Some Aspects of Forge River Ecology

A report prepared for the
Town of Brookhaven
Long Island, New York

by

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Introduction

The Forge River is a small microtidal partially mixed estuary discharging into Moriches Bay (Figure 1), a part of the Long Island south shore lagoonal system. New York State Department of Environmental Conservation (NYS DEC, 1974) has identified a variety of ecotones along the river separating it from the adjacent uplands. These include littoral materials, dredged materials and some 13.4 hectares (33.1 acres) of wetlands (Table 1). About 20 percent of these marshes are on both sides of the river north of Wills Creek, 64 percent between Poospatuck Creek and Lons Creek, again on both sides of the river.

During recent summer months, the water in the Forge was noticeably polluted as evidenced by fish and crab kills, foul odors, and rotting algal debris in the water. Sections of the river have sporadically turned milky white. The problems were especially severe during the summer of 2005. Deteriorated conditions also occurred in the summers of 2006 and 2007.

The river, particularly the upper reach, is often eutrophic during summer and has a documented history of being so for a half century. The sediments there are highly reduced, anoxic and devoid of macrofaunal organisms. Nichols (1964) found that benthic invertebrates and foraminifera did not occur. In the early 1960s, oxygen depletion was associated with sections in the river that were devoid of macrofauna (Myren, 1964). O'Conner (1972) in 1969 and 1970 determined that biomass was lower in clayey silt sediment and in dredged channels compared with sandy or transitional sediments of the more open Moriches Bay. With this as background, and using information drawn from our other reports prepared for the Town of Brookhaven and the County of Suffolk, the objectives of this report are to:

- summarize conditions leading to eutrophication in the river, and
- provide potential remediation measures.

To achieve these objectives we identify the primary sources of locally generated nutrients and organic materials and provide a nitrogen budget for the river. We describe how the Forge River responds to the nitrogen loading during the summer and discuss the merits of several approaches for alleviating the eutrophication problem.

With regard to the latter, it is hard to predict the effects of remedial measures due to the complex biogeochemical and physical interactions. Detailed, high resolution, time-dependent hydrodynamic and water quality modelling would provide very useful information about hypothesized outcomes and unforeseen consequences. At the very least, modelling could determine whether some remedial measures have any potential to make significant improvements in the Forge River ecosystem.

The hyper-eutrophic condition of the Forge River reflects the anthropogenic development of the area. It is an ecosystem that has been under stress for the better part of a century. The Woods Hole Oceanographic Institution (WHOI), in the 1950s, referred to the tributaries of Moriches Bay (Forge and Terrell Rivers) as "objectionable" and "highly contaminated" (Redfield, 1952). The pollution problems of the bay were highlighted as a case study in a report of the Environmental Pollution Panel of the U.S. President's Science Advisory Committee in 1965. Naturally occurring physical and engineered changes such as the opening and closing of inlets in the barrier beach have been influential in altering that ecosystem as well. Dredging of navigational channels in the river also led to ecosystem modifications.

The Forge River is a remnant streambed that cut through the southerly sloping glacial outwash plain deposited during the Wisconsin glaciation that ended some 20,000 years ago. The stream valley flooded as sea level rose and it now functions as a small estuary torpidly flowing into the northwest portion of Moriches Bay, a coastal lagoon protected from the Atlantic Ocean by a barrier island system. The river is surface watershed mostly falls within Hydrogeologic Zone VI of Suffolk County. This zone is described as being on the south shore of Long Island and as discharging to stream flow and underflow to Moriches Bay and Great South Bay (Koppelman et al., 1992). The northeast corner of the surface watershed is in Hydrogeologic Zone III and is part of the deep recharge region. Generally, the Soil and Conservation Service classifies the soils of the Mastic, Shirley, and Moriches area as part of the Riverhead-Plymouth-Carver Association (Warner et al., 1975). These soils are described as deep, nearly level to gently sloping, well-drained and excessively drained, moderately coarse textured and coarse textured soils on the southern outwash plain.

At the scale of the drainage basin, the river cuts through zones of Carver-Plymouth sands, Riverhead sandy loam, and Plymouth loamy sand (Warner et al., 1975). The surface soils throughout the drainage basin have been locally modified from those originally laid down, as cut and fill techniques have been used for the extensive housing developments in the area. Groundwater contamination from cesspools and septic tanks is generally associated with these soil types when the groundwater table is shallow (http://www.chipr.sunysb.edu/eserc/longis/geralsoilmap.html, downloaded 6 Nov. 2007), as is the case in this system. Munster et al. (2004) argued that the nitrate signal found in groundwater monitoring wells in Suffolk County is closely related to land use. Specifically, ground water near residentially developed areas using septic tanks and cesspools and having lawns can be distinguished from ground water associated with other land use categories such as open space or communities that have sewage treatment.

The surface watershed of the Forge River (Figure 2), including the river and all streams and tributaries, is 43.06 km^2 (10,641 acres). The basin, not including the river, streams and tributaries, is 39.93 km^2 (9868.2 acres). Some 8.49 km^2 (2098 acres, 21.3 percent) of the northeast portion of the terrestrial part of the drainage basin (mostly north of Montauk Highway) are in the deep groundwater recharge zone (Zone III) and thus may not contribute to eutrophication of the river.

The Forge River Watershed Map (Figure 2) depicts that most of the west side of the drainage basin with the exception of the William Floyd estate (part of the Fire Island National Seashore) is designated as high density (5-12 housing units /acre), medium density (2-4 housing units/acre) and low density (1 unit or less/acre) residential with some commercial use, particularly along Montauk Highway (Suffolk County Department of Planning, James Bagg, personal communication, Nov. 2, 2007). The William Floyd estate at the mouth of the Forge River consists of 2.48 km^2 (613 acres) of marsh, woods, and fields as well as the estate buildings. The use on the east side of the Forge River is considered high and mixed residential.

Low, medium, and high density residential zoning in the drainage basin is currently estimated to be 4.28, 10.11, and 2.65 km^2 (1058, 2498, and 655 acres), respectively. Thus, housing represents 42.7 percent of the total upland acreage of the drainage basin (Kathyrn Oheim, Suffolk County Department of Planning, personal communication, Nov. 2, 2007). About 6.43 km^2 (1590 acres) (16.1 percent) remain vacant and 4.35 km^2 (1075 acres) (10.9 percent) are devoted to recreation and open space. About 0.13 km^2 (33.1 acres) of the open space are wetlands (Table 1).

Ducks, Swans and People

Duck ranching on Long Island commenced in the 1880s (Suffolk County Planning Department, 1982), but was not an industry of consequence on the Forge River until the early to mid-twentieth century. The impacts from duck ranching dominated human development along the river. As duck ranching waned, the consequences of human population growth and its attendant sewage disposal issues throughout the water shed supplanted those of duck ranching.

In 1963, eight ranches were located in the Forge River watershed; three were located north of Montauk Highway. The effluent from the latter facilities was discharged into the stream at locations about 1.6 km, 0.8 km, and 0.4 km (1 mile, 0.5 miles, and 0.25 miles) north of the twin ponds (East and West Ponds). Three discharged directly to the Forge River and two discharged to Old Neck Creek (Villa, 1964).

By 1982, there were only 22 duck ranches remaining in operation in Suffolk County but they were still producing about 4.5 million ducks per year. Most of the duck industry was concentrated on Moriches Bay at the time but there were only two operating in the Forge River drainage basin. These were located north of the twin ponds (Suffolk County Planning Department, 1982) and are the sites of the current remaining duck ranches. The maximum number (maximum number at any given time) of ducks on these two properties in 1982 was 91,000, about evenly split between the two (Suffolk County Planning Department, 1982).

Recently, based on data and information from the Cornell University Duck Research Laboratory, the ratio of duck to human nitrogen generation in waste has been calculated to reflect the actual life cycle of the ducks on the site as they were raised for market. These studies indicated that a normal human consuming a normal diet generates 20 g (0.044 lb) of nitrogen per day or 7300 g/year (16.10 lb/year). A duck, over the seven weeks of growth to market size, excretes 93.6 g (0.206 lb) of nitrogen. Added to this waste is an additional 10.6 g (0.023 lb) nitrogen per marketed duck for the brooder duck waste, assuming that the brooder generates 100 ducks per annum. The brooder lives year round. This results in 104 g (0.229 lb) nitrogen per marketed duck (Dean, 2005).

On a daily basis, the 104 g (0.229 lb) of nitrogen per marketed duck amounts to 2.1 g (0.0046 lb) (7 weeks or 49 days). Thus, it takes about 9.5 ducks to produce the same amount of nitrogen in excrement as one human at 20 g/day. The duck rearing practices make a great deal of difference with regard to the timing and actual amount of nitrogen released to the environment.

Today the two remaining ranches are owned by the same proprietor. One discharges to West Pond and soon will be required to have tertiary treatment of its duck waste; the other to a treatment lagoon that discharges to ground water (Anthony Leung, New York State Department of Environmental Conservation, personal communication, Nov. 20, 2007). Approximately 80,000 ducks are kept at any one time, yielding 400,000 ducks for market based on the previously mentioned production model. The largest ranch produces about 275,000 ducks.

This amounts to a total population of 5700 in terms of human equivalents for the two ranches producing 114 kg/day (251 lb/day) of nitrogen when averaged over a year. However, when the larger ranch implements tertiary treatment, assuming a 90 percent reduction in nitrogen released to water only, the daily load to the watershed will be 7.8 kg (17.2 lb) from the larger ranch and 35.6 kg (78.5 lb) from the other ranch. The annualized mass loads of nitrogen from ducks and people are shown in Table 2 and Figure 3, and currently over the watershed amount to about 125 kg N per hectare per year (110 lbs N per acre per year).

The population of the entirety of the Town of Brookhaven was 14,592 in the 1900 census (Long Island Regional Planning Board, 1982). In 1963, the combined populations of Mastic, Mastic Beach, and Shirley were 11,000 (Table 2). These hamlets approximate the boundaries of the drainage area, with the exception of the southeastern part of the basin. The southeasterly portion of the drainage basin does not appear to have been heavily populated at that time based on aerial photography. By 1980, these community boundaries had been adjusted (Long Island Regional Planning Board, 1982). The 2005 population estimate for the hamlets of Mastic, Mastic Beach, Shirley, and Moriches, which also closely correspond to the drainage basin, was 59,000 (Long Island Power Authority, 2005). Relative to 1963, this is a population increase of 436 percent. The population of Mastic, like most of coastal America, is growing. According to Suffolk county census reports the population in the neighborhood just west of the Forge River has jumped by about 700 percent in the last 40 years (Smith, 2007). The runoff from local businesses and homes as well as cesspool leaching culminates in the Forge River and is likely a factor in its faltering status.

The net nitrogen contribution to a waterway by resident birds such as swans is zero (Valiela et al., 1997). This is because they remove as much nitrogen from the waterway as they contribute through feces.

However, even if swans only discharged (didn't consume) nitrogen to the Forge, the loading would be small. There is little information concerning nitrogen loading from Mute Swan (resident species on the river) feces. The feces of the Black Swan (about ¾ the size of the Mute Swan, but feeding similarly) contains nearly 1.2 g dry weight nitrogen per day (Mitchell and Wass, 1993). Adjusting for size, this equates to about 1.6 g dry weight nitrogen for the Mute Swan.

The New York State Department of Environmental Conservation claims that there are approximately 3,000 Mute Swans in the entire state – most on Long Island and in the lower Hudson Valley (http://www.dec.ny.gov/animals/7076.html, downloaded Feb. 25, 2009). Assume there are 1500 swans on the island and ten percent (150) live on the Forge River, then there is about 6425 mol nitrogen (90 kg nitrogen) discharged to the river annually. This is about 0.03 percent of the total nitrogen discharge to the river – thus insignificant. Even though the nitrogen contribution to the river via swans is extremely small, there may be other reasons to reduce their population, i.e., pathogenic pollution.

Physical Influences

In terms of its physical oceanography, the Forge River functions as an estuary driven by fresh water entering at its head and along its length and by a tidally driven influx of saltwater from Moriches Bay (Figure 4). Mean tide level and mean sea level are at the same relative elevation in the upper reaches of the Forge, indicating that the tide is neither flood- nor ebb-dominated. Being symmetrical with respect to flood and ebb implies that the tidal energy to transport suspended material out of or into the upper river is nearly balanced.

A considerable quantity of fresh water enters the upper Forge. In summer surface salinities average about 3-4 practical salinity units (PSU) less than bottom salinities. The major sources of surface discharge to the tidal Forge are East and West Ponds. These two ponds constitute about 80 percent of the total surface water runoff to the entire tidal Forge and 83 percent of the total surface flow north of a transect across the river through station 9, just north of Poospatuck Creek (Figure 1). This transect was used to approximate a salt balance for the most hypoxia-impacted portion of the river.

Over the period of December 1947 to April 1948, the measured flow of the east and west branches of the Forge River at Montauk Highway (where the East and West Ponds converge) was 21,600 m^3/day (0.764 million ft^3/day) (Redfield, 1952). Stream flow measurements at East and West Ponds entering the tidal Forge in January 2007 by the School of Marine and Atmospheric Sciences (SoMAS) amounted to 27,100 m^3/day (0.96 million ft^3/day). Redfield (1952) found that the volume of groundwater seepage to Moriches Bay was roughly 3.6 times that of stream flow. SoMAS found in 2007, based on a salt balance over a tidal cycle north of Poospatuck Creek where 97 percent of the stream flow occurs in the Forge, that groundwater seepage was 1.6 times that of stream flow. These two sets of measurements separated by some 60 years seem generally consistent, considering the early measurements represented the full length of the river, the latter the northerly portion. The ratio of ground water to stream flow will vary as a function of season, weather, and climate variability.

While the flow over the weirs at East and West Ponds seems to be uninterrupted, much of this water may be temporarily impounded north of the Long Island Rail Road (LIRR) bridge. Release may be a function of tidal stage and flux from the ponds. This may account for some of the salinity spikes observed in the continuous recordings at the Waterway Condominiums (just north of station 1 on the east bank). During summer, density stratification (primarily salinity) limits mixing in Wills Creek and the deepest parts of the main (dredged) channel. However, in much of the main channel of the Forge, mixing is taking place as evidenced by the dilution of nitrogen concentrations as a function of salinity (Figure 5). Here the gravitational flow of salt upriver is mixing with the more nitrogen contaminated water to the north. Also, as shown in the salinity sections through section 9 (Figure 6), the rather evenly spaced isohalines with depth and the isohaline water on the east side of the river at times during the day, suggest mixing as well.

It appears that a number of forces and conditions affect circulation in the Forge and its tributaries, besides classic tidally driven estuarine circulation. Among these are variations in stream flow, fluctuations in the height of groundwater table, and wind. Because the river is shallow, any of these conditions can significantly alter the conventional views concerning estuarine circulation. In addition, physical alterations to the river are modifying the estuarine circulation that does take place.

The entrainment of water north of the LIRR by the shoal under the bridge may be modifying the natural flow of fresh water into the Forge, impeding estuarine processes. The sill and the dredged deep behind it in Wills Creek (Figure 1) are clearly contributing to its sluggish, slough-like conditions. The dredged channel in the Forge apparently exacerbates stratification, as this is where the higher salinities were observed, possibly reducing mixing that had occurred historically.

Wind, at times, can be a dominating force controlling circulation in the Forge. The effect of the wind can be seen in the extended periods of high or low water and the large standard deviation (± 24 minutes) of the arrival of high and low water relative to the Sandy Hook reference tide station, depending on the direction of the wind. The generally shoal nature of much of the river creates a situation whereby potential stagnant conditions can be alleviated by overturning the water column via wind mixing.

Physical processes and topography are influential in controlling dissolved oxygen (DO) concentrations. Data indicate that both surface and bottom waters can be anoxic at night. However, during daytime, photosynthesis can create supersaturated conditions in surface waters, in some areas > 200 percent. Thus, on quiescent summer days and despite evidence of weak mixing when the water column is strongly stratified, there is little evidence of the supersaturated surface waters alleviating anoxic bottom waters.

Further examination of Figure 4 is warranted because it illustrates the effect daily weather can have on this small but complex estuary. Extremely low surface dissolved oxygen values were recorded for much of the northern river. This transect was taken in mid afternoon when one would expect dissolved oxygen concentrations to be supersaturated in summer. On this particular day, however, it was cloudy and thus photosynthesis reduced.

Nitrogen Budget of Inputs, Exports, and Remineralization

The Forge River suffers from summertime hypoxia caused by eutrophication which is stimulated by nutrient loading. We have defined hypoxia as levels of dissolved oxygen below 3 mg O_2/L, whereas anoxic conditions occur when there is a complete lack of oxygen (0 mg O_2/L). These conditions will inevitably cause decreases of marine life, biodiversity and overall habitat health. While seasonal hypoxia has occurred naturally for years in areas with poor water exchange, it is evident that unnatural occurrences are on the rise (Gray et al., 2002).

There are three key elements to eutrophication: 1) increased nutrient levels leading to 2) increased production of organic matter and 3) eventual microbial degradation of that organic matter and oxygen depletion (Gray et al., 2002). Research of other urbanized estuaries, like that of Long Island Sound, has shown strong connections between changing physical oceanographic processes and hypoxia (Wilson et al., 2008) and also between anthropogenic nutrient sources with recurrent hypoxic conditions (Parker and O'Reilly 1991). Significant efforts to better understand physical water column processes, to reduce the anthropogenic contributions to unnaturally eutrophic systems, along with increased research to understand the impacts of coastal population growth on waterways, are currently underway.

Suffolk County Department of Health Service collected phosphorus and ammonia concentration data over the period 1977 to 2006 in Moriches Bay which have been plotted in Figure 7 for station 080110 (0.32 km, or 0.2 miles, west-southwest of Masury Point). The timing and frequency of data collection varied considerably within and among years. Nevertheless, phosphorus concentrations generally appear to have declined (including many more non-detects in recent years) while ammonia concentrations remained steady. Nitrite plus nitrate concentrations appear to have slightly increased with time (Figure 8). The ratio of nitrogen to phosphorous (Figure 8) increased with time over the three decades. The latter may be indicative of the reduced influence of duck ranching as facilities closed and treatment of the wastes from those remaining became more stringent. It is of interest to note, that the conclusion that duck farming in Moriches Bay tributaries as a major contributor of pollution of Moriches Bay and Great South Bay was based in large part on the higher than normal ratios of P/N measured in the early 1950 studies by Woods Hole Oceanographic.

Gobler et al. (2009) estimated the nitrogen budget for the Forge River, which is summarized in Table 3. Nitrogen enters the river through its tributaries including the East and West Ponds. Nitrogen from duck wastes is included in the West Pond discharge. The independent estimate of nitrogen that may come from duck ranching (Table 2) is consistent with the estimate based on measuring flux to the river, giving us confidence in the nitrogen budget.

Other sources of nitrogen to the river include atmospheric deposition, surface water runoff, and ground water. The groundwater load includes that nitrogen contributed by cesspool and septic systems. The total of all the inputs amounts to approximately 19.5 million mol N per year of which about 74 percent is contributed by ground water and 16 percent by West Pond. Swanson et al. (2008) reported that 0.482 million kg N per year (34.4 million mol N per year) were estimated to be discharged to cesspools and septic systems in the drainage basin in 2009. Assuming 50 percent denitrification in soils, some 17.2 million mol N per year would then be discharged to the river via groundwater. Thus, there is also remarkably good agreement between the Gobler et al. (2009) estimate for groundwater input and that approximated from human waste production.

Internal recycling includes the flux of nitrogen from the benthos and the growth and decay of the macroalgae *Ulva lactuca*. Note that while annualized estimates are presented, most *Ulva* processes occur during spring and summer. During summer, denitrification in sediments is greatly reduced due to near anoxia in the sediment water interface.

Storm water runoff is only a small contribution to nitrogen loading to the Forge – about 2 percent. This is consistent with Valiela and Kinney (2008) who found the nitrogen contributed by surface runoff in Great South Bay was small as well.

There is a net removal of nitrogen from the river of about 18.1 million mol N per year via burial and tidal exchange. It is likely that a large portion of the nitrogen input is lost from the Forge by tidal exchange with Moriches Bay. For example, examination of Suffolk County water column chemistry data from 2005 and 2006 indicates that there is a significant inverse relationship between nitrogen concentrations along the main stem of the Forge and salinity. This suggests increased tidal mixing as one moves closer to Moriches Bay (Figure 5).

Characterization of Nutrients, Phytoplankton Blooms, Dissolved Oxygen Dynamics, Photosynthesis, and Respiration

During 2006, research was conducted to understand the role of eutrophication on the hypoxic conditions of the Forge River water column, by monitoring the nutrients, phytoplankton dynamics, and physical structure of the river from May to October. Bi-weekly time series water sampling, spatial cruises, light-dark respiration experiments, and a submerged water quality probe were used to collect information about the water column's physical structure, phytoplankton community biomass, diversity, productivity, and nutrient concentrations.

The Forge River experienced chlorophyll *a* levels exceeding 400 µg/L and dissolved inorganic nitrogen concentrations at greater than 100 µM (micromolar) through the summer and fall months. Bottom waters of the Forge remained hypoxic for extended periods of time during summer (i.e., several weeks during July and August).

Phytoplankton communities included several potentially harmful dinoflagellate species including *A. sanguinea*, *P. minimum* and *P. micans*. Light-dark respiration experiments indicated the water column was net heterotrophic, meaning oxygen consumption strongly outweighed oxygen production in the Forge River. This was likely caused by the great abundance of heterotrophic dinoflagellates and bacteria, and was a factor in the hypoxic conditions observed throughout the summer.

In 2007, similar studies indicated peak chlorophyll *a* levels persisted in the system during summer and fall months with peak levels at station 2, the Brookhaven Town Pier of 125 µg/L (Figure 9) and at a location on the west bank of the Forge southwest of station 12 of 75 µg/L. Most of the chlorophyll was due to large cells in the spring and fall, but was due to smaller cells during the summer. Ammonium levels peaked at levels 47.0 µM, nitrate levels at 20.0 µM, and phosphate at 4.50 µM at the Brookhaven Town Pier (Figure 10). At the site near station 12, the ammonium levels peaked at 10.0 µM, nitrate at 20.0 µM and phosphate at 2.50 µM. A reduction in nutrient concentrations in the Forge may ease the occurrence of algal blooms and improve bottom oxygen levels in the river.

Chlorophyll

Time series chlorophyll *a* collections in 2006 showed a relatively large summer bloom in early through mid-July. Peak levels during this bloom period for whole chlorophyll *a* was 430 µg/L, <5 µm chlorophyll *a* peaked at 260 µg/L, and >5 µm peaked at 250 µg/L. There is evidence from Lugol's counts of an extensive fall bloom during October and November as well when chlorophyll levels were approximately 100 µg/L. Lugol's counts during the summer and fall bloom were dominated by dinoflagellates. During the summer blooms, the dominant dinoflagellate species was *Prorocentrum minimum*. In the fall bloom, both *P. minimum* and filamentous cyanobacterial species were dominant. *P. minimum* along with *Akashiwo sanguinea*, and *Prorocentrum micans* are classified as potentially harmful and were all present in the samples collected. Time series nutrients showed elevated concentration of dissolved inorganic nitrogen (DIN) and phosphate (PO4): DIN~130 μM; PO4~150μM. These levels showed a decline which corresponded with the increase in phytoplankton later in the summer. There was a subsequent, slight rise in both DIN and phosphate prior to the fall bloom as well. Temperature measurements from time series sampling ranged between 17 °C in late fall to 30 °C in mid-August, while salinity ranged from 13 to 26 psu.

Spatial cruise samples were analyzed primarily to understand changes in dissolved oxygen, both along the river as well as with depth at each station. The fresh water site in West Pond along with sites most affected by tidal flushing from Moriches Bay showed surface and bottom dissolved oxygen measurements at non-hypoxic levels. The intermediate site, the marina on Old Neck Creek, experienced bottom water hypoxia, while Brookhaven Town Pier was nearly anoxic. These intermediate sites also displayed haline stratification. Lugol's counts are available only for the second cruise on August 8th. The predominant feature of this sub sample was high numbers of centric (62,000 cells/ml) and pennate (8,800 cells/ml) diatoms present in the freshwater site while dinoflagellates dominated the phytoplankton biomass of other sites. Chlorophyll *a* results from the cruises show that, especially during the August 8th cruise, the biomass was dominated by cells larger than 5 μm.

The chlorophyll *a* fluorescence data from a submerged sonde probe showed great variability in chlorophyll levels ranging from 10 to greater than 600 μg/L with the highest levels found during late July. Dissolved oxygen measurements, which varied in depth depending on the tide stage, collected from the probe were at an average depth of 1.9 m. Regardless, bottom oxygen levels showed occasional hypoxic periods for up to 24 hr in June and extended anoxic periods (weeks in July and August).

Light-dark respiration experiments showed a pattern of negative net metabolism, with rates of respiration exceeding photosynthesis. These respiration rates were on the order of 10 mg O_2 consumed in less than 24 hr.

Ulva Lactuca

Research was also conducted to understand the role played by *Ulva lactuca* (sea lettuce) in the nutrient cycling processes of the Forge River from May 2006 through 2007. In April, *Ulva* abundance peaked at the southern sites in the river. When summer temperatures exceeded 25 °C and when light was unable to penetrate to the bottom of the water column due to high chlorophyll *a* levels, there was a decrease in *Ulva* growth. Experimental incubations demonstrated that decaying *Ulva* both released nutrients and consumed oxygen. Therefore, the seasonal decline in *Ulva* may supply regenerated nutrients to pelagic algal blooms and may contribute to the hypoxic conditions in the Forge River, thereby exacerbating the symptoms of eutrophication during summer.

Ulva lactuca is a natural component of the low to mid shore zones of many estuarine ecosystems worldwide. Profuse growths of *Ulva*, in response to nutrient discharges and high tidal flushing have been recognized for years (Noemi Gil et al., 2005). *Ulva*, along with other types of sea lettuce have increased in abundance world wide since the latter half of the twentieth century (Mackenzie, 2005). *Ulva* is so responsive to nitrogen and phosphorus enrichment that it may be able to be used as a monitor of localized water column enrichment (Vermaat and Sand-

Jensen, 1987). It often covers shallow bottom areas, thus eliminating sources of food, altering food web dynamics, leading to eutrophication (Mackenzie, 2005).

Abundance surveys for *Ulva lactuca* began in April 2007, at the Brookhaven Town Pier, near the marina at Old Neck Creek, and near the mouth of Lons Creek (Figure 11). Observation at the site southwest of Old Neck Marina began in September 2007. At the Brookhaven Town Pier, there was low *Ulva* percent cover, 2.5 % in April, and no *Ulva* was present after until the survey's termination. In April, the site at the Old Neck Marina and the site at the Forge River mouth had the greatest *Ulva* cover, 97 percent and 45 percent, respectively. Percent cover at these sites declined dramatically in the following months, with coverage of less than 5 percent by June and July. There was a slight peak in coverage for the same sites in September and October 2007 to approximately 1-2 percent. The site southwest on Old Neck Creek on the west bank had 64 percent cover in September which soon decreased to zero by November 2007 (Figure 11).

Ulva growth from May 5-30, 2007 was approximately 0.009 g/day (± 0.002 standard deviation) at the bottom at the Brookhaven Town Pier over the 20-day experiment. From June 6-26, 2007, *Ulva* growth dramatically decreased to –0.005 g/day (± 0.002 standard deviation) at the bottom of the Brookhaven Town Pier, indicating that during this time, *Ulva* was degrading and not producing biomass. For the same time period of June 6-26, 2007 at the site southwest of Old Neck Marina, *Ulva* had a mean growth of 0.09 g/day (± 0.03 standard deviation) at the surface and 0.04 g/day at the bottom ($p = 0.02$). Progressing further into the summer months, during June 25-July 15, 2007 at the Brookhaven Town Pier, *Ulva* had a mean daily growth of 0.01 g/day (± 0.02 standard deviation) at the surface, and was still decaying at the bottom ($p = 0.025$). From June 25-July15, 2007, *Ulva* continued to grow more at the site southwest of the Old Neck Marina, with approximately 0.04 g/day (± 0.04 standard deviation) at the surface and 0.02 g/day (± 0.02 standard deviation) at the bottom (Figure 12; $p = 0.04$).

The Brookhaven Town Pier had a decrease in Secchi disk (a device to measure relative light penetration) depth from early to mid July, and a decrease in chlorophyll *a* during that time. The site southwest of Old Neck Marina had a decrease in Secchi disk depth from early to mid July as well, and there was also a concurrent increase in chlorophyll *a* during this time.

Light/dark experiments with the addition of healthy and decaying *Ulva* demonstrated that healthy *Ulva* was capable of contributing to photosynthesis while decaying *Ulva* enhanced respiration rates. For example , during the June and July experiments, the addition of decaying *Ulva* yielded respiration rates which were significantly higher than the control ($p = 0.05$). Similarly, during June, the net production of oxygen in the decaying *Ulva* treatment was significantly lower than all other treatments ($p < 0.001$). During the July experiment, the addition of *Ulva* yielded significantly higher oxygen production rates than all other treatments ($p < 0.002$).

Salinity, Oxygen, and Respiration

The water column in summer 2007 at Waterway Condominiums was strongly haline-stratified. Surface salinity values were lower than salinity at depth by several PSU, and on occasion by more than 10 PSU, likely indicating heavy rainfall events influencing freshwater flow at this portion of the river. Stratification likely contributed to the large disparity between surface and bottom dissolved oxygen levels with bottom levels dropping below 5 mg O_2/L often throughout the summer and surface values ranging from 6-20 mg O_2/L. From mid-July through early August, bottom oxygen levels rarely exceeded 2 mg O_2/L and were often anoxic (0 mg O_2/L).

Light-dark respiration experiments conducted during late spring using water from the surface and bottom showed a net generation of oxygen in the surface waters but a depletion of oxygen in the bottom waters. Statistical significance was verified through a statistical t-test analysis. During the May experiment, there were significantly higher respiration rates in the bottom waters compared and surface waters ($p = 0.001$) and significantly higher photosynthesis in the surface compared to the bottom ($p = 0.002$). These trends continued in June, although only the difference in photosynthesis between surface and bottom was significant ($p = 0.001$).

Discussion

The Forge River, particularly in the northern half, experiences extended periods of hypoxia in the main channel and several of its tributaries during many summers. Upstream at the freshwater source and close to Moriches Bay there is typically an abundance of dissolved oxygen. Microbial processes in the water column as well as nighttime respiration of massive amounts of algae within the main part of the river are the probable causes of the oxygen depletion there. The hypoxia is due to eutrophication created by *Ulva lactuca* growth, seasonal phytoplankton blooms, and dissolved oxygen consumption by organic material in the benthic substrate. Water column processes fueled by anthropogenic nutrient loading dominate dissolved oxygen consumption. Summertime physical oceanographic processes and weather conditions undoubtedly have a pronounced influence on the eutrophic conditions -- specifically those conditions such as excessive heat and reduced wind mixing that lead to intensifying water column stratification.

Nutrients have been found at elevated concentrations in the upper river at the Brookhaven Town Pier during spring prior to algal blooms of summer and fall (Figures 9 and 10). These nutrients are used by primary producers and are likely fueling the large *Ulva lactuca* and phytoplankton blooms seen in the Forge during spring and summer, respectively. The occurrence of these spring and summer algal blooms is interrelated, further contributing to a host of environmental problems in the Forge River, including hypoxia.

Ulva populations, which Myren (1964) observed in the early 1960s in the Forge River, display distinct patterns of growth and decay that are likely influenced by nutrients, light, and temperature. Percent coverage data indicate that *Ulva* in the Forge River is highest in early spring (April) and decreases into the warmer summer months. During spring months, *Ulva* growth stimulated by even small increases in nitrate or ammonium can lead to excessive biomass (Harlin and Thorne-Miller, 1981).

Rapid growth of *Ulva* in sewage-polluted water has been observed (Noemi Gil et al., 2005). *Ulva lactuca* is tolerant of low temperatures and even freezing temperatures (Vermaat and Sand-Jensen, 1987). However above 20 °C the growth rate of *Ulva* decreases rapidly (Taylor, 1996) with zero growth above 25 °C in Waquoit Bay, MA (Peckol and Rivers, 1996). Temperatures in the Forge generally exceed the upper limit of *Ulva's* temperature tolerance during summer. Hence, high temperatures likely contribute to the decay of *Ulva*, but light limitation following growth of phytoplankton and perhaps mineral precipitation may be an even greater deterrent to *Ulva* growth.

The interactions among phytoplankton, *Ulva,* and nutrients in the Forge River are complex and interdependent. As demonstrated by an *Ulva* nutrient experiment (Burson et al., 2007), decaying *Ulva* contributes to a regenerated nutrient supply in the river. These regenerated nutrients from decaying *Ulva* may promote the summer phytoplankton blooms (Burson and Gobler, 2007). Dense phytoplankton blooms act to shade the benthos and increase the *Ulva* decomposition. In 2007, areas of highest observed chlorophyll *a* levels, such as station 2 (Brookhaven Town Pier) (Figure 1), experienced reduced light penetration during summer. Growth rates of *Ulva* were always lower in bottom waters compared to surface waters and lower in the more turbid station 2 than at a station near the west bank, southwest of station 12 (Figure 12), demonstrating that growth of *Ulva* became light-limited during the dense phytoplankton blooms of summer. These observations support the hypothesis that shading from dense algal blooms would block light penetration to benthic macroalgae such as *Ulva*. A positive feedback loop is created. *Ulva* decay yields more nutrients which exacerbate pelagic phytoplankton blooms, further light-limiting *Ulva,* leading to additional macroalgal decay.

Peak blooms of phytoplankton, composed of predominantly dinoflagellates, often occur during summer and fall. Of the dinoflagellate species identified in 2006 (Burson and Gobler, 2007), several were classified as harmful and have traditionally been associated with shellfish kills; namely *A. sanguinea, P. micans,* and *P. minimum* (Anderson et al., 2002). While poisoning from these dinoflagellates hasn't been detected specifically in the Forge River, it may represent an additional source of stress to resident marine life already exposed to hypoxic conditions. Large dinoflagellates along the length of the river have dominated in some hypoxic years. Chlorophyll data indicated that the majority of phytoplankton biomass was greater than 5 μm in size.

Light-dark bottle respiration experiments have shown that the net metabolism of the Forge River water column was negative, or net heterotrophic. This was likely due to the respiration of both bacteria and dinoflagellates found in the river as well as samples used in the experiments. While dinoflagellates are algae, they are also well known for their heterotrophic activities (Taylor, 1987).

The nutrient concentrations (Figure 13) in the Forge River, especially DIN (dissolved inorganic nitrogen) and phosphate, have corresponded well with dinoflagellate populations. For example, there were increases in inorganic nutrients prior to dinoflagellate blooms that occurred in July and in the fall. The blooms probably were triggered by an excess of these nutrients that were not readily flushed from the river and its tributaries in summer. Regenerated sources of nutrients include the bacterial degradation of the abundant organic biomass in the sediments from the duck ranch history, and decaying macroalgae (*Ulva*); new sources include septic tank or cesspool leach fields, and yard fertilizer runoff.

There are probably still about 13 hectares (32 acres) of wetlands fringing the tidal Forge. It is generally accepted that wetlands actively take up nitrogen from upland areas, convert it to differing forms, and release a portion of it via denitrification to the atmosphere (Valiela and Teal, 1979). Davis et al. (2004) refer to marshes as transformers that can take up inorganic nitrogen and denitrify much of it to a biologically unavailable form. The efficiency of these processes varies with nitrogen loading (Davis et al., 2004), species of marsh grasses (Valiela and Teal, 1979), age of the marsh (Valiela and Teal, 1979), sediment organic content (Davis et al., 2004), and seasonality (Wolaver et al., 1980).

Valiela and Cole (2002) used estuarine sea grass meadows (area and production) as an indicator of impacts from terrestrial-based nitrogen. Seagrass beds, dependent upon light availability, were restricted when light transmissibility was reduced as a consequence of nitrogen stimulated phytoplankton growth. They indicate that fringing marshes around the estuary can protect sea grass beds as long as the land-derived nitrogen does not become overwhelming. The range of nitrogen loading that became excessive fell between 20-100 kg N per hectare per year (18-89 lb/acre/y) and when that loading was greater than 100 kg N/hectare/y (89 lb/acre/y) sea grass was nearly eliminated (Valiela and Cole, 2002). Sewage loading prior to any denitrification to the Forge River watershed is on the order of 125 kg N/hectare/y (110 lb N/acre/y).

Thus, even though the Forge has considerable fringing wetlands, their capacity to remediate may be exceeded. Undoubtedly the coastal fresh marsh located between Montauk Highway and the railroad is beneficial for reducing the impact of the twin ponds, although tidal dilution (September 2, 2005) appears to be sufficient to account for reduction in concentration of total nitrogen ($\approx$ 8 mg/L) between the spillways of the Twin Ponds to that near the railroad (2.8 mg/L) (data from Suffolk County Department of Health Services). Other fringing marshes may not be strategically located along the Forge given potential nitrogen loading. For example, there is no fringing marsh to speak of along the highly polluted Wills Creek. The marsh that apparently was there was destroyed decades ago to accommodate recreational boating.

Remediation

There are a number of remediation measures that might be considered to reduce eutrophication in the Forge River. However, the most sustainable approach would be to reduce the primary causes of the eutrophication, which are nitrogen from West Pond and sewage sources -- septic systems and cesspools. Without control of these sources, other measures may well be largely Band-Aids. Any techniques adopted should also specifically target the upper reach of the Forge and the tributaries discharging to that reach.

Options for reducing eutrophication include biological techniques, a variety of dredging approaches, and technological techniques.

Biological

Strategically increasing the acreage of fringing marsh could reduce nitrogen leakage to the river, say particularly along Wills Creek. However, for this to help significantly, there will probably have to be a concomitant reduction in septage to the drainage basin.

As has been pointed out, *Ulva lactuca* is a factor in the cycling of nitrogen in the river. In spring, available nitrogen stimulates its growth but as water temperature increases beyond its tolerance, it dies, sinking to the river bottom where nutrients are once again released, feeding phytoplankton growth that itself contributes to eutrophication and also limits light in the water column. Harvesting *Ulva* in the late spring, prior to water column temperatures reaching those that are intolerable to it, could benefit the river by removing a stored source of nitrogen that later in summer would be recycled back into the water column.

The addition of filter feeding bivalves to the estuary to reduce the intensity of algal blooms has proven successful in other water bodies and is now being tried in New York Harbor. Oysters were historically abundant in Moriches Bay and the Forge (Ryther, 1989) and the ability of oysters to control eutrophication and algal blooms to the benefit of coastal marine ecosystems is well known (Officer et al., 1982, Wall et al. 2008). In addition, the loss of dense shellfish beds has been associated with the occurrence of algal blooms (Cerrato et al., 2004). Burson et al. (2007) have deployed oysters in the Forge River, which have survived and grown over the period of 2007-2008. Enhancing wild and cultured stocks of oysters in the river may be ecologically extremely beneficial. However, they might not be able to survive and they too will be an oxygen demand and won't remove nutrients.

Dredging

Various dredging scenarios could be beneficial to relieving eutrophic conditions, but in many cases the negative consequences of dredging prove to be greater than benefits derived. See, for example, Wilson and Swanson (2008) concerning Jamaica Bay, NY. Amongst the dredging options that should be explored are:

- removing the sills that have grown across the mouths of the tributaries,
- removing sediment accumulated in the main channel of the river,
- removing the constriction at the Long Island Rail Road trestle,
- dredging the entire river,
- dredging the mouth of the river where it discharges into Moriches Bay,
- dredging and maintaining the channel at Moriches Inlet, and
- creating a new inlet in the barrier beach in the vicinity of the Forge.

Removal of the sills that have built up at the mouths of tributaries, especially at Wills Creek, will improve their estuarine circulation, causing improved mixing. Currently, these tributaries are functioning as small stagnant basins. Wills Creek has been dredged in the past to a depth greater than the river itself, which contributes to its polluted condition. Some filling of the creek to be more compatible with the river's topography would be beneficial as well.

Removal of the organic rich black muds in the main or navigational channel of the river will reduce some of the oxygen demand that has been identified. These muds serve as a nutrient sink as well (but not during summer), so the net effect on water column dissolved oxygen would need to be assessed through modelling. A much bigger consideration is that organic rich sediment will continue to accumulate after dredging. Any beneficial effect realized by sediment removal will be temporary unless nutrient and organic material loading is reduced.

There is little communication between the waters north of the Long Island Rail Road (LIRR) trestle and the river south of the bridge. Waters appear to be impounded behind the bridge except at higher stages of tide. Opening this impoundment could improve circulation in the upper Forge where it currently is quite torpid.

Dredging the entire river would be a costly endeavor for which dredge spoil disposal options are few. As with the dredging of the navigational channel, the sediments are both a source and sink of nitrogen. The net benefits of this may be minimal, and certainly temporary. Additionally, unless the major sources of the nitrogen (cesspools and septic systems) are eliminated, this extensive dredging may have to become a continual undertaking. Also, the Forge has historically been a shallow waterway, rich in organic material (Swanson et al., 2008). To remove all the sedimentary material would completely alter the ecological functioning of the river.

Just as sills isolate some of the tributaries in the Forge, there is an extensive sill that is developing at the mouth of the river. It is important to keep hydrologic exchange between Moriches Bay and the Forge open to stimulate circulation in the river. Dredging this sill so that the river itself is not a basin could make a positive impact on flushing of the river. A commitment to maintenance will also be essential.

There are many reasons to maintain Moriches Inlet, safety being one. Keeping the inlet open will improve circulation (as determined from tidal height measurements) in the bay as has been documented by Guillard et al., 1960 and Conley, 1999. Salinities have increased throughout the bay following both natural and anthropogenic intrusions through the barrier island. However, it is not clear that dredging the inlet will increase circulation in the upper reaches of the river so that eutrophic conditions would be reduced.

Creating a new inlet in the barrier island to the south of the Forge River would be a risky undertaking. It undoubtedly will have a positive impact on the eutrophic conditions in the Forge, but it would totally change the hydrodynamics of the Moriches Bay, altering physical and ecological conditions throughout. The potential negative impacts on other communities surrounding the bay may outweigh the benefits experienced in the Forge. Such an undertaking would, at the very least, be highly scrutinized under the State Environmental Quality Review Act process.

Technological Techniques

Infrastructure that can improve pollutant conditions in the Forge include stormwater treatment, installation of a bubbler system along the bottom of the upper Forge, and in selected tributaries, continued improvements to managing duck wastes, and construction of a sewage treatment plant.

Stormwater treatment will have little impact on eutrophication in the Forge (Table 2). However, there will probably be considerable reduction in pathogens reaching the river. The one benefit that might be derived from stormwater remediation that will help eutrophication is the removal of the stormwater discharge at the mouth of Wills Creek that appears to be discharging sediment, contributing to development of the sill that has formed there.

Construction of a bubbler aeration network along the bottom of the upper reach of the river and several of the tributaries would help to supply oxygen to the bottom waters and minimally stir the water column. Such systems are now in place in several considerably smaller tributaries than the Forge in New York City. A more sophisticated system is in operation in the highly polluted Gowanus Canal whereby some $760 \times 10^6 - 1140 \times 10^6$ L/d (200-300 MGD) of relatively well-oxygenated East River water is pumped into the upper reaches of the canal. Immediate improvements in dissolved oxygen concentrations were observed, along with associated improvements in ecological functioning (Swanson et al., 2000). The bubbler system, if applicable at this scale, would only have to be functional in late spring and in summer as the pycnocline develops and remains strong. Continuing maintenance would be required -- particularly in a high sedimentary environment.

The objective of requiring nitrogen removal at the duck ranches must continue to be pursued. Additionally, we raise concern that the drying beds for the duck wastes are probably not lined, allowing some nitrogen to be discharged to ground water. If so, provisions to eliminate this source of nitrogen should be explored.

The Forge River drainage basin cries out for sewage treatment including nitrogen removal. This may be the time, as plans are being developed to invest in infrastructure in the United States, to construct a regional sewage treatment plant for the area. A package sewage treatment plant for the area along the river would be a less desirable solution, and only address the local problem in the Forge. However, if funds are not available, this less attractive alternative would avoid the extensive sewerage that would be required to transport the waste to an area, say, on the Brookhaven Town Airport property.

Other remediation technologies that might be investigated include:

- increasing freshwater flow at the head of the river,
- intercepting groundwater flow, and
- treating nitrogen in cesspool/septic systems.

In order to make progress in reducing eutrophication in the Forge River, we recommend a program of hydrodynamic and water quality modelling for a combination of relative low-cost projects from the above menu along with construction of a sewage treatment plant. Beside construction of a sewage treatment plant, remove the constriction at the LIRR trestle, maintain the navigational channel in the Forge and remove the sills that have been built up at the tributaries. Dredge the mouth of the Forge to open communication with Moriches Bay. Install a bubbler aeration system to be operated seasonally at least until the sewage treatment plant is operational. Harvest *Ulva* and experiment with an oyster-rearing program.

Figures

Figure 1. Map of Forge River showing Suffolk County water quality sampling stations and oceanographic sampling transects.

Figure 2. Forge River watershed.

Figure 3. Annual mass discharge of nitrogen from human waste and duck waste to Forge River basin.

Figure 4. Longitudinal sections along Forge River on 5 June 2006 of a: temperature(°C), b: salinity (psu), c: dissolved oxygen concentration (mg O_2/L). Data at station 13 was from 8 June 2006. Data from Suffolk County Department of Health Services.

Figure 5. Total nitrogen concentrations (mg/L) as function of salinity along the Forge River for stations 7, 1, 2, 9, 11, 12, and 13 on 12 September 2005, 10 November 2005, 5 June 2006. Data from Suffolk County Department of Health Services.

Figure 6. Salinities (psu) along transect 9 in Forge River at approximately 0715, 1015, 1325, and 1545 EDT.

Figure 7. Ortho-phosphate and ammonia concentrations from 1977-2005. Data from Suffolk County Department of Health Services.

Figure 8. Temporal variation of the sum of nitrite and nitrate concentrations (mg/L) from 1977 to 2005; and ratio of nitrogen species to ortho-phosphate concentrations. Data from Suffolk County Department of Health Services.

Figure 9. Chlorophyll *a* (μg/L) versus time at station 2.

Figure 10. Nutrient concentrations (μM) versus time at station 2.

Figure 11. Mean *Ulva* percent cover for sites 2, 3, 4, and 5 at the Forge River for April 2007-March 2008.

Figure 12. *Ulva lactuca* growth June 25 through July 15, 2007.

Figure 13. (A) Plankton densities (cells/mL) and (B) nutrient concentrations versus time at Brookhaven Town Pier, May through November 2006.

Tables

Table 1. Area of marsh fringing the Forge River between Montauk Highway and a cross section from Masury Point to Sands Point scaled from the New York State Department of Environmental Conservation's Tidal Wetlands Map, 1974 at a scale of 1:2400.

Table 2. Human population, ducks produced, and annual mass discharge of nitrogen from human waste and duck waste.

Table 3. A budget of N inputs, exports, and remineralization in the Forge River.

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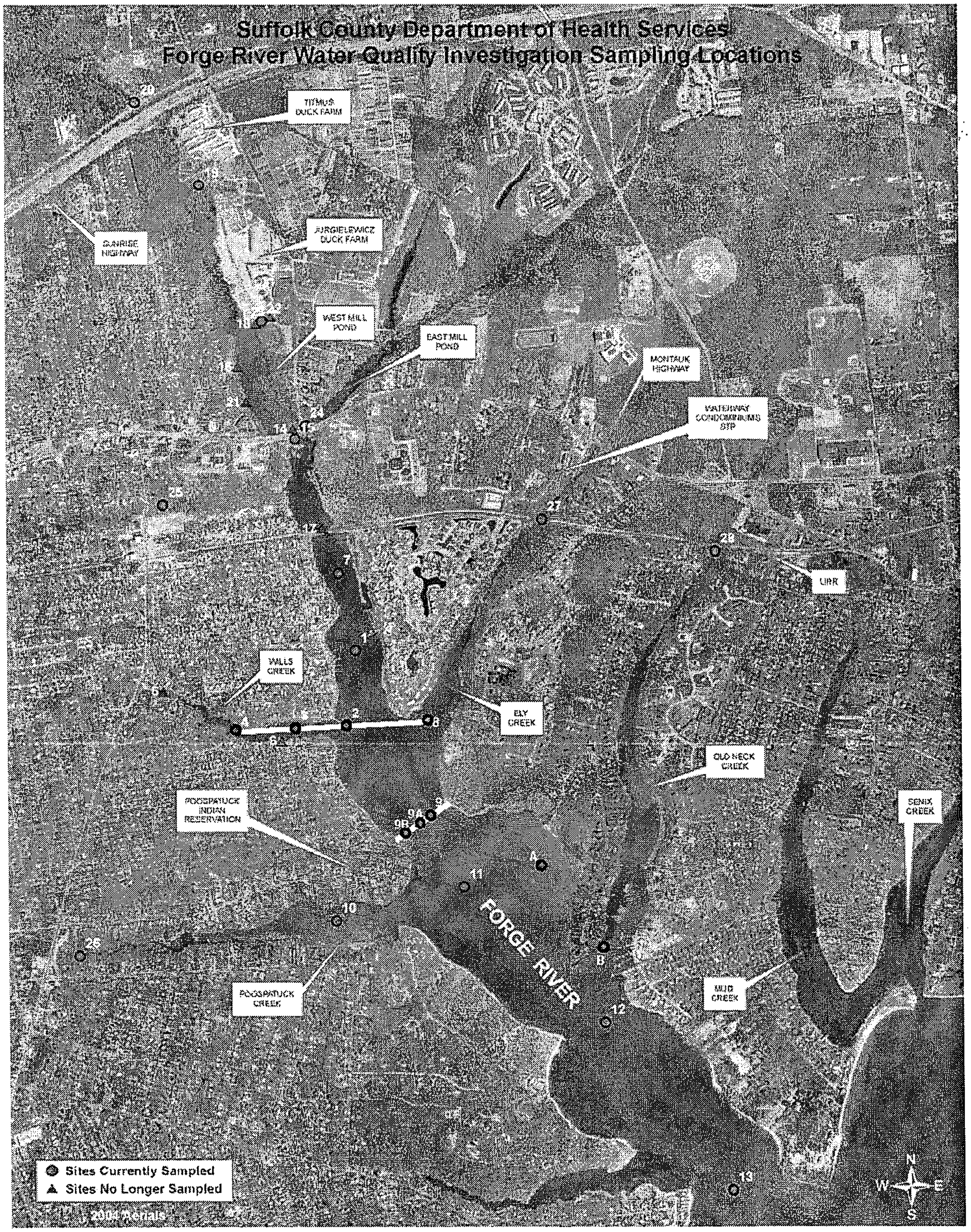

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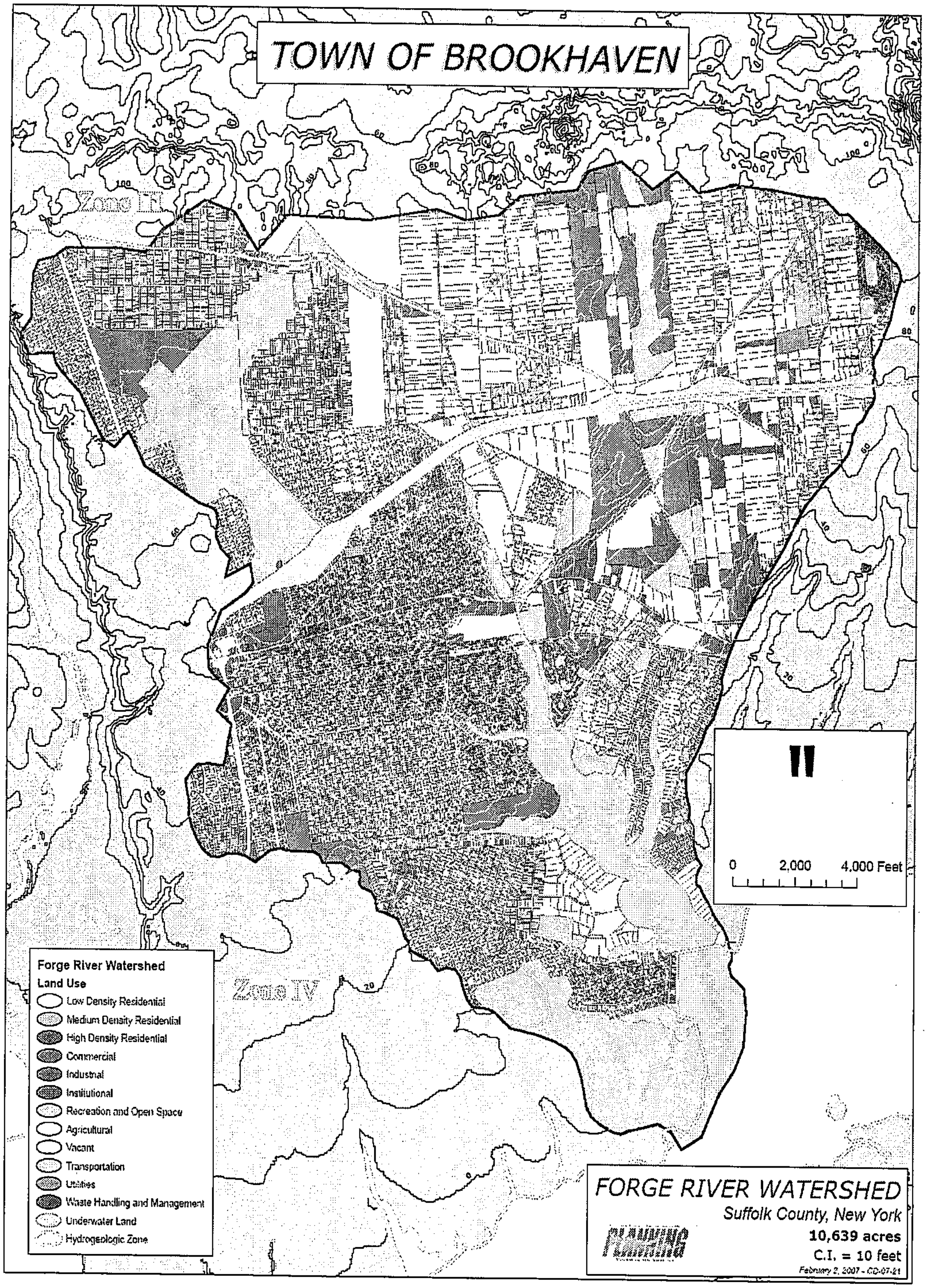

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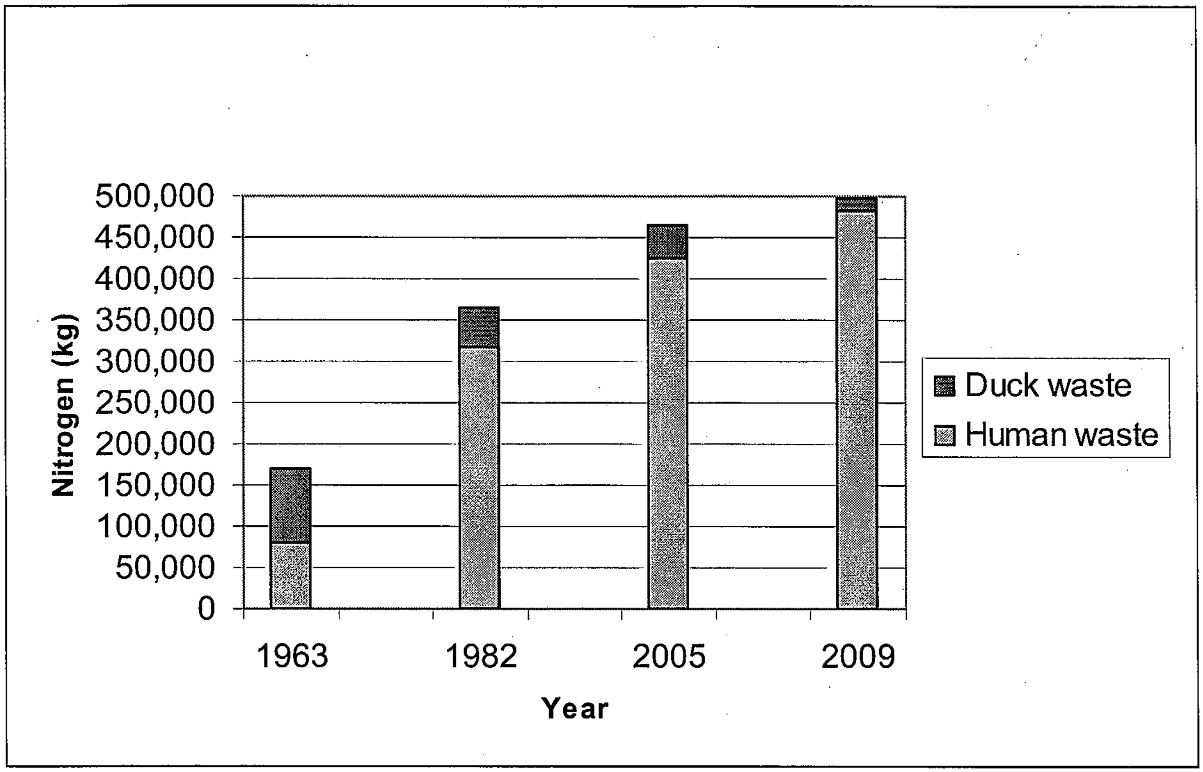

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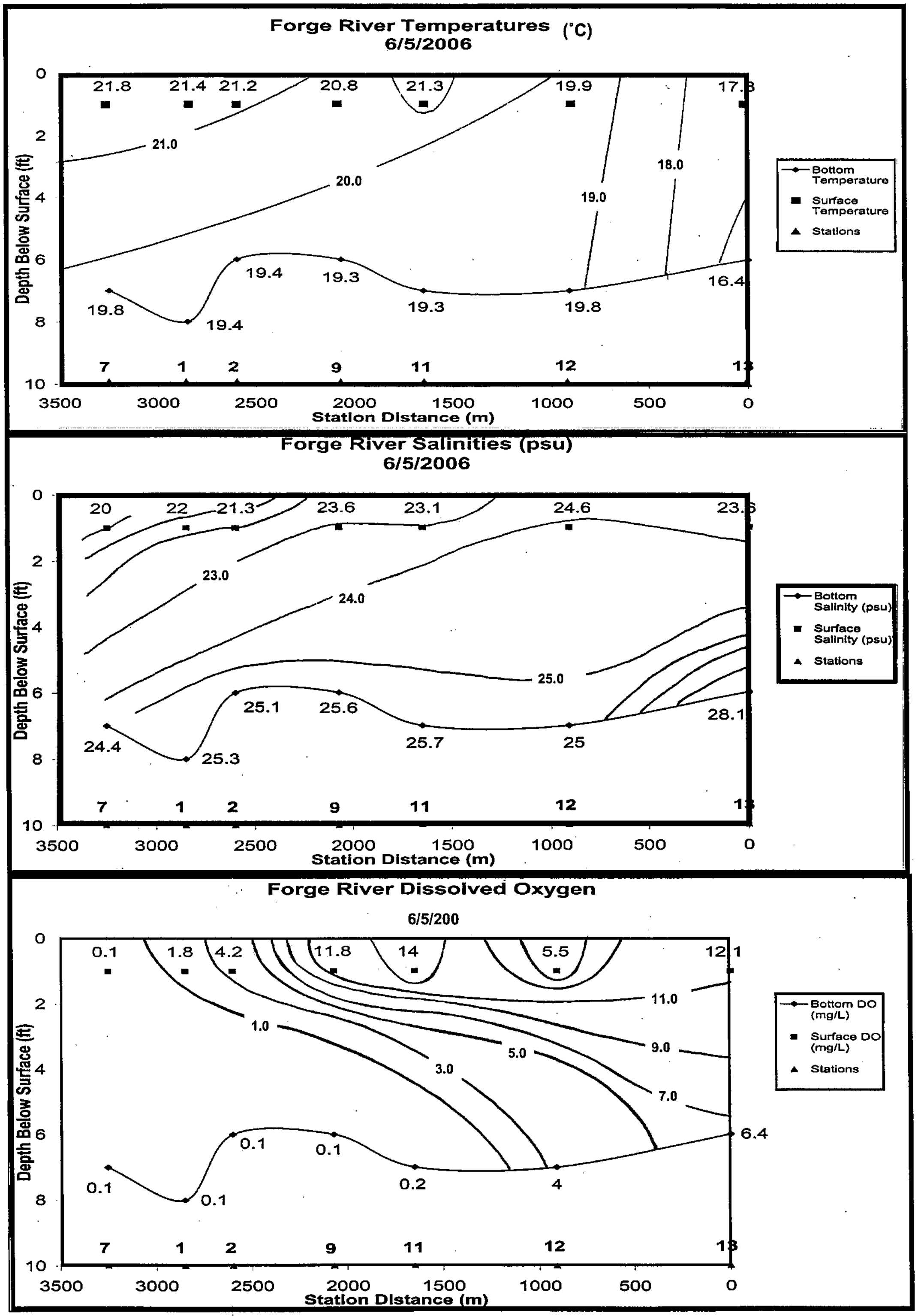

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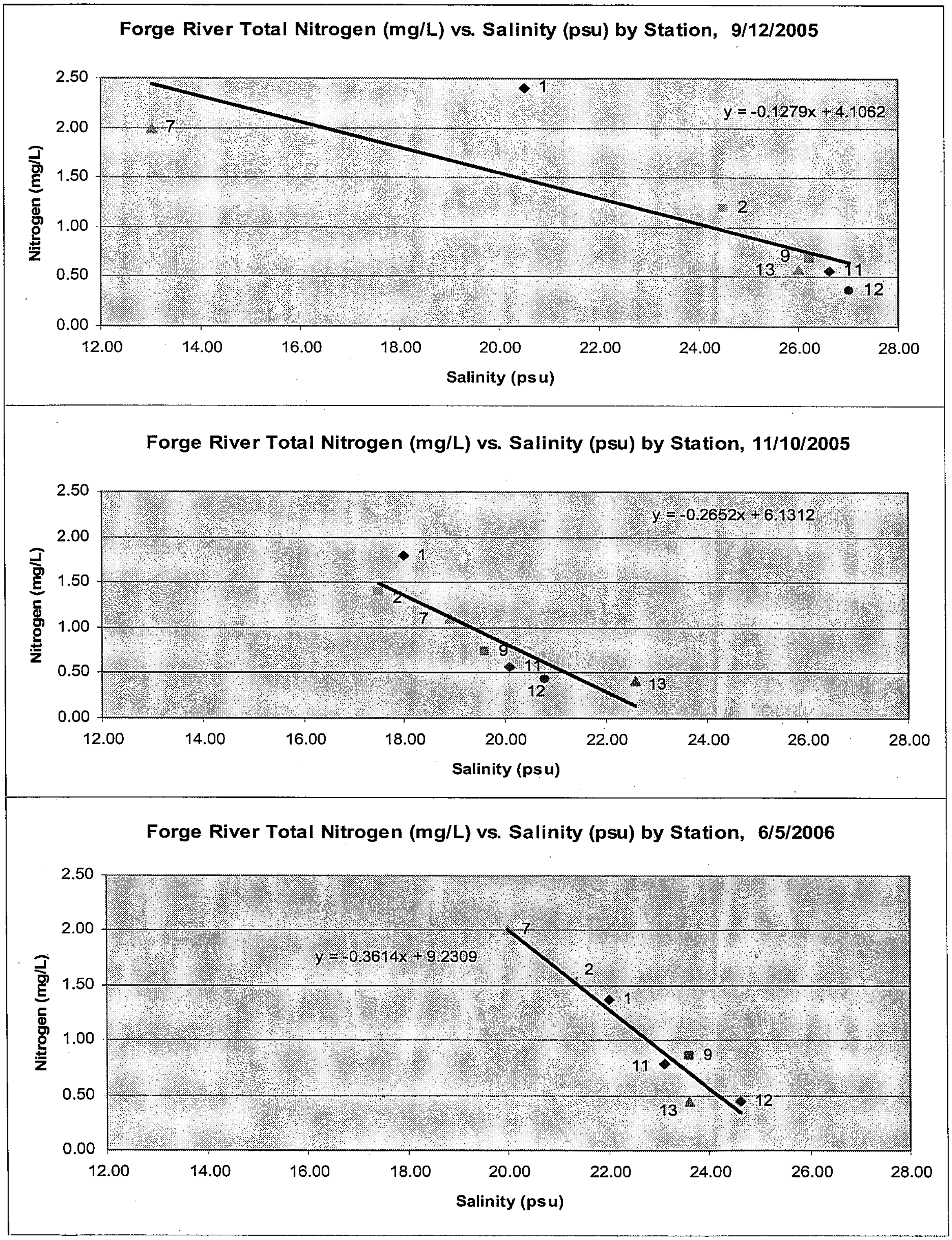

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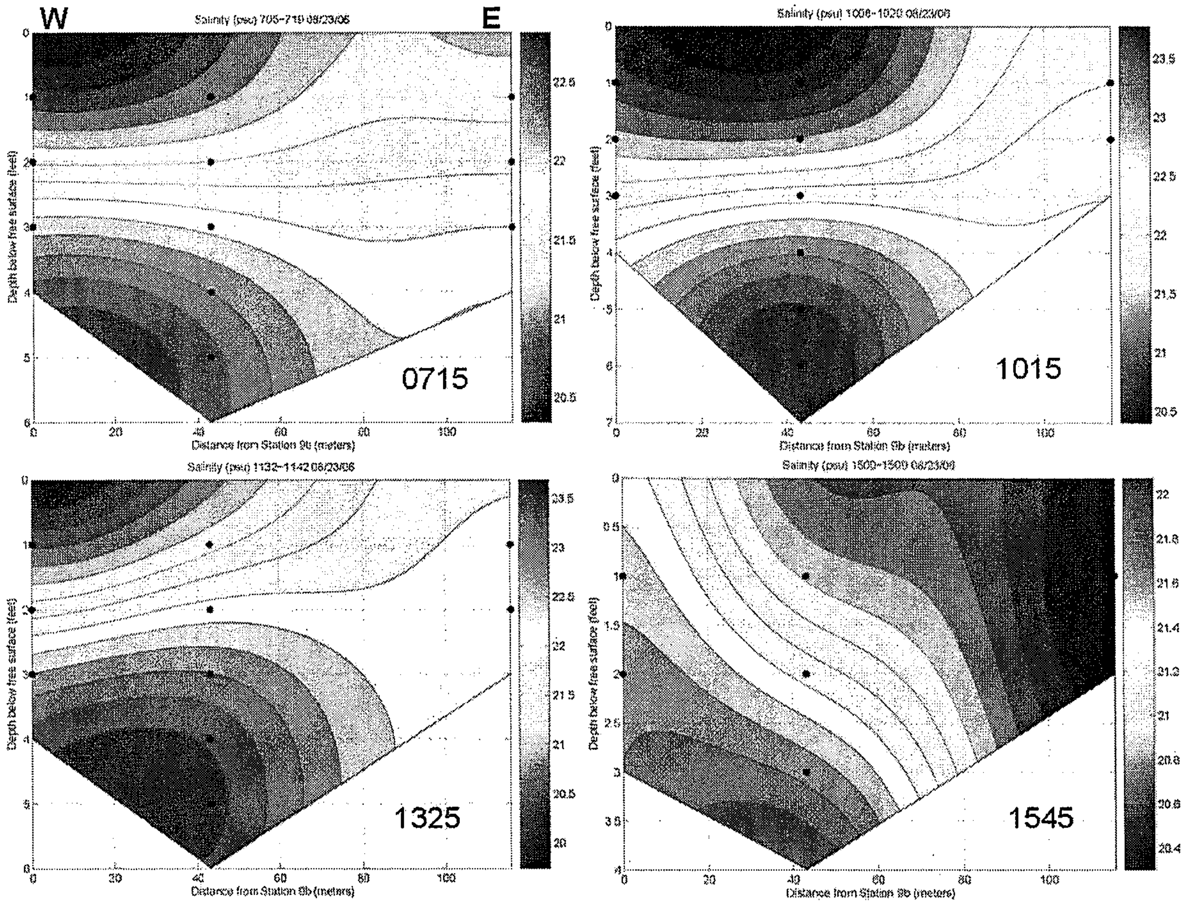

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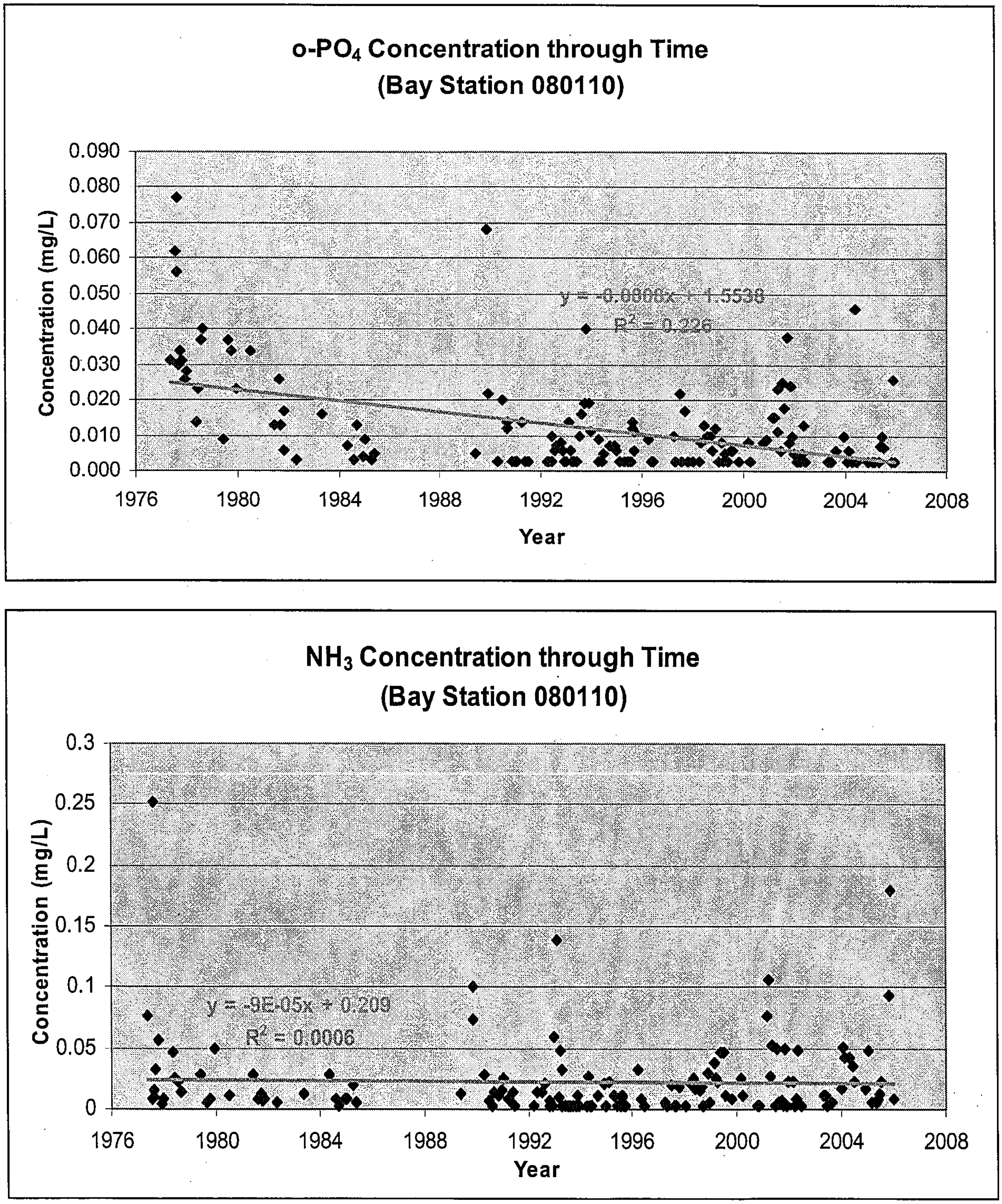

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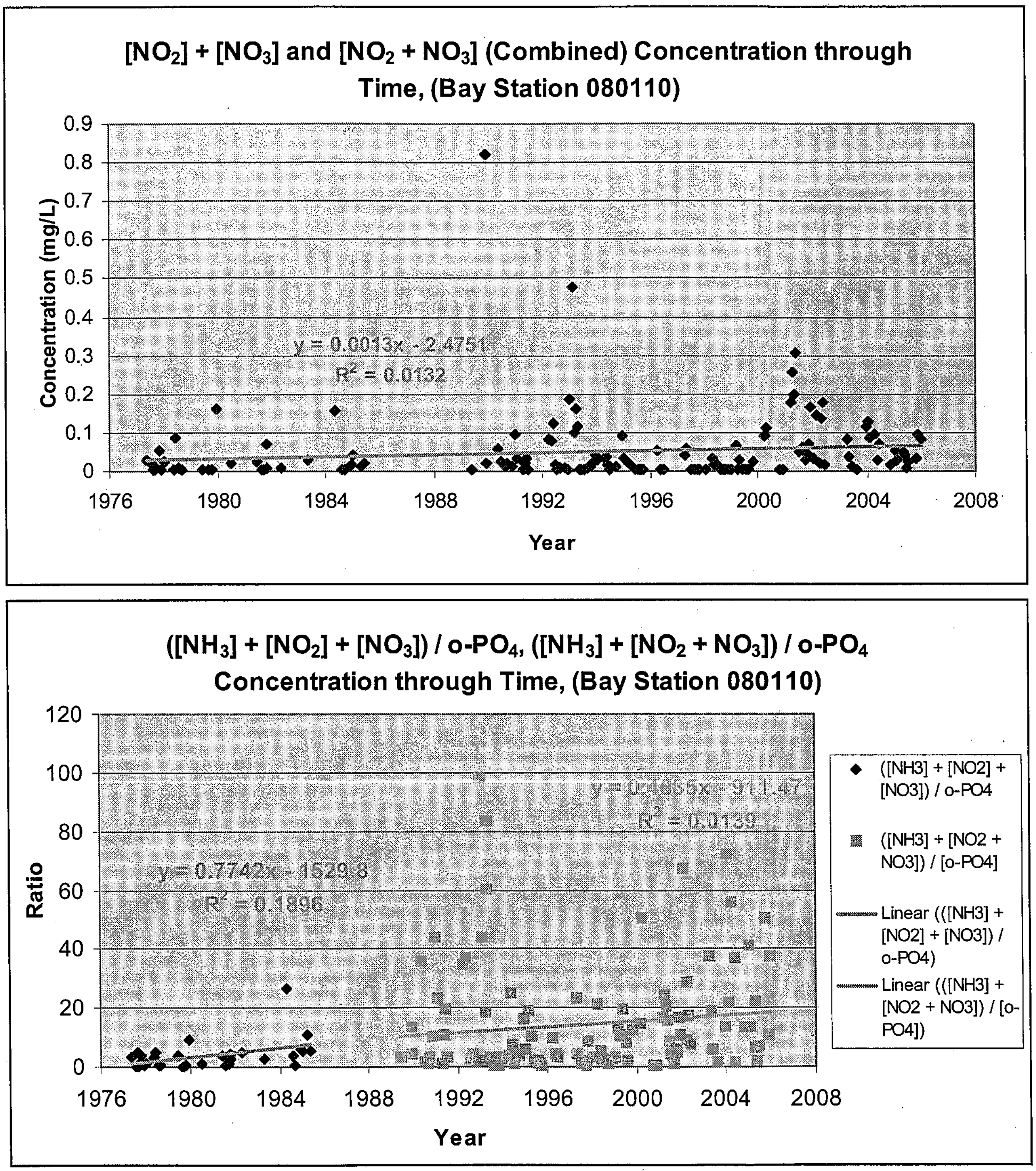

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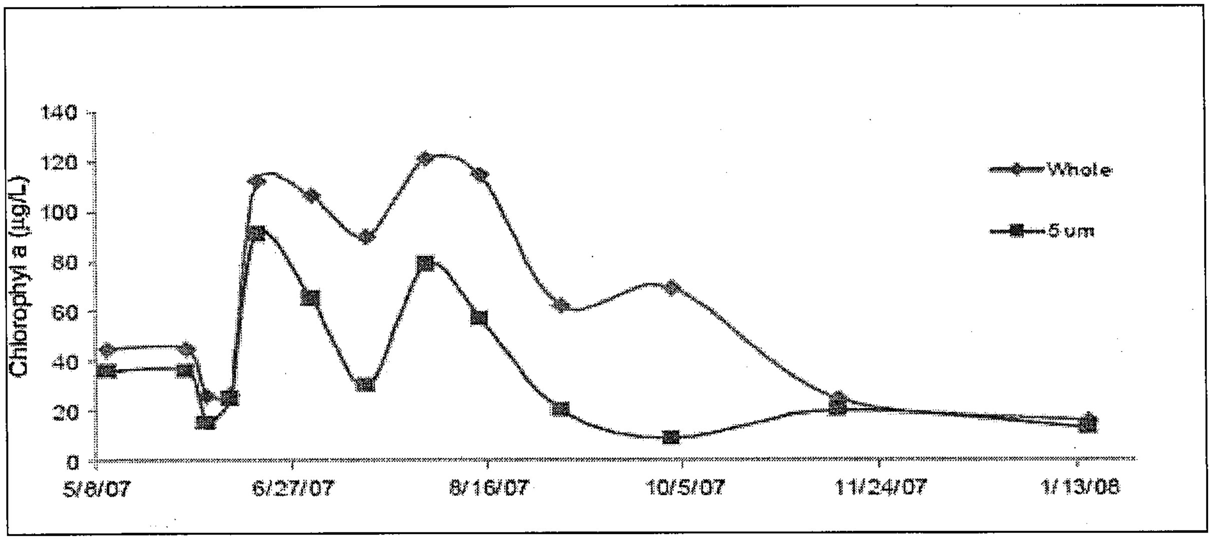


Figure 9. Chlorophyll *a* (µg/L) versus time at station 2, Brookhaven Town Pier.

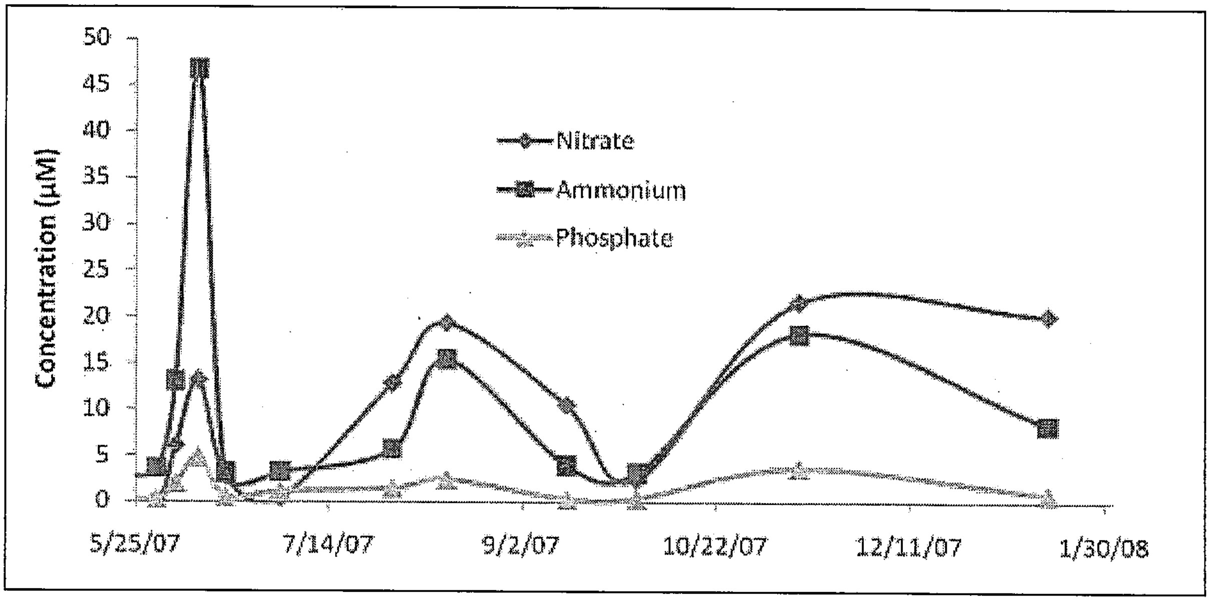
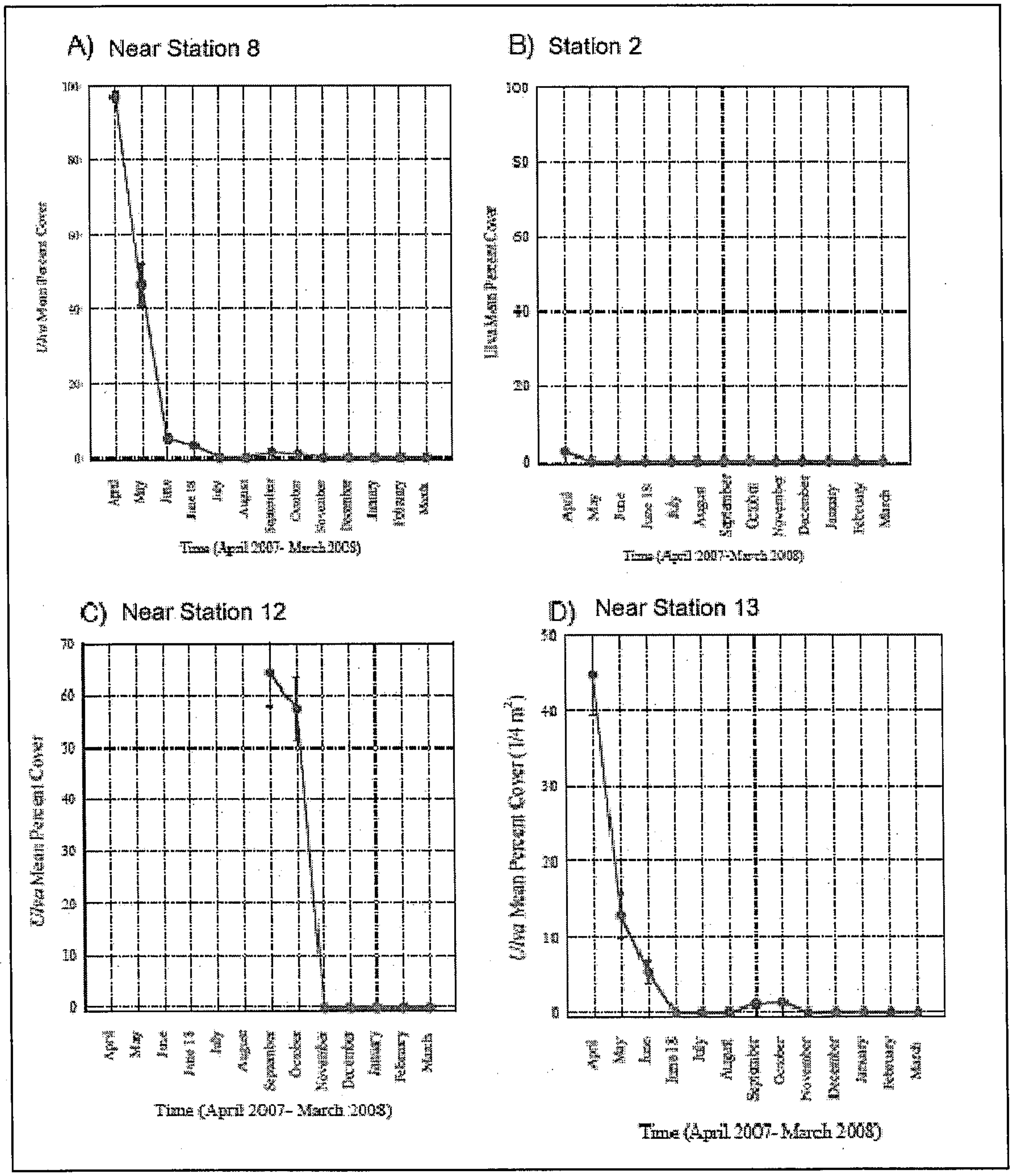


Figure 10. Nutrient concentrations (µM) versus time at station 2, Brookhaven Town Pier.

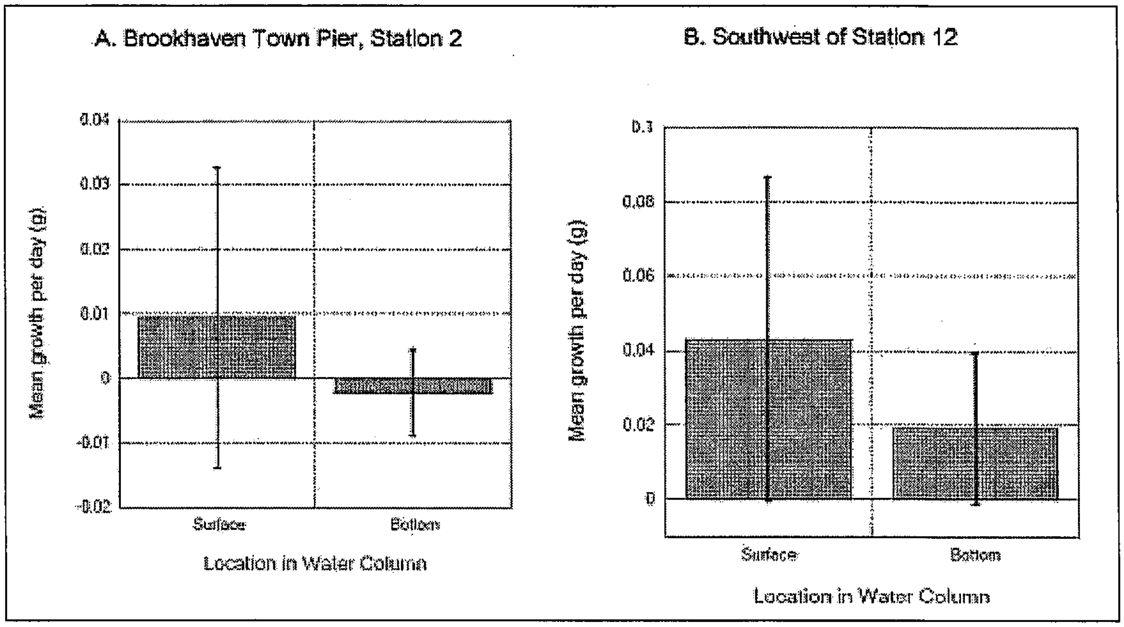

A) Near Station 8

B) Station 2

C) Near Station 12

D) Near Station 13

Figure 11. Mean *Ulva* percent cover for station 2, and near station 8, 12, and 13, at the Forge River for April 2007-March 2008.
A) Near Old Neck Marina; B) Brookhaven Town Pier; C) Southwest of Old Neck Marina; D) Mouth of Forge River


A. Brookhaven Town Pier, Station 2

B. Southwest of Station 12

Figure 12. *Ulva lactuca* growth June 25 through July 15, 2007.
B. Southwest of Old Neck Marina and Station 12.

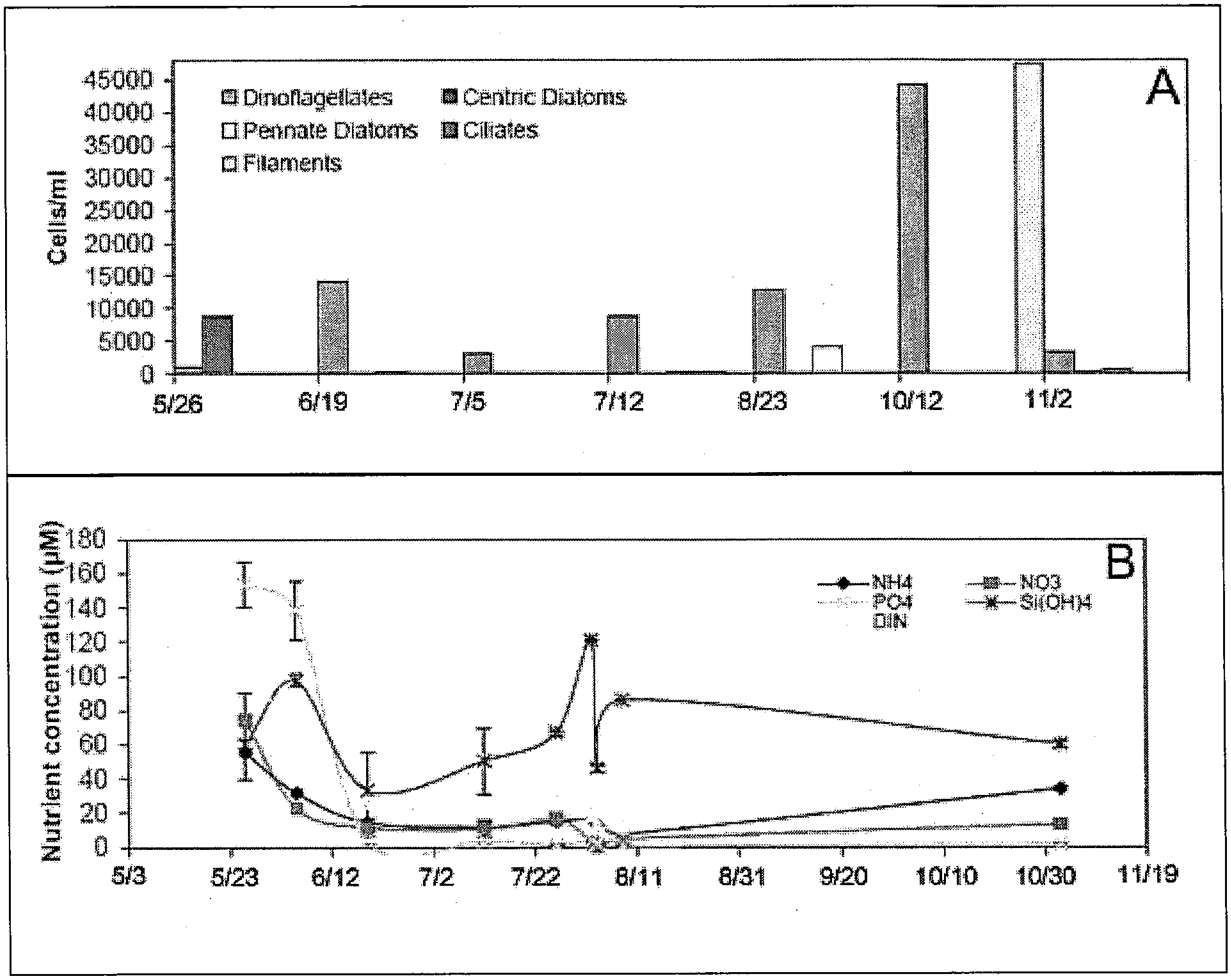


Figure 13. (A) Plankton densities (cells/mL) and (B) nutrient concentrations versus time at Brookhaven Town Pier, May through November 2006.

Marsh Type	**Hectares**	**Acres**
FM	2.29	5.65
FC	0.28	0.68
IM	7.50	18.54
HM	3.33	8.24
Total	**13.40**	**33.11**

FM – Coastal fresh marsh
FC – Formerly connected tidal wetlands
IM – Intertidal marsh
HM – High marsh or salt meadow

Table 1. Area of marsh fringing the Forge River between Montauk Highway and a cross section from Masury Point to Sands Point scaled from the New York State Department of Environmental Conservation's Tidal Wetlands Map, 1974 at a scale of 1:2400.

Year	Human population	Ducks produced	Nitrogen from human waste kg lbs	Nitrogen from duck waste kg lbs	Total nitrogen from human and duck waste kg lbs
1963	11,000	870,000	80,300 177,060	90,480 199,510	170,780 376,570
1982	43,630	455,000	318,500 702,290	47,320 104,340	365,820 806,630
2005	59,000	400,000	427,400[1] 942,420[1]	41,600 91,730	469,000 1,034,150
2009 projected	66,500	400,000	482,160[1] 1,063,160[1]	15,860[2] 34,970[2]	498,000 1,098,090

Table 2. Human population, ducks produced, and annual mass discharge of nitrogen from human waste and duck waste.

[1] assumes tertiary sewage treatment for 500 people in watershed.

[2] assumes tertiary waste treatment for 275,000 ducks.

INPUTS	**mol N/y**	**Percent of input**
Poospatuck Creek	127,000	0.7
Wills Creek	11,300	0.1
North stream	2,760	0
South stream	4,130	0
Swift Creek	728,000	3.7
Ely Creek	30,000	0.2
Old Neck Creek	323	0
East Pond	280,000	1.4
West Pond	3,060,000	15.7
Total tributaries	**4,240,000**	**21.8**
Atmospheric deposition	**501,000**	**2.6**
Storm (Surface runoff)	**424,000**	**2.2**
Groundwater	**14,300,000**	**73.5**
TOTAL INPUT	**19,500,000**	**100**
INTERNAL RECYCLING	**mol N/yr**	**Percent of input**
Benthic flux	8,760,000-17,500,000	45-90
Ulva remineralization	358,000	1.8
EXPORTS	**mol N/yr**	**Percent of export**
Burial	2,720,000	13.9
Tidal flushing	15,400,000	78

Table 3. A budget of N inputs, exports, and remineralization in the Forge River.