East River, to the head-of-tide on the NJ tributaries, and to the Sandy Hook-Rockaway transect. In contrast, for most of this report, the 'Harbor' is defined by its NYC limits **(Figure 2)**. These are the Westchester-Bronx border on the Hudson and in Western Long Island Sound; the Kill Van Kull and Arthur Kill around Staten Island; and the Sandy Hook-Rockaway transect. Figure 2 depicts this latter description of *the Harbor*, showing an approximation of municipal and CSO outfall locations.

Water Pollution Control Plants

Approximately 2.5 billion gallons per day (bgd) or 108 cubic meters per second (m^3/s of processed sewage were discharged in 1997 from 79 water pollution control plants (WPCPs) located in NYC, six coastal NJ counties, two coastal CT counties, and Westchester and Rockland Counties in NY (Interstate Sanitation Commission, 1997). Most of these WPCPs provide full secondary treatment, defined as 85% removal of biochemical oxygen demand (BOD) and total suspended solids (TSS), and/or effluent limits of 30 mg/l BOD and 30 mg/l TSS, as defined by the Federal Water Pollution Control Act. It is important to note that secondary treatment does not remove nitrogen from effluent. Of the 2.5 bgd total, NYC's 14 WPCPs discharged 1.44 bgd in 1997. The infrastructure associated with the NYC WPCPs includes: 6,344 miles of collection system piping; 130,000 catch basins; and 5,000 seepage basins. Further details on NYC's WPCPs are provided below.

Illegal Connections and Bypasses

Illegal connections to the sewer system which circumvent the WPCPs, and bypassing of sewage from the sewer system, can contribute an important pollutant load to receiving waters. Illegal connections can originate from unauthorized sanitary or industrial connections, indirect connections (e.g., infiltration from failing septic tanks), and unpermitted discharges into the storm water drainage system. Depending upon the source, illegal dry-weather flows can be continuous, or highly intermittent and may substantially impact localized waters. Concerning the bypassing of raw or partially treated sewage, this may be planned (as during WPCP construction, repair or expansion) or may occur due to malfunctions of the sewer regulator system.

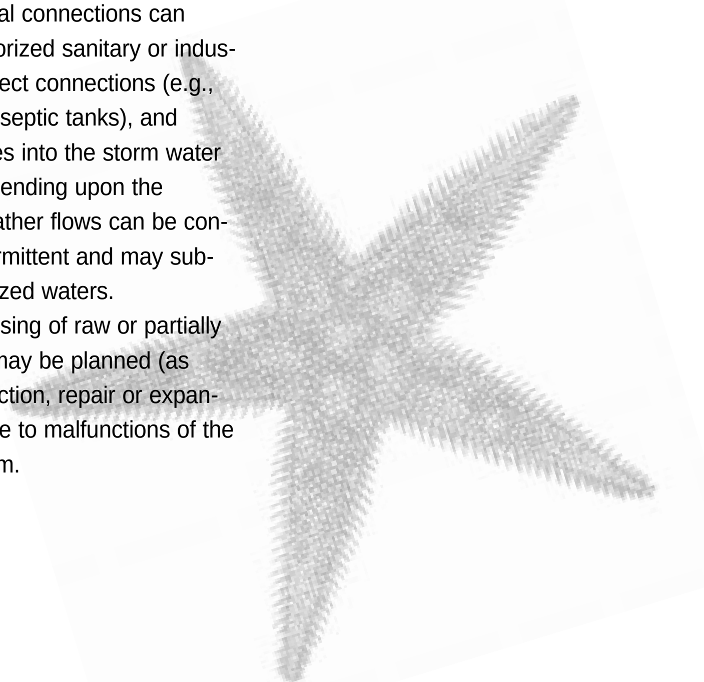


Figure 2 **New York Harbor / Location of WPCPs & CSOs**

Storm Water Runoff

Storm water runoff from urban and suburban impervious surfaces (streets, sidewalks, rooftops etc.) may contain large quantities of a variety of pollutants. Estimates from NYC's 208 Model indicate that 48% of the storm water flow to the Harbor comes from NJ, 18% from Westchester, 11% from NYC, and the remainder from upstream counties. Data on storm water pollutant concentrations are currently being collected as part of the *Storm Water Permit Program* (NYC DEP, 1994).

Combined sewer overflows...are the greatest single source of pathogenic and floatable pollutants.

Combined Sewer Overflows (CSOs)

Between 70-80% of NYC's ~6,300 miles of sewers are classified as combined sewers, i.e., they accommodate household and industrial waste during dry weather, as well as, rainwater and surface water runoff, during rain events (Gaffoglio, 1990). When runoff flows exceed the hydraulic capacity of the WPCPs the combined sewage (runoff plus untreated domestic sewage) is discharged to the Harbor, causing episodic deteriorations in water quality. For some regulators, this can occur with as little as 0.04 in/hr of rainfall.

Combined sewer overflows from NYC, NJ, and Westchester County effect water quality in the Harbor, and are the greatest single source of pathogenic and floatable pollutants (HEP, 1996; Wagner, 1992; Interstate Sanitation Commission, 1988). Virtually the entire Harbor is bordered by ~730 CSOs (see figure 2 for an approximation), including: 460 from NYC, 248 from NJ, and 22 from Westchester County (HEP, 1996). A comparison between discharges shows CSO fecal coliform loadings to exceed that from chlorinated WPCP effluents by more than 10,000 times, during an average storm event (Wagner, 1992). Together with storm water runoff, CSOs contribute 85% of the Harbor's floatable debris (Leo et al., 1992; HydroQual, Inc., 1992), which reduces aesthetics, may close bathing beaches, and can adversely impact biota.

Industrial Dischargers

Greater than 90 % of NYC's waste water is comprised of residential and commercial domestic sewage, with less than 1 % of the flow from industrial sources (NYC DEP, 1998). In New York City, 721 industrial facilities are currently under regulation (see *Industrial Pretreatment*, page 17). These include such industrial categories as electroplating, metals molding, casting, and finishing, pharmaceutical manufacturing and organic chemical manufacturing. Flow contributions from these industries to NYC WPCPs are relatively small, and are no longer a significant source of priority pollutants to the Harbor.

A marine vessel and crew move out from Staten Island pier

Nonpoint Source Pollution, Upstream Sources and Atmospheric Deposition

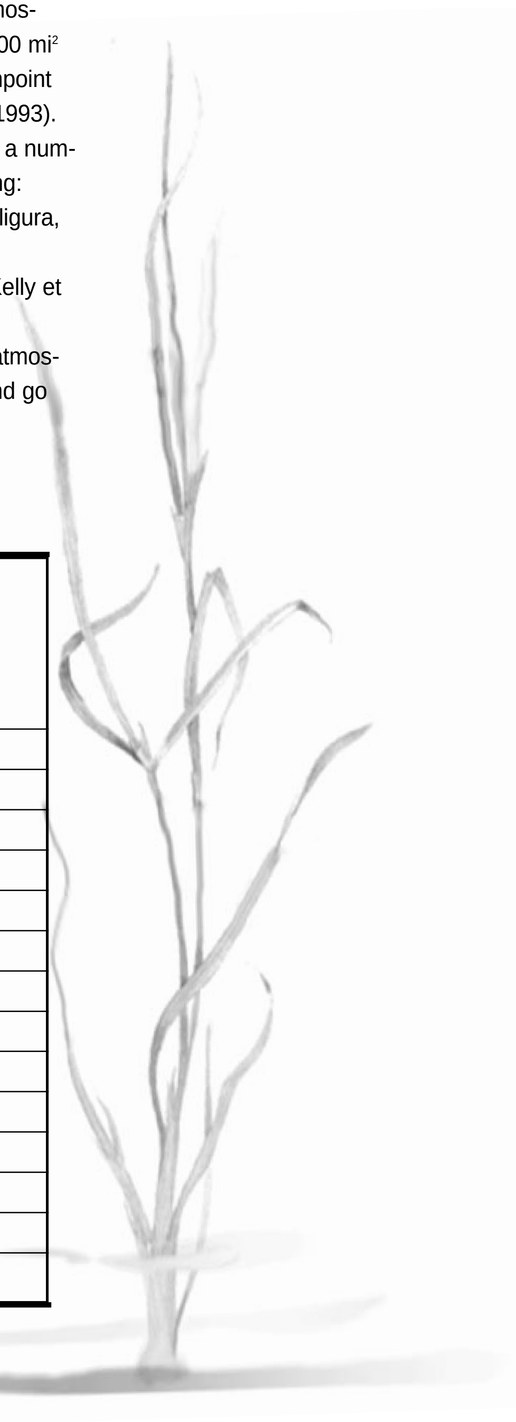
According to the United States Environmental Protection Agency (US EPA), due to its diffuse nature, nonpoint source pollution is the largest single factor preventing attainment of water quality standards nationwide. This is deemed especially true for those waters impaired by nutrients and siltation (US EPA, 1991). By their very nature, estuaries tend to concentrate particulate pollutants discharged into their watersheds. Sustained development of suburban and rural lands within the Hudson-Raritan's 16,300 mi^2 watershed and in the Long Island Sound drainage basin, have accelerated nonpoint runoff. This, in turn, has increased the loading of a variety of pollutants to surrounding waters. These pollutants continue to concentrate and affect water and sediment quality in the lower estuary and Long Island Sound (Rohmann and Lilienthal, 1985). Wet and dry atmospheric deposition to the estuary's 16,300 mi^2 drainage area represents a further nonpoint source of importance (van Jaarsveid, 1993). Atmospheric deposition can contribute a number of pollutants to the Harbor, including: nutrients, PCBs, PAHs and metals (Valigura, et al. 1998; HEP, 1996; Bidleman and McConnell, 1995; Giusti et al., 1993; Kelly et al. 1991). Again due to its diffuse and ambiguous nature, the importance of atmospheric loadings are often minimized and go unrecognized.

TABLE 1

CHRONOLOGY OF NYC WATER POLLUTION CONTROL PLANTS

Wastewater Pollution Control Plant	Primary Treatment Attained	Secondary Treatment First Attained	Last Upgrade Completed	Current Capacity (MGD)
Coney Island	1936	1963	1994	100
Wards Island	1937	1937	1997	250
Bowery Bay	1939	1942	1973	150
Tallman Island	1939	1939	1976	80
Jamaica	1943	1943	1971	100
26th Ward	1944	1951	1990	85
Hunts Point	1952	1952	1979	200
Owls Head	1952	1952	1995	120
Rockaway	1952	1962	1971	45
Port Richmond	1953	1978	1979	60
Oakwood Beach	1956	1956	1978	40
Newtown Creek	1967	1967*	1969*	310
North River	1986	1991	1991	170
Red Hook	1987	1989	1990	60

*Currently operated as modified aeration, with planning for upgrade to full secondary ongoing.



POLLUTANT ABATEMENT AND WATER QUALITY IN NEW YORK HARBOR

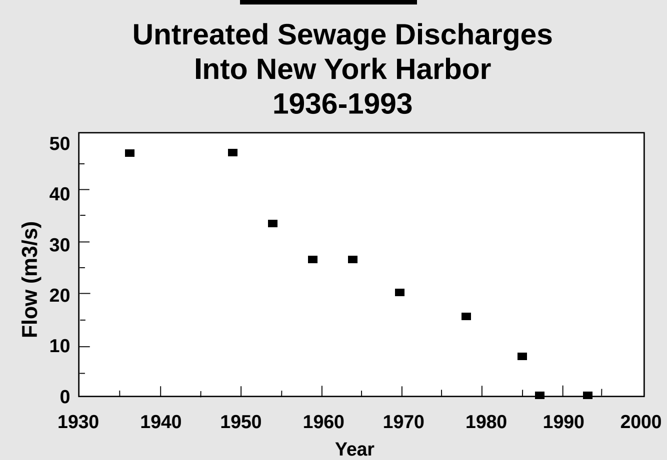
Historical Changes to Sewage Treatment

Water quality conditions necessary to attract and support aquatic life have significantly improved in most areas of the Harbor in the past 20 years, as most recently evidenced by increased numbers of waterfowl and improvements to certain local fish stocks and benthic communities. This is primarily attributable to enhanced control of sewage and industrial discharges, and product bans (e.g., DDT, PCBs, lead etc.). Wastewater collection and sewer construction in NYC began in 1696 (O'Connor, 1990), with much of lower and central Manhattan's sewers constructed between 1830 and 1870. Today there are ~6,300 miles (10,000 km) of sewers in NYC's five boroughs.

Water quality conditions necessary to support aquatic life have improved...

Construction of WPCPs throughout the region during much of the twentieth century has reduced discharges of untreated wastewater into the Harbor from approximately 1,070 mgd (46.9 m^3/s) in 1936 to less than one mgd (0.04 m^3/s) by 1993 **(Figure 3)** (Interstate Sanitation Commission, 1970; 1978; 1985; and 1993). The first wastewater treatment plant in the region, built in 1886 to protect bathing beaches on Coney Island, consisted of a crude facility designed to capture floatable materials. Construction of modern facilities in NYC began in 1935 with the Coney Island WPCP, and culminated with the completion of the North River WPCP in 1991. **Table 1** lists the 14 NYC WPCPs along with associated startup and treatment modification dates.

FIGURE 3



More Recent Changes to Sewage Treatment

Improvements to the sewage treatment system, innovative pollution prevention or abatement programs, and improved operational procedures since 1986 have resulted in the abatement of illegal connections, reduced raw sewage bypassing, and increased capture of combined sewage during rain events. Reductions to pollutant loadings from NYC facilities since 1986 are attributed to the following programs:

Water Pollution Control Plant Construction

New York City's 14 WPCPs currently process 1.44 bgd (63.5 m^3/s), which is roughly equivalent to 10% of the Hudson River flow. As noted in Table 1 the last two NYC WPCPs to be constructed, North River and Red Hook, went on line in 1986 and 1987, respectively. Of NYC's 14 WPCPs, thirteen are now operating at secondary treatment. Treatment plants that were most recently upgraded to full secondary include: Red Hook (1989), North River (1991), Coney Island (1994), and Owls Head (1995). Planning and evaluation of the upgrade for the 310 mgd Newtown Creek plant is ongoing.

Shoreline Survey and Sentinel Monitoring

As noted above, illegal connections to the sewer system which circumvent the WPCPs can contribute a significant pollutant load to receiving waters. The NYC DEP is currently engaged in identifying and remediating these illegal connections through the Shoreline Survey Program (NYC DEP, 1993b) and the Sentinel Monitoring Program, as described below.

Shoreline Survey Program This program, tasked with identifying illegal connections to the sewer system and abating dry weather discharges, completed two full shoreline inspections of the NYC drainage area by 1993. In all, the program identified 3,901 outfalls along the City's 425 miles of shoreline. Of the total, 451 outfalls were observed to have discharges, with 60% of these confirmed to contain sewage contamination; representing a relative flow of greater than 3 million gallons a day (mgd). Since 1989, the Shoreline Survey Program has abated over 2 mgd from these sources. In addition, following identification through the Shoreline Survey, the NYS DEC has acted to abate another 150,000 gallons per day. Together, NYC DEP and NYSDEC have reduced over 71% of estimated dry weather sanitary discharge and abated 176 outfalls, harbor-wide.

Sentinel Monitoring Program This program was established to supplement the Shoreline Survey Program. To continue to monitor the Harbor for illegal connections the Sentinel Monitoring Program has established a total of 99 monitoring stations **(Figure 4)**, which include 53 Harbor Survey stations and an additional 46 open water sites. Quarterly fecal coliform sampling at these stations will be compared to an established baseline; the exceedance of which will trigger intensive surveillance of the adjacent shoreline.

Reduced Raw Sewage Bypassing

Increased surveillance and maintenance of regulators and pumping stations, and improved WPCP operations have reduced bypassing from these sources by 93%, from 1,845 mg (equivalent to 5.1 mgd) in fiscal year 1989 to 84 mg (0.2 mgd) in FY97. In addition to reducing coliform concentrations, discharge abatement has also reduced loadings of TSS, BOD, and total Kjeldahl nitrogen (TKN) by an estimated 3,000, 2,900, and 300 lbs/day, respectively (O'Shea and Brosnan, 1997). Though not as easily quantified, metals, organic priority pollutants, floatables and other pollutant loadings from these sources have also declined. In addition, the connecting of an area of Tottenville, Staten Island, to the Oakwood Beach WPCP in 1993, resulted in the capture of 0.7 mgd of previously uncaptured raw sewage.

Increased surveillance, maintenance, and improved operations have reduced bypassing...

Recent operational improvements that will continue to reduce sewage bypassing are described below:

Enhanced Beach Protection Program Most recently, implementation of an Enhanced Beach Protection Program (EBPP) has further reduced bypasses associated with malfunctions at key pumping stations and regulators. This program was initiated in July 1997, in response to a series of collection system failures in the Borough of the Bronx. These failures caused the release of <1 million gallons into Eastchester Bay and ~5 million gallons into Westchester Creek, resulting in two single-day beach

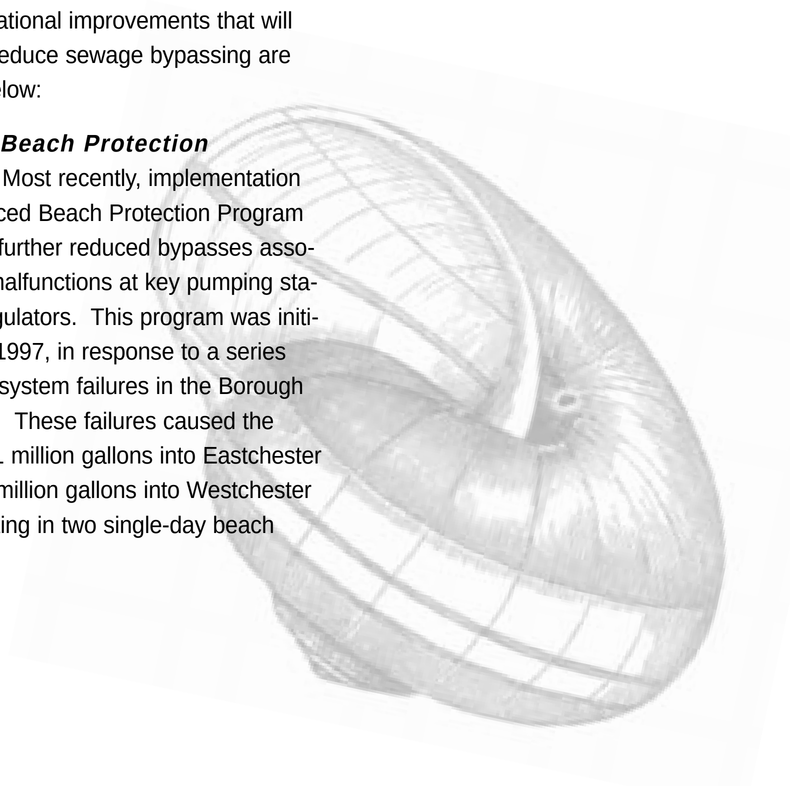
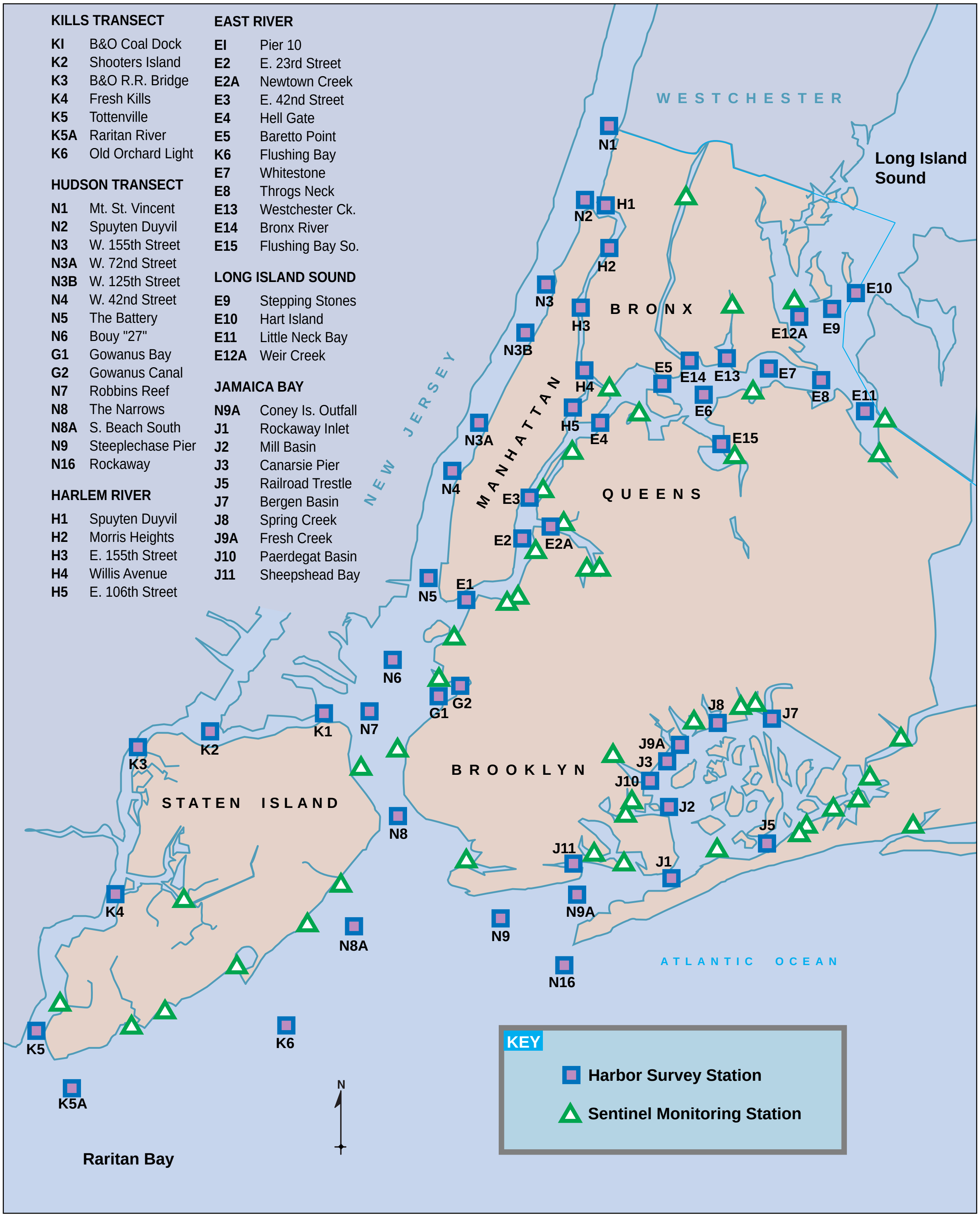


Figure 4 Sampling Locations for Harbor Survey / Sentinel Monitoring



closures at Orchard Beach. Under the EBPP, increased surveillance and preventative maintenance was conducted for the remainder of the summer at key sewer regulators and pumping stations. This allowed for rapid response to potential system failures and ultimately the reduction of dry weather sewer discharges. The EBPP proved successful, reducing dry weather discharge from these sources by 76%, relative to the same period in 1996 (Loncar, 1997). Further evidence of its success is that no additional beach closures occurred following initiation of the EBPP.

Telemetry Installation of telemetry at 89 NYC pumping stations will provide for improved monitoring and communications between these facilities and DEP plant engineers. Upon completion, this system will enable DEP personnel to view from personal computers historical or real-time data for all connected pump stations. Automatic alarms at up to a dozen critical points will notify shift engineers as to condition changes, including: force main pressure, wet and dry well liquid level, electric power supply, pump operation, and sluice gate position. Installation and testing of the telemetry program is currently 95% complete and is anticipated to be fully operational by the end of 1998. This program is expected to further reduce dry weather bypassing and better enable DEP personnel to respond to adverse weather conditions.

Storm Water Program

Presently, NYC DEP is completing a characterization of storm water runoff from five different land use locations, including: highways, commercial areas, heavy industrial zones, and high and low density residential areas. As part of this effort an inventory of industrial and waste handling facilities that discharge to the separate storm system is being compiled, and pollutant loads estimated. Other planned initiatives under the *Storm Water Program* include: control of construction and contaminated site runoff, a spill response program, stenciling of catch basins, and enforcement against improper disposal of spent vehicle fluids (Burns, 1997).

Abatement of Combined Sewer Overflows

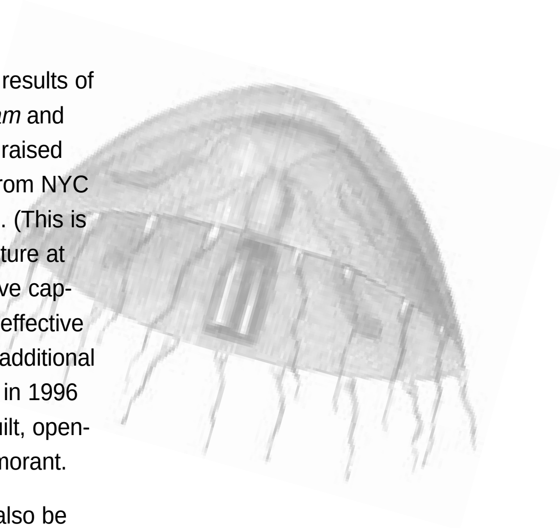
As part of a multi-year, Citywide CSO Abatement Program, NYC has committed $1.5 billion for construction of CSO abatement facilities over the next 10 years. Water quality studies have been used to determine where and to what extent capture and treatment of CSOs is necessary to meet NYS DEC water quality standards. Facility planning is proceeding and includes: sewer system improvements, in-line storage, and underground, off-line storage tanks, ranging from 7-30 million gallons (Moutal, 1992; Smith, 1992). A prototype CSO facility was constructed as early as 1972 at the head of Spring Creek in Jamaica Bay. The Spring Creek facility provides for ~10 mg of CSO storage, with another 20 mg of available in-line storage and further allows for overflow disinfection, and floatables and suspended solids removal. After a storm, the captured overflow is fed back to the 26th Ward WPCP for secondary treatment.

More immediate steps to reduce CSO impacts have also been achieved through full implementation of the USEPA's recommended *Nine Minimum Controls* (NMCs). Some elements of the NMCs implemented over the past 9 years are decribed below:

Increased Wet Weather Capture From 1989 to 1997, NYC DEP instituted operational changes at many of its plants and made improvements to the functioning of its regulators. These changes have resulted in an increase in the capture of rainfall that enters the combined sewer system from an estimated 18% in 1989 to 41% in 1997. Tide gate infiltration also has been reduced by 40 mgd (151,400 m^3/d) since 1985. Water conservation (see *Other Pollution Reduction Programs*, p. 18) has also increased capacity for CSO capture at the plants.

Floatables Control Floatables consist primarily of manmade debris that floats on or below the water surface. They contribute to several problems in the region including beach closings, interference with navigation, entanglement of wildlife, and aesthetic impairments. Excluding pier debris, approximately 95% of floatables in the Harbor originate from combined sewers and storm sewers conveying street litter.

To better control and capture floatables, NYC DEP began a *Boom and Skim Program* in 1993. This program currently consists of 18 containment booms and 5 netting systems placed at key tributary locations, and four skimmer vessels. For calendar years 1996 and 1997 combined, this program collected over 3,200 $yrds^3$ of floatable trash (Head & Associates, Ltd., 1998). Combined results of NYC DEP's *Boom and Skim Program* and increased wet-weather capture has raised the quantity of floatables captured from NYC CSOs since 1989 from 18% to 68%. (This is based on the above noted 41% capture at the plants, plus an estimated effective capture of 75% at the booms and 95% effective capture of the netting systems.) An additional *77 tons* of floatables were collected in 1996 and 1997 by NYC DEP's custom-built, open-water skimmer vessel, the S/V Cormorant.



Several intervention programs can also be credited with limiting the discharge of floatables into the Harbor. These include: the use of floating curtains around marine transfer stations and the use of nets to cover barges transporting garbage between these stations; public awareness and public education programs aimed at reducing littering; an increase in street sweeping within some watersheds; and city-wide catch basin cleaning and covering. New York City also participates with community groups, and is an annual co-sponsor of *Beach Cleanup Day.* In addition, collaborative efforts by the United States Army Core of Engineers, USEPA, and NJDEP, to collect large floatable debris and skim litter from open waters and shorelines, has further reduced floatables. These efforts and interim measures continue to provide temporary control of floatable discharges until other, long-term elements of the *CSO Abatement Plan* can be implemented.

...approximately 95% of floatables in the Harbor originate from street litter.

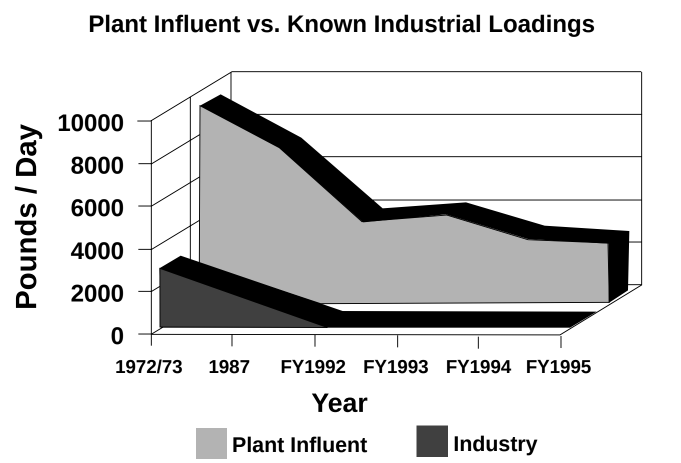
Industrial Pretreatment

New York City's *Industrial Pretreatment Program (IPP)* regulates the types and quantities of chemicals which industry may discharge into municipal sewers. Since becoming a control authority in 1987, the NYC DEP has strengthened the *IPP*, previously overseen by USEPA, by performing intensive screening of industrial discharges and developing monitoring and enforcement programs. Active amendment of sewer use regulations have also been aggressively pursued to maintain sewage collection and treatment facilities, and improve effluent and sludge quality.

As of January 1996, 721 facilities were regulated under the *IPP*. Of these facilities, 402 are listed as Significant Industrial Users. Total metals contributions from industry have decreased due to this program from 3,000 pounds/day in 1974, to less than 155 pounds/day by the end of fiscal year 1995 (**Figure 5**). While most of this decrease in mass is attributable to zinc, loadings of seven other heavy metals to the treatment plants have been shown to have declined by 50-93% from 1985-1993 (Brosnan et al., 1994; Stubin and Brosnan, 1994). These declines are attributed to the combined efforts of the *IPP* and *Corrosion Control Program* (see below), as well as, the institution of "clean techniques" for metals monitoring.

The *IPP* is now implementing strategies to both determine and reduce previously unquantified metal loadings to the sewer system. A 1993 headworks analysis indicated that one-fifth of the total load of nine toxic metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc) entering the plants could not be accounted for (NYC DEP, 1993a). Potential sources, other than industry, include residential and commercial waste, and street runoff. A second headworks analysis is now being conducted to improve the accuracy of metal loadings data. As part of a track-down effort, oxidation-reduction potential meters have been employed at key locations within the sewage system to determine if metals are being improperly disposed. Enforcement actions have been brought against several firms believed to be disposing of metals in exceedance of regulations.

FIGURE 5 **TOXIC METAL LOADINGS**



Other Pollution Reduction Programs

Additional DEP programs that have contributed (secondarily) to reductions in pollutant loadings to NYC facilities and the Harbor include the following:

Corrosion Control Initiated in 1992, this program has reduced leaching of copper, lead, and zinc into NYC drinking water. Consequential to source water reductions, metal loadings to WPCPs would likely decline, further improving effluent and biosolids quality.

Water Conservation Since 1986, NYC has promoted efforts to preserve drinking water supplies. To date, this effort has reduced demand by about 200 mgd. Lower flows result in enhanced pollutant removals at the WPCPs, and allow for greater capture and treatment of CSOs.

Landfill Remediation As of February 1991, NYC DEP took responsibility for remediating four landfills that have been declared Inactive Hazardous Waste Sites by the NYS DEC. Leachate capture and treatment, and reduction of contaminated seepage will reduce these nonpoint source contributions to the Harbor.

Biosolids Program As mandated by the Ocean Dumping Ban Act of 1988, June 30, 1992 marked the last day of ocean dumping of sewage sludge biosolids at the 106-mile dump site in the Atlantic Ocean. As an alternative to open water disposal, NYC's *Beneficial Reuse Program* is transforming biosolids into pelletized fertilizer for croplands and planning direct application for restoration of grasslands for grazing and wildlife use (Maracic, 1996).

Nutrient Removal To off-set the impacts of increased nitrogen loads due to biosolids de-watering operations, NYC DEP is implementing full biological nutrient removal at seven WPCPs (Tallman Island, Hunts Point, Bowery Bay, Wards Island, Red Hook, Oakwood Beach, and 26th Ward). In addition, pilot tests for biological and physical-chemical nutrient reduction are being conducted at Tallman Island, 26th Ward, and Newtown Creek to achieve the 58.8% nitrogen reduction called for as part of the Long Island Sound Study agreement (LISS, 1997). This agreement calls for cost-effective reduction actions to be revisited every five years, pursuant to improved technologies and ecological conditions.

Herring Gulls

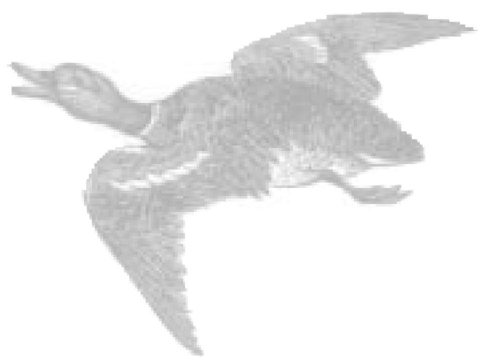
METHODS

Sampling

New York City DEP personnel sampled surface and bottom waters at each of 53 stations (**Figure 4**) approximately 2-4 times per month. Additional year-round sampling (two times per month) for many parameters has been performed since October 1990. Unless noted otherwise, all methods conformed to Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 1985). A synopsis of the Harbor Survey sampling plan, aspects of which was initiated as early as 1909, is presented in **Table 2**.

Water samples were collected from onboard the Harbor Survey Vessel, the Osprey, an aluminum-hulled 55-foot twin-engine diesel craft. Stations are located in the field by loran, latitude-longitude and line-of-site.

Some changes to station locations have been made in recent years. For example, due to shoaling at the mouth of Fresh Creek, station J9 was relocated to ~100 meters south of the mouth and renamed J9A in 1990 (**Figure 4**). Shoaling has also forced the abandonment of E12 at the mouth of the Hutchinson River. In 1996 it was relocated south to Eastchester Bay and renamed E12A. This site provides better coverage for the Bronx private beaches. Finally, a new station, N8A, was added in 1996 to provide better coverage of the northern Staten Island beaches.



Crew members collecting water samples from stern of Osprey

Water samples were collected from surface waters (1 meter below the water surface), using a 3.2 liter Kemmerer sampler. Bottom waters (1 meter above the sediment surface) were collected using 5 liter Teflon-lined Niskin and Go-Flo samplers. Blank analyses and duplicate sampling were performed daily to insure data quality.

The below listed parameters are measured at 53 sampling stations, 2-4 times per month, at both surface and bottom waters, unless otherwise noted. (Summer sampling began in 1909. Monthly sampling began in 1990.)

Fecal Coliform

The membrane filter (MF) technique has been used to determine fecal coliform concentrations in Harbor waters since 1974. Prior to 1985, daily surface and bottom water samples at each site were composited; since 1985, surface and bottom samples have been analyzed separately. Samples were aseptically filtered on-board through 0.45 micron membrane filters with the aid of a vacuum pump. The amount of sample filtered was determined based on expected

TABLE 2

NYC DEP New York Harbor Water Quality Survey Program

Analysis	Year Started & Initial # of Sites	Status
Dissolved Oxygen	1909 at 12 sites	Ongoing
Temperature/Salinity	1914 at 18 sites	Ongoing
BOD (5 day)	1935 at 33 sites	Discontinued in 1997
Tidal Cycle Studies	1923 at 3 sites	Discontinued in 1996
Total Coliform	1935 at 33 sites	Discontinued in 1997
Fecal Coliform (MF)*	1974 at 40 sites	Ongoing
Nutrients†	1974 at 40 sites	Ongoing
Plankton†	1978 at 40 sites	Ongoing at 27 sites
Chlorophyll 'a'†	1986 at 52 sites	Ongoing
pH	1985 at 52 sites	Ongoing
Secchi Transparency	1985 at 52 sites	Ongoing
CTD	1990 at 52 sites	Ongoing
TSS	1990 at 52 sites	Ongoing

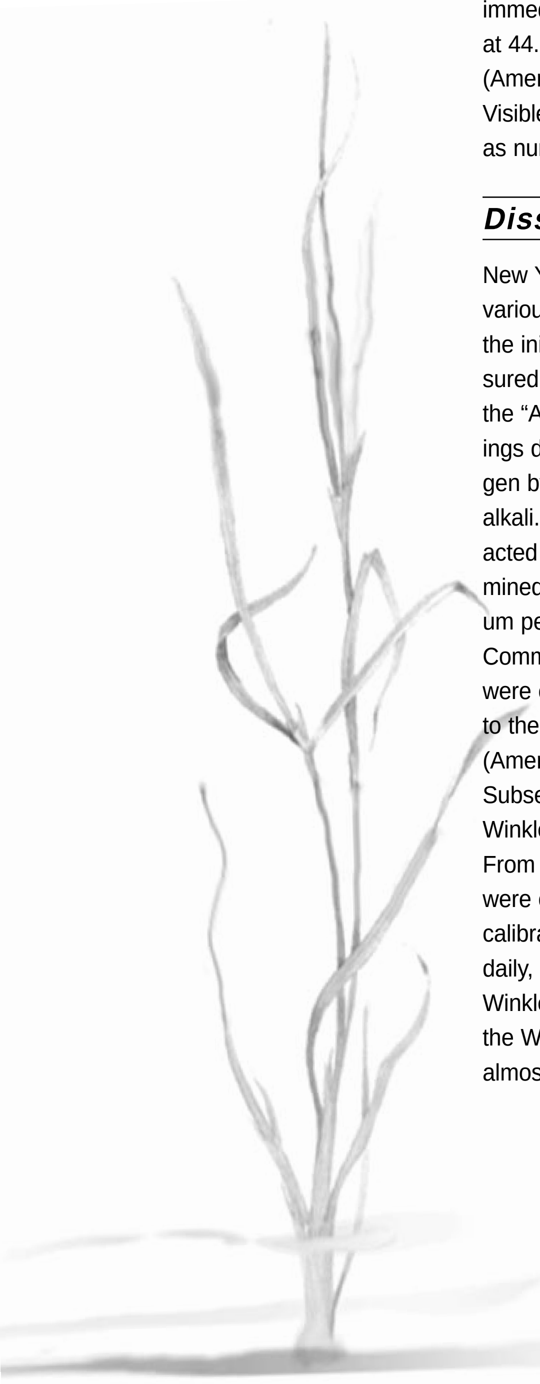
* *Coliform is only measured June - September*
MF *Membrane Filter Method*
† *Nutrients, Plankton and Chlorophyll 'a' measured only in surface waters*
CTD *Conductivity, Temperature and Depth (transmissometer and fluorometer added in 1992)*

Priority pollutants, i.e., volatile organics in water and metals in sediment, have also been measured infrequently (see earlier Harbor Survey Reports).

fecal coliform concentrations. The membrane was aseptically removed from the filter holder and placed into a 47 mm petri dish containing M-FC media. Petri dishes were immediately placed in portable incubators at 44.5°C for 24 +/- 2 hours of incubation (American Public Health Association, 1985). Visible colonies were counted and reported as number of fecal coliform/100 ml.

Dissolved Oxygen

New York City has been monitoring DO in various stations in the Harbor since 1909. In the initial years of the survey, DO was measured using a procedure sometimes called the “Albert Levy Method,” in which DO readings depended upon the absorption of oxygen by ferrous sulphate in the presence of an alkali. The amount of ferrous sulphate not acted upon by the oxygen was then determined by acidifying and titrating with potassium permanganate (Metropolitan Sewerage Commission, 1912). This method’s results were certified at that time to be identical to the more familiar Winkler method (American Public Health Association 1985). Subsequently, the azide modification of the Winkler method was used through 1984. From 1985 through 1987, YSI DO meters were often used. These DO meters were calibrated and rechecked two or three times daily, using the azide modification of the Winkler method. From 1988 through 1997, the Winkler method was once again used almost exclusively.



Nutrients

Sampling for ammonium (NH4-N), nitrate-nitrite (NO3-N and NO2-N), total phosphorus, and orthophosphate (PO4-P), has increased from a single sample per site each summer (1974-1983) to monthly surface and bottom sampling in 1985, 1986 and 1987. Laboratory constraints in 1988 forced a decrease in sampling to half the stations monthly, as top and bottom composites. From 1989 to 1997, in an effort to assess the within-season variability of these nutrients, surface waters were sampled at all stations twice per month. In 1996, analysis of Total Kjehldahl Nitrogen (TKN) was added.

Total phosphorus and TKN samples were placed directly in sample-rinsed 125 ml polypropylene bottles, acidified with sulfuric acid to pH <2, and placed in coolers for transport back to the Wards Island laboratory. For ammonium, nitrate-nitrite, and orthophosphate samples, 250 ml were immediately filtered on-board through pre-rinsed 0.45 micron membrane filters, preserved with sulfuric acid in polypropylene bottles, and transported back to the lab. Prior to 1989, nutrient concentrations were measured using a Technicon Auto Analyzer II, according to Methods for Chemical Analysis of Water and Wastes (US EPA, 1979). Since 1989, a TRAACS 800, using the modified Industrial Method (Bran and Luebbe, Inc., 1986) has been used.

In support of modeling and clean-up activities associated with the Long Island Sound Study, and at the bequest of USEPA and NYSDEC, the Harbor Survey Program has been expanded since 1989 to include more intensive monitoring of the East River-Long Island Sound transect. In coordination with the Connecticut Department of Environmental Protection (CT DEP) and the Interstate Sanitation Commission (ISC), monthly monitoring of the entire Long Island Sound, from the Battery to the Race, is performed year-round. Samples collected for this program are analyzed by CT DEP's contractor laboratory and provide data on particulate and dissolved carbon, nitrogen, phosphorus, silica, chlorophyll 'a', total suspended solids, 5-day BOD, DO, and conventional parameters.

Chlorophyll 'a' and Plankton

Chlorophyll 'a' is measured and plankton samples are taken from surface waters only. Chlorophyll 'a' (corrected for phaeophytin) is determined fluorometrically following on-board filtration of 250 ml through a 0.45 micron membrane filter and extraction in aqueous acetone, as detailed in Standard Methods (American Public Health Association 1985).

Chlorophyll 'a' has been measured since 1986 as an estimate of phytoplankton biomass. It was recognized that the previous monthly sampling rate was often inadequate to capture natural variability for this parameter. In response, the frequency of chlorophyll collections was increased to twice per month at 26 of 52 stations starting in 1988, and for all 52 stations beginning in 1989. Sampling for chlorophyll 'a', initially conducted from June-September, was increased to year-round for years 1991-1996. November and December sampling was not performed in 1997.

Monthly phytoplankton sampling of surface waters (June - September) was initiated in 1978 at 40 Harbor Survey stations. Sampling rate was increased to twice monthly, year-round, in 1992, for 27 sites found to have highest chlorophyll 'a' concentrations.

For plankton samples, 0.8 L of surface water were preserved with 5.6 ml of Lugol's solution, and transported to the Oakwood Beach Laboratory for analysis. Following a 48-hour settling period, samples were concentrated to a final volume of 100 ml; a portion of which was stored in a clean glass screw cap vial for analysis.

Plankton counts were performed through use of a Sedgewick-Rafter cell. This cell is 50 mm long by 20 mm-wide by 1 mm-deep, providing a volume of 1 ml. A calibrated Zeiss Photo microscope III, equipped with a Whipple ocular micrometer, was employed to identify and count plankton cells contained in this concentrated sample. Ten or twenty random Whipple disc fields, at magnifications of 125x, 200x and 320x, were counted for more abundant forms. Concentrations of rare forms were estimated by 'strip counts' or by 'survey counts'. Calculations and methods were performed according to Standard Methods (American Public Health Association, 1985).

Secchi Transparency

Determination of surface water transparency has been performed since 1985 through use of a standard black and white quadrant Secchi disk. Measurements are recorded to the nearest half foot demarcation.

Temperature, Salinity, and Density

Beginning in June 1992, temperature, salinity, and density profiles of the water column for each station were obtained using a Sea-Bird SBE 25-03 Sealogger CTD (see previous Harbor Survey Reports for earlier instrumentation employed). This instrument is capable of taking four readings per second of conductivity and temperature. Software supplied by the manufacturer enables the calculation of salinity from these values. The instrument is also configured with other sensors, including a fluorometer, a 10cm wavelength transmissometer, and a polarographic dissolved oxygen sensor. These data are used to generate profiles for each parameter down through the entire water column (to within one meter of the bottom) at each sampling station. Duplicate analyses were performed at one random station per day.

Additional Parameters

For sampling and methods pertaining to additional parameters collected as part of the Harbor Survey Program (see table above), but not described in this report, the reader is referred to the 1995 Harbor Survey Report (O'Shea and Brosnan, 1997).

Marine Sciences Section personnel perform fecal filtrations aboard Osprey

Statistical Analysis and Data Presentation

Long-term linear trends were evaluated by regression analysis at a significance level of probability ($p < 0.05$), unless otherwise noted, using Statistical Analysis System (SAS). Data sets which did not display normal distributions (i.e., coliform) were log-transformed prior to trend analysis. Descriptive statistics (average, range, coefficient of variation, number of samples, etc.), as well as, raw data are available upon request.

This report displays high to low parameter gradients through use of concentration distribution maps. Concentration gradients depicted on these maps reflect standards (e.g., DO and coliform) or other environmentally meaningful concentrations, where available. Note that these concentrations are really site specific and extrapolation to other areas depicted should be interpreted with caution. Maps and waterways are not drawn to scale.

Quality Assurance/ Quality Control

Daily quality control procedures for parameters included: analysis of duplicate, spike, and blank samples, as well as, two reference standards; instrumentation check; replicated and documented calibrations of meters; and comparison of results between analysts.

Sampling Hudson River waters along side Battery Park

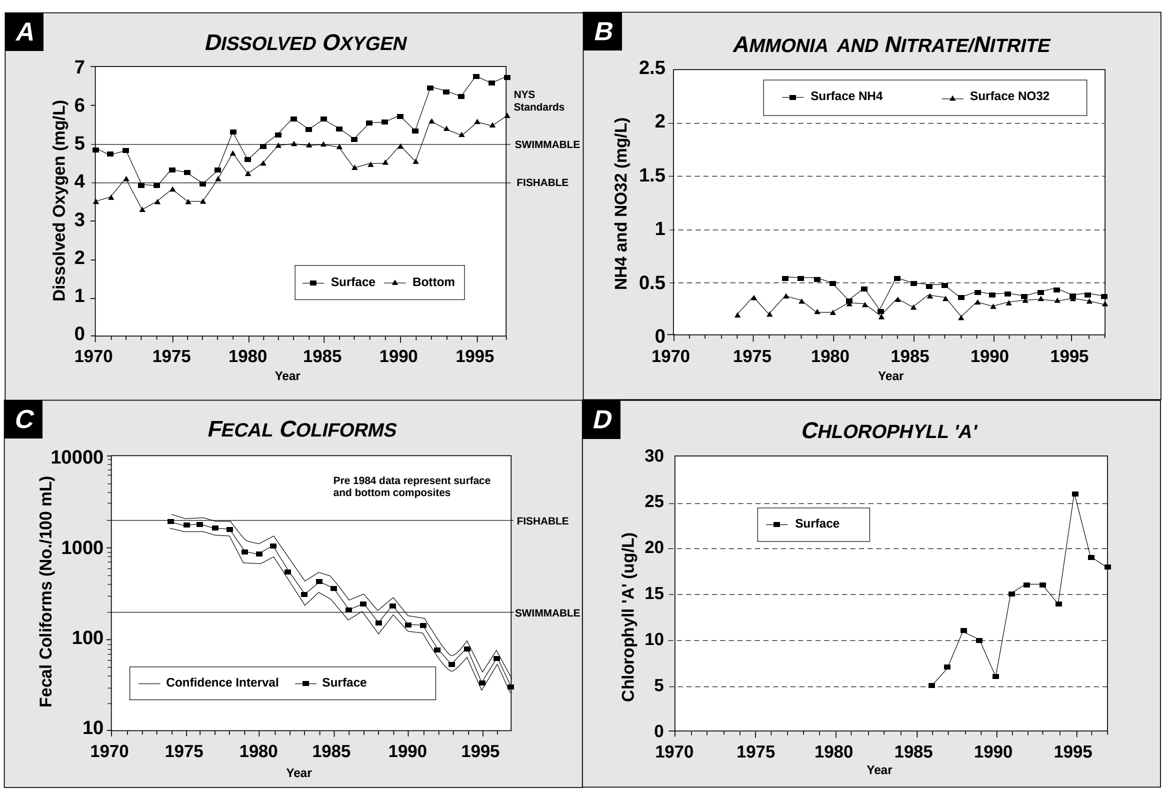
RESULTS AND DISCUSSION

No single indicator fully or adequately describes the quality of estuarine waters. Instead, a suite of indicators is used to provide information relative to sanitary quality, ability to sustain aquatic life, ecosystem productivity, and aesthetics. Indicators of water quality used by the Harbor Survey Program include: fecal coliform bacteria; dissolved oxygen; nutrients; chlorophyll ‘a’; and water clarity. Harbor-wide trends for several of these indicator parameters are shown in **Figure 6** and discussed in more detail in the following sections. Where possible, indicators are compared to NYSDEC standards. These standards reflect a range of acceptable water quality conditions (**Table 3**), as determined by the state-designated ‘best usage’ of the water body (**Figure 7**).

Coliform Bacteria

Coliform bacteria are measured in the Harbor as indicators of sewage-related pollution. Primary regional inputs of coliform to Harbor waters include: illegal sewage connections; intermittent, unplanned sewer system bypasses due to equipment malfunctions; permitted dry weather bypasses due to construction and upgrading; WPCPs; separate storm water outfalls; and most important, combined sewer overflows (CSOs), during and immediately after rain events. Smaller sources which can be locally important include non-point sources, (e.g., leaking septic tanks and direct storm water runoff), boat discharges, and tributary sources (HEP, 1996).

FIGURE 6 HARBORWIDE ANNUAL INDICATOR TRENDS
SUMMER AVERAGES



* Harborwide averages represent 40 stations

FIGURE 7 **STATE-DESIGNATED BEST USE CLASSIFICATIONS FOR NEW YORK HARBOR WATERS**

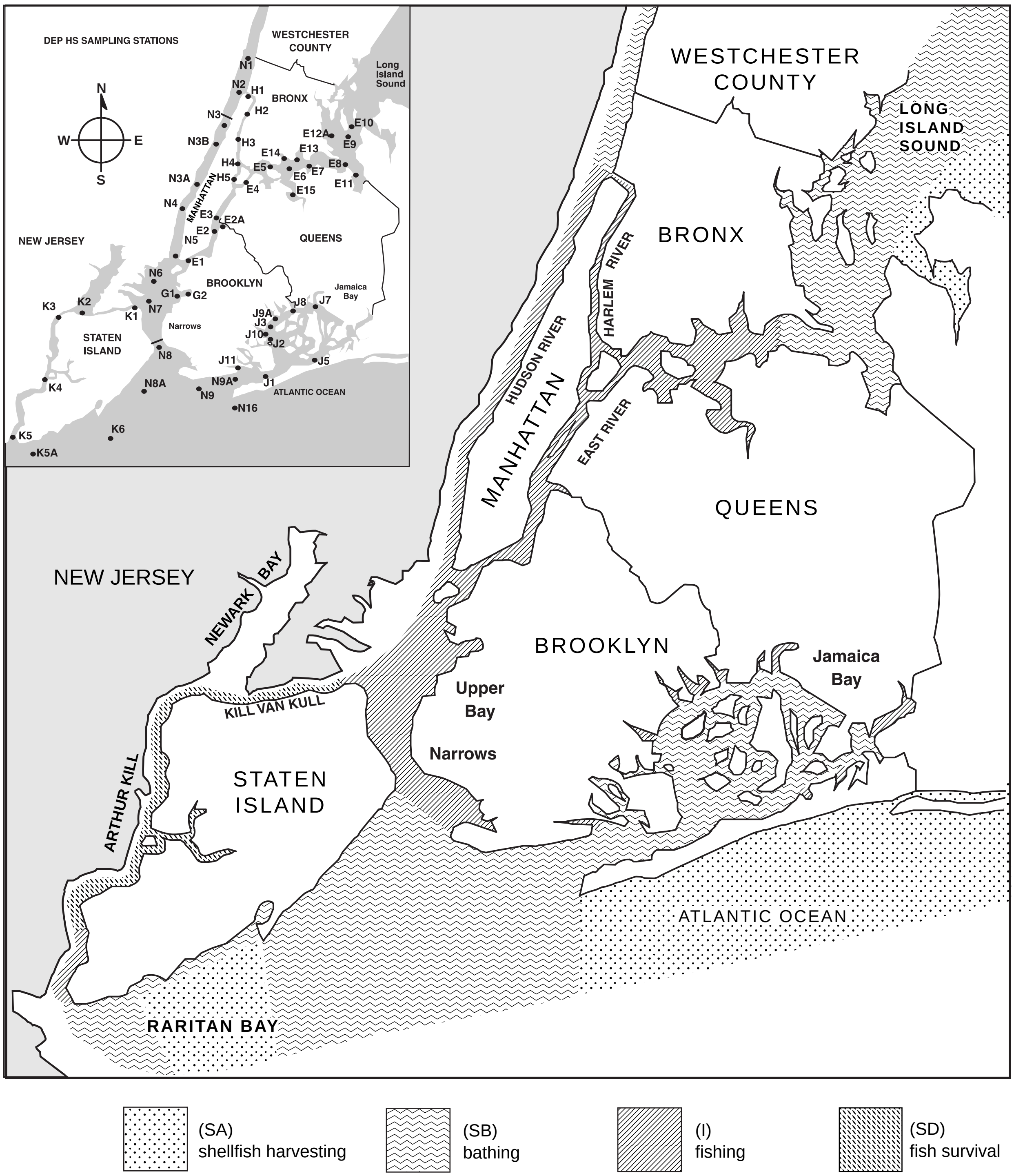
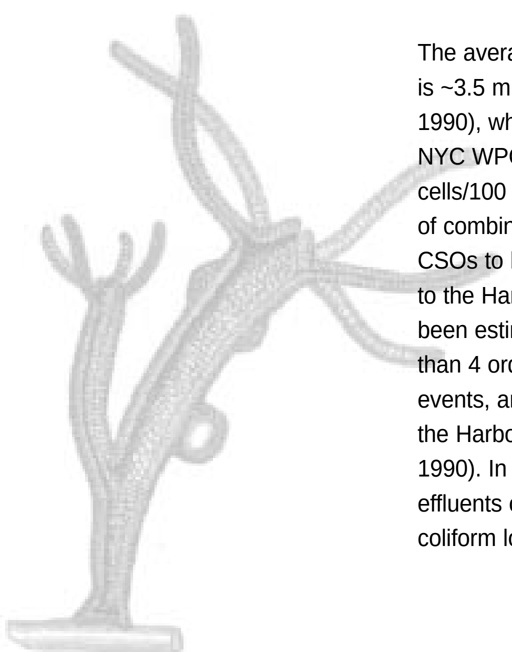


TABLE 3

Water Quality Standards
New York State Department of Environmental Conservation

Classes and standards for saline and fresh surface waters
(adapted from part 701.5 of "Title 6: Environmental Conservation" of the Official Compilation of Codes, Rules, and Regulations of the State of New York, 1974.)

Class	Best Usage of Waters	Total Coliform	Fecal Coliform	Dissolved Oxygen
SA	Shellfishing for market purposes and primary and secondary contact recreation.	Median MPN value ≤70MPN/100 ml in any series of samples.	No standard	5.0 mg/l
SB	Primary and secondary contact recreation and any other use except shellfishing for market purposes.	Monthly median ≤2,400 cells/100ml from 5 or more samples; no more than 20% of the samples >5,000 cells/100ml. Standard to be met during disinfection season.	Monthly geometric mean ≤200 cells/100 ml from 5 or more samples. Standard to be met during disinfection season.	5.0 mg/l
I	Secondary contact recreation and any other uses except primary contact recreation and shellfishing for market purposes.	Monthly geometric mean ≤10,000 cells/100ml from 5 or more samples. Standard to be met during disinfection season.	Monthly geometric mean ≤2,000 cells/100 ml from 5 or more samples. Standard to be met during disinfection season.	4.0 mg/l
SD	Fish survival	No standard	No standard	3.0 mg/l



The average fecal coliform content of CSOs is ~3.5 million cells/100ml (Appicella et al. 1990), while the average discharged from NYC WPCPs (in 1989) ranged from 6 to 43 cells/100 ml. Considering the predominance of combined sewers in NYC, this suggests CSOs to be the dominant source of coliforms to the Harbor. In fact, regional CSOs have been estimated to increase loadings by more than 4 orders of magnitude, during rain events, and account for more than 95% of the Harbor coliform load (Apicella et al., 1990). In contrast, disinfected WPCP effluents contribute less than 1% of the total coliform load to the Harbor.

Estimated Attainment of Water Quality Standards

Assessment of compliance with NYS DEC water quality standards for fecal coliform (FC) requires the testing of five or more samples per month. Since the Harbor Survey Program typically tests each site only 2-4 times per month, a true determination of compliance is not possible. Instead, a seasonal attainment of standards is inferred by comparing seasonal geometric mean data (from at least eight samples) to the appropriate monthly numeric standard (**Table 3**).

TABLE 4

Number of Stations (out of 52) Potentially Exceeding NY State Coliform Standards[a]

Year	Total Coliform	Fecal Coliform
1989	8	3
1990	3	6
1991	na	1
1992	1	0
1993	0	0
1994	1	2
1995	1	2
1996[b]	1	1
1997[b]	na	0

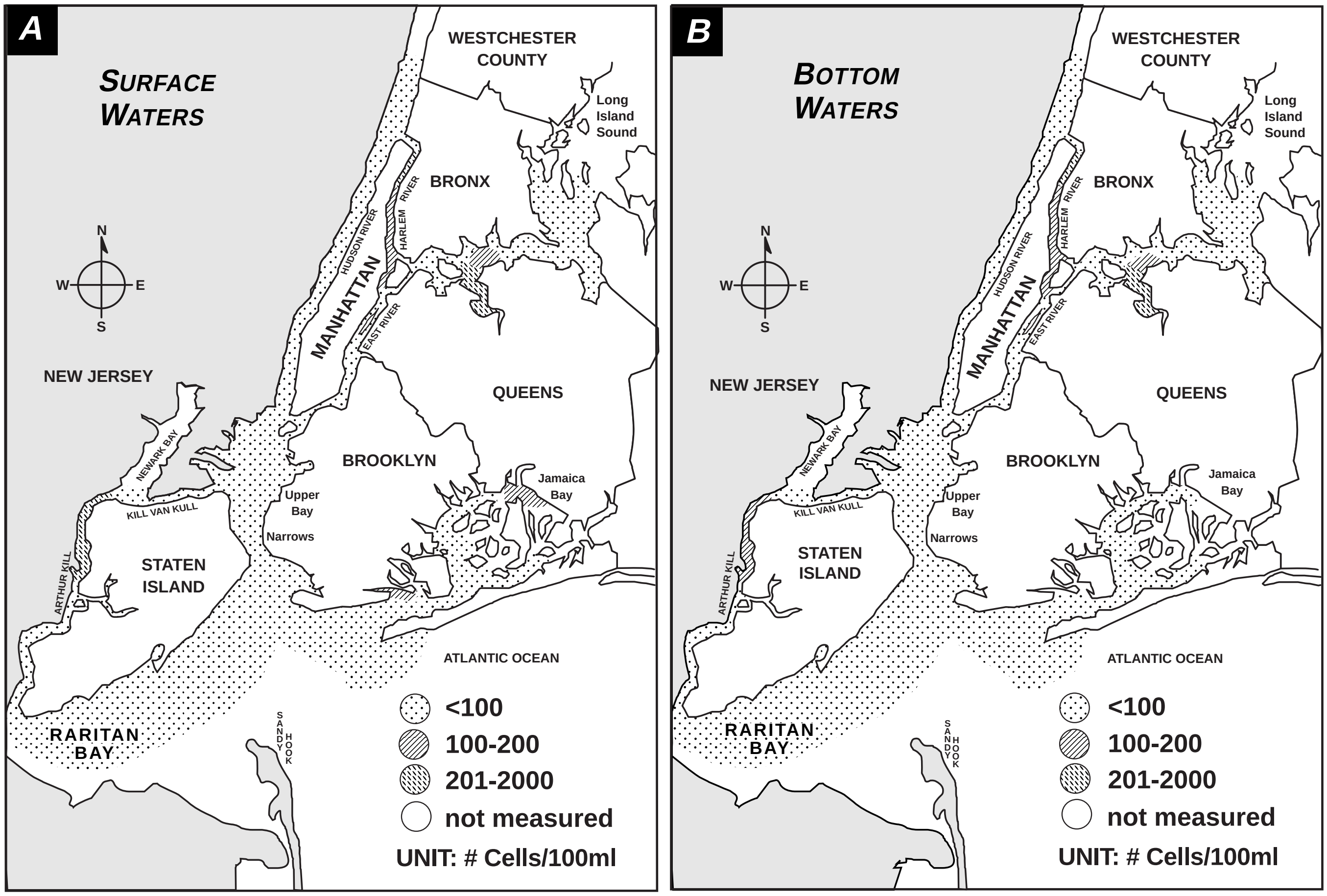
a Based on seasonal (summer) geometric mean data
b 53 stations monitored in since 1996
na Insufficient data available in 1991; TC not measured in 1997

Since 1991, no more than 2 stations have been estimated to exceed FC standards in any given year.

Red Hook WPCP stacks as seen over wetland areas

FIGURE 8 **FECAL COLIFORM IN SURFACE & BOTTOM WATERS**

Summer Geometric Means, 1997



NYS Standards: ≤ 200/100ml=SB (Bathing); ≤2000 Cells/100ml=I (Fishing)

An examination of seasonal geometric means, shows estimated attainment of FC standards to have remained high in 1997 (**Table 4**), with no station found to exceed NYS FC standards. Data for 1996 also showed high compliance, with only a single station failing to comply with its bathing standard designation. In fact, since 1991 no more than 2 stations have been estimated to be out of compliance in any given year.

Average FC concentrations for summer 1997 were less than 100 cells/100ml for most of the Harbor (**Figure 8**;a and b). Only 3 scattered sites, i.e., the Northern Arthur Kill, Flushing Bay, and a portion of the Harlem River showed average conditions to exceed the bathing standard of ≤200 cells/100ml.

Average conditions, however, may mask short-term effects of wet weather and associated CSO and storm water discharges. Following precipitation, large portions of the Harbor exhibit increases in FC concentrations of as much as two orders of magnitude (**Figure 9**;a and b). Due to these sporadic increases in Harbor loadings, it is not surprising that the best sanitary quality (i.e., the lowest coliform concentrations) continues to be found at the Harbor limits in Western

Long Island Sound, the Hudson north of Manhattan, portions of Jamaica Bay, and the Raritan Bay-Lower NY Bay complex.

Trends

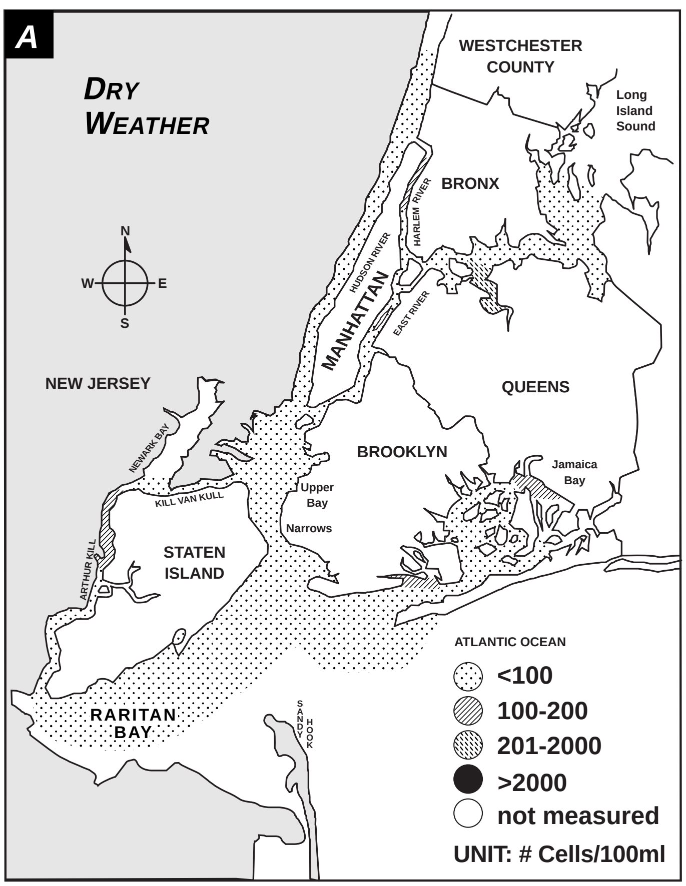
Coliform concentrations harbor-wide (**Figure 6**c) have exhibited significant (near two orders-of-magnitude) declines from the early 1970s to the present time (O'Shea and Brosnan, 1997; Brosnan and O'Shea,1996a). Examining FC trends separately for distinct areas of the Harbor (**Figure 10**;a-d) shows greatest improvement (nearly three orders of magnitude) to have occurred in the Inner Harbor Area (10a).

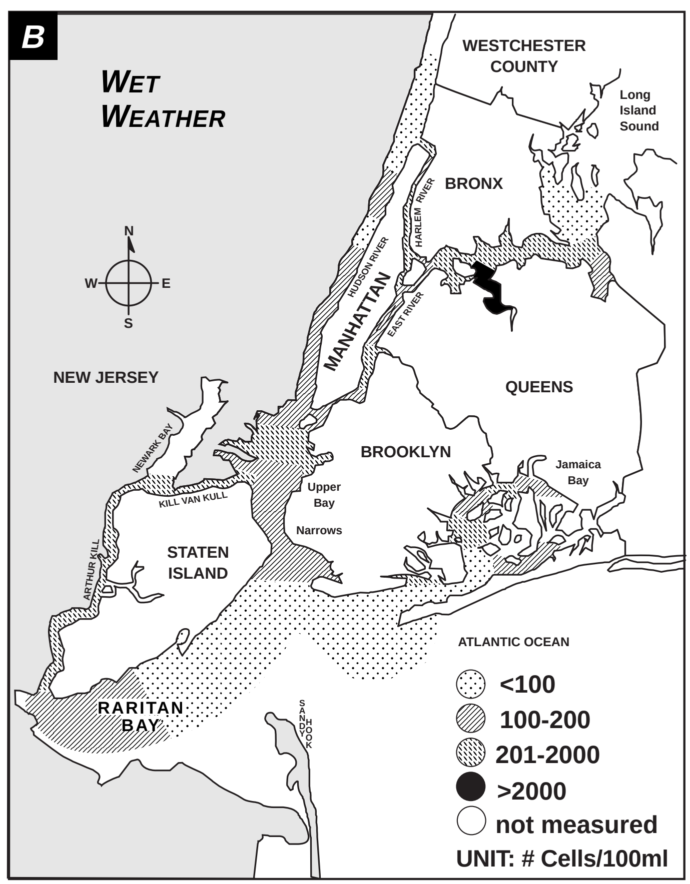
Coliform decreases in the Upper East River-Western Long Island Sound (10b) have been closer to 2 orders of magnitude. The Lower NY Bay-Raritan Bay and Jamaica Bay (10; c and d), which displayed lower FC concentrations in the 1970s, have subsequently experienced improvements closer to a single order of magnitude.

Coliform...have exhibited significant harbor-wide declines...

Figure 9 **Effect of Precipitation on Fecal Coliform Levels**

Summer Geometric Means For Surface Waters, 1995-1997





NYS Standards: ≤ 200/100ml=SB (Bathing); ≤ 2000/100ml=I (Fishing)

FIGURE 10

FECAL COLIFORM TRENDS FOR DISTINCT HARBOR AREAS

Summer Geometric Means For Surface Waters, 1974-1997

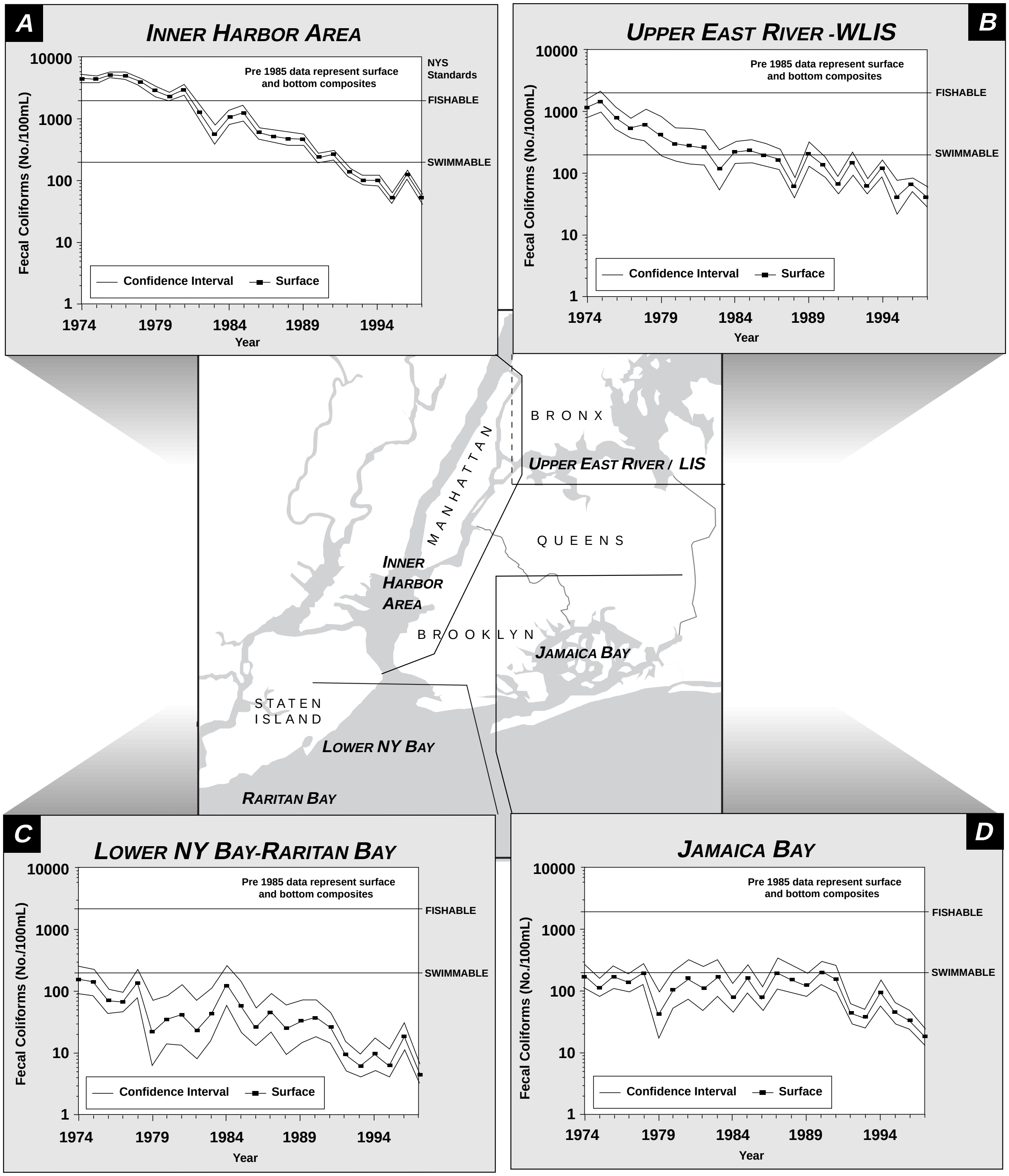
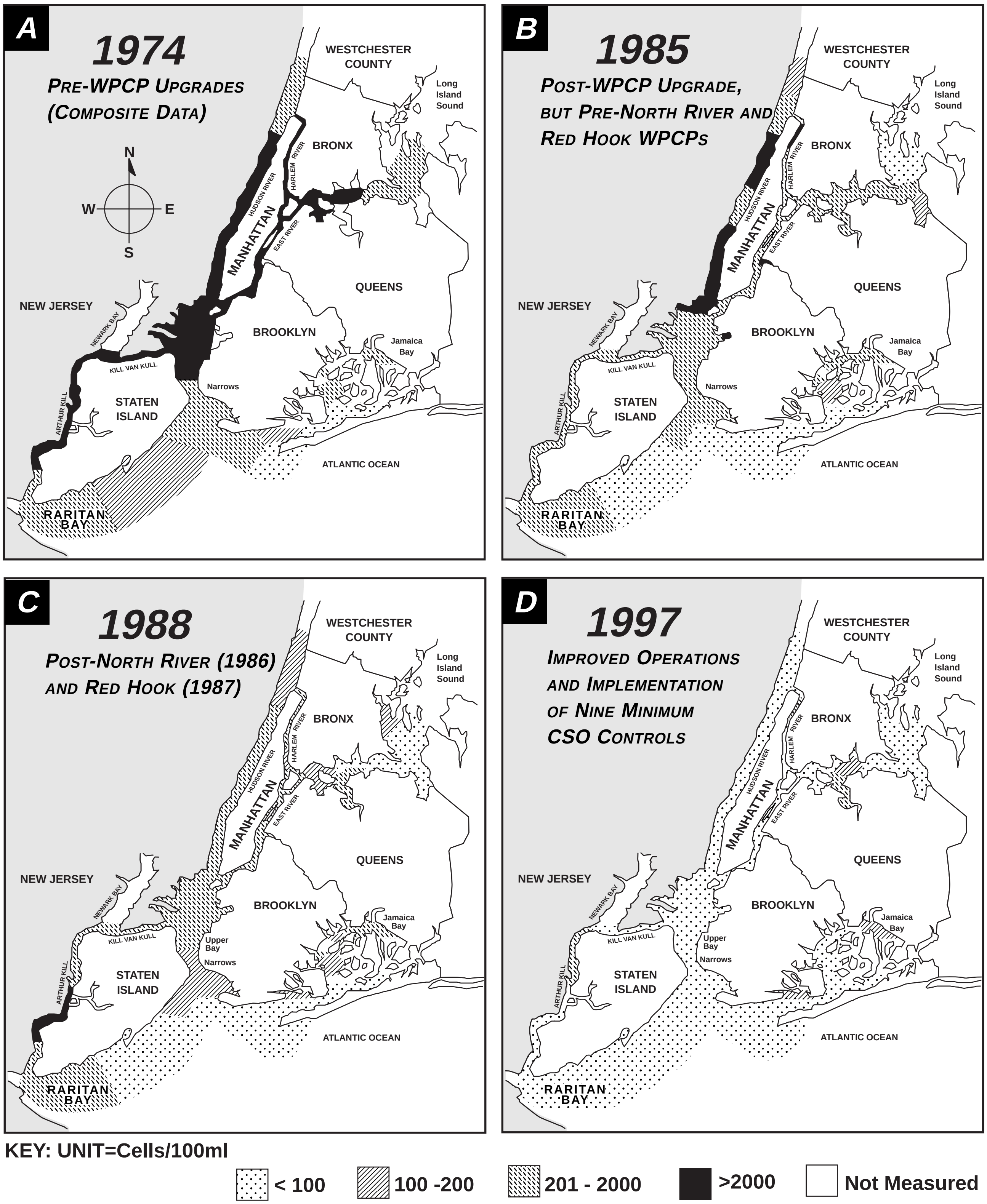


Figure 11 **Reductions in Fecal Coliform Over Four Time Periods**

Summer Geometric Means for Surface Waters



Discussion

Declines in coliform and sanitary improvements in Harbor waters are primarily attributed to the abatement of raw sewage discharges through construction and upgrading of WPCPs (O'Shea and Brosnan, 1997; Brosnan and O'Shea, 1996b).

This is depicted in **Figure 11**; a-d, where progressive improvement over four time periods (each reflective of enhanced treatment and operational controls) is shown. In 1974, prior to secondary upgrades (**Figure 11**a), average FC concentrations exceeded fishing standards throughout the Inner Harbor area and exceeded bathing standards in most outlying areas. Improvement is evident following the expansion and upgrades of eight WPCPs (**Figure 11**b) and after the startup of the City's last two WPCPs (**Figure 11**c). Operation of the North River and Red Hook plants ended the discharge of approximately 210 million gallons per day (mgd) of untreated sewage from the Manhattan and Brooklyn shorelines. This resulted in FC decreases of 78% in the Hudson River, and 63% in the East River (Brosnan and O'Shea, 1996a). Average FC counts at this time, however, still did not meet swimming standards in Inner Harbor Areas.

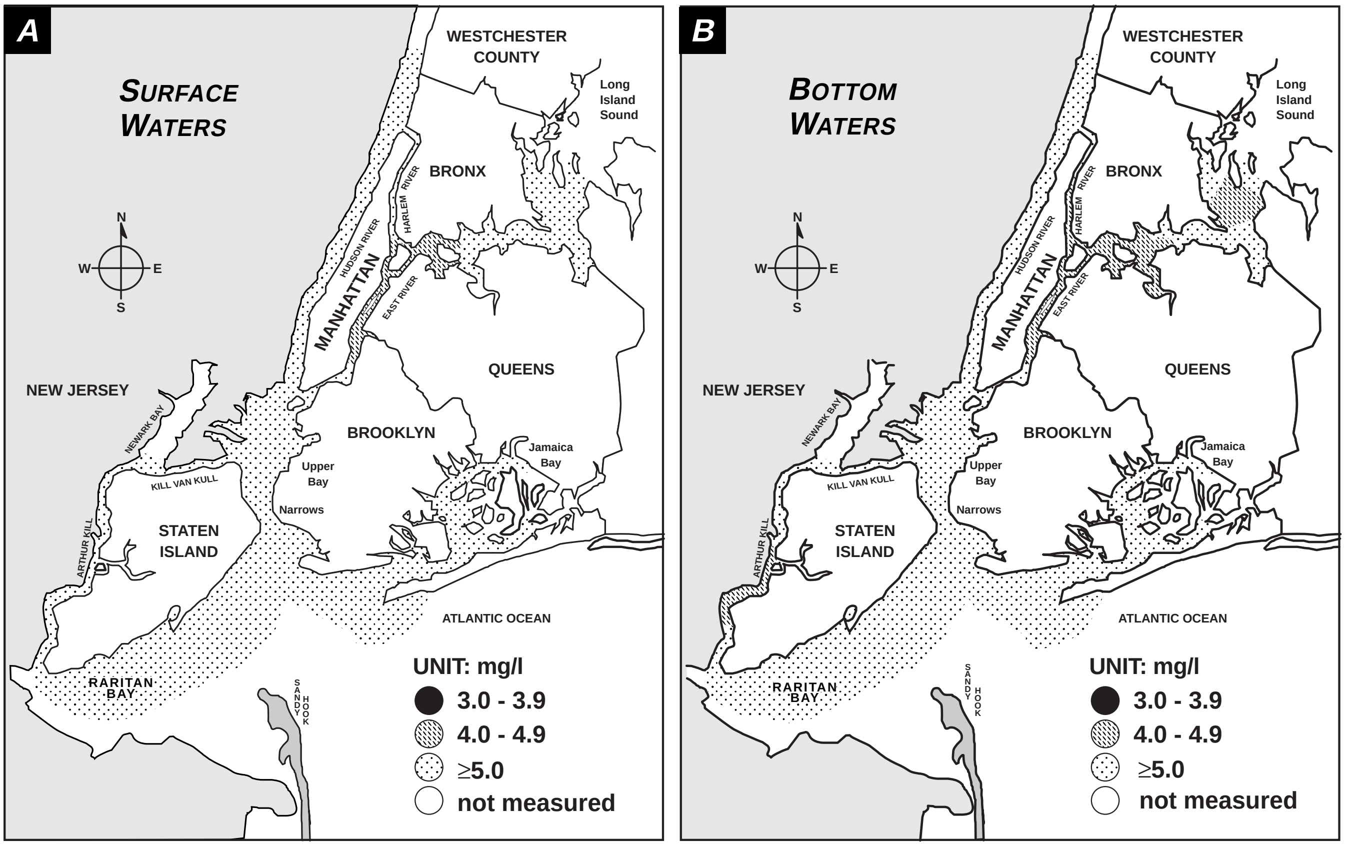
Further declines in coliform concentrations which have occurred subsequent to plant construction and upgrades (**Figure 11**d) are attributed to implementation of NYC's 1988 Special Pollution Discharge Elimination Permits. Certain aspects of these permits have now been adapted by USEPA as part of their National CSO Control Policy, *The Nine Minimum Controls*. For New York City these controls have included increased surveillance and maintenance of the entire sewage distribution system, including abatement of over 2.2 mgd of illegal discharges, reduced raw sewage bypassing by 5 mgd, and greater than 63% capture of wet weather (combined sewer) overflows at some treatment plants. In addition, previously un-intercepted sewage from Tottenville, Staten Island was sewered, beginning in 1993.

Average FC in 1997 met bathing standards for all waters, with the exception of Flushing Bay and portions of the Kills and Harlem River. (Note that each of these areas still met their designated best use classifications for secondary contact, i.e., fishing.) These improvements have been so substantial as to be apparent for both dry and wet weather conditions. Dry weather improvements are due primarily to decreased bypassing and abatement of illegal connections, whereas wet weather improvements are due to abatement of CSOs.

Dissolved Oxygen

Oxygen dissolved in the water column is required for respiration by all aerobic forms of life, including fish, and invertebrates such as crabs, clams, zooplankton, etc. The bacterial breakdown and natural decomposition of high organic loads from various sources can consume and deplete dissolved oxygen (DO). This, at times combined with water column stratification, can produce low DO levels, which when persistent may degrade habitat and cause a variety of sublethal effects upon aquatic organisms. Under extreme conditions or prolonged durations low DO can cause mortality. For example, studies conducted by USEPA and CTDEP have shown DO levels between 5.0 mg/l and 3.5 mg/l to be generally protective of

FIGURE 12 AVERAGE DISSOLVED OXYGEN FOR SUMMER 1997



NYSDEC DO Standards: ≥ 3.0 mg/l = SD(Fish Survival); ≥ 4.0 mg/l = I(Fishing); ≥ 5.0 mg/l = SB(Bathing)

all but the most sensitive aquatic species. Concentrations below 2.0 mg/l may cause severe effects, even for periods of short duration (LISS, 1997). Consequently, DO is one of the most universal indicators of overall water quality in aquatic systems.

Harbor dissolved oxygen or DO concentrations tend to follow a seasonal cycle, being lowest in summer and highest in early winter and spring. During the summer of 1997, each of the 53 Harbor Survey stations was monitored a minimum of nine times. Average summer DO values for 1997 Harbor waters are shown graphically in **Figure 12**; a and b. These values were never below 4.0 mg/l, with only 13 survey stations having average values between 4.0-4.9 mg/l, and the remainder at or above 5.0 mg/l. These DO concentrations are typical of average summer conditions reported for the Harbor over the past three years.

Figure 13; a and b, shows the minimum DO values recorded for summer 1997. Dissolved oxygen measurements of <3.0 mg/l (defined as, hypoxia) were recorded a single time at each of four bottom stations in the Upper East River-Western Long Island waters. For summer 1996, readings below 3.0 mg/l were recorded 15 times, at least once at ten different stations (Boniecki and Lochan, 1998).

DO measurements of <3.0 mg/l were recorded a single time at each of four bottom stations in the Upper East River-WLIS.

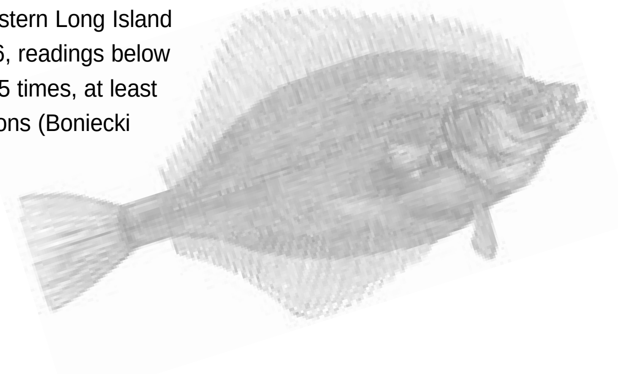
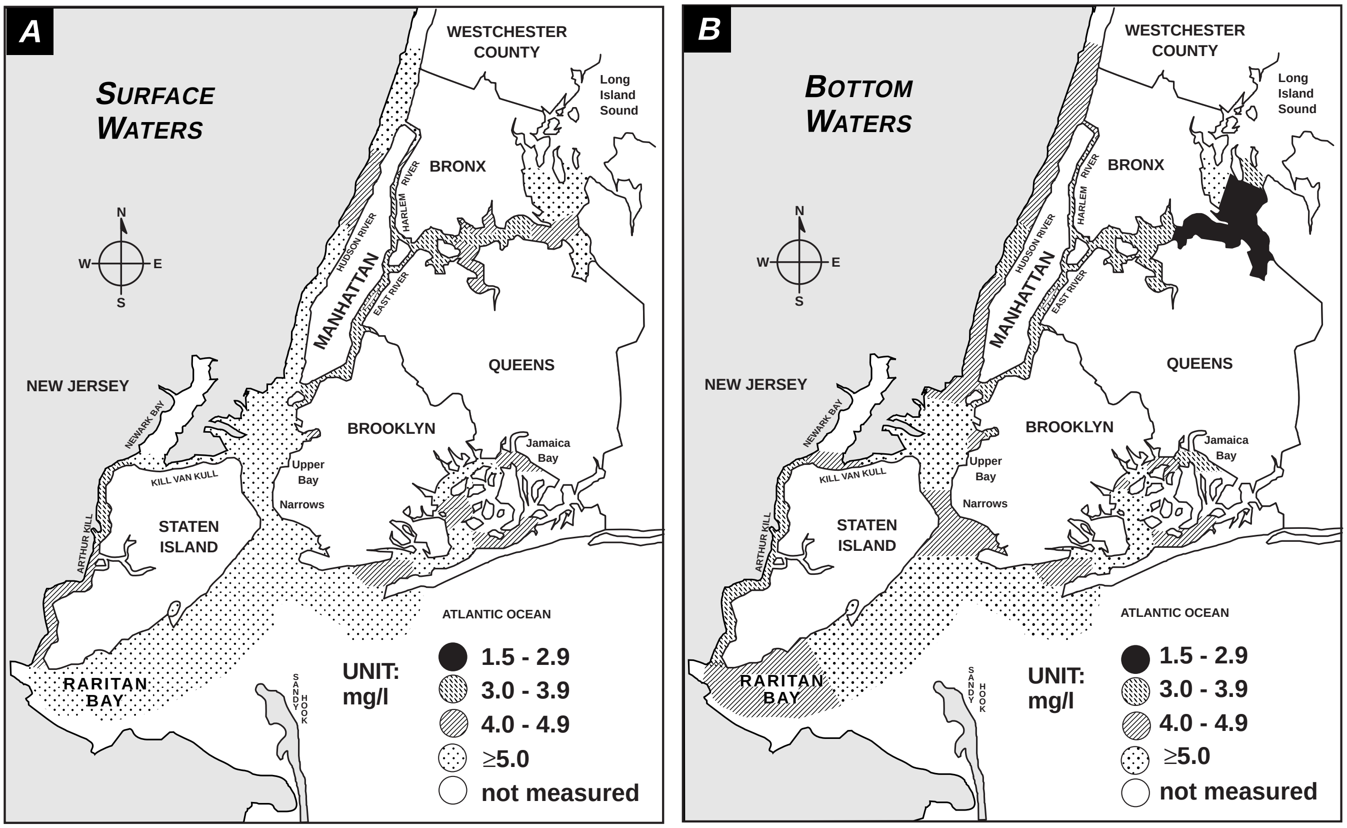


Figure 13 ***Minimum Dissolved Oxygen for Summer 1997***



NYSDEC DO Standards: ≥ 3.0 mg/l = SD(Fish Survival); ≥ 4.0 mg/l = I(Fishing); ≥ 5.0 mg/l = SB(Bathing)

Average dissolved oxygen achieved NYS standards...with exception of one site in WLIS.

Attainment of Water Quality Standards

Assessment of the adequacy of DO present in the Harbor is performed by comparing actual concentrations to NYS DEC Standards, which vary between 3-5 mg/l, depending on the designated best use of the waterway (**Figure 7** and **Table 3**). New York State standards require that measured dissolved oxygen is "never less than" the regulatory value. Consequently, in 1997, 30 stations were out of compliance with the applicable standard at least once due to either surface or bottom measurements. The most chronic 1997 violators of the "never less than" standard (i.e., > 50% of summer samples below standards) were two Western Long Island sites (E8 and E10), and two sites along the northeastern shore of Jamaica Bay (J7 and J8). The remainder of sites contravened standards less than 40% of the time, with 23 sites (representing a considerable portion of the Inner Harbor Area and Lower NY Bay-Raritan Bay) in full compliance for the summer.

A somewhat less rigorous comparison is to examine average summer DO values to standards. While this is not a true assessment of compliance, it is more characteristic of summer conditions at sampling locations and allows for comparison of yearly variability and water quality improvement (or decline). For Summer 1997, average DO achieved NYS standards throughout the Harbor, with exception of one site in Western

TABLE 5

Comparison of Summer Dissolved Oxygen (DO) and New York State Standards

Year	Number of Stations where average DO values were lower than the Standard	Number of Stations where DO values were lower than the Standard *at least once*
1986	9	45
1987	24	41
1988	20	44
1989	22	46
1990	8	39
1991	16	45
1992	2	30
1993	4	35
1994	8	35
1995	3	32
1996	5	31
1997	1	30

...attainment of DO standards in the Harbor is clearly better than previously achieved...

Long Island Sound. Seasonal attainment of NYS DEC standards at 53 stations (52 before 1996), using both the "summer average" and the "never less than" approach for recent years, is presented in **Table 5**.

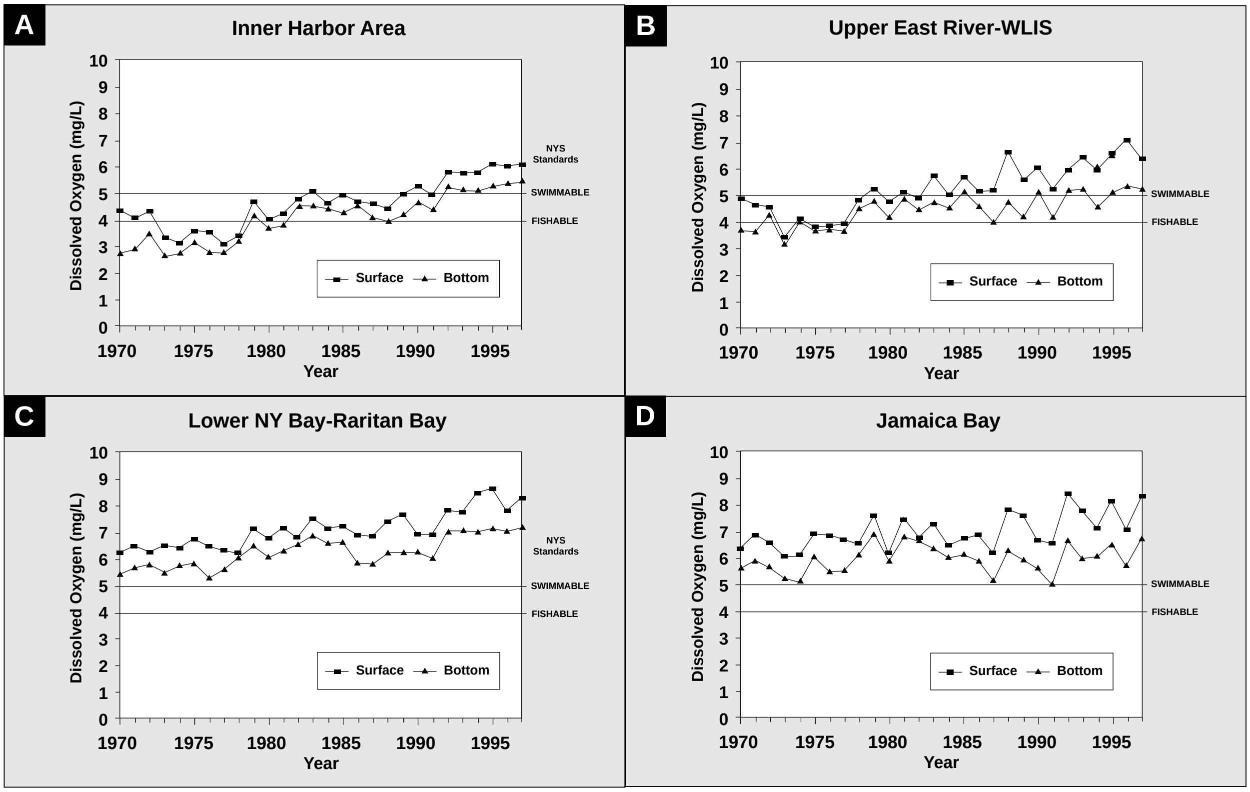
In general, from 1992 and on, attainment of DO standards in the Harbor is clearly better than previously achieved, with most sites demonstrating long term improvements. These improvements were evident throughout the Harbor, with exception of several sites in Jamaica Bay and Western Long Island Sound.

Trends

Dissolved oxygen concentrations have increased significantly (~2 mg/l) over the past 28 years (**Figure 6**a). Average DO trends for four distinct areas of the Harbor (**Figure 14**) show greatest improvement (between 1.7 and 2.7 mg/l) to have occurred in the Inner Harbor Area and the Lower NY Bay-Raritan Bay. Improvement for the Inner Harbor Area are noteworthy in view of the multitude of CSOs that may discharge into these waters (**Figure 2**) and the magnitude of increased loading known to occur during wet weather events. From the 1970s through the mid-1990s DO values rose from below secondary contact (i.e., fishable) standards to above primary contact (i.e., swimmable) standards (**Figure 14**a). These improvements are due to decreased sanitary loadings associated with WPCP construction and upgrades, and improved CSO capture. For the same time period, the Upper East River-Western Long Island Sound and Jamaica Bay show high DO variability, with an increasing gap between surface and bottom waters since the mid-80s (**14**;b and d). This suggests that formation of two separate water masses or pronounced *stratification* is occurring in these areas. (See **Salinity, Temperature, and Density**, p. 53)

FIGURE 14 **DISSOLVED OXYGEN TRENDS FOR FOUR HARBOR AREAS**

Summer Averages, 1970-1997



Discussion

Year-to-year variability in the frequency, duration and severity of low DO or hypoxia are linked to variations in vertical density stratification; wind mixing; tidal and gravitational circulation; and the quality of water coming into an area (Diaz et al., 1992). For example, DO minima in the Hudson appear to be related to summer river flow and flushing time (Clark, 1995). Recent declines in bottom DO in Western Long Island Sound have been linked to increases in the timing and intensity of stratification (HydroQual, Inc., 1995).

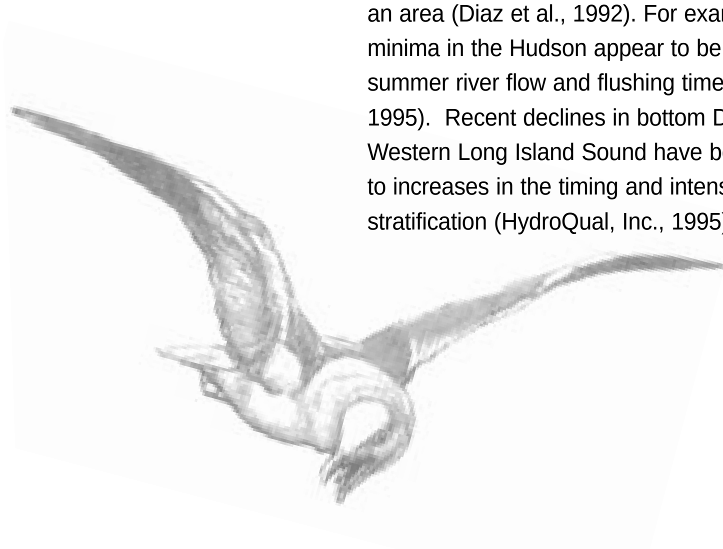
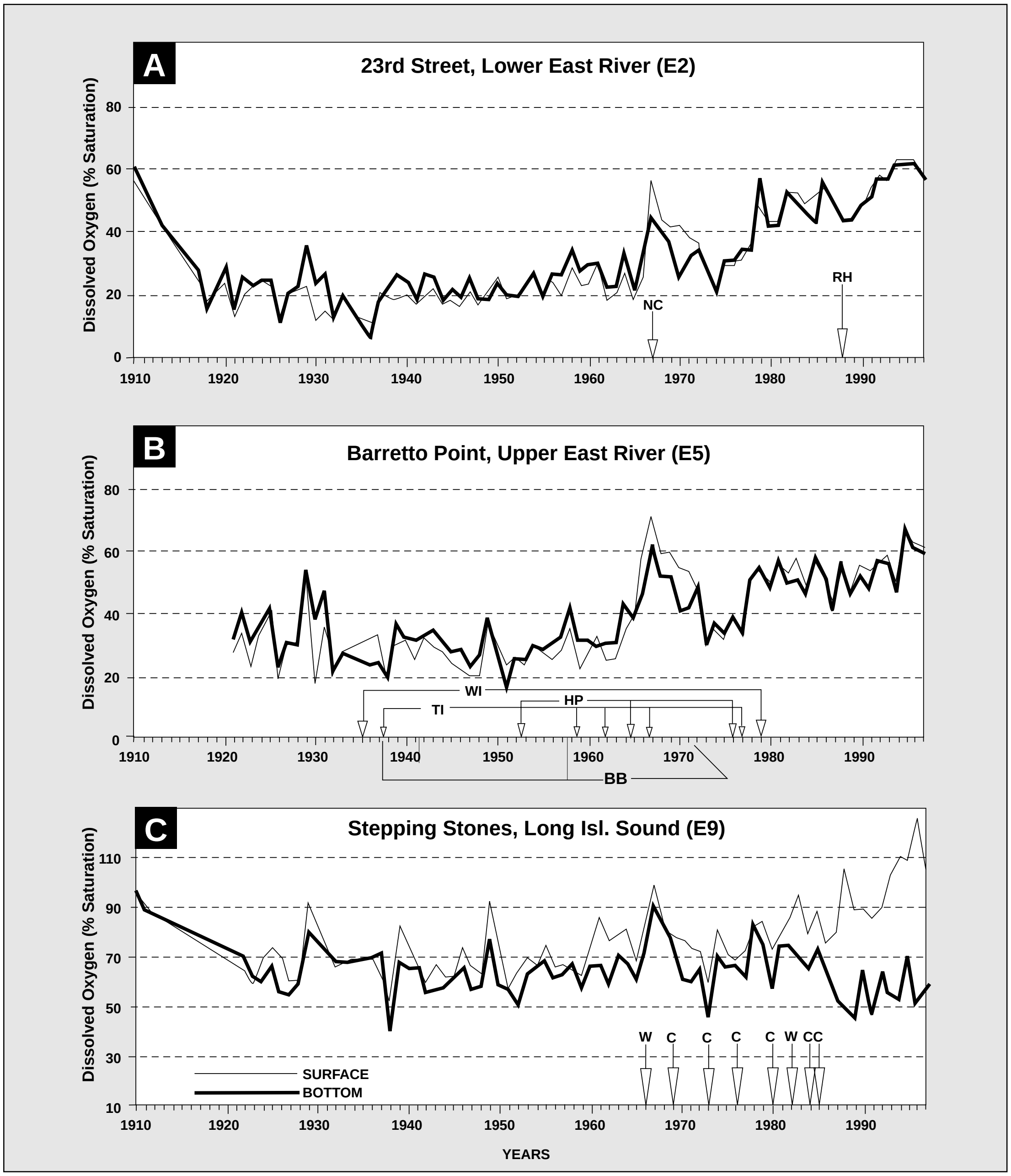


Figure 15 illustrates progressions of DO improvement at three points in the East River; a lower and upper East River site, and a Western Long Island Sound (WLIS) site. The effect of cumulative organic loadings (as one moves downstream) can be seen as lower DO levels at the two East River Sites (Figures 15a and b) compared to the WLIS site (15c). For the Lower East River Site (**Figure 15**a), average summer DO ranged between 7-37% saturation between 1918-1940. Levels then stabilized at or above 20% through the late 1950s; a period coinciding with construction and start-up of a number of WPCPs. Increased DO saturation

FIGURE 15

EAST RIVER-WESTERN LONG ISLAND SOUND DISSOLVED OXYGEN TRENDS

Summer Averages



Construction of, and significant upgrades to NYC WPCPs on the East River are depicted:
Wards Island (WI), Bowery Bay (BB), Tallman Island (TI), Hunts Point (HP), Newtown Creek (NC), and Red Hook (RH).
For bottom graph, Westchester (W) and Connecticut (C) WPCPs (west of the Housatonic River and >10 mgd) are depicted.

and greater year-to-year variability, evident during 1960-1980, parallel WPCP upgrades and start-up of the North River Plant. Dissolved oxygen substantially increased in the 1980s and especially in the 1990s; surpassing levels recorded at the beginning of the century.

For the same duration, an Upper East River Site (**Figure 15**b) showed higher variability, with DO saturation typically between 20-40%, until increasing in the late 1960s. More consistent improvements and highest DO levels are again evident in the 1980s and 1990s.

Sampling from Osprey to determine dissolved oxygen levels

Percent DO saturation in the WLIS (**Figure 15**c) shows greater variability and surface-to-bottom water differences than the East River Sites. Levels of DO were typically between 50-70% saturation until the 1960s, with single year peaks in surface water. Beginning in the 1960s, summer averages for surface waters show strong (more consistent) increases in DO saturation. From the late 1980s and through the 1990s, average DO is often super-saturated or greater than 100% (a condition indicative of algae blooms and eutrophic waters). In contrast, bottom water DO levels, seen to parallel surface conditions through most of the century, drop-off notably since the mid-1980s. Average values for recent years are lower than those recorded at the beginning of the century. This has occurred despite the virtual elimination of raw sewage discharges and concomitant decreases in BOD and TSS point source loads throughout the Harbor and region (Brosnan and Stubin, 1992).

Although the Western Sound has exhibited elevated nutrient concentrations for many years, sustained low summer DO or hypoxia is a relatively recent phenomenon. During the late 1980s and early 1990s the area of hypoxic waters documented in the Sound by the Long Island Sound Study (LISS) extended from 65 to 180 km^2 and lasted from 2 to 6 weeks (Stacey, 1990). Given the point source load reductions noted above, the concurrence of declining pollutant loads and worsening water quality is counter-intuitive.

While there is little consensus as to why the Sound's water quality has recently declined, a LISS-funded study revealed low DO to be closely related to changes in salinity and temperature between the Western Sound and the Verrazano Narrows (HydroQual, Inc., 1995). Together these factors increase stratification and restrict oxygen replenishment from the surface.

To improve Long Island Sound waters NYC DEP, together with Westchester County and the states of New York and Connecticut have developed a comprehensive management plan (LISS, 1993). The goal of current efforts is to substantially reduce nutrient loadings and thereby reduce eutrophication of Sound waters and demands upon DO (LISS, 1997)(see *Nutrient Removal,* p.18).

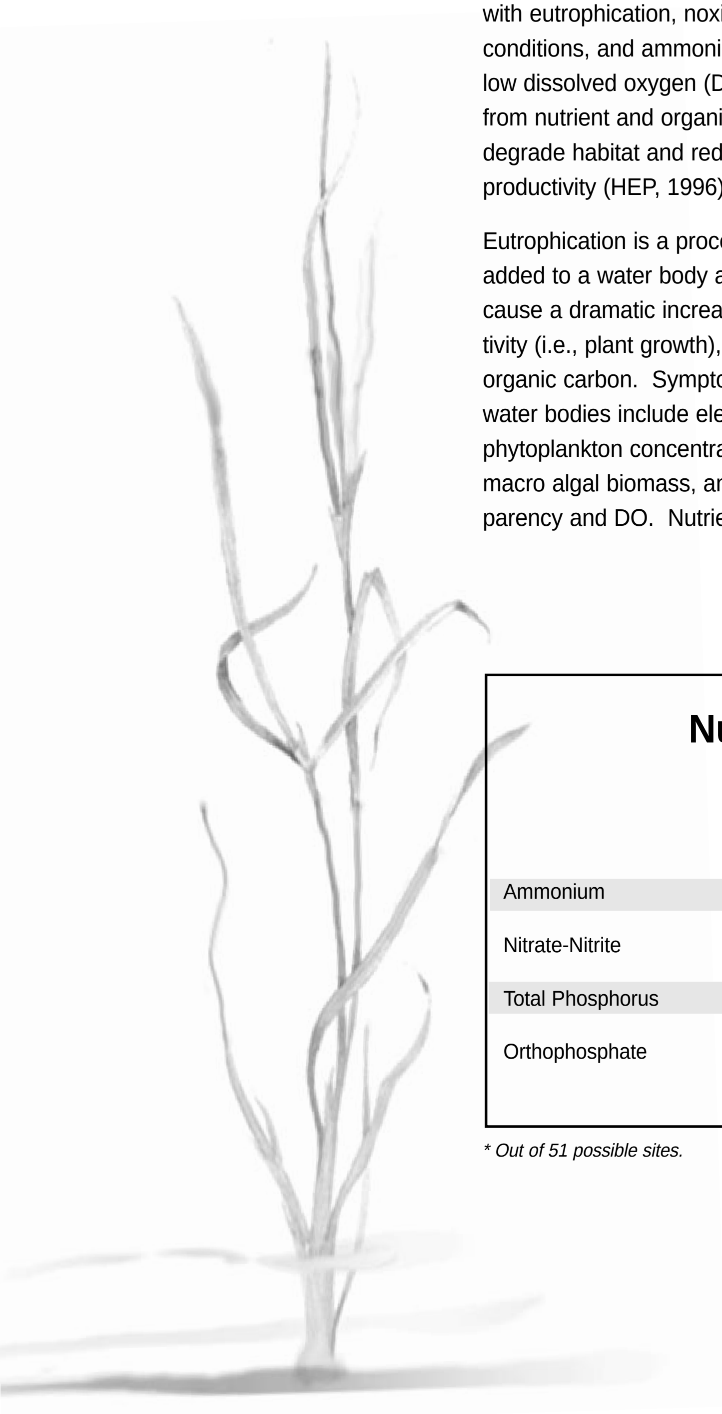
For a further discussion of DO trends in the Harbor and Western Long Island Sound, see Brosnan and O'shea, 1997; Brosnan and O'Shea, 1996b; Brosnan and Stubin, 1992.

Nutrients

Nutrients, natural life sustaining substances, are critical to maintaining an appropriate balance for the health and productivity of aquatic systems. For estuarine waters of the Harbor major nutrients of importance include nitrogen, phosphorus, carbon and silica (HydroQual, 1996). These elements form the basis of the food chain, controlling, either individually or in combination, phytoplankton growth in various parts and reaches of the Harbor.

Important nutrient sources to the Harbor include tributaries and oceanic transport, regeneration from coastal sediments, atmospheric deposition, CSO, storm water, and water pollution control plant effluents (Mueller et al., 1982; Lee et al., 1982; Malone, 1982; Lee and Jones, 1987; Jones and Lee, 1985; Gunnerson, 1982; Malone et al., 1985). The relative importance of these sources to the overall nutrient load that any area of the

A family enjoys a day of fishing



Harbor receives is typically a function of local hydraulics and proximity to sources. High nutrient concentrations have been associated with eutrophication, noxious water quality conditions, and ammonia toxicity. In addition, low dissolved oxygen (DO) that may result from nutrient and organic enrichment, may degrade habitat and reduce fish and shellfish productivity (HEP, 1996).

Eutrophication is a process whereby nutrients added to a water body at excessive rates cause a dramatic increase in primary productivity (i.e., plant growth), and associated organic carbon. Symptoms of eutrophic water bodies include elevated nutrient and phytoplankton concentrations, excessive macro algal biomass, and reduced transparency and DO. Nutrients measured include nitrogen (as ammonium, and nitrate plus nitrite), and phosphorus (as total phosphorus and orthophosphate). In marine water bodies, excess nitrogen is generally associated with eutrophication.

Attainment of Water Quality Standards

While there are no NYS DEC Standards for maximum allowable nutrient concentrations in marine waters, nutrient loadings to waters of Jamaica Bay and the East River are being carefully monitored and reduced to control eutrophication of these waters and limit algal growth (see *Nutrient Removal*, p.18).

TABLE 6

Nutrient Trend Data, 1985-1997

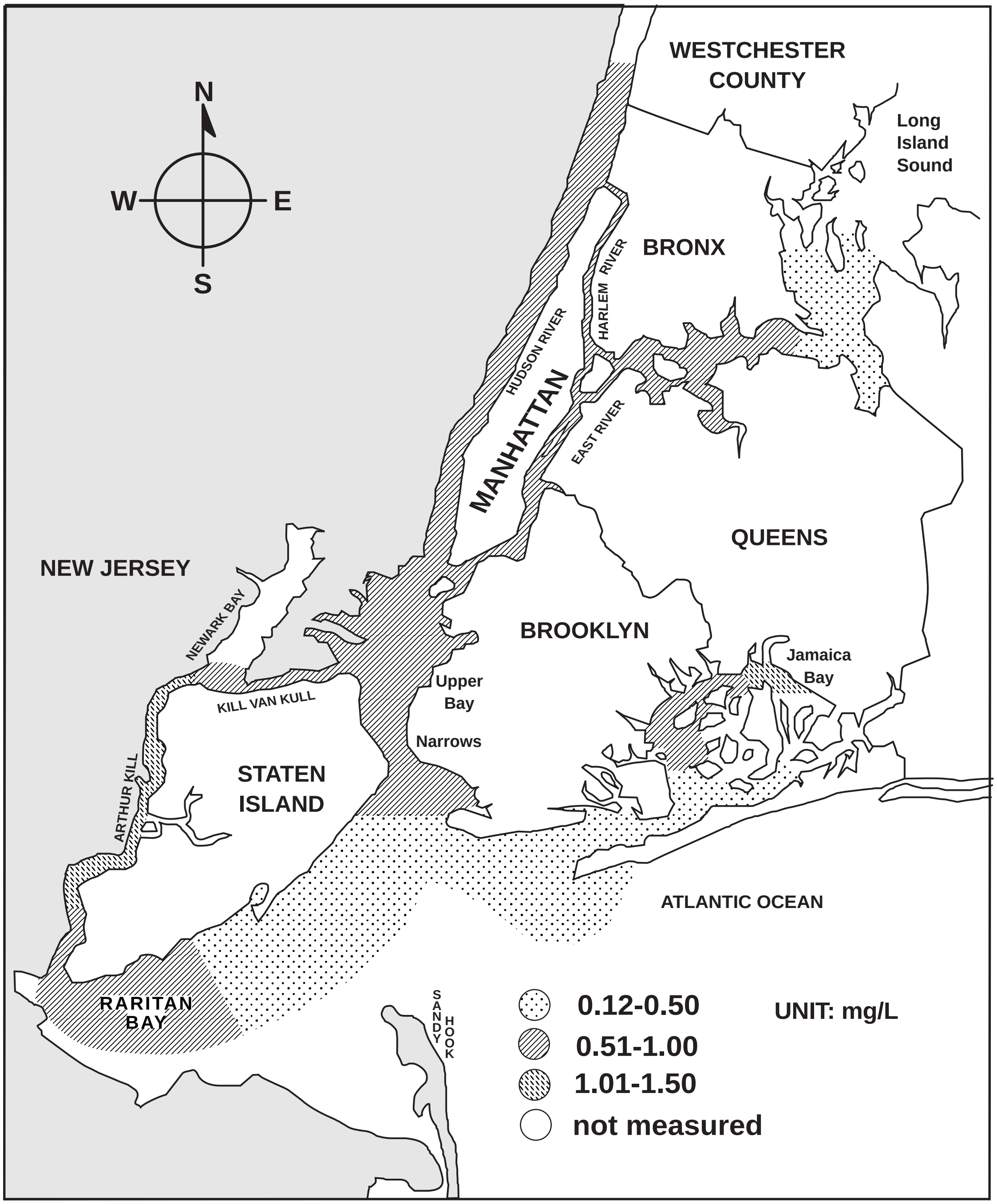
	Number of Stations* With:		
	Increasing Trend	**Decreasing Trend**	**No Trend**
Ammonium	1	13	37
Nitrate-Nitrite	2	5	44
Total Phosphorus	3	20	28
Orthophosphate	0	18	33

** Out of 51 possible sites.*

FIGURE 16

TOTAL DISSOLVED INORGANIC NITROGEN (NH_4 & NO_{3-2}) IN SURFACE WATERS

Summer Averages, 1997



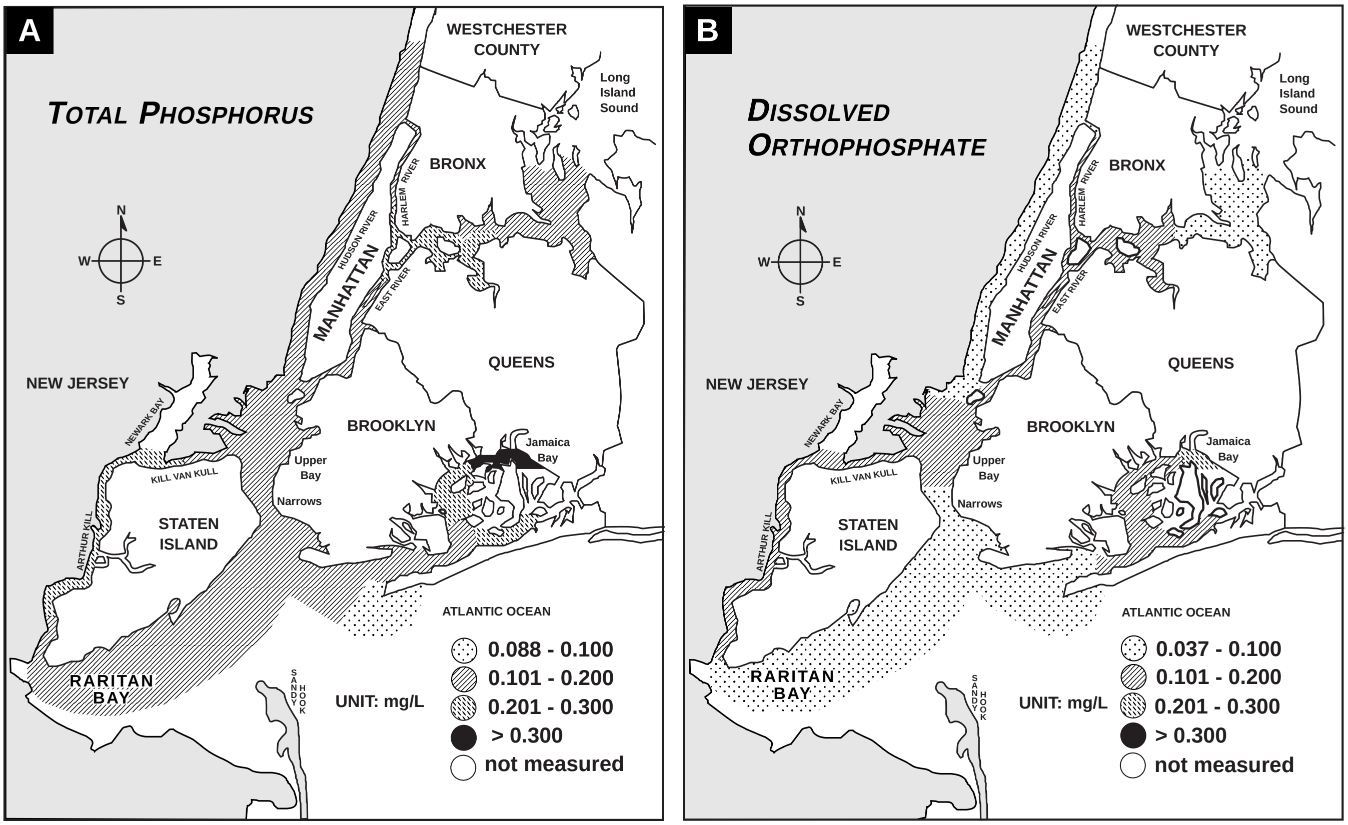
Highest summer averages (>1 mg/l) for total dissolved inorganic nitrogen (ammonium- plus nitrate- and nitrite-nitrogen) were observed (as in years past) in the northeastern portion of Jamaica Bay and the Arthur Kill (**Figure 16**). Overall, concentrations of measured nitrogenous components were very similar to values observed in 1995, though average values for 1997 never exceeded 1.5 mg/l. This is true despite a 1996-observed increase of ammonium concentrations in Jamaica Bay (Boniecki and Lochan, 1998). It should be noted that high nutrient variability (both within a season and year-to-year) is common in Harbor waters.

Total phosphorous values were high (>0.2 mg/l) in Jamaica Bay, the Kills, the lower Harlem River and the East River, north of Roosevelt Island to, and including, Flushing Bay (**Figure 17**a). Highest average values (>0.3 mg/l) were recorded in the northern portion of Jamaica Bay. Average concentrations for dissolved orthophosphate (Figure **17b**) were typically less than 0.20 mg/l for Jamaica Bay and most of the Inner Harbor Area, and less than 0.10 for the Hudson River, Western Long Island Sound, and Raritan Bay. Highest values (>0.20 mg/l) were observed in the northeastern portion of Jamaica Bay. Relative to values depicted in 1995, average 1997 values for total phosphorous and dissolved orthophosphate appear to have decreased for the Hudson

Bridge over Harlem River

Figure 17 **Total Phosphorus & Dissolved Orthophosphate in Surface Waters**

Summer Averages, 1997



River, the lower East River, the Arthur Kill, and Raritan Bay. Again reflective of the high temporal variability of Harbor nutrients, this decrease appeared more substantial in 1996 (Boniecki and Lochan, 1998).

Within-season variability was highest for total ammonium and nitrate-nitrite, with variability showing a tendency to increase, moving away from Inner Harbor Areas to outlying waters of the Western Sound and Lower NY Bay. Note that areas showing high variability also contain the lowest average nitrogen concentrations relative to the rest of the Harbor.

Trend Analysis

A trend analysis of the summer average 1985-97 data set was performed on 51 stations using SAS Pearson product-moment correlations and is summarized in **Table 6**, p.41.

Stations showing declining nutrient concentrations were widely scattered throughout the Harbor and largely outnumber sites for which increasing concentrations were observed. However, most sites displayed no significant trend for nutrients over the past 13 years.

This is not surprising, in that *secondary treatment,* at which WPCPs are federally mandated to operate, does not remove nitrogenous compounds. Advanced secondary processes and innovative biological nutrient removal technologies are now being implemented and evaluated by NYC DEP (see *Nutrient Removal*, p.18). Sites exhibiting an increasing nutrient trend are located in Jamaica Bay and Flushing Bay. Both of these bays seasonally display characteristics symptomatic of eutrophic conditions (see p.41).

...federally mandated, secondary treatment does not remove nitrogenous compounds

Discussion

The relatively low nitrogen-to-phosphorus ratio of Harbor waters (<7:1) suggests nitrogen to be more apt to limit phytoplankton growth. However, recent hydrodynamic modeling has disputed the feasibility of controlling algal growth (and secondarily, low DO), through high level nitrogen removal at WPCPs for most areas of the Harbor (HydroQual, 1996b). This strengthens a widespread assertion that primary productivity in the Harbor is not nutrient limited (Lee et al., 1982; Malone, 1982; Mayer, 1982). Instead, for many parts of the Harbor, summer productivity appears to be limited by turbidity from river-borne suspended sediments, flushing rate, zooplankton grazing, and weather (Lee et al., 1982; Malone, 1982; NYC DEP, 1986).

Fishing in Jamaica Bay

In contrast to the above, modeling of Long Island Sound has shown that the lowest DO values can be raised and that the duration of hypoxic events can be greatly diminished in WLIS through significant reductions of nitrogen. As noted above (p.40), NYC DEP, together with others, have embarked on an aggressive nutrient reduction program (LISS, 1997) to provide for these water quality improvements.

Chlorophyll 'a' and Phytoplankton

Chlorophyll 'a'

Chlorophyll 'a' is a plant pigment whose concentrations in the water is used as an estimate of phytoplankton biomass. The presence of algae may be reflective of eutrophic or other water quality conditions, (see *Plankton*, p.48) or in itself influence aspects of water quality, e.g., pH, color, taste, odor (American Public Health Association, 1985). Chlorophyll 'a' and plankton counts in some areas can vary dramatically over a period of days. This is due to the formation and dissipation of algal blooms which respond rapidly to environmental conditions.

Average 1997 chlorophyll 'a' concentrations (**Figure 18**;a and b) appear to have declined relative to 1995-1996 levels. This is true for winter/spring values (**Figure 18**a) in portions of the Upper East River-Western Long Island Sound and, with the exception of Jamaica Bay, near harbor-wide for summer concentrations (**Figure 18**b). In 1995, 30 stations had average summer concentrations in excess of 20 ug/l (generally indicative of eutrophic conditions). For summer 1997, only 18 stations (ten in Jamaica Bay; five in the Upper East River-Western Long Island Sound; and three in the Lower NY Bay-Raritan Bay) had average chlorophyll 'a' concentrations greater than 20ug/l. Highest summer time averages and the widest range of recorded values (from 3.7 to 285 ug/l) were observed in Jamaica Bay. Lowest summertime averages (<10 ug/l) were observed in the Inner Harbor Area.

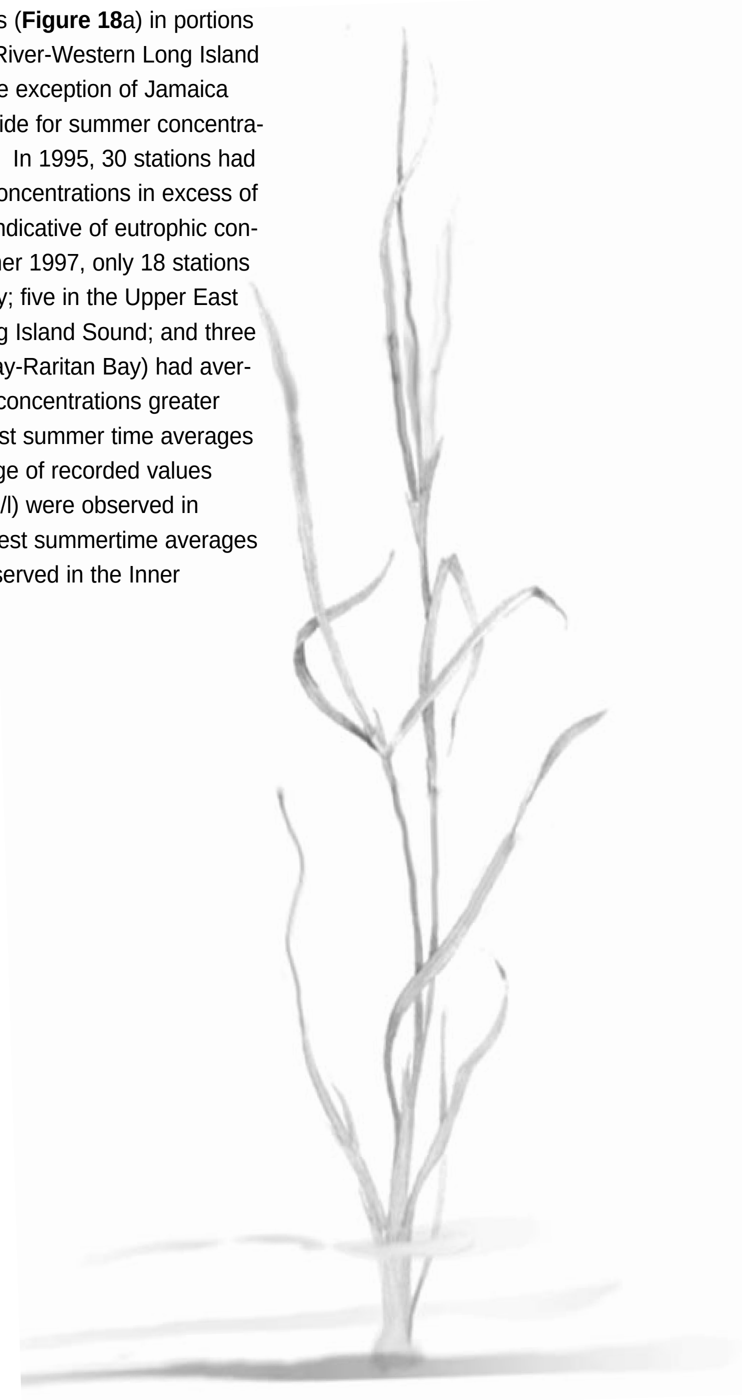
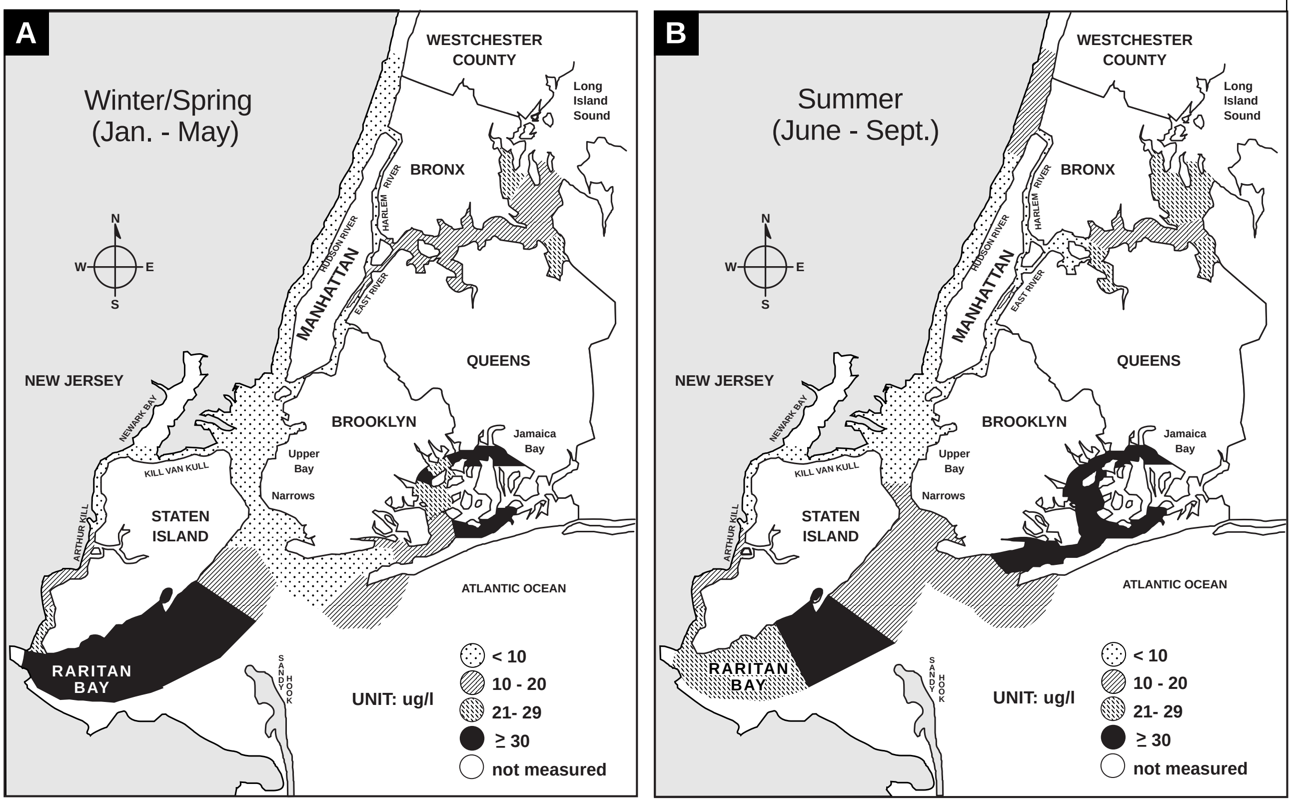


FIGURE 18

AVERAGE CHLOROPHYLL 'a' CONCENTRATIONS

Surface Waters, 1997

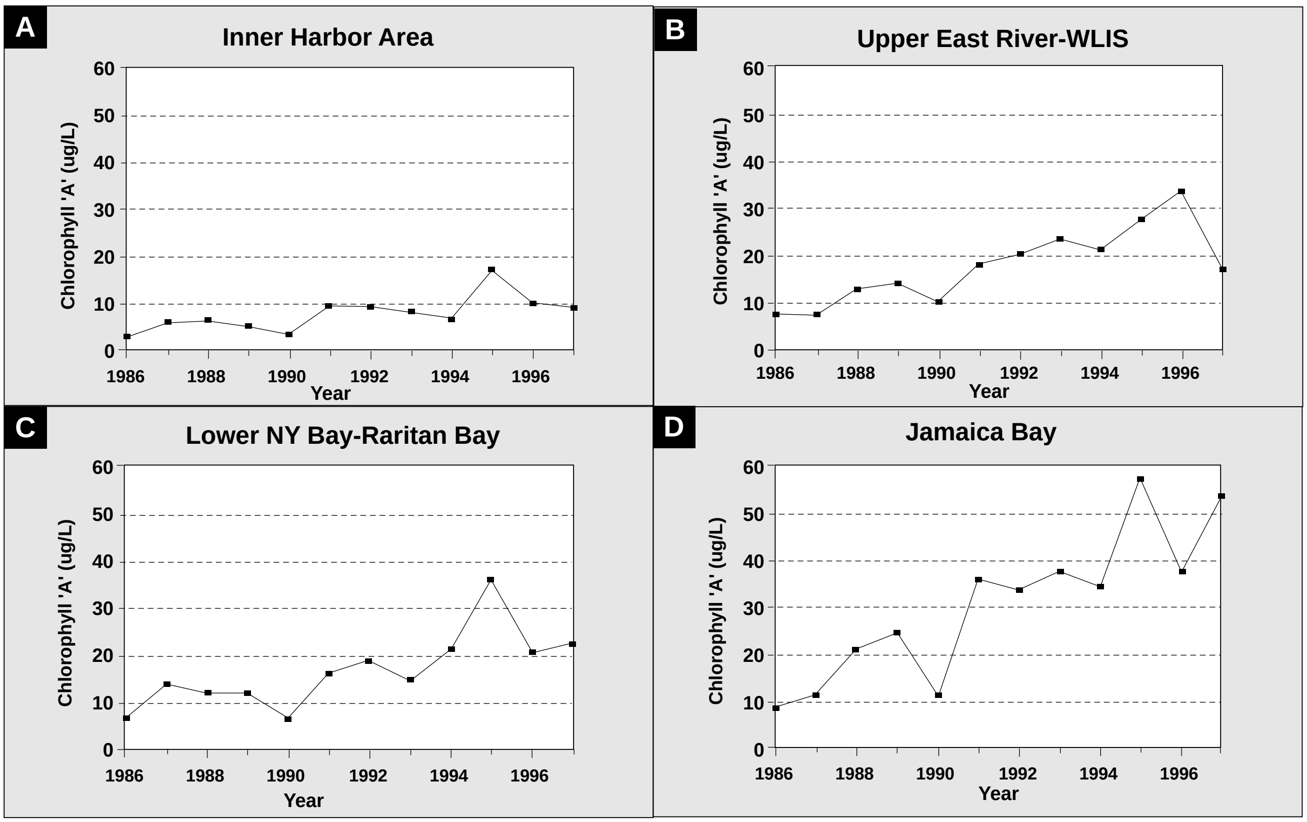


Trend Analysis

High variability inherent in chlorophyll 'a' measurements (both seasonably and on a year-to-year basis) combined with a limited number of pre-1989 chlorophyll 'a' samples makes temporal trends difficult to establish. Nevertheless, a regression analysis of 1989-97 summer averages revealed significant ($p<0.05$) increases at 20 sites, including those of Jamaica Bay and Lower NY Bay-Raritan Bay, a portion of the Upper East River-Western Long Island Sound, and other scattered sites. This is despite the immediate short-term decrease relative to 1995-1996 values noted above. While a depiction of Harbor-wide trends (**Figure 6**d) suggests increases in chlorophyll 'a' to be considerable, an examination of trends for four distinct Harbor areas demonstrates most change to have occurred in Jamaica Bay (**Figure 19**;a-d).

FIGURE 19 **HARBORWIDE CHLOROPHYLL 'a' TRENDS**

Summer Averages in Surface Waters



In general, high chlorophyll 'a' concentrations observed in the Harbor are typically associated with declining secchi depths (see p.52), a decrease in light transmittance (O'Shea and Brosnan, 1997), and an increase in top-to-bottom DO variability; conditions symptomatic of eutrophic conditions.

Plankton

Plankton, free-floating, often microscopic, aquatic plants (phytoplankton) and animals (zooplankton) form the basis of the food web. Since these organisms respond quickly to environmental changes, their species abundance and composition are potentially useful indicators of water quality (Gannon and Stemberger, 1978). The presence of certain species may indicate eutrophic (nutrient-rich) waters (Palmer, 1963), while the absence of others, may be indicative of chemical pollutants (Palmer, 1969). Additionally, the abundance of phytoplankton may further effect other basic aspects of water quality (see *Chlorophyll 'a'*, above).

While phytoplankton have been found to be a useful water quality indicator elsewhere, to date phytoplankton have been underutilized as environmental indicators for the Harbor. Limiting their use in this context has been their patchy distribution and transient nature in the Harbor, as well as, uncertainty

...high chlorophyll 'a' concentrations... are associated with declining Secchi depths...

concerning their origin and duration of exposure. Though subtle changes in phytoplankton assemblages may be indicative of ecosystem change, documentation of such change is lacking for the Harbor (HEP, 1996). Indeed, high variability of phytoplankton concentrations may be attributable to many factors, including seasonal changes in temperature and light, nutrient availability and grazing pressures.

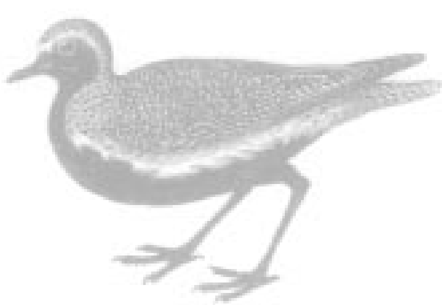
Harbor phytoplankton concentrations tend to loosely follow a geographic distribution similar to chlorophyll 'a'. Harbor areas that typically contain high phytoplankton concentrations (or blooms) are outlying areas (Western Long Island Sound and Lower NY Bay/Raritan Bay) and embayments (Flushing Bay and Jamaica Bay). Blooms are cyclic in their intensity and foremost Harbor areas appear highest in early spring and late summer. (Monthly average summer cell counts in 1995 ranged from 5200 to 85,000 cells/ml (O'Shea and Brosnan, 1997)).

Species composition for selected high-chlorophyll sites suggest diatoms *Skeletonema costatum* and *Thalassiosira nordenskioldii* and the green algae *Nannochloris atomus* to be the most abundant species in 1997. This appeared true throughout the Harbor and for sites as diverse as Bergen Basin, Jamaica Bay and Hart Island, Western Long Island Sound. Both of these localities had a winter abundance of diatoms, with green algae becoming more predominant in early summer. Other areas, such as Flushing Bay and the Lower NY Bay appear to be almost exclusively dominated by diatoms. Zooplankton species appear notably scarce throughout the Harbor. Future Harbor Survey efforts will further explore the effective use of plankton assemblages as indicators of water quality.

Bloom Activity

Using Chlorophyll 'a' data as a surrogate for phytoplankton productivity helps determine bloom activity associated with Harbor waters. Average 1997 Summer Chlorophyll 'a' values were compared to an eleven year average (1987-1997) for major Harbor transects (**Figure 20**;a-d). With the exception of Jamaica Bay, 1997 averages closely coincided with eleven-year averages for these transects. This suggests recent phytoplankton activity to be typical of productivity common to these waters. For the Hudson River (**Figure 20**a), phytoplankton activity decreases slightly as one approaches the Battery (upper NY Bay) and then rises again at the Narrows, perhaps due convergence of surrounding waters.

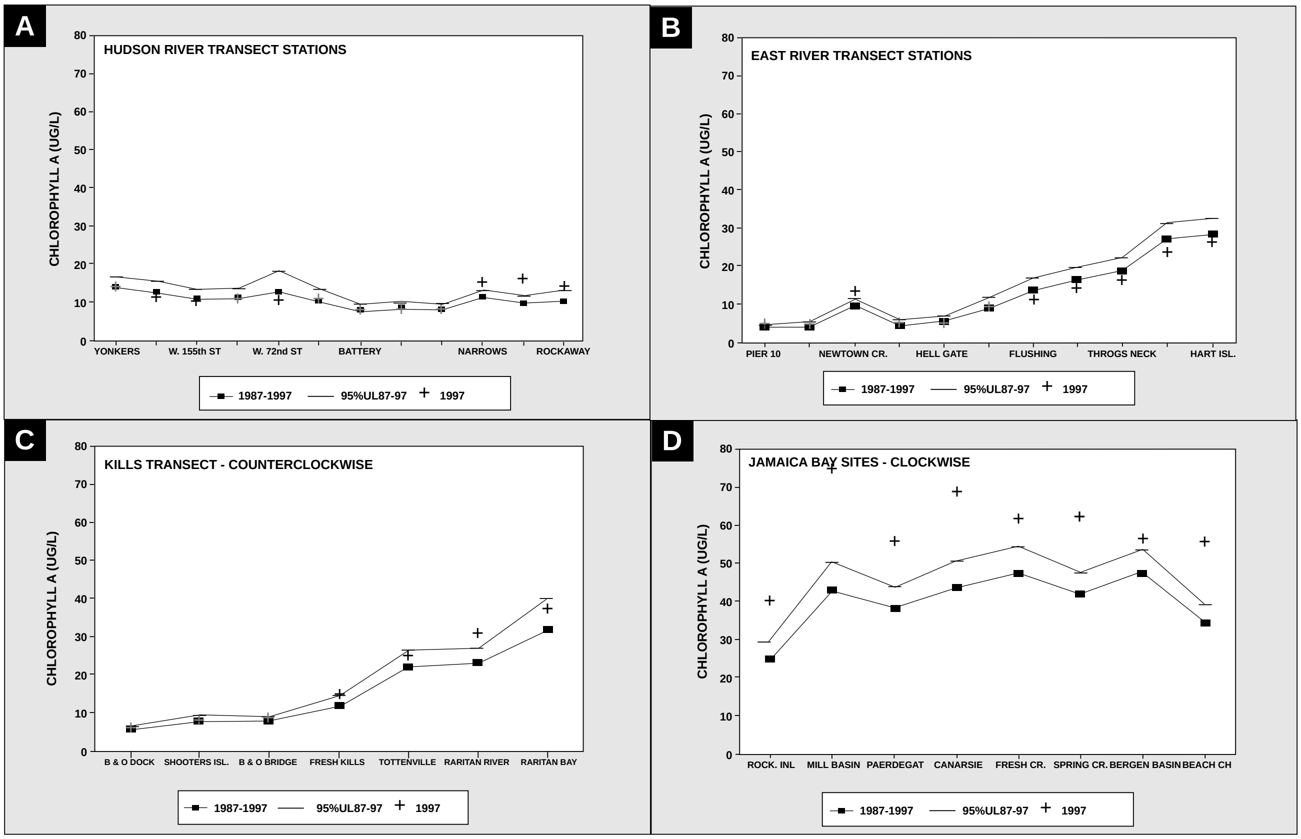
Along the lower East River transect (**20**b) lower chlorophyll 'a' concentrations (indicating less productivity) are apparent south of the Throgs Neck Bridge, with some bloom activity at Newtown Creek. Productivity is seen to increase moving into Western Long Island Sound.



...future Harbor Survey efforts will explore the use of plankton assemblages as indicators of water quality.

FIGURE 20 **CHLOROPHYLL 'a' IN SURFACE WATER TRANSECTS**

Summer Averages, 1987-1997 and 1997



Along the Kills transect (**20**c), moving counterclockwise around Staten Island, average productivity increases sharply through the southern Arthur Kill into Raritan Bay. Areas which exhibit high plankton activity typically exhibit more variable water quality, as algae blooms form and dissipate in response to local environmental conditions.

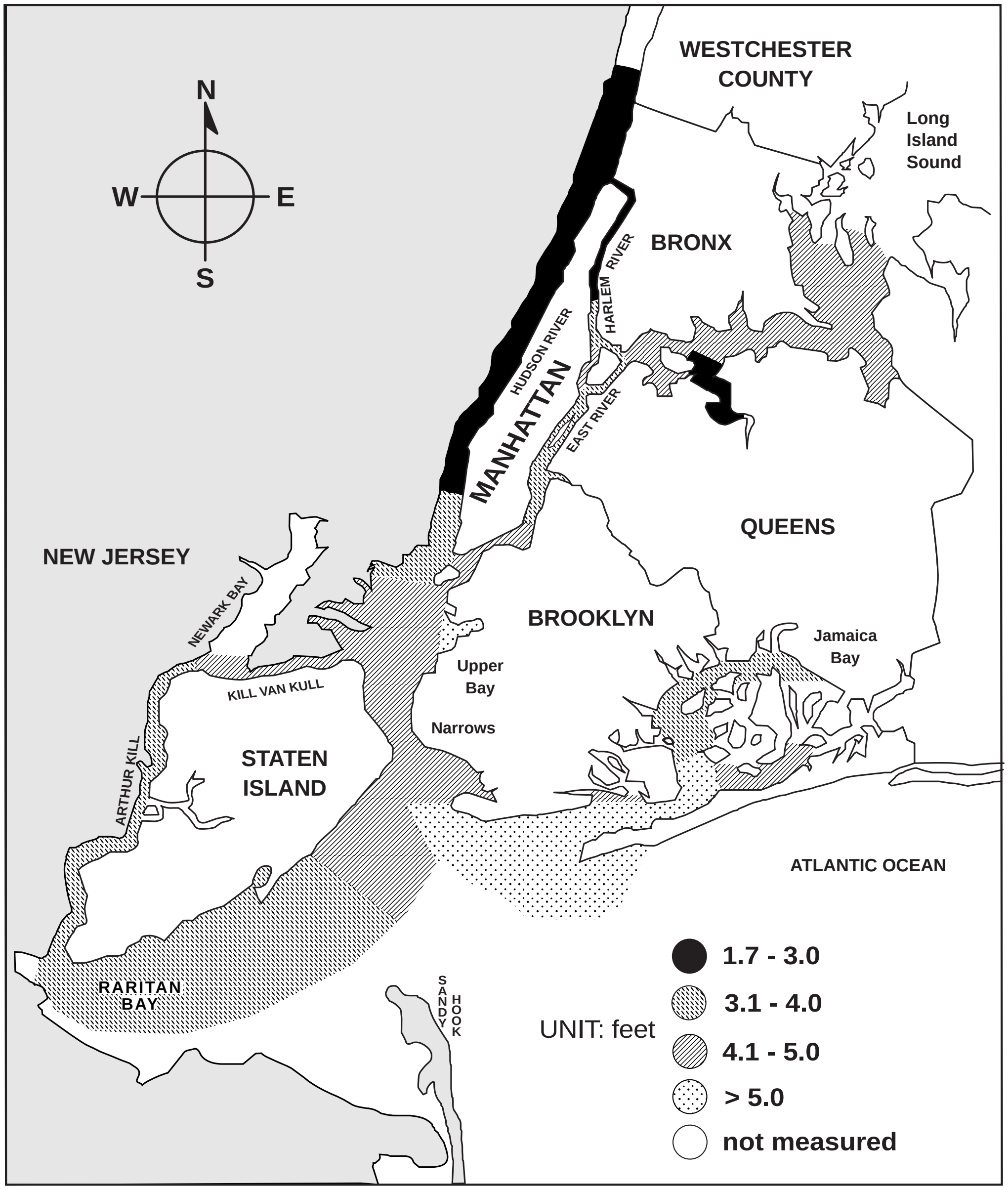
For Jamaica Bay (**20**d) average summer chlorophyll 'a' concentrations for 1997 are seen to be well above the running eleven-year average. This indicates a recent increase in bloom activity in Jamaica Bay. Jamaica Bay waters consistently exhibit the greatest average chlorophyll 'a' concentrations and highest levels of variability (see figures 18 and 19, above). Variability, (expressed as 95% upper confidence level) is a useful indicator of algal growth, because it reflects the degree of planktonic activity at a site. As alluded to before, sites with higher variability reflect a more dynamic bloom and die-off pattern, while low variability indicates a more constant level of productivity.

Secchi Transparency

A Secchi disk is used to estimate the transparency of surface waters. High Secchi transparency is indicative of clear water, with declines in Secchi depth typically produced

FIGURE 21 **SECCHI TRANSPARENCY OF SURFACE WATERS**

Summer Averages, 1997



by high concentrations of suspended solids or plankton blooms. Suspended solids can include: clay and silt from rivers or resuspended material from bottom sediments, and both inorganic and organic particles from point and nonpoint sources. The relative contribution of these factors varies from site to site. Low Secchi readings typically associated with degraded waters, are indicative of light limiting conditions, which in turn affect primary productivity and nutrient cycling.

Highest average summer transparencies (>5.0 ft) were located in portions of Lower NY Bay, Jamaica Bay Inlet, and Gowanus Canal, (**Figure 21**). Lowest secchi transparencies (<3 ft) were observed in the Hudson River and Upper Harlem River, and Flushing Bay.

Trend Analysis

A trend analysis of summer Secchi data from 1985-97 showed declines in transparency throughout the Harbor, with exception of the Kills. This decrease in Secchi transparency appears to follow increases in chlorophyll 'a'; concentrations. Over 70% of stations found to have increases in chlorophyll 'a', show decreases in Secchi transparency for virtually the same time period.

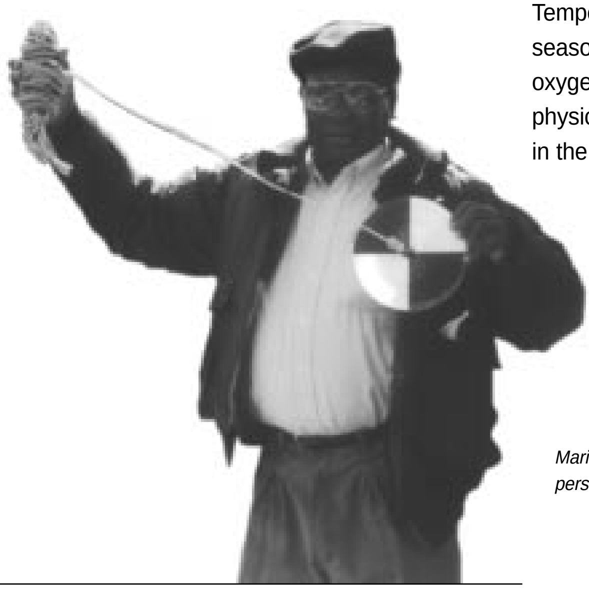
Discussion

In the Harbor, water clarity varies both seasonally and spatially. For example, in spring Secchi readings are likely a result of the suspended solid loads contributed by the spring freshet and snowmelt runoff. The onset of the spring phytoplankton bloom also decreases springtime water clarity. In the fall, algae blooms that are fed by the fall turnover can cause a similar decrease in transparency. Beyond seasonal changes, reduced clarity in the Harbor is also dependent on site differences. While some low transparency areas (Flushing Bay, Jamaica Bay and Raritan Bay) are likely due to high densities of phytoplankton, low Secchi readings in the Hudson are likely associated with higher concentrations of river borne suspended solids, and resuspension of bottom sediments from tidal scouring (O'Shea and Brosnan, 1997). Still other areas, such as the Upper Harlem River, may have poor transparencies due to storm-related runoff or combined sewer overflows.

...Secchi data show declines in transparency throughout the Harbor...

Salinity, Temperature, and Density

Salinity and temperature are important variables in estuarine systems, due to their influence on several key physical and biological processes. Salinity is a measure of the soluble salts present in the water, which fluctuates in response to tides and fresh water discharges. Along with temperature, salinity determines water density, and stratification. Salinity is also important in defining species habitat, as most organisms can only tolerate salinities within a selective range. Temperature also affects the spatial and seasonal distribution of species, and affects oxygen solubility, respiration, and other physical, biological, and chemical processes in the water column and sediment.



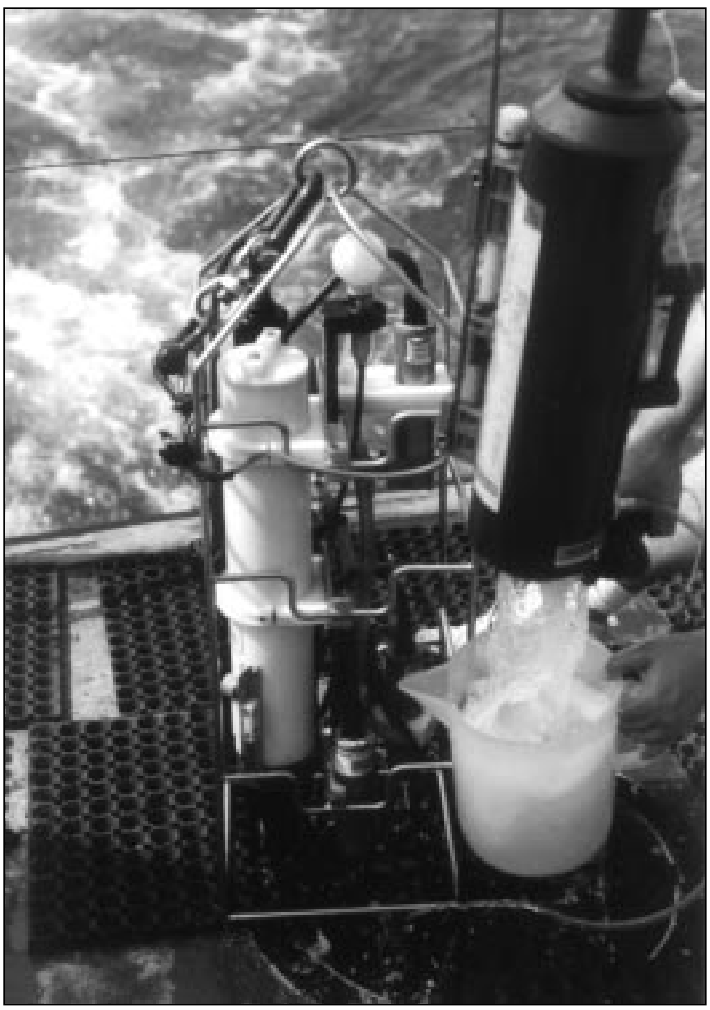
Marine Sciences Section personnel with Secchi disk

Average 1997 summer top and bottom salinity in the Harbor were lowest (<15 practical salinity units (psu)) in the Upper Hudson and Harlem Rivers and highest (>25 psu) in lower NY Bay/Raritan Bay, Jamaica Bay, and Long Island Sound. Surface-to-bottom salinity differences were greatest in the Hudson River and upper NY Bay, with average differences as high as 6.3 psu and 6.6 psu, respectively.

Average 1997 summer water temperatures (from 18 to 23°C) differed by less than 6 degrees throughout the Harbor and average surface-to-bottom differences were less than 2°C for any locality. Lowest summer temperatures were recorded in bottom waters of Western Long Island Sound and deep waters of Lower NY Bay. Highest temperatures were observed in surface waters of Jamaica Bay and the southern Arthur Kill.

Water density (expressed as Sigma-T) was derived from Sea-Bird CTD salinity and temperature readings and used to determine water column stratification (**Figure 22**). Lower salinities and higher temperatures produce less dense waters which overlay more saline, cooler waters. In turn, density stratification tends to inhibit the mixing of surface and bottom waters, contributing to lower dissolved oxygen in bottom waters. High stratification for extended durations can result in degraded bottom waters and reductions in habitat quality.

In the Harbor, stratification is more directly related to salinity than temperature (except for summer conditions in Western Long Island Sound), with greatest stratification occuring in the Hudson River and upper NY Bay (**Figure 22**). Surface-to-bottom water densities are most uniform in the tidal straits of the Harlem and East Rivers, and sections of the Kills, Jamaica Bay, and the Lower NY Bay.

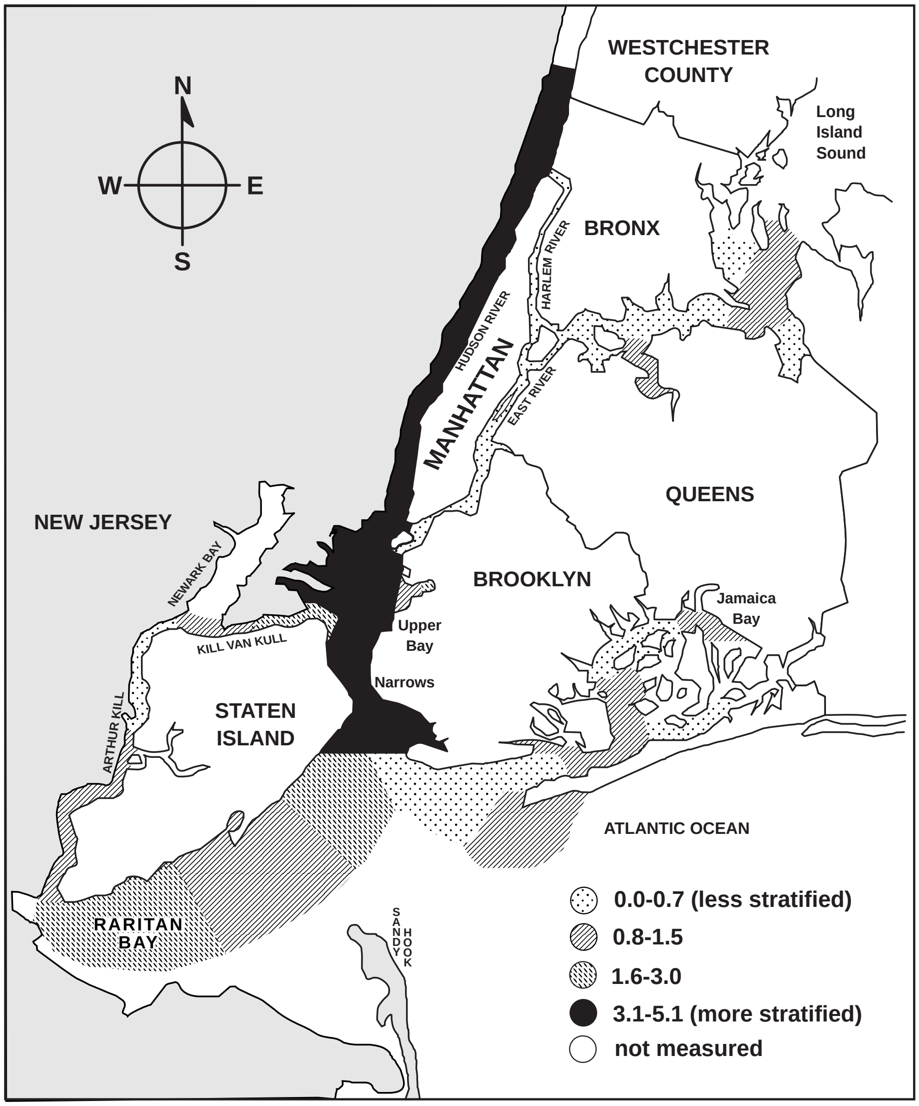


Sea-Bird CTD (conductivity, temperature, density) probe and Go-Flow water sampler

FIGURE 22

WATER COLUMN STRATIFICATION

Summer Averages, 1997



Sigma-T density calculated from raw salinity and temperature at each station.
(Difference between surface and bottom water densities, expressed as Sigma-T)

Trends

Salinity, temperature, and density vertical profiles can be quite variable between sites, and even at a single site over time. While significant long-term temperature and salinity trends have not been determined for most of the Harbor, hydrodynamic modeling has revealed an increase in vertical density stratification for waters of the Western Long Island Sound, beginning in the mid-80s (HydroQual, Inc., 1996a; 1995). This trend towards increased stratification coincides with a period of lower DO in Western Long Island Sound (see *Dissolved Oxygen*, p.39). Analyses indicated a strong correlation (R^2=0.72) between bottom DO and water temperature for the 1981-1995 period (HydroQual, Inc., 1996a).

BENEFITS DUE TO IMPROVED WATER QUALITY

...future Harbor Survey Programs will strive to provide data more representative of ecological change...

To date, the *Harbor Survey Program* has focused primarily on collecting and publishing measurements which describe conditions and changes to pollutant loads and water quality. To provide greater evidence of environmental change pursuant to pollution abatement initiatives, the below published findings are cited. In the future, the Harbor Survey Program will strive to provide data more representative of ecological change, in addition to its primary data collection efforts. Researchers and volunteer/citizen monitoring programs are encouraged to submit similar findings for inclusion in future reports and publications.

Evidence of Recent Changes in Ecosystem Quality

Signs of improved conditions in Harbor water quality follow.

- Dramatic decreases of ambient sewage-indicator bacteria, and increases in dissolved oxygen (NYC DOH 1990; 1991; 1992b; O'Connor 1990; Brosnan and Stubin 1992).
- The re-establishment of breeding populations of peregrine falcons in several areas of the Harbor, herons, egrets and other wading birds in the Arthur Kill and Kill Van Kull, and ospreys in Jamaica Bay (West-Valle et al. 1992), as well as what is believed to be the first productive bald eagle nest on the Hudson River in at least 100 years (NYS Governor's Office, 1997).
- Improved benthic (bottom-dwelling) communities in lower NY Bay (Steimle and Caracciolo-Ward 1989; Cerrato et al. 1989).
- Signs of the re-establishment of shortnose sturgeon (Woodhead and McEnroe 1991).
- The heavy re-infestation of woodpilings by marine wood-borers (van Allen 1989; Gruson 1993).
- The upgrading of 67,864 acres of shellfish beds in the estuary since 1985, including the removal of restrictions on 30,000 acres off the Rockaways and Raritan Bay in the late 1980's (Gottholm et al. 1993; HEP, 1996).
- Reduced water quality related beach closings in NY and NJ (Swanson and Bortman 1994) and the virtual elimination of closures due to floatables (the last floatables closure occurring in 1989 for NYC and 1991 for NJ beaches (HEP, 1996)).
- The re-opening of Seagate Beach on Coney Island in 1988, for the first time in 40 years; the re-opening of South Beach and Midland Beach on Staten Island in 1992, for the first time in 20 years, (NYC DOH 1990; 1991; 1992a; 1992b); the lifting of the New York City Department of Health's wet weather advisory for 7 of 10 NYC public beaches (NYC Mayor's Office, 1993); and, the reduction of wet weather advisory from 48 hours to 12 hours at the remaining three beaches.
- Recently increased striped bass stocks (McHugh et al. 1990; Hogan 1995), and decreases in the concentrations of PCBs in their tissues (NYS DEC 1988); and, the subsequent relaxing of the NYS DEC advisory for human consumption of striped bass taken from the Hudson River, south of the Bridge at Catskill (from zero to one meal/month) (NYS DOH 1995).

- Decreases in lead concentrations in the estuary and nationwide due to the federal ban on tetraethyl leaded gasoline (Smith et al. 1987; Bopp and Simpson 1989); sediment decreases of PCBs and the insecticides p,p-DDD and chlordane (Bopp and Simpson 1989); and, the dramatic recovery of the 12-mile sludge disposal site in the NY Bight since dumping there ended in late 1987 (NOAA 1991).
- A 50-90% reduction from peak levels (reached in the 1960s-70s) of most trace metals and chlorinated organic compounds found in fine-grained sediment in the Hudson River (Chillrud 1996).

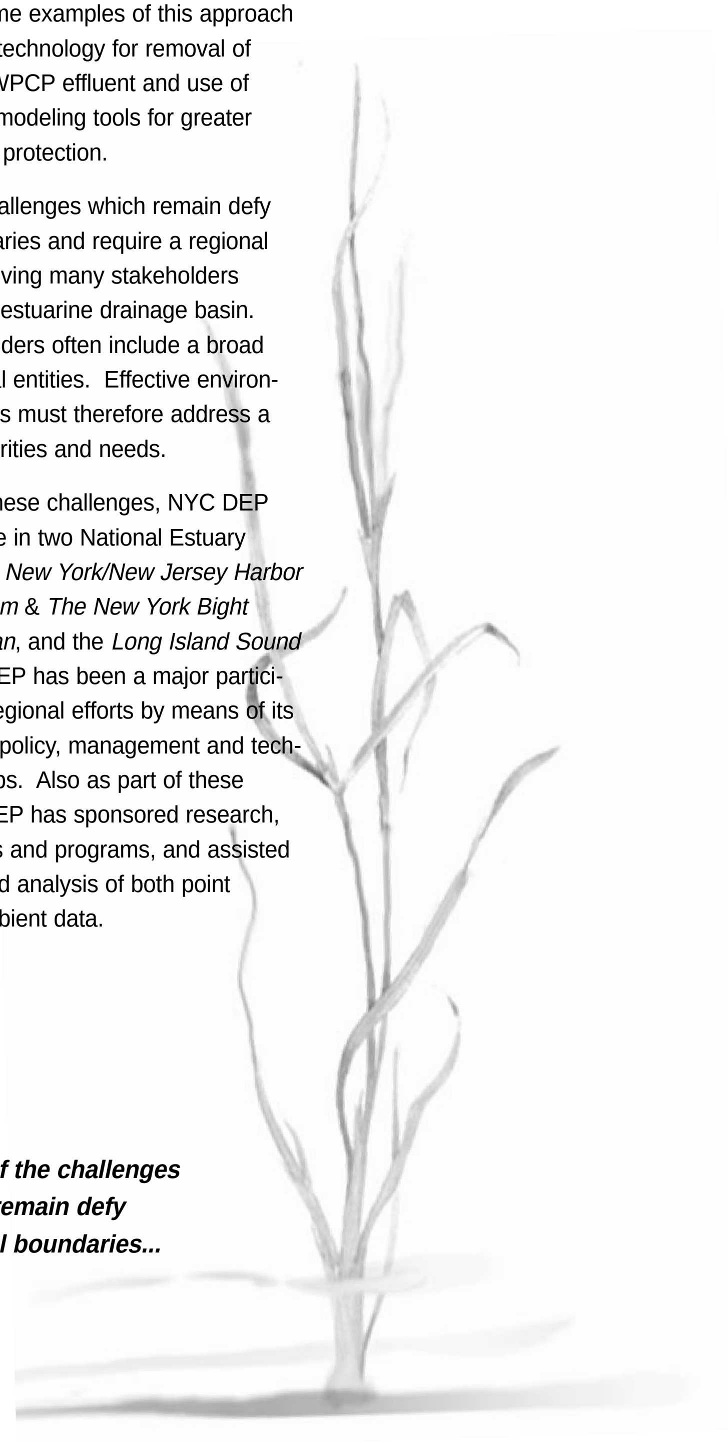
Continuing Challenges

While the above citations reflect important improvements to regional water and environmental quality, efforts to further enhance the region's estuarine resources continue. Despite noteworthy improvement to New York Harbor and its environs, many environmental problems must still be resolved. These concerns include: periodically closed shellfish beds and beaches; episodically low dissolved oxygen; eutrophication; areas of high sediment contaminant concentrations and problems with dredge disposal; floatables; oil spills; fishing advisories; over-fishing; and, accelerating nonpoint source pollution from continued over-development within the drainage area.

To address many of these problems, NYC DEP seeks to identify and implement cost-effective solutions, and develop innovative programs. Some examples of this approach include retrofit technology for removal of nitrogen from WPCP effluent and use of hydrodynamic modeling tools for greater regional beach protection.

Many of the challenges which remain defy political boundaries and require a regional approach, involving many stakeholders throughout the estuarine drainage basin. These stakeholders often include a broad array of political entities. Effective environmental solutions must therefore address a diversity of priorities and needs.

To best meet these challenges, NYC DEP has been active in two National Estuary Programs: *The New York/New Jersey Harbor Estuary Program* & *The New York Bight Restoration Plan*, and the *Long Island Sound Study*. NYC DEP has been a major participant in these regional efforts by means of its involvement in policy, management and technical workgroups. Also as part of these efforts, NYC DEP has sponsored research, initiated studies and programs, and assisted in collection and analysis of both point source and ambient data.



Many of the challenges which remain defy political boundaries...

Conclusion

This report summarizes the NYC DEP's efforts to monitor and characterize the quality of the Harbor's waters. Concurrent with the Harbor Survey, several other DEP programs are actively collecting a variety of site specific water quality and point source data.

Examples of these programs include:

- *the CSO Abatement Program;*
- *the Shoreline Survey Program;*
- *Storm Water Monitoring;*
- *Toxics Trackdown;*
- *the Landfill Remediation Program;*
- *the Citywide Floatables Program;*
- *Effluent Biomonitoring; and,*
- *Wetlands Protection;*

Data from these programs are available upon request.

For more information about the Harbor Water Quality Survey or related NYC DEP programs, please contact the Bureau of Public and InterGovernmental Affairs at 718-595-6600 or visit our Web site at

www.ci.nyc.ny.us/dep

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