Integrated Reconnaissance of the Physical and Biogeochemical Characteristics of Jamaica Bay: Initial Activity Phase

A Coordinated Program of the Gateway National Recreational Area
and the Columbia Earth Institute

1.0 Executive Summary

Researchers at Columbia Earth Institute have carried out an integrated, coordinated pilot reconnaissance of the physical, chemical, geological, and biological systems within Jamaica Bay, entitled "Integrated Reconnaissance of the Physical and Biogeochemical Characteristics of Jamaica Bay". We believe that such an integrated approach is necessary to fully understand the complex inter-relationship of the wetland ecosystem. This effort was jointly funded by the US National Park Service/Gateway National Recreational Area and the Columbia Earth Institute of Columbia University.

The program focused on obtaining a synergistic view of the varied elements of Jamaica Bay by carrying out coordinated research in four areas: submarine sediment morphology, sediment and soil sampling, circulation and mixing, and chemical analysis of the Bay waters.

Results of the research can be summarized by the following key points:

Jamaica Bay is an energetic system:

- There is significant transport of coarse sediment in the channels; Grassy Bay is a sediment sink.
- The Jamaica Bay system is stratified, at least during summer; inflow to the Bay via Rockaway Inlet is likewise stratified.
- Stratification is highly time dependent; tidal influences have a profound impact on vertical structure throughout the Bay.
- Flushing times vary for different portions of the Bay; estimates using two independent methods yield a flushing time on the order of 1 week for the upper 5 meters of Grassy Bay.
- Multiple sources of freshwater contribute to the Bay—Hudson plume, sewage treatment outfalls, and surface runoff.
- Nitrogenous nutrients remain abundant throughout the summer, and we noted periods of suboxic conditions at the sediment-water interface in Grassy Bay.
- During hyper-eutrophic conditions the phytoplankton appear to be limited by the availability of carbon dioxide.

Jamaica Bay is an evolving system:

- In JoCo Marsh, the present *Spartina patens* marsh began forming 2000 years ago as a shallow pool atop sand.
- Marsh pollen and seed stratigraphy show the impact of human development in the region.
- Recent loss of salt marshes has been rapid; the high rate is difficult to explain.

This pilot reconnaissance study has raised a host of questions worthy of further investigation:

- What is the sediment/energy budget of the system? Is marsh loss associated with a net change in sediment budget within Jamaica Bay and sediment transport between the surrounding lowlands and coastal ocean?
- How do two-layer flow & vertical mixing vary throughout the Bay over tidal cycles?
- What are the seasonal variations of stratification? residence times? freshwater sources?
- How significant are storm events on sediment movement, water properties & mixing times?
- Will the observed trend toward greater Bay production over the last two decades induce more frequent and extensive sub-oxic conditions?
- Can isotopic data be useful to gauge the amount of excess nutrients in the Bay?
- Do mainland marshes share the same history as the island marshes? What is the age and development of the marsh at Old Mill Creek (site 5)?
- What accounts for the high rate of salt marsh loss?

Submitted by:

Arnold L. Gordon,
Coordinator of the Columbia Jamaica Bay Program

Robin Bell, Suzanne Carbotte and Roger Flood - *Geophysical Mapping of Submarine Environments*

Ellen Hartig, Alexander Kolker and Vivien Gornitz - *Investigations into Recent Salt Marsh Losses in Jamaica Bay*

Dorothy Peteet and Louisa Lieberman - *Paleoenvironmental History of Jamaica Bay Marshes*

Arnold Gordon, Robert Houghton and Bruce Huber - *Temperature, Salinity and Currents in Jamaica Bay; Dye Tracer Experiments in Jamaica Bay*

James Rubenstone - *Stable Isotope Evidence for Water Mass Mixing in Jamaica Bay*

Renee Takesue and Alexander van Geen - *Patterns of Nutrient Enrichment and Depletion in Jamaica Bay*

Chris Langdon - *Trophic Status of Jamaica Bay: Spatial and Temporal Patterns*

Ray Sambrotto - *Nitrogenous Nutrients and Plankton Production in Jamaica Bay*

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4.0 Acronyms Used

CSO	combined sewage outflow
CTD	Conductivity, Temperature Depth profiler
GNRA	Gateway National Recreation Area
JBWR	Jamaica Bay Wildlife Refuge
LDEO	Lamont-Doherty Earth Observatory
MEC	Metro East Coast
NPS	National Park Service
NYC	New York City
SLR	sea level rise

5.0 Introduction and Objectives

Jamaica Bay offers a unique opportunity to study a complex salt marsh environment in an urban setting. This diverse ecosystem is threatened by landfill seepage, combined sewer overflow, JFK Airport expansion pressures and illegal fishing induced by the high urban population.

To effectively manage the Jamaica Bay region, and to insure its health and survival, requires an understanding of the complex interplay of materials and energy flow within the system and its coupling to its urban surroundings. It is essential that the system be viewed in its entirety.

Researchers at Columbia Earth Institute have carried out an integrated, coordinated pilot reconnaissance of the physical, chemical, geological, and biological systems within Jamaica Bay, entitled "Integrated Reconnaissance of the Physical and Biogeochemical Characteristics of Jamaica Bay". We believe that such an integrated approach is necessary to fully understand the complex inter-relationship of the wetland ecosystem. This effort was jointly funded by the US National Park Service/Gateway National Recreational Area and the Columbia Earth Institute of Columbia University.

5.1 Objectives of the program

The overall objective was to obtain a synergistic view of varied elements of Jamaica Bay: its diverse ecosystems; the sediment geomorphology and layering; circulation and mixing of its waters; chemical, natural and anthropogenic properties of the Bay waters and sediments. A suite of measurements was carried out which enhances the monitoring program of the NPS within Jamaica Bay by providing a broader range of measurements and a high resolution snap-shot view of the spatial scales.

This objective was pursued through a series of focussed studies, whose results are given in this report:

[A] The sediment morphology of the Bay floor from sonar and sidescan:

Geophysical Mapping of Submarine Environments (Robin Bell, Suzanne Carbotte and Roger Flood)

[B] Sediment and soil sampling:

Investigations into Recent Salt Marsh Losses in Jamaica Bay (Ellen Hartig, Alexander Kolker and Vivien Gornitz)

Paleoenvironmental History of Jamaica Bay Marshes (Dorothy Peteet and Louisa Lieberman)

[C] Circulation and mixing:

Temperature, Salinity and Currents in Jamaica Bay (Arnold Gordon, Bruce Huber and Robert Houghton)

Dye Tracer Experiments in Jamaica Bay (Robert Houghton, Arnold Gordon and Bruce Huber)

Stable Isotope Evidence for Water Mass Mixing in Jamaica Bay (James Rubenstone)

[D] Nutrient and Other Chemistry of the Bay waters:

Patterns of Nutrient Enrichment and Depletion in Jamaica Bay, Summer 2000 (Renee Takesue and Alexander van Geen)

Trophic Status of Jamaica Bay: Spatial and Temporal Patterns (Chris Langdon)

Nitrogenous Nutrients and Plankton Production in Jamaica Bay (Ray Sambrotto)

6.0 Study Area

Measurements were obtained throughout Jamaica Bay. Specific sites are described in the program descriptions which follow.

7.0 Project Reports

7.1 Geophysical Mapping of Submarine Environments

Suzanne Carbotte, Robin Bell, Roger Flood

7.1.1 METHODS

In April 2000 we deployed the R/V Onrust, operated by MSRC at SUNY Stony Brook, for 2 days of high resolution geophysical mapping within Jamaica Bay. Multibeam sonar, side-scan sonar and Chirp subbottom profiler data were collected as well as 4 sediment cores for the Rubenstone/Chillrud effort. Our survey operation was conducted out of Kingsborough Community College, CUNY, located on Sheepshead Bay. The first survey day focused on the inlet to Jamaica Bay between Sheepshead Inlet and the Marine Park Bridge and only the high resolution multi-beam mapping system was deployed. During the second survey day two circumferences of the entire Bay were made targeting, where water depths permitted, the interface from the deep channel to the tidal flats. For this work we deployed the multibeam bathymetric tool, the side scan sonar system and the high resolution chirp sonar. Descriptions of each of these instruments and the data processing procedures carried out are provided in the following section.

7.1.1.1 Multibeam sonar

Multibeam data were acquired using an EM 3000 sonar, a 300 kHz system which provides co-registered depth and backscatter data for 120 beams over a swath width that is four times the water depth. Sonar beams are each nominally 1.5º wide and spaced 0.9º apart. In water depths of 10 m and at typical survey speeds of 8 kts, the sonar footprint is ~30 cm. The nominal depth resolution is 10 cm. Navigation and orientation data for the multibeam sonar are obtained using a POS/MV attitude sensor. A differential GPS system (supplemented by inertial navigation; also part of the POS/MV system) enables ship positioning to within 1 meter. During survey operations, real time differential corrections were provided by Omnistar. CTD casts were conducted to obtain sound velocity profiles which were integrated into the data acquisition to provide corrections for acoustic ray bending through the water column. Tide gauges were deployed to determine local sea level changes during the survey.

Processing of the multibeam data involved editing of navigation and ping files for erroneous values. During ping editing the sonar data from approximately 80 pings at a time were reviewed and outliers were flagged and excluded during final map generation. Depth data were then corrected for tidal fluctuations during the survey and gridded at a 2 m interval to create a digital terrain map (Figure 7.1-1). A sun-illuminated image was also created by shining a synthetic sun across the digital terrain map. The sun-illuminated image reveals small bathymetric features which are often difficult to resolve in contoured bathymetry data (Figure 7.1-2).

7.1.1.2 Side Scan Sonar

The side scan sonar system used for this program was an Edge Tech DF-1000 dual frequency sonar with a Triton Elics ISIS data acquisition topside. The system acquires data at two frequencies (100Khz and 384 kHz) and was operated with a total swath width of 400m (200m port and starboard). The Triton Elic topside unit also recorded several auxiliary data streams including the ship's compass heading provided by a KVH compass, real time navigation obtained from a Trimble AG-132 unit with differential corrections provided by Omnistar, as well as the navigation stream from the POS/MV system used with the EM3000.

The sidescan vehicle was towed from the stern port side of the RV Onrust. Tow points for the side-scan fish were surveyed in, so that layback corrections could be applied during post-processing. The layback corrections account for the offset between the GPS antenna mounted on the ship and the location of the side scan tow fish.

Following the field program the raw field data were demuxed, merged with layback corrected final navigation and digitally mosaicked using an in-house side-scan sonar processing package. Mosaicking was carried out assuming a flat bottom for positioning of side-scan pixels across each swath. Adjoining side-scan swaths were systematically seamed at their point of overlap. Mosaics of both the 100kHz and 384 kHz sidescan data are shown in Figure 4.1-3 and Figure 7.1-4. Navigation for the sidescan and Chirp subbottom data are shown in Figure 7.1-5.

7.1.1.3 Chirp

Subbottom data were acquired using the X-Star topside data acquisition unit and the SB 4-24 tow fish, both manufactured by Edge Tech. This is a Chirp or swept frequency sonar system, which emits a broadband FM source pulse with low frequencies providing depth penetration into the subbottom and higher frequencies providing high vertical resolution. The X-Star acquisition unit controls all data transmission, recording and signal processing including Analogue to Digital (A to D) conversion, compression of the FM pulse and spherical divergence correction. The recorded signal is the output of the correlation filter used for pulse compression and is stored in SEG-Y format.

Data were acquired at a transmission rate of 5-6 pings/second. Survey speeds for the combined sidescan/subbottom survey were ~5 knots. At this speed, the Chirp transmission rates provide one trace for each 0.83 m of ship motion. Pulse power was set at 50-60% of maximum available output in order to avoid ringing and generation of cross-talk interference with the side scan sonar data. The SB 4-24 tow vehicle offers the ability to transmit a variety of pulses with a frequency range from 4 to 24 kHz. For this survey, the lowest frequency sweep pulse (4 to 16 kHz) was chosen to obtain maximum possible penetration with this fish.

The Chirp vehicle was towed from the stern starboard corner using a tow line to keep the fish to the side. Tow points for the subbottom fish were surveyed in, so that layback corrections could be applied during post-processing. Real time GPS navigation was passed from the Trimble AG-132 unit directly to the X Star acquisition unit via an RS-232 serial port. Problems with the data recording system prevented acquisition of Chirp data during the portions of the survey within the western Bay (Figure 7.1-5, JWN001 and JWN002).

Processing of the Chirp sub-bottom data was carried out using a combination of in-house code for reading the raw data files and the Seismic Unix package maintained by the Colorado School of Mines. Processing steps include demux of the field data and merging with final layback corrected navigation. Chirp technology incorporates signal processing techniques into the control units that automatically deconvolves the wide-band signal pulse during data acquisition. Hence deconvolution for pulse compression is not needed as a post-processing step. Spherical divergence corrections are also applied within the data acquisition unit.

Images of the Chirp data are shown in Fig 4. For each line the total data range is scaled to 256 grey levels, and the grey level legend is displayed on the right hand side of each image. Data are plotted in seconds two-way travel time (twtt). Assuming a sound velocity of 1500 m/s, 0.005 sec twtt is equivalent to 3.75 m.

7.1.2 Results

The geophysical survey has enabled us to define the major sedimentologic terrains within Jamaica Bay. These include a high energy regime close to the Marine Park Bridge where large-scale sediment waves are observed, the narrow, possibly erosional marginal channels - also characterized by intermittent sediment waves, and the deep depositional site in Grassy Bay. We had hoped to image the linkage between the marsh and the channels but were unable to detect the marsh structure in the sidescan data. This may be the result of the early spring time of our deployment.

Very minimal penetration into the sediments below the seafloor was observed with the Chirp subbottom data. This lack of penetration is likely due to the presence of methane gas bubbles within the shallow sedimentary section. In many places the gas appears to reach the seafloor giving rise to a strong seafloor reflection. Elsewhere the gas appears to lie a few 10s of cm below the seafloor (e.g. within Grassy Bay, Figure 7.1-6 and Figure 7.1-7). These differences may reflect regional variations in biological activity dependent on sedimentologic terrain. These differences could also reflect changes in the solubility of methane as a function of bottom temperature and salinity.

The 384 kHz side-scan sonar mosaic (Figure 4.1-3) reveals low backscatter, presumably fine-grained sediments covers the seafloor throughout most of the region surveyed. In contrast, the 100 kHz data (Figure 7.1-4) reveals high backscatter associated with the floor of the main channels through the Bay. Due to the lower frequency, the 100 kHz sonar can penetrate up to a few 10’s of cm into the shallow subsurface. The high backscatter observed with these data could reflect shallowly buried coarse grain material or methane gas presence. Grassy Bay is a low backscatter region in both the 100 and 384 kHz data consistent with the presence of a thicker section of fine-grained sediment than elsewhere within the Bay.

Outstanding questions are the relative transport of sediment from the marshes into the main channel and the portion of the sediment budget being deposited in Grassy Bay. Other questions include what is the origin of the regional variations in methane gas content suggested by the geophysical data.

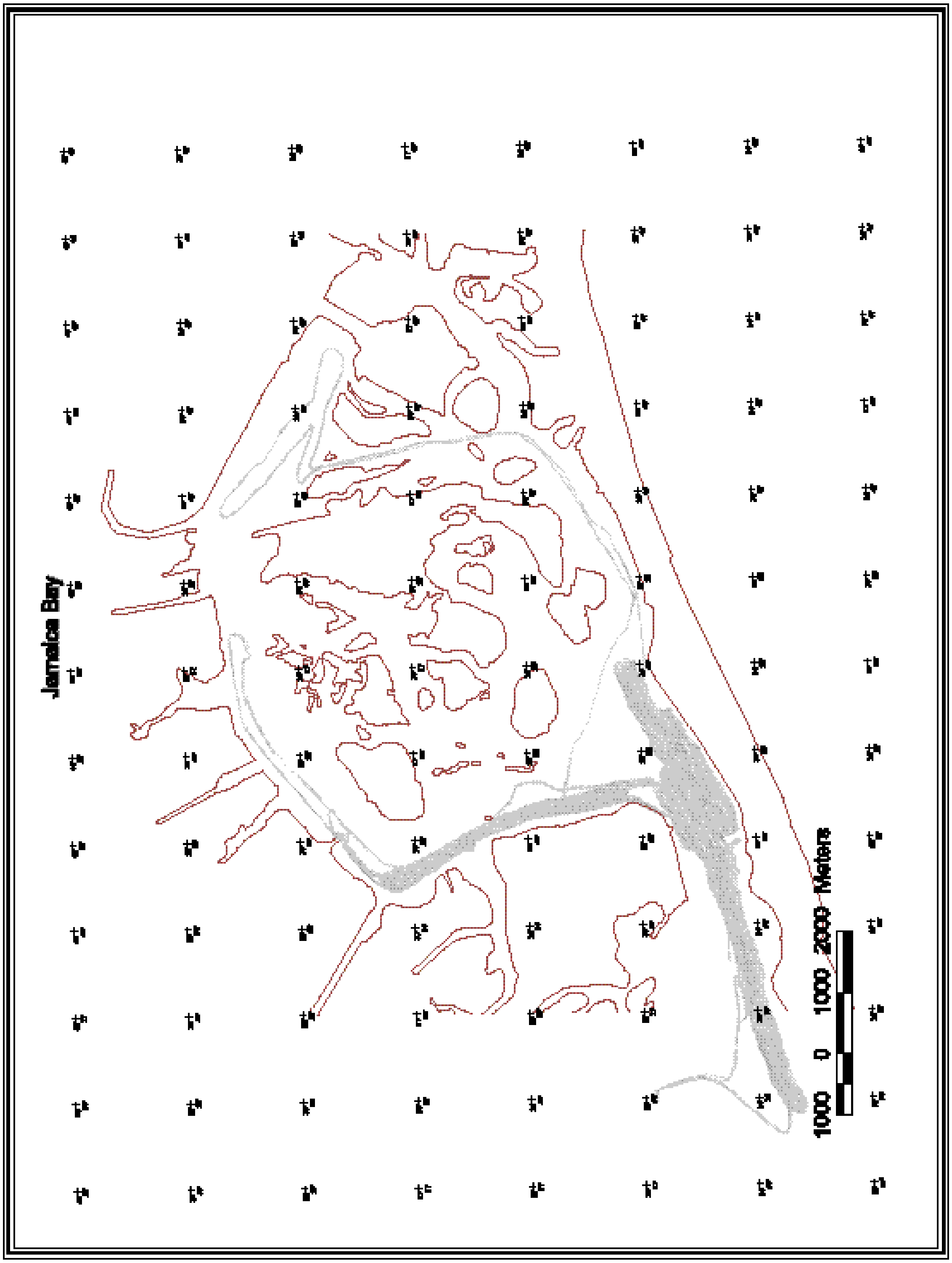

Figure 7.1-1

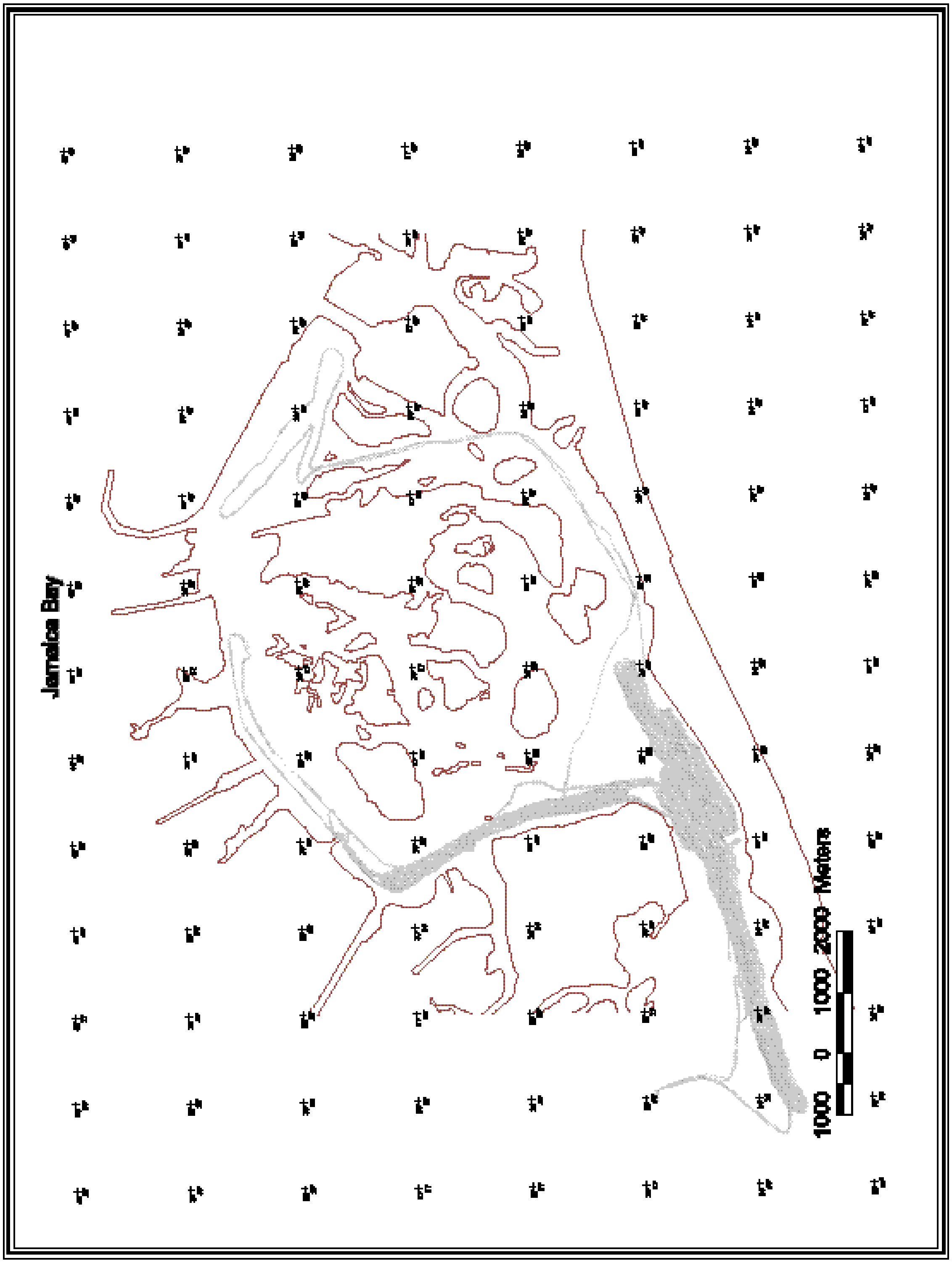

Figure 7.1-2

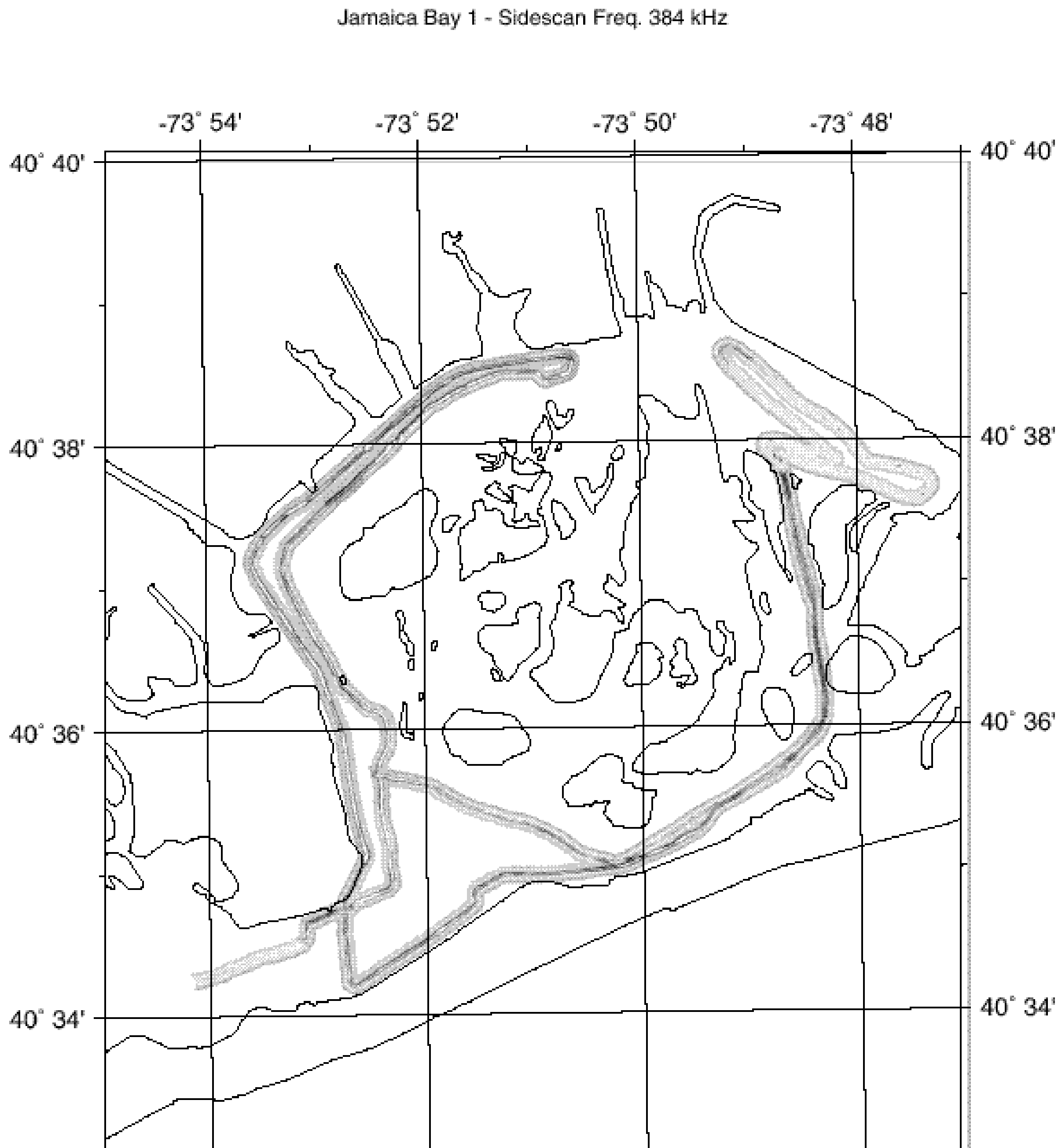
Jamaica Bay 1 - Sidescan Freq. 384 kHz
-73° 54'
-73° 52'
-73° 50'
-73° 48'
40° 40'
40° 38'
40° 36'
40° 34'

Figure 7.1-3

Jamaica Bay 1 - Sidescan Freq. 100 kHz

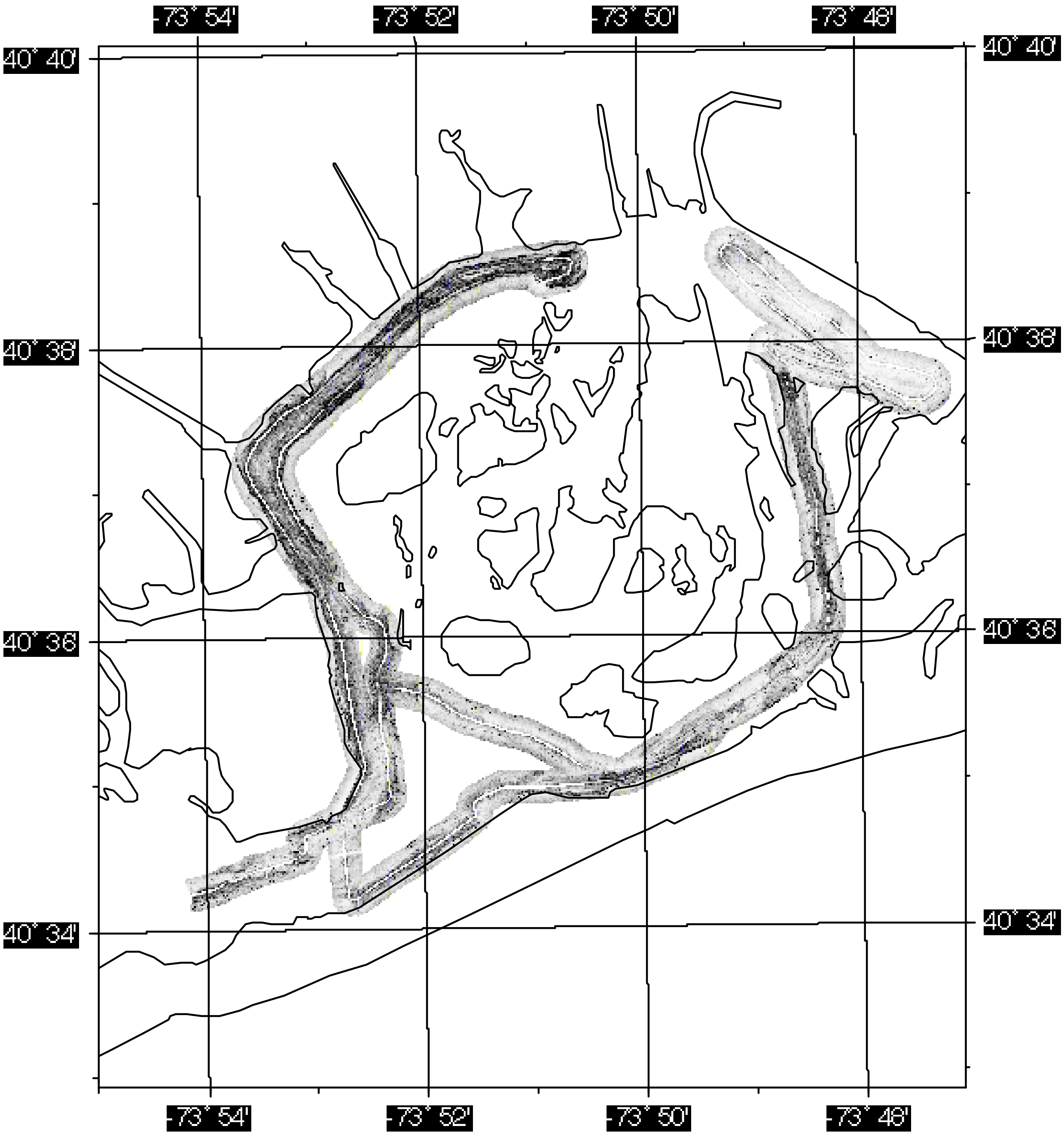

Figure 7.1-4

CGIF - Jamaica Bay Survey Navigation

Side-scan and Chirp sonar lines

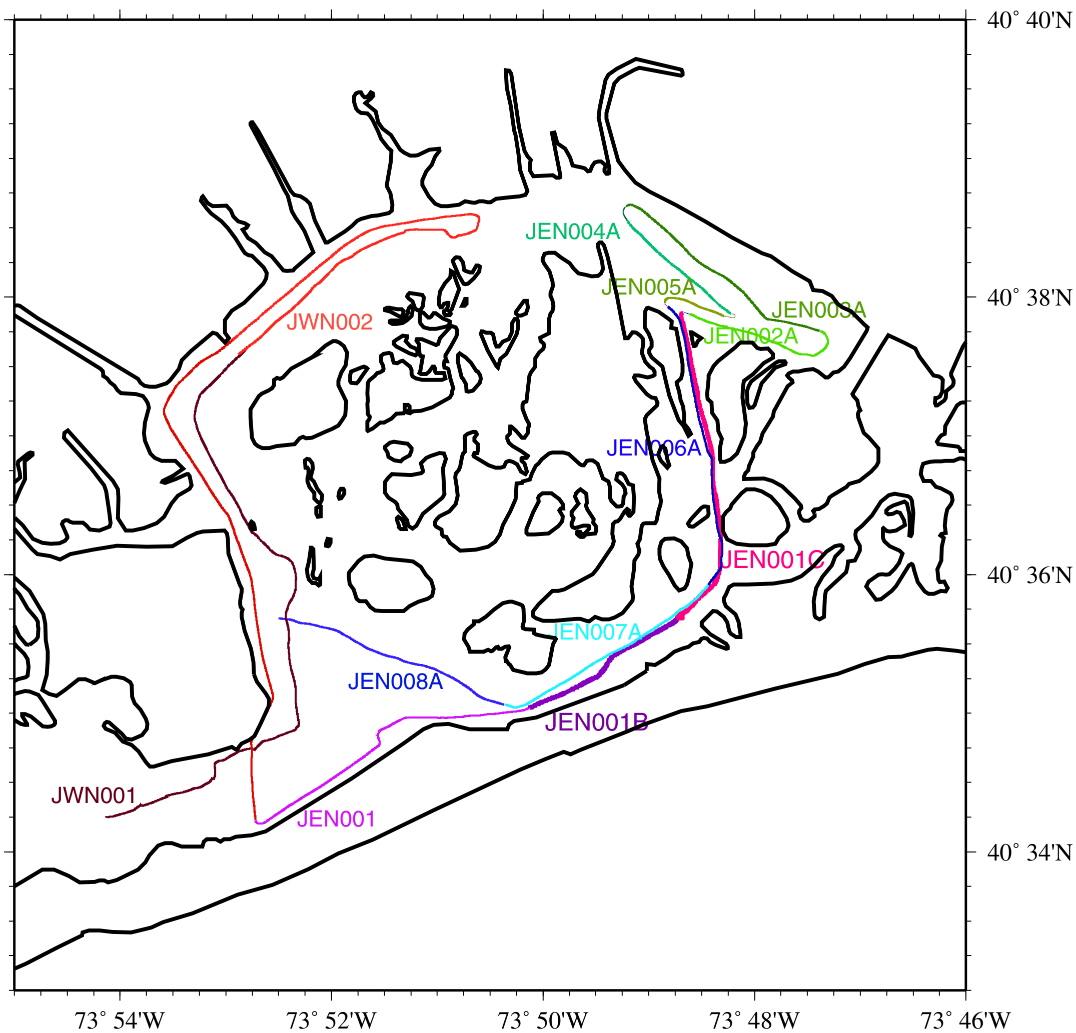

Figure 7.1-5

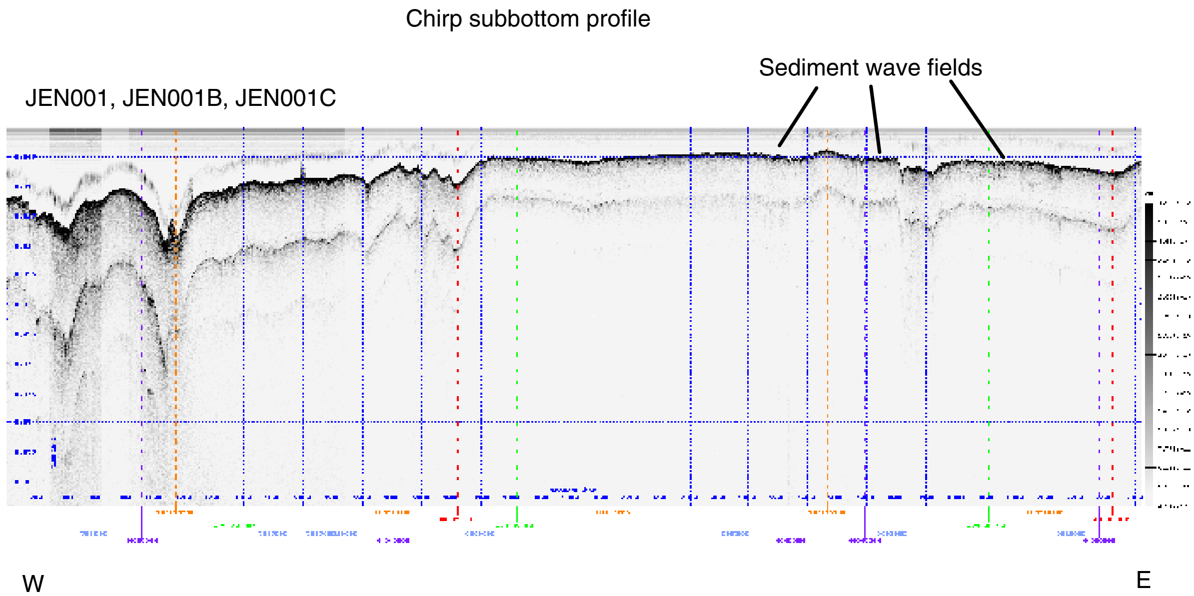

Figure 7.1-6

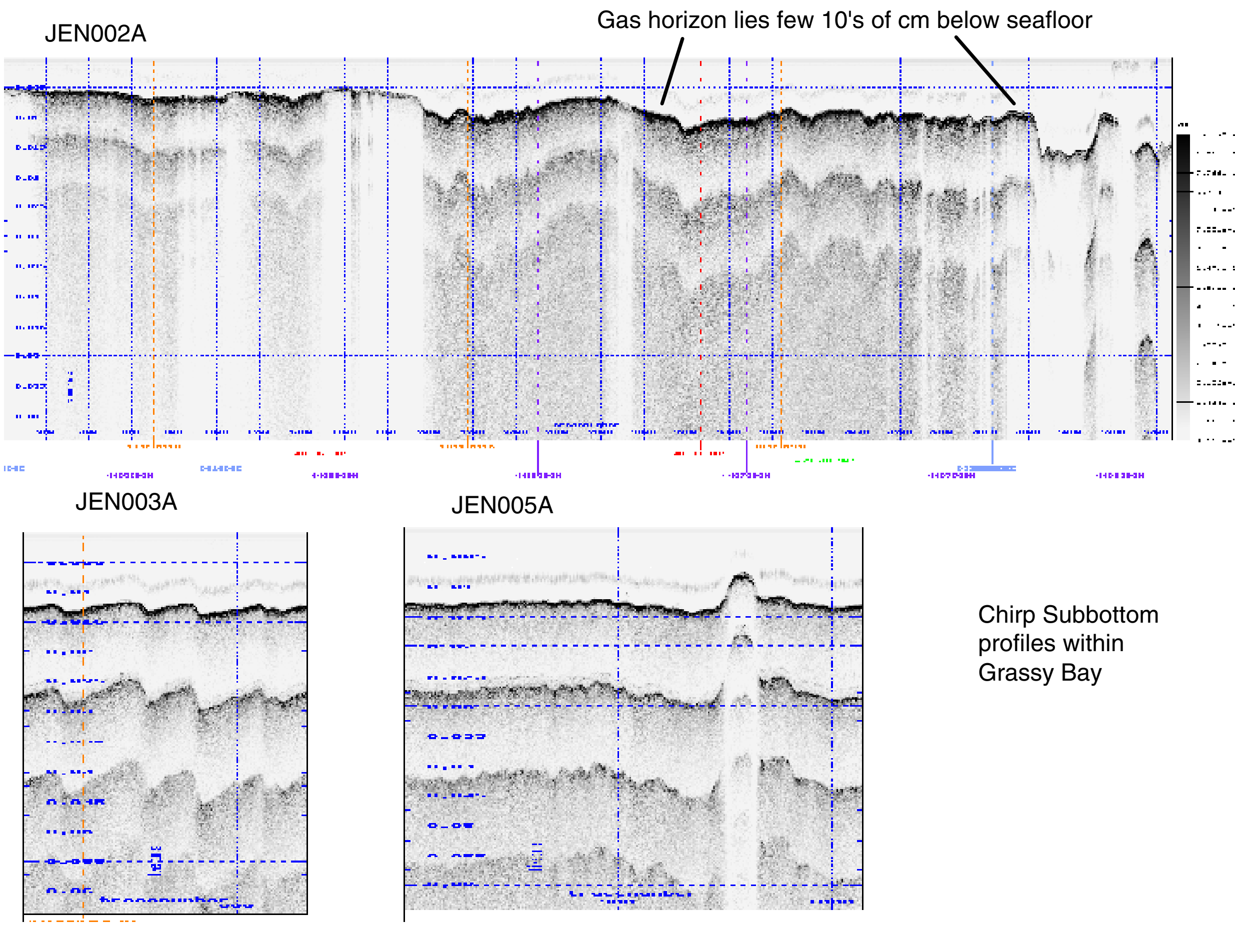

Figure 7.1-7

7.2 Investigations into Recent Salt Marsh Losses in Jamaica Bay, New York

Ellen Kracauer Hartig, Alexander Kolker, and Vivien Gornitz

7.2.1 INTRODUCTION AND OBJECTIVES

Coastal salt marshes of the northeastern United States, including those of New York City, Long Island and northern New Jersey, formed within the last 2000 to 6000 years, as the post-glacial rise in sea level slowed. Within the last 100-150 years, however, the marsh-building process has reversed in a number of locations, possibly linked in part to the recent acceleration of sea-level rise, relative to trends of the last few thousand years (Varekamp and Thomas, 1998; Kearney, 1996). This recent tidal wetland loss through erosion, submergence and related processes is well-documented in Louisiana, Chesapeake Bay, and elsewhere (e.g., Boesch et al., 1994; DeLaune et al. 1994, and Wray et al., 1995). However the phenomenon has not been reported from the New York metropolitan region. Field studies conducted as part of the JBERRT project during the summer of 2000 reinforces our initial findings in the Metro East Coast regional report prepared for the U.S. National Assessment of Climate Variability and Change (U.S. Global Change Research Program) that sections of Jamaica Bay salt marshes in New York City are currently in an erosive state (Hartig, 2001; Hartig, et al., 2001).

In this study, as part of the Goddard Institute for Space Studies/Columbia University contribution to the JBERRT project, selected salt marsh islands were examined on the ground in order to field check previous remote sensing observations, and to obtain additional data on *Spartina alterniflora* productivity. These data were collected in order to compare with regional marsh vegetation growth, to measure interannual variability, and to establish a preliminary baseline against which future changes can be assessed. Field work included measurements of *Spartina alterniflora* above-ground biomass, a survey of marsh vegetation distribution along transects, placement of feldspar horizon markers, and documentation of biogeomorphological indicators of salt marsh degradation.

7.2.2 STUDY AREA

7.2.2.1 Overview

This report concentrates on island salt water marshes of Jamaica Bay, one of the largest remaining coastal ecosystems in the New York City area. Jamaica Bay encompasses the Jamaica Bay Wildlife Refuge (JBWR), established in 1948 by New York City Department of Parks and Recreation and included by legislation since 1972 in the Jamaica Bay Unit of Gateway National Recreation Area (GNRA), National Park Service (Tanacredi and Badger, 1995). Located near John F. Kennedy International Airport, the geographical coordinates of Jamaica Bay are 41° N, 74°W (Figure 7.2-1).

The Jamaica Bay Unit of Gateway includes uplands, wetlands, and waters south of the Belt Parkway in Brooklyn and Queens. Although most of the island marshes lie within the Jamaica Bay Wildlife Refuge, inside GNRA, some fringing bay marshes are located outside the boundaries of the refuge and the GNRA. Jamaica Bay is a lagoon with diverse habitats including open water (littoral zone), coastal shoals, bars, mudflats, intertidal low to high marshes, and upland areas.

JBWR provides prime habitat for migratory birds. The intertidal mudflats are principal feeding grounds for migratory shorebirds such as Black Skimmers, plovers, and knots (Tanacredi and Badger, 1995). The Bay is also a major wintering ground for Brant, Mallards, American Black Duck, Canvasback Duck, and other waterfowl. Other wildlife, such as reptiles, amphibians, and small mammals can be found at JBWR (Tanacredi and Badger, 1995).

Much of the original tidal wetlands of Jamaica Bay have disappeared due to human activities for infrastructure development. Jamaica Bay in 1900 encompassed 24,000 acres (9717 hectares) of waters, marsh islands, as well as an extensive network of shoreline marshes extending beyond today's Belt Parkway (Englebright, 1975). Marshes covered an estimated 16,170 acres (6549 hectares). Bay waters covered 7,830 acres (3170 hectares) much of it shallow channels averaging 3 feet (1 meter) in depth. By 1970, total acreage with remaining shoreline marshes covered 13,000 acres (5263 hectares) of which 4000 acres (1619 hectares) were marshland. Waters covered approximately 9000 acres (3642 hectares), much of it dredged for filling (e.g. Grassy Bay) or for navigation maintained to depths greater than 30 feet (10 meters).

7.2.2.2 Salt Marsh Ecology

Salt marsh vegetation forms distinct zones in response to a combination of biophysical factors. At lower elevations, species composition is largely governed by physical and chemical forces. At higher elevations, interspecific competition determines the plant community (Bertness 1991a). Along the Atlantic Coast, Spartina alterniflora (salt marsh cordgrass), the dominant plant species of the low marsh intertidal zone, provides food and shelter for wildlife and physical structure (for peat accretion) to the marsh. It is replaced by the high marsh species *Spartina patens* (salt hay) at mean high water (MHW, Bertness 1991b). Flooding is less frequent in the high marsh portion of the intertidal zone. *S. patens* is rarely found in the low marsh, where oxygen flow to its rhizomes becomes limited by frequent inundation. On the other hand, *S. alterniflora* is restricted from the high marsh by *S. patens* competition. *Salicornia virginica* (glasswort) can also be present in the low marsh (Bertness and Ellison, 1987). Floristically, the high marsh is much more diverse than the low marsh, although all are halophytes–plants adapted to saline environments. The drier high marsh zone contains species such as *Juncus gerardii* and *Distichlis spicata*. *Iva frutescens* (high tide bush) and *Phragmites australis* (common reed) are found in the highest regions of the marsh.

Frequency of tidal flooding is the dominant factor in determining species location (Bertness 1991b). The high correlation between inundation time and zonation permits changes in salt-marsh plant community zonation to be used as sensitive indicators of sea-level rise. Wetland plant communities respond to sea-level rise by shifting from high to low marsh, to coastal shoals, and finally to mudflats, and also by migrating inland. On an unobstructed coastal plain, upland habitat will be ultimately converted to salt marsh. In the New York metropolitan area, extensive development limits opportunities for salt marsh migration onto adjacent upland or freshwater zones (e.g., Blanchard and Burg, 1992).

7.2.2.3 Sea-Level Rise and Accretion Rates

Rates of local sea-level rise (SLR) in the region range from 2.2 mm/yr in Port Jefferson, Long Island to 3.94 mm/yr at Sandy Hook, New Jersey. The rate of SLR at Jamaica Bay is around 2.76 mm/yr, based on tide gauge data (1856-1999) from Battery Park in Manhattan (Figure 7.2-2). Regional SLR trends exceed the mean 20th century global SLR of ~1.5 mm/yr, due in part to the recent global warming, and, in part, to local subsidence resulting from crustal readjustments to the removal of ice following the last glaciation (Gornitz, 2001; Gornitz et al., 2001).

Coastal salt marsh accretion in this area is generally fast enough to keep up with present rates of sea level rise. As can be seen from Table 7.2-1, which lists published data for the intertidal zone in Connecticut and New York, accretion rates generally equal or exceed local sea level rise trends. The only measurement of marsh accretion at Jamaica Bay was 8 mm/yr for the low marsh; that for high marsh was 5 mm/yr (Zeppie, 1977). These values lie near the upper range of the regional values (Table 7.2-1). However, the sampling covered a period when accretion may have been anomalously high due to dredging and filling activity associated with construction of John F. Kennedy International Airport, landfills (e.g., Penn and Fountain Avenue, and Edgemere landfills), residential development, and uncontrolled outfall from sewage treatment plants and combined sewage overflow (CSO). New, stricter environmental controls (in addition to landfill closure and completion of major construction activities around the Bay) have likely reduced the inorganic (sediment) accretion rate. The actual accretion rate at Jamaica Bay has not been measured since Zeppie's 1977 study, and new determinations are urgently needed.

7.2.3 Previous work

To determine changes in land extent of Jamaica Bay marshes, three sets of historic aerial photographs covering a central section of Jamaica Bay from 1959 to 1998, were analyzed, using stereopairs with greater than 60% overlap. Measurements of marsh area on aerial photographs for three island salt marshes (Yellow Bar Hassock, Black Wall Marsh, and Big Egg Marsh), revealed discernable land losses on island peripheries and expansion of tidal creeks. Table 7.2-2 summarizes acreage and percent land remaining since 1959 (Hartig et al., 2001). These three island marshes showed an average 12% reduction in landmass between 1959 and (Table 7.2-2; Figure 7.2-3). Inasmuch as the 1959 data were collected during high tide, when most of the marsh was inundated, the percent reductions calculated from later photographs, taken at mid to low tide, are considered to be conservative estimates.

In related work, the New York State Department of Environmental Conservation (NYSDEC) used Geographic Information System (GIS) analysis of digitized navigation charts and topographic maps dating from 1900, as part of their tidal wetlands mapping inventory for regulatory purposes. Based on more extensive aerial photo-coverage, they find even more significant marsh losses and accelerating erosion trends (Fred Mushacke, Dave Fallon, NYSDEC, priv. comm; see also:www.dec.state.ny.us/website/dfwmr/marine/twloss.html.).

7.2.4 Methodologies

7.2.4.1 Selection of Study Sites

Of more than 15 named island salt marshes in Jamaica Bay, three relatively undisturbed marshes were selected for detailed field observations and vegetation sampling. The three study sites include: 1) Big Egg Marsh, 2) Rulers Bar Hassock, bordering on upland zones associated with the Broad Channel Island community the Jamaica Bay Wildlife Refuge, and 3) Yellow Bar Hassock. Adjacent to Rulers Bar Hassock Marsh are the uplands dominated by shrubs and thickets including extensive stands of Northern Bayberry (*Myrica pennsylvanica*) within the Jamaica Bay Wildlife Refuge. Yellow Bar Hassock and Big Egg are peat-rich marshes with extensive meandering tidal channels, whereas Rulers Bar Hassock is a sandy shore tidal marsh with limited channel inlets. All three marshes are dominated by *Spartina alterniflora*. The mean tidal range (difference between mean high and mean low water) for Jamaica Bay is typically 1.6 meters (5 feet).

7.2.4.2 Geomorphological Investi gations.

Noting that significant changes in marsh size had occurred between 1959 and 1998 from a survey of aerial photographs, field work during the summer of 2000 focused on documenting additional ground evidence of salt marsh transformations. This latest effort expanded upon the work of the previous summer, which had begun a photographic survey and classification of erosive landforms.

Feldspar markers. In addition, an attempt was made to measure marsh accretion, using the well-established methodology of feldspar horizon marker plots (Richard, 1978). A layer of white feldspar grains (particle size in fine sand range, 0.625 to 1mm), several millimeters thick was spread over each test plot, and the locations marked with flags.

7.2.4.3 Vegetation Sampling

Biomass data collection. Measurements of *Spartina alterniflora* standing crop biomass were taken from the middle to close to the end of the growing season, July through October, 2000. Such baseline data collection was conducted in order to: 1) determine above-ground *Spartina alterniflora* biomass in Jamaica Bay and to compare with data from the previous year, 2) compare with regional values, and 3) evaluate the effects (if any) of recent erosion and inundation on salt marsh grass growth. Below-ground production also contributes to vertical accretion and soil organic matter (Reed, 1995); however, this study was limited to above-ground production--a frequently used measure of vegetation status (e.g., Bertness, 1991; Nixon and Oviatt, 1973).

At the three marsh sites in Jamaica Bay (Big Egg Marsh, Rulers Bar Hassock, and Yellow Bar Hassock), quadrats were placed 50 feet apart along linear transects for sampling (Figure 7.2-1, see insets A, B, and C). On Yellow Bar Hassock, transects were conducted with the aid of a compass from the point where the field team disembarked from the National Park Service boat, on the south side of the island, heading northwest, facing the World Trade Towers in Manhattan, up to a large tidal channel, which prevented further sampling (see Fig. 1, inset A). Shoreline transects at Rulers Bar Hassock were traversed, eastward starting at the most seaward vegetated zone accessible by foot, to the wetland-upland boundary (Figure 7.2-1). At Big Egg Marsh (Figure 7.2-1), the traverse went from upland boundary toward a tidal channel in a northwesterly direction. Within preselected swaths based on accessibility, transect starting locations were randomly selected. Transects were conducted at least twice within the growing season at each marsh. In the summer of 2000, the three sites were sampled over two periods, the first between July and August, and then again in October. For each transect, species composition was recorded in $1m^2$ quadrats; *Spartina alterniflora* was clip-harvested from a $0.25\ m^2$ corner of each plot. Collected material was dried to constant weight at 105^o C (e.g., Nixon and Oviatt, 1973).

Species composition. Species composition at Big Egg Marsh, Rulers Bar Hassock and Yellow Bar Hassock was recorded from $1m^2$ plots during transect sampling procedures. Additional species observed during a field survey at Jo Co Marsh were also recorded. Species were listed on field data sheets (summarized in Table 7.2-3). They are listed according to the frequency with a species occurs in a wetland versus upland setting.

7.2.5 Results

7.2.5.1 Geomorphologic Changes

Geomorphological characteristics of marsh loss observed at Jamaica Bay include island perimeter erosion, tidal channel enlargement, and expansion of tidal pools. Erosion occurs by slumping and undercutting of peat along both island edges and interior tidal channel banks (Figure 7.2-4 , Figure 7.2-5 and Figure 7.2-6). The retreat of low marsh along a tidal channel at Yellow Bar Hassock, for example, has exposed underlying peat layers (Figure 7.2-7), showing an early stage in the conversion of marsh to mudflat.

Enlargement and coalescence of both interior tidal pools and pools near the edges of channels, as well as development of mudflats at the expense of low marsh, may be early signs of marsh inundation (Figure 7.2-8, Figure 7.2-9). Closely associated with the expansion of these pools is the decline in low marsh vegetation (e.g., compare Figure 7.2-10 showing a stand of healthy *Spartina alterniflora* on Rulers Bar Hassock with Figure 7.2-8 and Figure 7.2-9, from Big Egg Marsh). At Big Egg Marsh, the *Spartina alterniflora* vegetation cover has decreased, *Ulva* is taking over, and the peaty substrate is decomposing to a more soupy consistency. Unusually dense concentrations of ribbed mussels (*Geukensia demissus*) are frequently found attached to the bases of *Spartina alterniflora* stems (Figure 7.2-11). These may accumulate into mounds, where *S. alterniflora* has died off. These observed biogeomorphological features, taken together, indicate an increased level of waterlogging leading to the disintegration of the underlying peat root network and the undermining of marsh stability. They represent elements of the process of low marsh transformation to mudflats. The geomorphological changes can be summarized as follows:

A. Erosion.

1. Slumping, undercutting, and inward retreat of peat from bank ledges along island peripheries and tidal creeks (Figure 7.2-4, Figure 7.2-5, Figure 7.2-6 and Figure 7.2-7).
2. Widening of tidal channels (Figure 7.2-4).

B. Inundation.

1. Progressive enlargement of internal tidal pools (Figure 7.2-9).
2. Residual mounds from die-off of mussel beds (*Geukensia demissus)*, some still attached to vegetated remnants of *Spartina alterniflora* (Figure 7.2-11)
3. Widespread deterioration of marsh vegetation, leading to generalized scour and surface lowering (Figure 7.2-8 and Figure 7.2-9).
4. Excessive peat porosity, with “soupy” consistency.
5. Conversion of low salt marsh to more aquatic wetland types (e.g., mudflats, bars, and coastal shoals) (Figure 7.2-8).

Feldspar markers. Attempts to measure local accretion rates by the feldspar horizon marker method proved unsuccessful. While the feldspar horizon marker plot locations had been clearly identified during the 2000 field season, no marker plots were recovered. At four separate plots on Big Egg Island, the marker flags still remained, but the feldspar had been washed away, although there had been no major storms that summer. Possible reasons for the disappearance of the feldspar layer include: 1) bioturbation, 2) mixing with darker organic sediments, and 3) resuspension by tides. While bioturbation cannot be ruled out, no significant burrowing activity was noted on the test plots. If feldspar had become admixed with organic, peaty sediments (i.e., through accretion), then traces of the feldspar should still remain. Its white color and granular texture would stand in sharp contrast to the dark, nearly black color of the peat. The feldspar was probably resuspended by tidal currents or waves. The loss of feldspar is consistent with the other evidence for active erosional processes in this area.

7.2.6 Vegetation Studies

The dominant species in low marsh areas, including all of Yellow Bar Hassock, was *Spartina alterniflora.* High marsh vegetation assemblages occupied restricted areas or were missing altogether from the communities sampled, particularly on Yellow Bar Hassock. Isolated patches of *Spartina patens* and *Salicornia virginica* were growing at a few higher elevation sites, while *Ulva lactuca* was found in the mudflats and in scattered, bare areas in between *S. alterniflora* (Table 7.2-3, Figure 7.2-8 and Figure 7.2-9). Any former extensive stands of high marsh on Yellow Bar Hassock, originally present, as inferred from textural analysis of some marsh vegetation on the 1959 photographs, were no longer present during the 1999-2000 field seasons. All rooted low marsh species were either obligate or facultative wetland species (Table 7.2-3). Additional facultative species were found in the high marsh zones of Big Egg Marsh and Rulers Bar Hassock, including *Iva frutescens, Myrica pensylvanica,* and *Phragmites australis*. However, due to logistical constraints, field work in Big Egg Marsh was limited to the drier, more interior marshes, since the large channels were not passable by foot during low tide.

Mean biomass in the three selected marshes in 2000 ranged from 833 gm/m^2 to 1394 gm/m^2 with an overall mean of 1106+/-200 gm/m^2 by dry weight (Table 7.2-4, Table 7.2-5 and Table 7.2-6). These values are similar to those measured in the 1999 field season (695-1442 gm/m^2, with a mean of 992+/-234 gm/m^2 by dry weight (compare Table 7.2-4 and Table 7.2-5). These productivity levels are typical of healthy marshes in this region (Table 7.2-6), in spite of evidence of erosion and inundation, mentioned above. The quadrats included the nearest vegetated edge to barren microgeomorphological features such as pools and creeks that crossed the transect. Needless to say, the presence of such barren features diminished the total standing crop density. Averaging low biomass patches near pools along with stands of healthy, dense-vegetation within a quadrat may have reduced the biomass average somewhat, but gave a more overall representative value for growing marsh vegetation. Our transects intersected marsh areas that are still relatively intact, and may therefore underestimate the status of marsh areas that are in a more advanced stage of transformation to mudflats. The relatively high variability in mean biomass measured from marsh to marsh in a given year is likely caused by the unevenness in vegetation density (Table 7.2-4, Table 7.2-5 and Table 7.2-6). On the other hand, the differences in mean biomass at any given marsh over the two-year sampling period are generally lower than the spatial variability among the marshes.

7.2.7 DISCUSSION

Above-ground plant biomass of *Spartina alterniflora* at Jamaica Bay is comparable to regional values (compare Table 7.2-4 and Table 7.2-7), in spite of the biogeomorphological features indicative of erosion and inundation, described above. Paradoxically, increased above-ground productivity may accompany increased marsh flooding or immersion (Reed, 1995). Some studies suggest that growth may be stimulated even as tidal heights increase. The observed declines in salt marsh grass density, associated with enlargement of tidal pools and mudflat encroachment onto low marsh in some areas, point to increased soil waterlogging (e.g., Figure 7.2-8 and Figure 7.2-9). These features may represent the first effects of rising sea level.

The survival and growth of a salt marsh is a delicate equilibrium between changes in sea level, compaction and subsidence, upward accumulation of peat, inorganic sediment deposition, and erosion by waves. In most places, marshes are keeping pace with current rates of relative sea level rise. However, where rates of relative sea level rise exceed rates of mineral sedimentation and vertical peat accretion, as is already happening in Louisiana and in the Chesapeake Bay (Kearney, 1996; Boesch et al., 1994; DeLaune et al. 1994, and Wray et al., 1995), the marsh may begin to drown in place. In Connecticut, Warring and Niering (1993) found high marsh converting to low marsh, not inconsistent with the recent period of sea level rise (see also Varekamp and Thomas, 1998). Similarly, Fallon and Mushacke (1996) have recorded examples of high to low marsh conversion and the disappearance of several tidal wetland islands at various sites on the South Shore of Long Island.

Although *S. alterniflora* is well-adapted to the intertidal zone, longer periods of flooding during the tidal cycle leads to gradual build-up of hydrogen sulfide (H_2S) in marine sediments, which is generally toxic. While *S. alterniflora* normally oxygenates its roots to prevent excessive H_2S build-up, as sea level rises, intertidal pools on the seaward side of the marsh become progressively submerged over a greater portion of the tidal cycle. As these pools become anoxic, due to H_2S accumulation, *S. alterniflora* ultimately dies. Plant death may lead to collapse of the peat layers, due to deterioration of the dense root network which holds the peat together. The patchy decreases in *S. alterniflora* density, excessive peat porosity (sediment has "soupy" consistency), apparent expansion of tidal pools and surface lowering in places, and invasion of *Ulva* show marshes in the process of changing to mudflats.

In Jamaica Bay, the historic rise in sea level may be an important causative factor leading to the observed signs of marsh erosion and inundation. However, it does not completely explain the recent <u>acceleration</u> of marsh loss (Fallon and Mushacke, 2001, priv. comm.), inasmuch as the rate of SLR in this area has remained relatively constant throughout the 20th century (Figure 7.2-2; Gornitz et al., 2001). Storm activity along the Atlantic Coast, although displaying considerable interdecadal variability, has not shown an upward trend during this period (Zhang et al., 2000; Dolan and Davis, 1994.). Some erosion due to storm waves may be increasing with rising sea levels, as the return period of high wave events decreases (for an analogous example regarding coastal flooding, see Gornitz, 2001).

Nevertheless, other processes must contribute to current marsh losses, although their exact causes still remain uncertain. Among these are reduced sediment loads available for vertical marsh accretion, cessation of landfill activities, pollutants, waterfowl herbivory, and boat traffic.

Most of the tidal wetlands losses between 1900 and 1974 were probably linked directly and indirectly to anthropogenic activities (e.g., filling and dredging, development in Brooklyn and

Queens in and around the Bay, including Broad Channel Island and JFK International Airport, and rail and highway construction) (Englebright, 1975). Earlier dredging of navigation channels may have initiated an erosive cycle, which may have reached a critical threshold in recent years. Furthermore, the historic westward growth of the Rockaway spit and its subsequent stabilization may have prevented offshore sediments from entering the Bay and the widespread twentieth century urbanization of Long Island may have eliminated upland sediment sources, as well as overwash deposits from storms. This sediment deficit may have increased in recent decades, as dredge and fill operations were curtailed, after establishment of Gateway. A critical level of mineral sediment input is necessary for salt marsh survival; if soil bulk density is too low, plant growth cannot be maintained (DeLaune, et al., 1994). Waves triggered by barge and boat traffic along navigation channels could also be responsible for some marsh erosion.

The salt marshes of Jamaica Bay may be more vulnerable to the impacts of future sea level rise than neighboring marshes on Long Island. Jamaica Bay marshes are either on islands or constrained on their landward sides by existing urban development, which limits their potential to migrate inland with rising sea levels.

The areal expanse of low marsh *Spartina alterniflora* is already in decline. Interior tidal pools appear to be enlarging. As these pools expand and coalesce over time, total biomass production by the marsh will be eventually reduced. If significant portions of *Spartina alterniflora* salt marshes were to disappear, this would adversely impact the entire Jamaica Bay ecosystem as it relates to wildlife habitat, marsh productivity, biodiversity, and flood control.

Further research is urgently needed to determine the extent to which past channelization and changes in sedimentation rates have affected Jamaica Bay marsh growth. A key variable is the accretion rate, which determines the ability of the salt marsh to keep pace with accelerated sea level rise. The accretion rate depends on the sediment load, the biological input, and the hydraulic movement of particles. Other than a single study by Zeppie (1977), these factors are largely unknown in Jamaica Bay. A priority research objective will be to measure the accretion rate at a number of sites within Jamaica Bay. Possible techniques include feldspar marker horizons, radioisotope geochronology, and Sediment Erosion Tables (SETs). Installation of the latter devices has been proposed within Jamaica Bay, in collaboration with the USGS. These platforms have been used internationally and are effective at separating the components of surface accretion and shallow subsidence in marshes. Other methods of measuring accretion rates involve isotope geochronology (i.e., ^{210}Pb, ^{137}Cs, and ^{7}Be) of sediment cores. Additional monitoring of marsh loss by remote sensing as well as field mapping of erosional processes should be undertaken. Data collection should continue at various locations over a multi-year period, to assess changes in salt marsh biomass productivity and to determine the range of spatial and interannual variability.

7.2.8 Conclusions

Field work undertaken during the JBERRT program provides further evidence that a number of the island salt marshes of Jamaica Bay may be eroding and drowning. The ground truth data substantiate remote sensing observations of significant marsh losses, particularly during recent decades (Hartig, 2001; Hartig et al., 2001; NYSDEC, 2001). Processes of erosion include slumping and inward retreat of peat along banks of creeks and island edges, and widening and extension of tidal channels. Lack of accretion is indicated by the disappearance of feldspar markers over the field work season. Inundation is manifested though expansion and coalescence of interior tidal pools, patchy decreases in salt marsh grass density, collapse of the peat root network, leading to excess peat porosity, general surface lowering and conversion of low marsh, in the affected areas, into mudflats. The processes of marsh loss through erosion and inundation seen at Jamaica Bay are very similar to those reported for Louisiana and Chesapeake Bay (DeLaune et al., 1994, Kearney, 1996; Boesch et al., 1994; Wray et al., 1995), although the causative mechanisms may differ somewhat from one locality to the other. While regional sea level rise may be an important underlying cause, other local processes may be even more significant. Several possible factors, potentially interacting synergistically, have been proposed, among which the general sediment deficit may be the most critical. Other potential factors include the erosive effects of previous dredging for navigation channels and wave action due to boat traffic, as well as excessive waterfowl grazing. Vegetation productivity of low marsh (standing crop biomass) ranged from 800 to 1400 g/m^2 in 2000 and 700-1440 g/m^2(dry weight) in 1999. These values compare favorably with other healthy marshes in the region, in spite of the biogeomorphological deterioration, detailed above.

Regardless of the ultimate causes of marsh losses, their diminution is occurring rapidly and may even be accelerating (NYSDEC, 2001). At current rates of reduction, most of the island *Spartina alterniflora* wetlands could be lost within the next few decades, even without any further increases in mean sea level. Further studies, including measurement of accretion rates, are needed immediately to establish the processes responsible for the decline of Jamaica Bay wetlands, before appropriate remedial action can be undertaken.

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7.2.10 TABLES

Table 7.2-1 Surface accretion rates measured in the metropolitan New York region as compared with the mean rate of sea level rise.

State	Salt Marsh Zone	Accretion Rate (mm/yr)	Time (years)	Method	SLR (mm/yr)
CT	low	8.0-10.0	10	Particle layer	2.1
CT	high	2.0-6.6	10	Particle layer	2.1-2.9
CT	high	1.8-2.0	58	^{210}Pb	2.1
	low	3.3	58	^{210}Pb	2.1
NY	low	4.7-6.3	103	^{210}Pb	2.2
NY	low	4.0	88	^{210}Pb	2.2
NY	high	5.0	100	^{210}Pb	2.8
	low	8.0	100	^{210}Pb	2.8
NY	low	2.5	171	Historic record	2.2
NY	low	2.0-4.2	1	Particle layer	2.2

Sources: see Hartig et al. 2001 for complete citations.

Table 7.2-2Changes in area at three selected island salt marshes, Jamaica Bay Wildlife Refuge, Gateway National Recreation Area, New York.

	1959	1976		1998		
Marsh Name/ (Salt Marsh Zone)	**Acres (Ha)**	**Acres (Ha)**	**% Loss Since 1959**	**Acres (Ha)**	**% Loss Since 1976**	**% Loss Since 1959**
Yellow Bar Hassock (Low)	189 (76.5)	173 (70)	8	165 (66.8)	5	13
Black Wall Marsh (Low)	44 (17.8)	43 (17.4)	2	41 (16.6)	5	7
Big Egg Marsh (Low)	75 (30.4)	76 (30.8)	-1	64 (25.9)	16	15
Total area	**308 (125)**	**292 (118)**	**5%**	**270 (109)**	**8%**	**12%**

Note: Acres are listed first, then hectares (ha) in parentheses.

Table 7.2-3 Plant species observed in 1.0m^2 plots along transects from three island salt marshes, Jamaica Bay.

Scientific name	Common name	Regional Ind. Status	Marsh
Spartina alterniflora	Smooth cordgrass	OBL	Big Egg, Rulers Bar Hassock, Yellow Bar Hassock
Spartina patens	Salt hay grass	FACW+	Big Egg, Yellow Bar Hassock
Spartina cynosuroides	Big cordgrass	OBL	Big Egg
Phragmites australis	Common reed	FACW	Big Egg, Rulers Bar Hassock
Salicornia virginica	Glasswort, samphire	OBL	Big Egg, Yellow Bar Hassock
Iva frutescens	Marsh elder, Big-leaf sumpweed	FACW+	Big Egg, Rulers Bar Hassock
Myrica pensylvanica	Northern bayberry	FAC	Big Egg
Toxicodendron radicans	Poison ivy		Big Egg
Fucus sp.	Brown seaweed, Rockweed	NL	Yellow Bar Hassock
Ulva sp.	Sea lettuce	NL	Yellow Bar Hassock, Rulers Bar Hassock

Notes:

1. OBL = Obligate wetland species–occurrence more than 99% of the time is in wetland habitats.
2. FAC, FAC+ = Facultative wetland species–occurrence more than 66-99% of the time is in wetland habitats.
3. NL = Not Listed–aquatic algae are not included in the National List for wetland species.

Table 7.2-4 Mean biomass of *Spartina alterniflora*, 1999 field season.

Location	Sampling Period	Mean Biomass gms x 1.0m^{-2}	Mean Biomass gms x 1.0m^{-2}
Big Egg Marsh	July	1065	
	August/Sept	768	
	October	1053	962
Rulers Bar Hassock	July	1442	
	August/Sept	1156	
	October	1012	1203
Yellow Bar Hassock	July	695	
	August/Sept	998	
	October	744	812
Total		**992.5 ± 234**	**992**

Table 7.2-5 Mean biomass of *Spartina alterniflora*, 2000 field season.

Location	Sampling Period	Mean Biomass gms x 1.0m^{-2}	Mean Biomass gms x 1.0m^{-2}
Big Egg Marsh	July	833	
	October	1001	917
Rulers Bar Hassock	August	1262	
	October	1394	1328
Yellow Bar Hassock	August	1020	1073
	October	1125	
Total		**1106 ± 200**	1106

Table 7.2-6 Summary of 1999 and 2000 measurements of mean biomass of *Spartina alterniflora,* Jamaica Bay.

Location	Year	Mean Biomass (gm x m^2)	N
Big Egg Marsh	1999	962	18
	2000	917	12
Rulers Bar Hassock	1999	1203	8
	2000	1328	8
Yellow Bar Hassock	1999	812	13
	2000	1073	11
Mean Biomass		**1049 ± 191**	**70**

Table 7.2-7 Mean biomass of *Spartina alterniflora* at regional salt marsh ecosystems.

Marsh Location	Biomass (gm x m^{-2})
Virginia	1290
Maryland	1100
Delaware	560
New Jersey	1600
Long Island	827
Rhode Island	840

(Source: Nixon & Oviatt, 1973)

7.2.11 FIGURES

Figure 7.2-1 Index map of the Jamaica Bay Unit, Gateway National Recreation Area. Insets show (A) Yellow Bar Hassock, (B) Rulers Bar Hassock, and (C) Big Egg Marsh. (Sources: Hagstrom Map of the Borough of Queens, City of New York, Hagstrom Map Company, Inc. and USGS Far Rockaway and Jamaica, N.Y. Quadrangles, 7.5 minute topographic series).

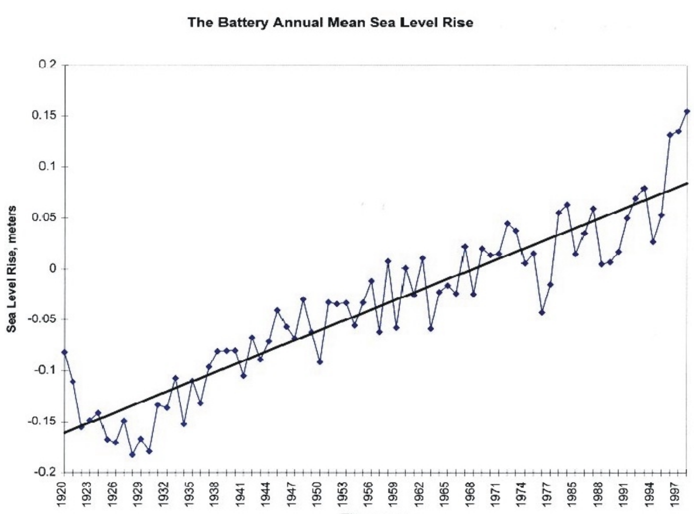

Figure 7.2-2 Historic sea level rise, the Battery, New York City.

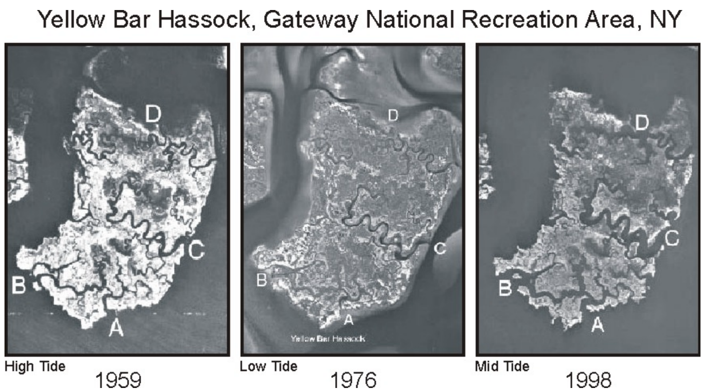

Figure 7.2-3 Aerial photographs of Yellow Bar Hassock showing marsh loss over a 39-year period. (A) April 7, 1959, high tide; (B) March 29, 1976, low tide; and (C) March 13, 1998, mid-tide.

Figure 7.2-4 Slumped peat block adjacent to intact marsh along tidal creek, Yellow Bar Hassock, at low tide.

Figure 7.2-5 The same as Figure 7.2-4, at mid-tide.

Figure 7.2-6 Incised edge of low marsh adjacent to slumped block, Yellow Bar Hassock, mid-tide view.

Figure 7.2-7 Erosion of low marsh along tidal channel, Yellow Bar Hassock, exposing underlying peat layers. This illustrates a transitional stage in the transformation of low marsh to mudflats.

Figure 7.2-8 View of Big Egg Marsh near low tide, looking southwest toward the Marine Parkway Bridge. Note extent of exposed mudflats and sparse growth of salt marsh grass.

Figure 7.2-9 View of Big Egg Marsh at low tide, looking southeast toward Rockaway Beach. Note mudflats covered with *Ulva* and sparsity of salt marsh grass

Figure 7.2-10 View of Rulers Bar Hassock, looking west, showing dense, healthy *Spartina alterniflora* growth. Note contrast in vegetation density between this and Figure 7.2-8 and Figure 7.2-9.

Figure 7.2-11. Dense accumulations of *Geukensia demissus on Spartina alterniflora* at low tide, Beach Channel Island, near North Channel Bridge.

7.3 Paleoenvironmental History of Jamaica Bay Marshes, New York

Dorothy Peteet and Louisa Lieberman

7.3.1 INTRODUCTION

Jamaica Bay Wildlife Refuge, a U.S. National Park, is internationally and nationally renowned as a prime birding location for thousands of migratory birds. Recent erosion of the salt marshes threatens this important urban habitat. The reasons for this loss are poorly understood. Our study of the stratigraphy within one of the marshes is an initial step towards understanding rates of sea level rise, local vegetational changes, climatic changes, fire history, carbon accumulation rates, and anthropogenic changes in the marshes. It also provides a coastal salt marsh stratigraphy to compare with our nearby Hudson River marsh paleoecology.

7.3.2 METHODS

7.3.2.1 Field Work

Depth of marsh sediment was probed throughout Jamaica Bay islands including Jo Co Marsh, Silver Hole Marsh, Big Egg Marsh, Little Egg Marsh, Yellow Bar Hassock, and Stony Creek Marsh. All of the probes indicate marsh peat atop sand. The depth of the marsh peat ranges from 0.3 to 2.0 meters. Several cores were retrieved for pollen, seed, foraminifera, and charcoal analysis.

JoCo Marsh (JABERRT Site 11),lies at the eastern end of the bay near the John F. Kennedy Airport (see Figure 7.3-1). A 2.86-m sediment core was taken from JoCo Marsh in Jamaica Bay in July of 2000, using both the Hiller corer and a Livingston Piston corer. The top 2 meters were sub-sampled on site every 5 cm, while the third drive was extruded as a core section.

7.3.2.2 Sampling

The core was sampled at 2-cm cm intervals for macrofossils and at 10 cm intervals for pollen and spores. Each sample from the bottom two meters contained an approximate volume of 15 - 20 cc. The top meter retrieved by the Hiller corer captured less sediment, and was more water-saturated.

7.3.2.3 Macrofossils

All the samples containing clay were soaked for a few hours in 10% KOH to loosen the sediment. They were then washed with tap water through 500 micron and 250 micron mesh screens. Macrofossils were picked from the water using a 40X dissecting microscope. We scanned the samples at 25 to 30X for the small fraction to ensure that even the small foraminifera were found. The large fraction samples (greater than 500 microns) were examined for charcoal, plant macrofossils and large foraminifera. Two samples of the small fraction (between 250 and 500 microns) were examined for microfauna, primarily including foraminifera. The very bottom of the core (Drive 3: 84-86 cm) contained a large amount of sediment. 10% of the fraction was examined, which equals about 2.5 ml of sediment. The second sample taken from drive 2: 56-58 cm only contained 5 ml of sediment. The entire fraction was examined for foraminifera.

Seeds were identified using the reference collection at Lamont Doherty Earth Observatory. Plates and descriptions from seed and plant identification guides were also useful. Foraminifera were identified using the plates from modern foraminiferal keys. A large shell found in drive 3: 70-72 cm was removed for O-18 analysis.

7.3.2.4 AMS C-14 Dating:

Samples were selected from macrofossil identification and sent to first Zurich, Switzerland, and then Woods Hole, Massachusetts for AMS C-14 dating.

7.3.2.5 Pollen and Spore Analysis

Samples were processed for pollen and spores using standard acetolysis procedures. Residues were mounted in silicone oil and counted at 400x with a Leitz microscope. Exotic *Lycopodium* marker tablets were added to determine pollen concentration. A minimum of 100 pollen grains have been counted to date, but a total of 300 will be the final tally for each sample.

7.3.3 Results

7.3.3.1 Lithology and chronology

The composition of the core changes early in the marsh development. The core is very sandy at the bottom. A basal date on wood in the sand is 2065 ±110 yr BP. Clay increases around 2.5 meters depth, and from 246 cm to 200 the core appears higher again in sand. Clay reappears at 2 m up to 1.9 m where the core gradually increases in peat content. The upper 1.9 m are consist mainly of sandy, clayey peat.

7.3.3.2 Macrofossil Results (Figure 7.3-2):

Zone 1: 286-200 cm depth

There appears to be a major change in the marsh around 2 m. depth. Sedge does not appear in the core above this boundary. The only *Scirpus* and *Typha* seeds in the core were found in this lowermost section at 2.86 m and 2.76 m respectively. The two unknown seeds are also found in the lower part of the core. Charcoal predominately occurs in this section, with a brief reoccurrence up-core around .5 m. All the fish scales were found in the deepest meter as well. Wood appears in two distinct sections of the core. The largest quantities were found in the deepest sample of the core (2.86 m). Smaller amounts were found sporadically up the core until 2.35 m. The bottom of the core is noted by a dominance in *Elphidium* species of foraminifera. A few *Trochammina* species, and the only *Rotamorphina* species found in the core, are present in this section.

Zone 2: 200-0 cm depth

Grass and stems only occur above the 2m boundary as mentioned previously. Wood was found again at .8 m, where it occasionally appears in the samples up to 10 cm depth. The wood does not seem to be linked to any other plant in the area. It is the only plant macrofossil (besides charcoal) which appears in both the top meter and the bottom meter. Charcoal recurs briefly about .5 m. *Salicornia* occurs in the top meter at .8 m. Most of the seeds were found even further up-core in the upper 30 cm. At 2 m, in accord with the lithological change, the foraminifera change to include mainly *Trochammina* species and other undifferentiated agglutinates. The top of the core has a large percentage of *Trochammina*, but the predominate genera appears to be *Mailman* or *Quinqueloculia*.

7.3.3.3 AMS C-14 Results

Dating of the Jamaica Bay macrofossils is still in progress. Early results show the base of the core to be 2065 ±110 C-14 yr BP. (result from Zurich, Switzerland), but this date is on wood in the sand. Dates upcore (from Woods Hole, Mass.) are incomplete at present.

7.3.3.4 Pollen and Spore Results

Three major pollen zones have been identified with preliminary counts of 100 pollen grains/sample. The earliest pollen zone (190-115 cm) is dominated by *Quercus* and *Pinus*, and *Gramineae* pollen is lowest in this zone. *Ambrosia* values are very low. The overlying zone (110-40 cm) shows increases in *Ambrosia*, and decreases in *Quercus* and *Pinus*. The topmost zone (30-0 cm) records declines in *Ambrosia* and increases in *Gramineae*.

7.3.4 Conclusions

Sandy, shallow pools characterized the present-day JoCo marsh environment about 2000 years ago. Foraminferal species such as *Elphidium* were dominant. Preservation of killifish scales indicate that this area was probably a low-energy environment, similar to shallow pools where killifish enter Jamaica Bay today. Regional vegetation shows a dominance of *Pinus* (pine) forest compared with *Quercus* (oak) today. Sometime after 2000 years ago, marshes began growing on the sand and keeping up with sea level rise. Charcoal abundance dropped, suggesting fewer fires, and sedges were the dominant plant type. Salt marsh peat accumulated, and *Trochammina* spp. became the dominant foraminiferal type, followed by other marsh species such as *Milliamina* and *Rotamorphina*. The rise in *Ambrosia* (ragweed) reflects the forest destruction and the open environment that resulted as Europeans colonized the region. It is only in the uppermost sediments (30 cm) that *Salicornia* seeds are continuously present, suggesting more saline conditions. The last century shows a resurgence of the *Quercus-Pinus* forest after the decline due to early European influence.

7.3.5 FIGURES

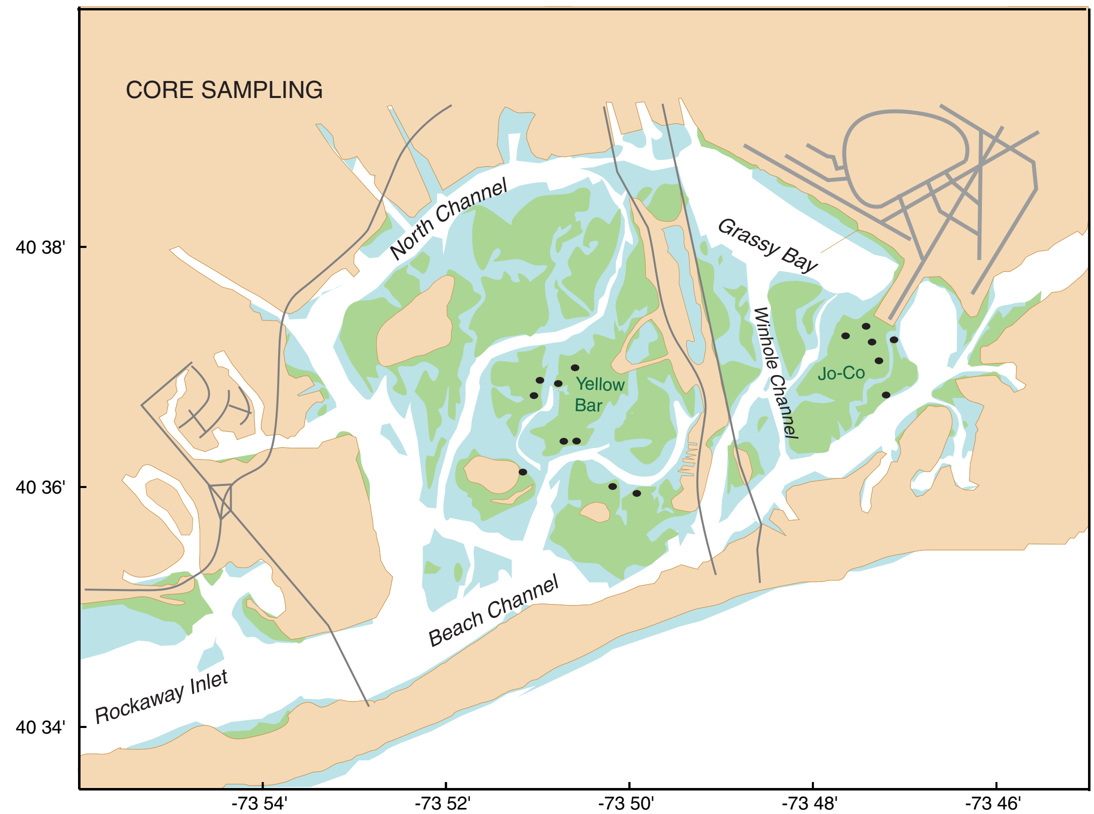

Figure 7.3-1 Location map of Jamaica Bay with core probe sites throughout and JoCo Marsh site as the easternmost site.

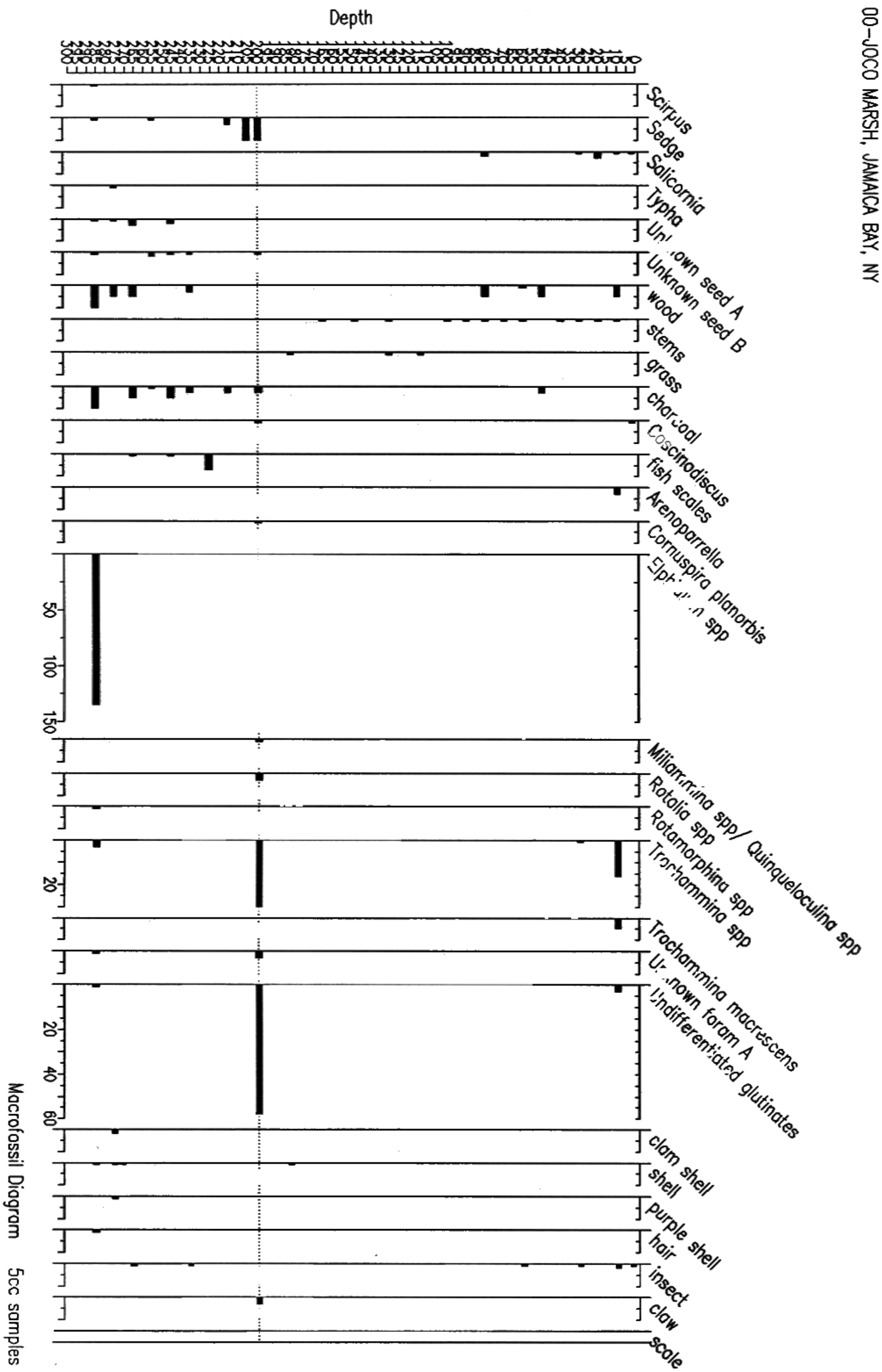

Figure 7.3-2 Macrofossil diagram from JoCo Marsh, Jamaica Bay.

7.4 Temperature, Salinity and Currents in Jamaica Bay

Arnold Gordon, Bruce Huber and Robert Houghton

7.4.1 INTRODUCTION

Jamaica Bay stratification is weakly indicative of a shallow, tidally active environment, with flood tide dominating slightly over ebb flow. Tidal excursions cause a non-stationary field, as water column properties sweep back-and-forth. Removing the spatial element with a temperature-salinity (T/S) relationship reveals the blending of the three inputs to Jamaica Bay water: coastal water (New York Bight), freshwater input (mostly treated sewage) and sea-air fluxes. We have two realizations of the T/S distribution: June and September 2000, defining the beginning and end of summer conditions, respectively.

7.4.2 METHODS

Profiles of temperature and salinity with depth were collected at numerous sites within Jamaica Bay in June and September 2000. Sampling sites are summarized Table 7.4-1 and in Figure 7.4-1. The profiles were obtained with a Sea-Bird Electronics SBE19 Seacat CTD, sampling at a rate of 2 samples per second, yielding an effective vertical resolution of approximately 25 cm. Post-project calibration of the instrument is being carried out as of the writing of this report, so final estimates of instrument uncertainty are not yet available. However, previous experience indicates uncertainties (1 std dev) for temperature, salinity and pressure of 0.01°C; 0.02 psu and 0.3 decibars.

The CTD stations were carried out from the NPS vessel Herbert Johnson in early June, and thenceforth from the US Park Police Marine Unit vessel.

An effort was made to reoccupy several selected sites to enable comparison of tidal and seasonal influences.

An acoustic current meter with integrated CTD was deployed 7 June - 19 July 2000 near the bridge in Rockaway Inlet, to monitor tidal fluctuations and to attempt to derive a mean flux estimate at the inlet. The instrument used was a Falmouth Scientific 2D-ACM/CTD, mounted in a weighted PVC frame which was deployed on the inlet bottom. The frame was recovered by Park Service Police divers. The CTD components failed prematurely due to flooding through the pressure port. The mooring frame was evidently knocked over on or about 4 July, presumably by recreational fishing.

Table 7.4-1. Jamaica Bay CTD Profiles - LDEO

Date	Yearday	Number of Profiles	Canarsie High Tide	Canarsie Low Tide
06/01/00	153	3	7:59	13:49
06/02/00	154	5	8:50	14:41
06/07/00	159	5	13:35	19:13
06/08/00	160	21	14:33	20:20
06/09/00	161	26	15:29	21:28
07/19/00	201	4	10:57	17:05
09/11/00	255	6	7:30	13:15
09/12/00	256	18	8:10	13:59
09/13/00	257	34	8:47	14:42
09/14/00	258	35	9:22	15:24
09/15/00	259	29	9:56	16:04

7.4.3 Results

September: The T/S (Figure 7.4-1) depicts a three point mixing environment. For salinity less than 26.5 (mainly eastern and northern Jamaica Bay) the temperature resides in the 23-24°C range, 5 to 6 °C warmer than the June condition. This represents the equilibrium surface temperature for the regional sea-air forcing. For salinity greater than 26.5 (western and southern Jamaica Bay) the temperature decreases with increasing salinity, with the most saline water of slightly over 30, at Rockaway Inlet floor, representing the coastal water end-member. At 26.0, below a depth of 5 meters Grassy Bay is filled with cooler water, 22-23°C. As this is 5°C above the June temperature at the bottom of Grassy Bay (17.5°C), the isolation is clearly less than three months.

June: The T/S scatter depicts a similar pattern, but regional equilibrium to a fixed SST has not yet been reached. Cool, saline coastal water end-member is slightly less than 16°C and 30 salinity. The warm, fresher end-member is about 19 to 20°C and 22-24 salinity, and is located within the Grassy Bay surface layer. Cool (<18°C and relatively freshwater (<25) is found throughout. The origin of these waters is not yet clear.

An advection/diffusion model as follows is envisioned: cool, saline coastal water flows into Jamaica Bay via Rockaway Inlet; freshwater is injected at various points via treated sewage, with Grassy Bay in NE Jamaica Bay representing the area most remote from the coastal end-member, most strongly influenced by freshwater input; strong vertical mixing couples the inflow and outflow throughout Jamaica Bay. Below 5 meters, Grassy Bay water is relatively isolated from the more active advective environment of the shallower layer. A simple salinity mixing recipe (assumes no net sea-air freshwater flux, not necessarily a good assumption for the rainy summer of 2000), finds that the coastal end-member is about 4 times that of the freshwater flux. If the volume of Jamaica Bay above 5 meters is 50 x 10^6 m^3 and the freshwater flux is 50 m^3/s, then the bulk residence time of Jamaica Bay (not counting the portion of Grassy Bay below 5 m) is: 7 days.

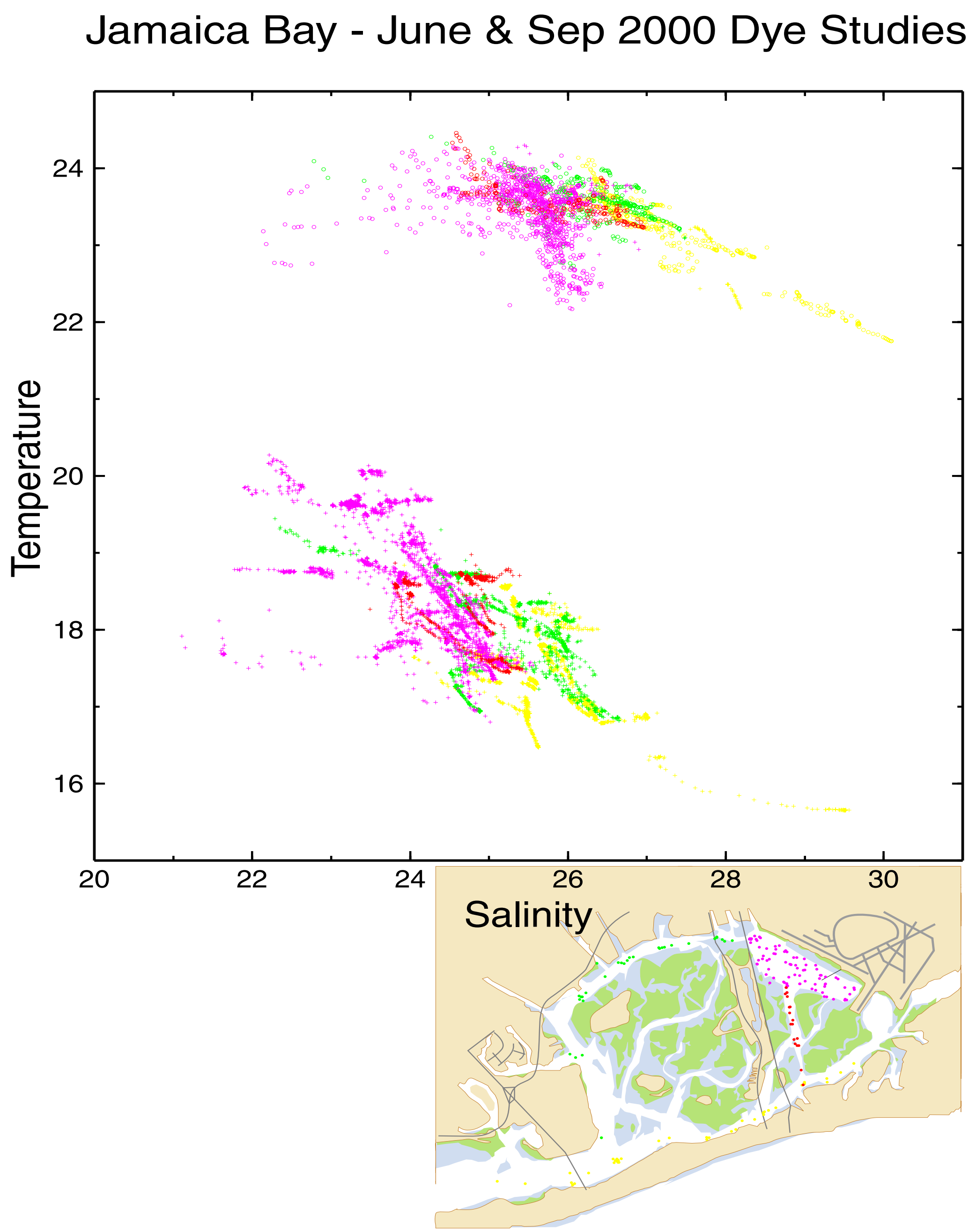

Figure 7.4-1. Temperature-Salinity distribution from the June and September, 2000 CTD stations. T/S points are color coded by region within the Bay. June points are displayed as '+' marks and September points as 'o'. Sample sites are identified in the inset map.

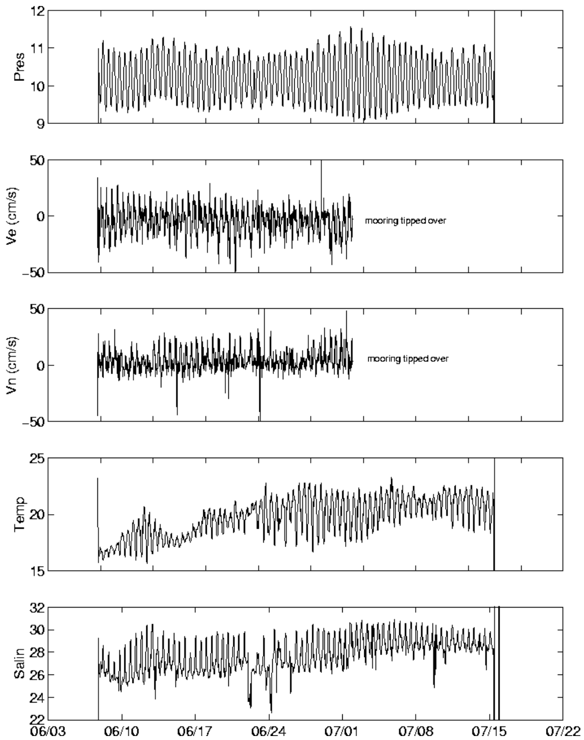

Figure 7.4-2. Data from Rockaway Inlet current meter/CTD mooring June-July 2000.

Mooring: The current meter/CTD mooring was deployed in Rockaway Inlet on 7 June and recovered 19 July. The moored CTD data (Figure 7.4-2) clearly show a seasonal trend toward warmer, more saline conditions. Salinity peaks at high tide. The east-west speeds vary from 35 cm/s to the west to 55 cm/s to the east, with effective a zero mean (3.8 cm/s towards the west). When the zonal flow component was towards the east, the meridional speed was near zero; when the zonal flow was towards the west the meridional flow was towards the north. This is likely due to the siting of the mooring within 0.5 m of the bottom, and also may be due to its placement on the south side of Rockaway Inlet and may not represent the mean coupling of coastal and Jamaica Bay waters.

Tidal effects: It is clear from the CTD sampling and moored data that a comprehensive study of Jamaica Bay must include a thorough assessment of tidal effects on stratification and circulation. While this study was not designed to undertake such an assessment, the data show qualitatively the impact of tidal flow on the stratification and points in and near the inlet (Figure 7.4-3). Future studies will require careful examination of tidal influences on data collected to avoid tidal aliasing of time-series.

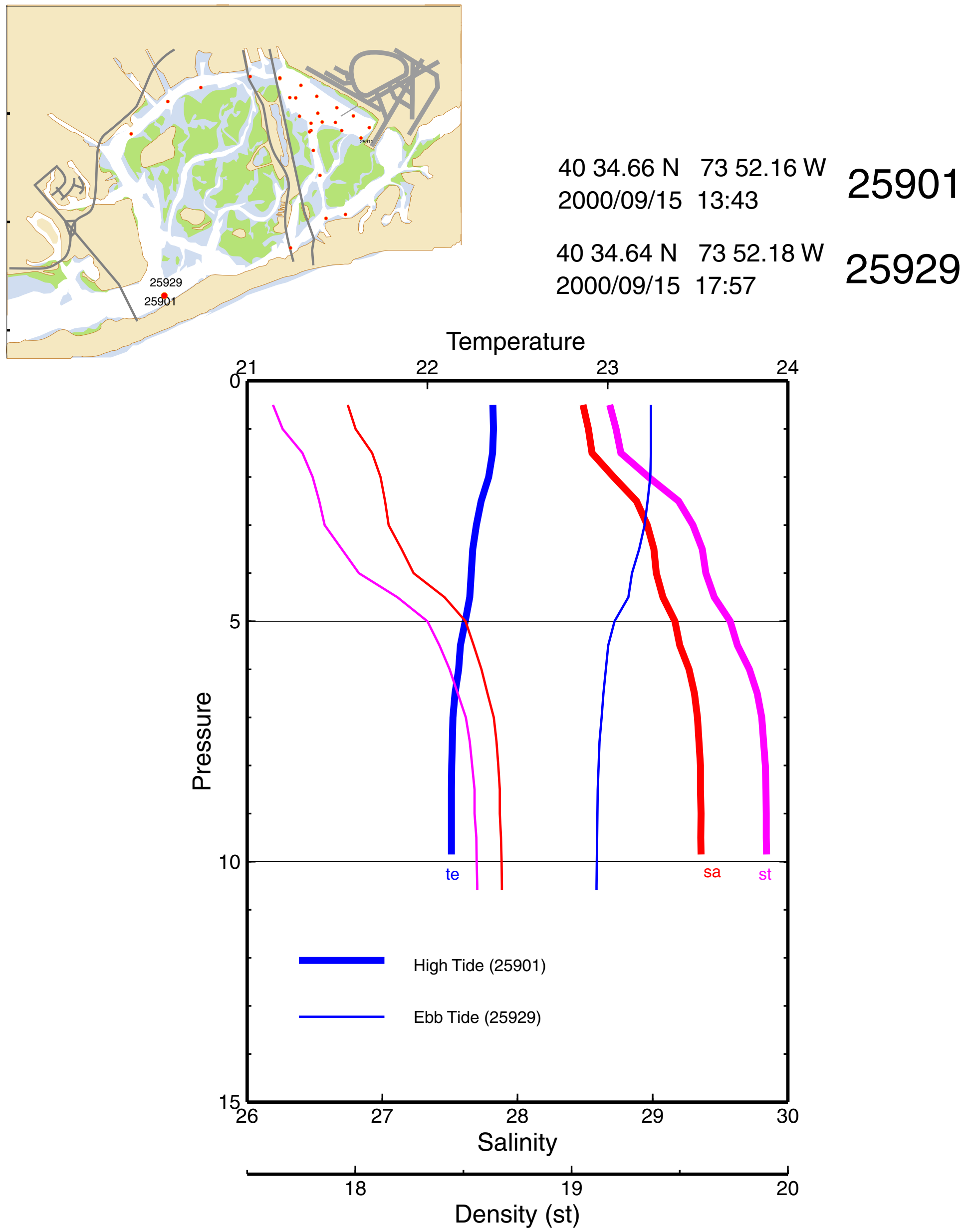

Figure 7.4-3. CTD data at a single site collected at different tide stages. Note the significant impact on stratification.

7.5 Dye Tracer Experiments in Jamaica Bay

Robert Houghton, Arnold Gordon and Bruce Huber

7.5.1 Introduction

The residence or flushing time of Jamaica Bay has increased due to dredging. The commonly quoted value (see, for example, West-Valle et al., 1992) is that the resident time increased from 10 days to 35 days as dredging increased the mean depth of Jamaica Bay from 3 feet to 16 feet. All literature references of this fact go back to the National Academy of Science and National Academy of Engineers Report of the Jamaica Bay Environmental Study Group, vol. II (1971). Here the 35 day residence time is simply stated with no supporting reference or indication how the number was derived.

To confirm or revise this residence time the dispersion of a purposeful tracer was studied. To make the experiment tractable Grassy Bay was chosen as the study site.

Two injections of fluorescein dye into Grassy Bay were conducted in the summer of 2000. On June 7 19 kg of dye was injected at 5.5 m depth and on September 11 54 kg of dye was injected at 10 m depth. There were surveys of the dye distribution for the subsequent 2 days in June and 4 days in September. The dye surveys were carried out in conjunction with CTD surveys throughout Jamaica Bay as described in the section on temperature, salinity and currents in Jamaica Bay.

7.5.2 Methods

The fluorescent dye, fluorescein, was injected by pumping an approximately 30 % solution mixed with isopropanol to achieve in situ density through a garden hose to the required depth; either the bottom or 5 m below the surface. The dye is then detected in situ using a Chelsea Ltd. Aquatracka III fluorometer attached to a Sea-Bird Electronics SBE19 CTD. The fluorometer could detect the dye down to concentrations of 1 part per 10^{11} by weight. Through a series of rapidly-taken, closely-spaced stations we were able to map the dye distribution throughout Grassy Bay and the adjacent channels.

7.5.3 Results

The flushing rate is given as an e-folding time of an exponential decay. For tidal exchange it is given by

$$T_f = 1/(1-b)\ VT/P$$

Where V is the volume, P the tidal displacement, T the tidal period, and b the fraction of the water from the ebb flow that returns into the bay on the subsequent flood.

For Grassy Bay $V = 28 \times 10^6 m^3$ and $P = 5.6 \times 10^6 m^3$, for a 1.5 m tidal range, so $T_f \sim 3.5$ days for b=0. From the dye measurements we estimate that b=1/2 which yields $T_f = 7$ days. This is a lower bound assuming barotropic flow in a homogeneous basin. In fact Grassy Bay is weakly stratified with a pycnocline at approximately 5 m, a mean depth of 9.5 m, maximum depth 12.5 m and sill depths of 6 m into the North Channel and 8 m into Winhole Channel.

From the decay of the dye inventory in Grassy Bay we get e-folding times of 2 to 4 days. This could be an under estimate since adsorption of the dye on particles in the water column will reduce its fluorescence. However, subsequent lab tests show that adsorption on inorganic particles is approximately 10%. A test using Jamaica Bay water taken during a plankton bloom showed little additional adsorption although it is difficult to recreate the Bay in situ conditions in the lab. It is unlikely that adsorption could decrease the observed time constant by more than 50%.

The dye experiments do show that dye injected at depth (10 m) has a greater residence time than the dye injected at mid-depth. Lateral diffusivity is approximately 10 m^2/s and vertical diffusivity is approximately $3x10^{-5}$ m^2/s in the interior where the stratification has a Brunt-Väisälä period of 1-4 minutes.

There is evidence of shear during the ebb flow in Winhole channel near Grassy Bay. The outflow from Grassy Bay is predominantly in the upper half of the water column. The lower half is water with characteristics of the western Jamaica Bay. The vertical mixing of this water prior to the next flood effects water exchange with Grassy Bay and reduces the flushing time.

From the dye experiments we estimate a Grassy Bay bulk flushing time of approximately one week.

7.5.4 References

National Academy of Science and National Academy of Engineers, 1971. Jamaica Bay and Kennedy Airport. Report of the Jamaica Bay Environmental Study Group, vol. II . Port Authority of New York and New Jersey. 149pp.

West-Valle, A.s, Decker, C.J., and Swanson, R. L., 1992. Use Impairments of Jamaica Bay. Special Report #99, Reference # 92-4, Marine Sciences Research Center, the University at Stony Brook, 187pp.

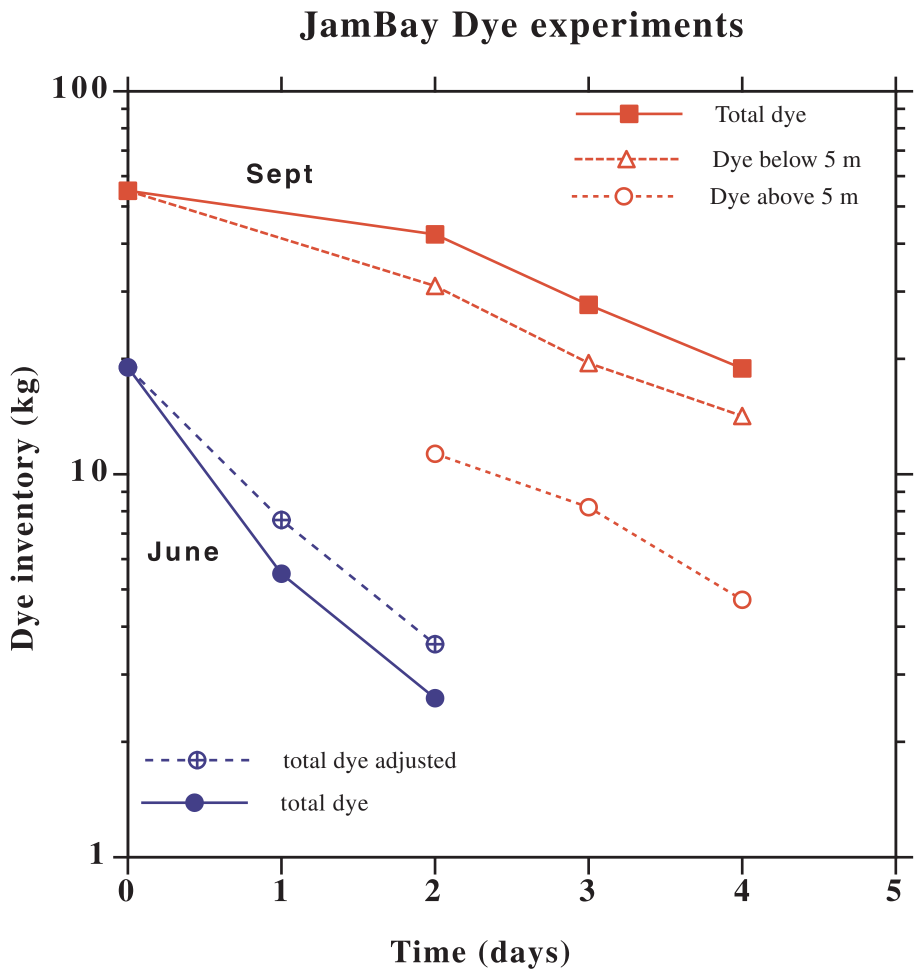

Figure 7.5-1. A log-linear plot of dye inventory for the 2 experiments. Exponential decay will be a straight line. The decay time in June, injection at mid depth, is approximately 2 days while for September, injection at bottom, is approximately 4 days. These are lower bounds since adsorption onto particles could reduce the dye fluorescence.

7.6 Stable Isotope Evidence for Water Mass Mixing in Jamaica Bay

James Rubenstone

7.6.1 INTRODUCTION: $\delta^{18}O$ AS A WATER MASS TRACER

Natural processes in the hydrologic cycle fractionate the heavier isotopes of oxygen from the lighter ones. Oxygen isotopes in water are conventionally given in δ notation, as per mil (‰; parts per thousand) deviation of $^{18}O/^{16}O$ relative to standard ocean water. The fractionation in surface waters of eastern North America exceeds 10‰ (e.g. Fairbanks, 1982). Stable isotopes then can serve as a tracer of freshwater mixing in estuaries such as Jamaica Bay. The surface water gradient in $\delta^{18}O$ means that different potential freshwater sources in Jamaica Bay will have distinct isotopic signatures: local precipitation, for example, is less isotopically depleted than freshwater advected from the Hudson River, which averages water from a large drainage in upstate New York. Freshwater outfalls from sewage treatment plants feeding into the bay will also show $\delta^{18}O$ values intermediate between local precipitation and Hudson River water, as New York City municipal water is drawn from upstate reservoirs.

In mid-latitudes $\delta^{18}O$ is conservative in water masses, and is positively correlated with salinity; fresh water is isotopically lighter (more negative $\delta^{18}O$) than seawater. As noted by Paren and Potter (1984), expressing ^{18}O as $\Delta = (\delta^{18}O^* (1-S))$ gives linear mixing relations on plots of Δ against salinity.

7.6.2 SAMPLING AND METHODS

Water samples were taken on nine separate dates in 2000, during June, July and September. The September sampling included a contiguous four day period, during which stations were reoccupied several times over the course of the tidal cycle. Sampling locales are shown in Figure 7.6-1. Note that sampling for stable isotopes included portions of the bay which

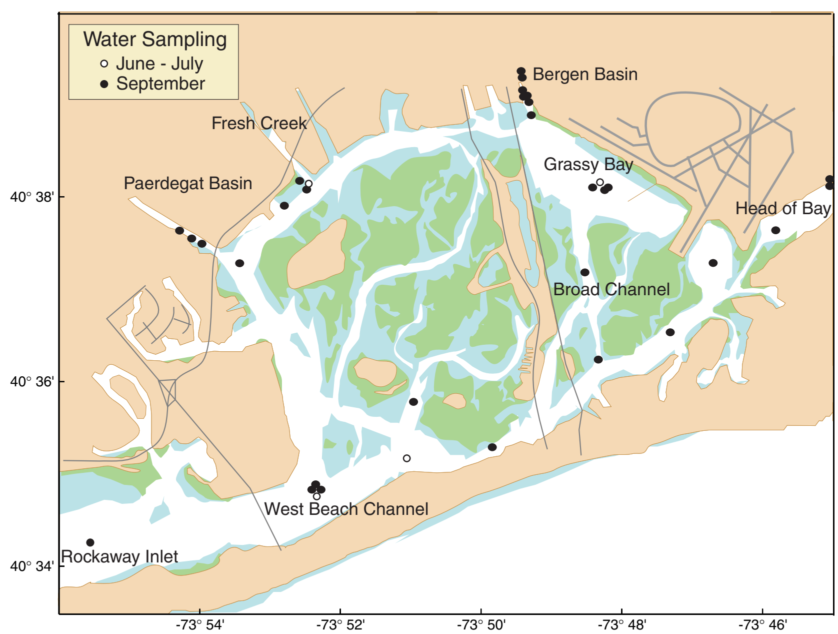

Figure 7.6-1 Water sampling locations in Jamaica Bay

were not subject to the detailed CTD studies described elsewhere in this report. Specifically, these are the small basins on the northern margin (Paerdegat Basin, Bergen Basin), and the eastern end of the bay (Head of Bay, Thurston Basin, and Grassy Bay east of the runway 4-22L extension). Depth profiles were sampled using a peristaltic pump with the water intake attached to a real-time monitored CTD for depth control.

Stable isotopes were measured on a VG Prism dual-inlet mass spectrometer, and are reported relative to V-SMOW water standard. Repeated analysis of standards indicates a measurement accuracy of better than 0.01‰. Salinity was measured on all samples on a Guildline Portasal, calibrated to IAPSO standard seawater.

7.6.3 Results: $\delta^{18}O$ variations and vertical structure in Jamaica Bay

Although Jamaica Bay is relatively small and tidal exchange is strong, stable isotopes can resolve distinct water signatures within different portions of the bay. While not as sharply defined as traditional oceanographic water masses, these signatures have geographical coherence and appear to follow circulation (and isolation) patterns within the bay. The following discussion draws mostly on the more extensive sampling during September, when late summer conditions prevailed. Similar patterns are suggested for the earlier samplings, and differences will be discussed in a later section.

Four such signatures are discerned. Figure 7.6-2 shows the mean $\delta^{18}O$ of surface water at 9 representative stations sampled in September 2000, which illustrate the four sets described here.

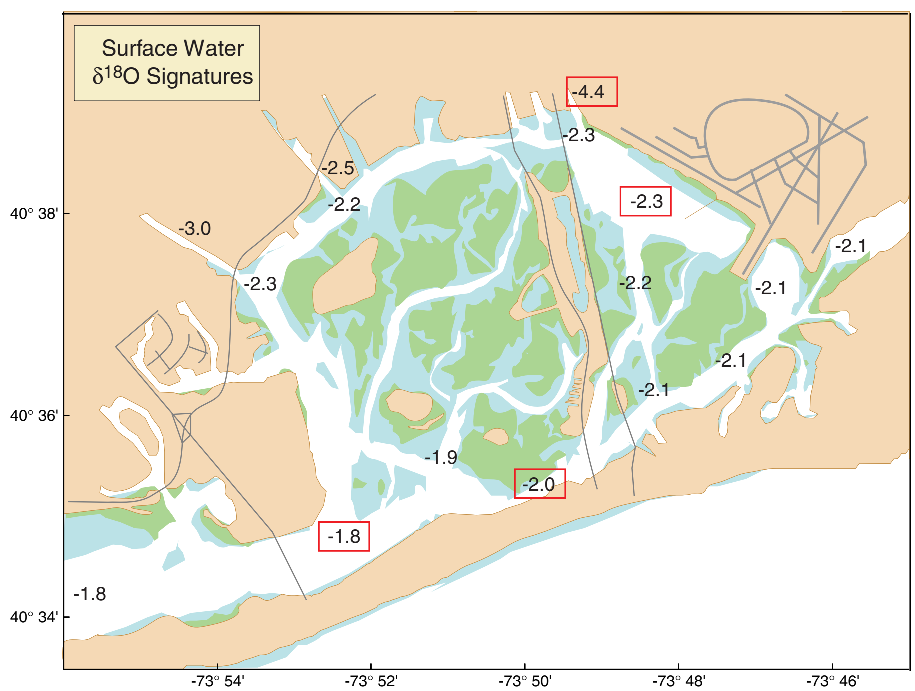

Figure 7.6-2. $\delta^{18}O$ signatures of Jamaica Bay surface water types. Values are shown (‰) for representative analyses, from the September survey. Red boxes mark the four "signatures" discussed in text: West Beach Channel (-1.8); South Channel (-2.0); Grassy Bay (-2.3); northern basins (-4.4).

The first is water that occupies western end of Beach Channel and Rockaway Inlet. Not surprisingly, this water is the most like the coastal marine waters found outside the bay, but is measurably fresher and isotopically lighter, reflecting the freshwater contribution from within the bay. During the September surveys this water had $\delta^{18}O$ of –1.8‰, and showed essentially no stratification, with less than 0.05‰ difference in $\delta^{18}O$ in any profile. The vertical mixing is consistent with the strong tidal currents at the bay entrance.

Water filling the channel along the south side of the bay also appeared well mixed vertically and was fairly uniform in its stable isotope composition, although isotopically distinct from that in West Beach Channel. Water at a station about 3km east of the West Beach Channel station is slightly fresher and has $\delta^{18}O$ of –2.0‰. A small gradient in salinity and $\delta^{18}O$ exists from this point east to Head of Bay and the east end of Grassy Bay (east of the runway extension), but with little if any vertical stratification. In these basins $\delta^{18}O$ was as low as –2.09‰, reflecting a relatively small freshwater contribution. Values as low as –2.16 were measured in surface water of the small Thurston Basin at the far eastern end. Overall, mixing along this southern margin of the bay appears more complete than in the more restricted min part of Grassy Bay.

Grassy Bay represents the third isotopic signature. Water here showed the strongest vertical stratification in salinity and $\delta^{18}O$ within the bay (Figure 7.6-3). At its most stratified,

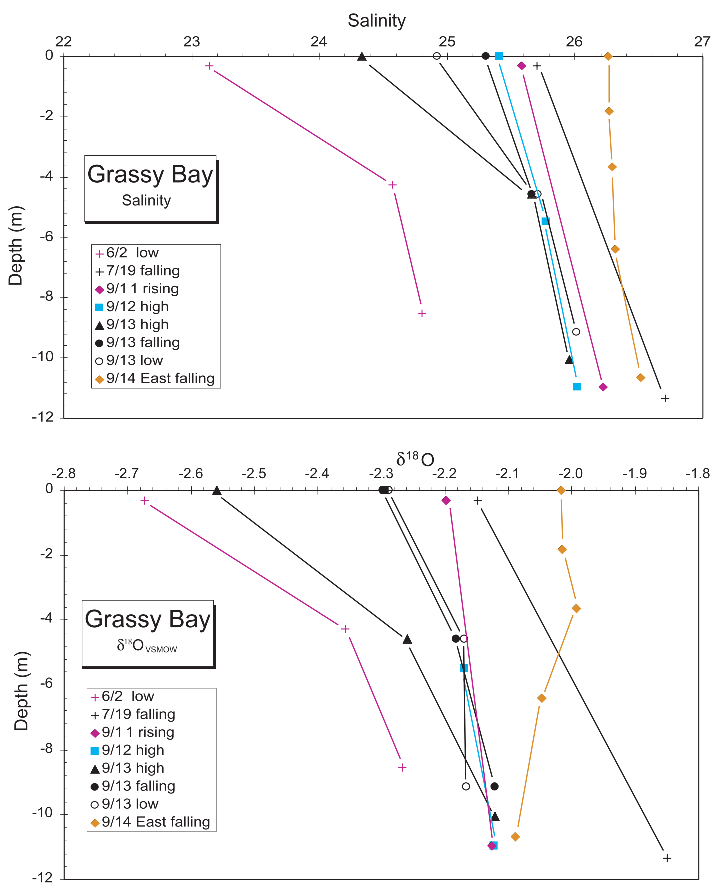

Figure 7.6-3. Salinity and $\delta^{18}O$ profiles in Grassy Bay, west of runway extension (one to east is noted). Date and tidal stage given in legend.

Grassy Bay surface water is about 1.4‰ fresher and 0.4‰ lower in $\delta^{18}O$ than at depth. The relatively low $\delta^{18}O$ of Grassy Bay surface water is similar to that seen in surface water along the north channel, consistent with this being the main flushing path for Grassy Bay. The gradient in surface $\delta^{18}O$ through Broad Channel, the other main opening to Grassy Bay, suggests that this route is of lesser significance. Notably, while their surface waters are distinct, the bottom waters on either side of the runway extension in Grassy Bay are more similar in salinity and $\delta^{18}O$.

The fourth distinct component observed in the bay is found in the small basins along the northern side, especially Bergen and Paerdegat Basins. The lowest salinity and $\delta^{18}O$ was found in Bergen Basin (15.8‰ and –4.4‰, respectively), in a thin (<1 m) surface lens overlying saltier water. The other small basins show similar though less dramatic freshenings. These freshwater sources are presumed to be water treatment plants. These freshwater sources, that release into small restricted basins, persist until the water enters the main northern channel. In contrast, stations near treatment plant outfalls in deeper basins or channels (i.e., in Head of Bay, in Beach Channel and in Rockaway Inlet) do not show fresher or isotopically lighter water. Mixing within the latter areas is more robust and rapidly disperses the local input.

7.6.4 Seasonal variation

Waters in both Grassy Bay and Beach Channel showed greater variability but were generally fresher and isotopically lighter in June and July compared to the September sampling (Figure 7.6-4). The differences are more pronounced in Beach Channel, which shows a mean increase of 2‰ in salinity and 0.3‰ in $\delta^{18}O$ between the early summer and September. The covariation of salinity and $\delta^{18}O$ (or Δ) mostly follows the main trend of the Jamaica Bay data, but there is

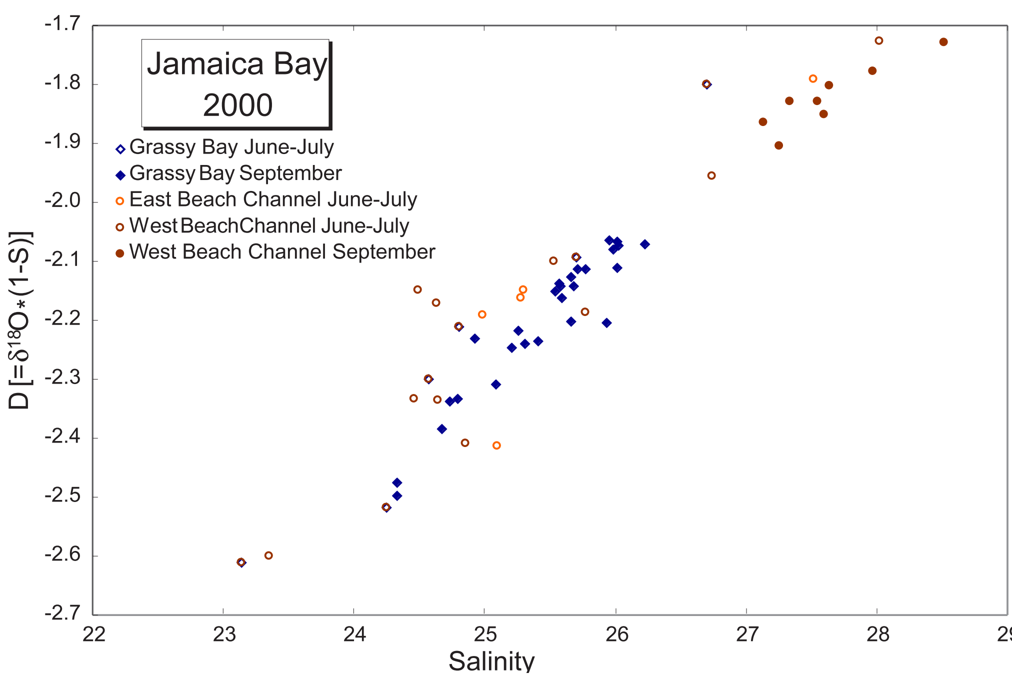

Figure 7.6-4. Changes in salinity and Δ between early and late summer in Grassy Bay and west Beach Channel.

some suggestion of a shallower slope in the shift between early June and September in Beach Channel. This may indicate that local precipitation was a more significant freshwater source early in the summer.

7.6.5 Water sources in Jamaica Bay

The present measurements in Jamaica Bay fit nicely into the known regional pattern of stable isotope in coastal waters. Figure 7.6-5 shows all of the Jamaica Bay data relative to water sampled off Breezy Point in September 2000, and to lines defined by previous studies of the offshore waters (Fairbanks, 1982). Surface waters of the New York Bight are mixtures of slope water and a freshwater component with $\delta^{18}O$ = -10, identified as mean Hudson River outflow. The Breezy Point water is remarkably consistent with the New York Bight line, considering the samples were taken at different seasons (and more than 20 years later).

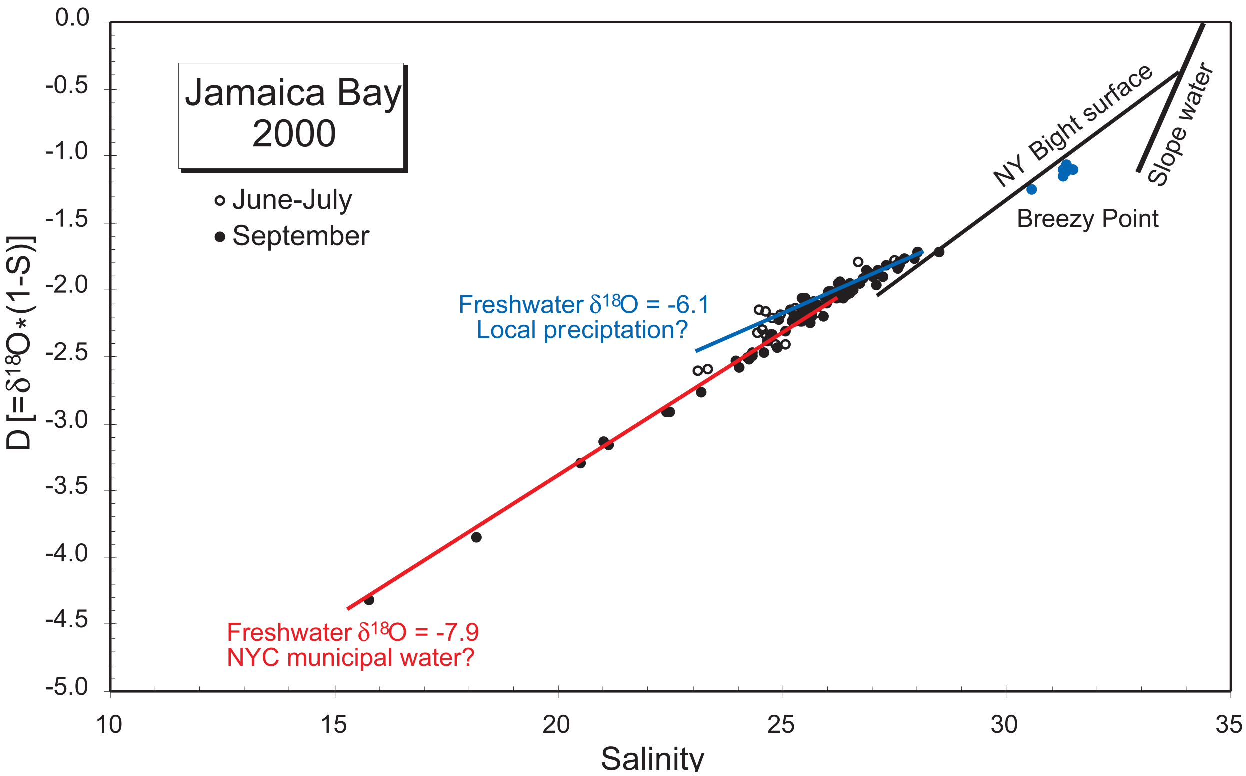

Figure 7.6-5. Salinity and Δ in Jamaica Bay in relation to nearby coastal waters. Black lines are defined for offshore slope water and surface water of the New York Bight (Fairbanks, 1982). The red line is a regression for the northern basins of Jamaica Bay, including Grassy Bay. The blue line shows the regression for the remainder of the Jamaica Bay samples.

Regressing the Jamaica Bay water data as a group in Δ-salinity gives a reasonably good line (r^2 = 0.983) whose intercept gives an average freshwater component with $\delta^{18}O$ = -7.4‰. The scatter within the data however suggests that more than one freshwater component may be involved in Jamaica Bay. The waters found in the northern basins follow a mixing line with a slightly steeper slope than the entire data set, and indicate a freshwater endmember that is more depleted in ^{18}O than the average, with $\delta^{18}O$ = -7.9‰. The spread within the remaining data are better fit with a shallower slope, whose freshwater intercept has $\delta^{18}O$ = -6.1‰. These two endmembers may represent New York City municipal water and local precipitation (plus surface runoff), respectively. The former is "imported" from upstate reservoirs and enters Jamaica Bay through treatment plants. We have no direct measurements of NYC water from September 2000. A sample taken in February 2001 had $\delta^{18}O$ = -8.45‰; a seasonal offset of ~0.5‰ is reasonable based on seasonal sampling of New York rivers (Fairbanks, 1982). We likewise have no contemporary measurements of Jamaica Bay rainfall $\delta^{18}O$, but the inferred precipitation signal is also consistent with regional patterns.

These values can be used to quantitatively constrain the freshwater budgets within the bay. In Grassy Bay, 18-21% of the surface water and 14-15% of the bottom water is contributed by treated NYC municipal water, exclusive of any precipitation component. The data would require 21-24% freshwater if local precipitation were the only source. The main mass of water in West Beach Channel requires a freshwater component of 14% precipitation/runoff, or 10% NYC water. As both components contribute, these values represent limits for the total freshwater budget. As previously discussed, NYC water is a more significant contributor to Grassy Bay and the northern basins compared to the southern and eastern portions of Jamaica Bay.

7.6.6 References

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Paren, J.G., and J.R. Potter, Isotopic tracers in polar seas and glacier ice. J. Geophys. Res. 89, 749-750, 1984.

7.7 Patterns of Nutrient Enrichment and Depletion in Jamaica Bay, Summer 2000

Renee K. Takesue and Alexander van Geen

7.7.1 INTRODUCTION

Large inputs of the nutrients nitrogen and phosphorus into Jamaica Bay from waste water treatment plants, sewage outflows, and in runoff are serious concerns because they fuel phytoplankton blooms, which in turn may lead to eutrophication and hypoxic (low oxygen) conditions in the lower water column. Dissolved nutrient concentrations were measured throughout the summer (June-September 2000) in Jamaica Bay in order to determine spatial and temporal patterns of nutrient enrichments as well as the role of biological productivity and tidal flushing as nutrient sinks content of Jamaica Bay.

7.7.2 METHODS

Surface water samples were collected in de-ionized water-rinsed polyethylene bottles mounted on a plexiglas holder attached to a 10 foot-long fiberglass pole. Waters were sampled upstream of the boat's wake and as far off the side as possible to avoid contamination. Mid-depth and bottom water samples were drawn from a 1.7 L Niskin bottle. Immediately after collection, a 60 ml aliquot was filtered though a 0.45 µm pore size polypropylene syringe-tip filter and preserved with 0.1% by volume hydrochloric acid.

The nutrients nitrate+nitrite ($N_{NO2+NO3}$), phosphate (PO_4), and silicate (Si) were measured at the Lamont-Doherty Earth Observatory by standard colorimetric methods (Strickland and Parsons, 1965; Grasshoff, 1976) using a QuikChem 8000 flow-injection analyzer (Lachat Instruments). Detection limits, calculated as three times the standard deviation of a NaCl blank measured every 10 samples, were 0.1, 0.1, and 0.2 µmol kg^{-1} for $N_{NO2+NO3}$, PO_4, and Si, respectively. Measurement precisions for 15 µmol kg^{-1} $N_{NO2+NO3}$, 1.5 µmol kg^{-1} PO_4, and 40 µmol kg^{-1} Si standards were ±2%, ±1%, and ±1%, respectively.

7.7.3 RESULTS

In general, Jamaica Bay waters were enriched in phosphate (~5 µM) relative to coastal waters but $N_{NO2+NO3}$ and Si concentrations ($N_{NO2+NO3}$, Si ~20 µM) did not appear to be anomalously high (Duedall et al., 1977; NYDEP, 1999). All nutrient levels were higher in the northern regions of Jamaica Bay than in the well-mixed southern channel.

Over the four sampling dates throughout the summer, surface dissolved inorganic $N_{NO2+NO3}$ concentrations were highest throughout Jamaica Bay on June 1 (up to 30 µmol/L or 0.4 mg/L), were at intermediate levels on June 28, and on July 18 had were almost totally depleted, presumably by the extreme phytoplankton bloom observed in surface waters (Figure 7.7-1, Table 7.7-1). By mid-September $N_{NO2+NO3}$ levels had returned to intermediate levels. PO_4 in surface waters generally followed the same pattern as $N_{NO2+NO3}$, but reached maximum concentrations (up to 6 µmol/L or 0.2 mg/L) on June 28 and did not experience the degree of depletion shown by $N_{NO2+NO3}$except in Grassy Bay (Figure 7.7-1, Table 7.7-1). Nutrient profiles show very little variability with depth except in Grassy Bay, where circulation is restricted (Figure 7.7-2; Table 7.7-1). In June and July surface waters were depleted in $N_{NO2+NO3}$ and PO_4, likely due to consumption by plankton. Bottom waters were depleted in $N_{NO2+NO3}$ but not PO_4.

In the northern region, Bergen Basin was extremely enriched in PO_4 (26 µM) and Si (69 µM) relative to bay waters, and Paerdegat Basin in Si (65 µM) (Table 7.7-2). Some indication of mixing with these fresher, PO_4 and Si-enriched waters may be apparent in the observed surface enrichments of P and Si in Grassy Bay and Fresh Creek. An anomalously high $N_{NO2+NO3}$ concentration (39 µM) was measured only near the Rockaway Treatment Plant outfall, 9 ft below the surface (Table 7.7-2)

Over half a tidal cycle, nutrient concentrations showed the greatest variability near the mouth of Jamaica Bay. All nutrients were lowest at high tide and highest at low tide, consistent with the pattern of nutrient-enriched bay waters flushing through Rockaway inlet during ebb tide. The opposite relation between nutrient enrichments and tidal stage was observed in Grassy Bay, where tidal flushing appeared to have a somewhat smaller effect on the range of nutrient concentrations, likely due to the restricted circulation in Grassy Bay.

7.7.4 Conclusions

Patterns of nutrient depletions throughout the summer suggest that surface concentrations of $N_{NO2+NO3}$, PO_4, and Si were regulated by biological productivity in the early to mid-summer: depletions of Si in late June suggest a diatom-dominated plankton assemblage and the recovery of N and Si in September may suggest a shift to smaller algae that utilize a different nitrogen source. Depletions in bottom water $N_{NO2+NO3}$ in Grassy Bay relative to surface waters may have resulted from denitrification under low oxygen conditions. From early to late summer there was an overall increase in P and decrease in $N_{NO2+NO3}$ throughout the water column of Jamaica Bay.

Dissimilar trends of $N_{NO2+NO3}$ and PO_4 with depth in Grassy Bay suggest that different processes affect surface and bottom water $N_{NO2+NO3}$ and PO_4 concentrations. While low nutrient concentrations in surface waters are likely due to phytoplankton uptake of $N_{NO2+NO3}$ and PO_4, low $N_{NO2+NO3}$ levels measured in the bottom waters of Grassy Bay may be the result of water column denitrification, which occurs under low oxygen conditions. Elevated PO_4 levels in the bottom waters of Grassy Bay are the highest observed anywhere in Jamaica Bay and suggest that either phosphorus is sequestered in Grassy Bay or that there may be a sedimentary source of dissolved phosphorus to the overlying water column, since under low oxygen conditions phosphate is released from iron-hydroxide phases in the sediments.

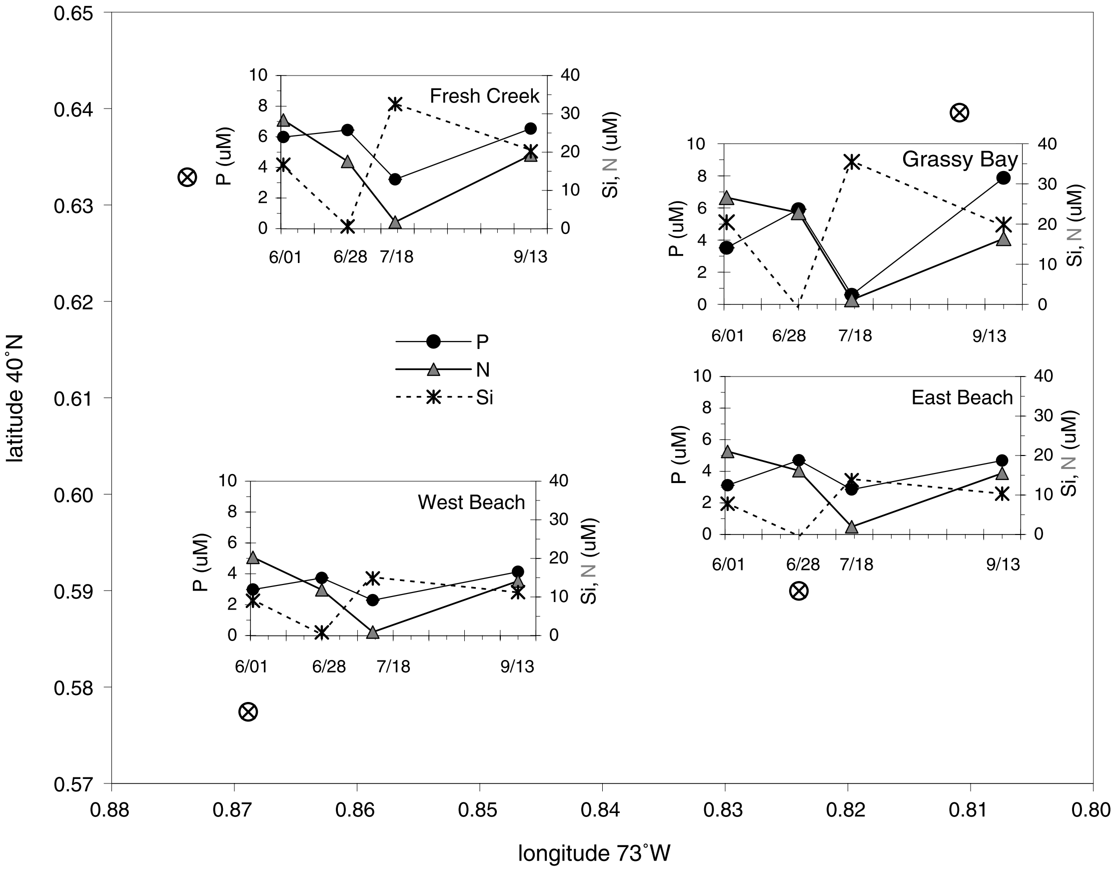

Figure 7.7-1. Summer time series of surface dissolved inorganic phosphate (P; circles), nitrate (N; triangles), and silicate (Si; asterisks) plotted at the latitude and longitude (decimal degrees) of each station in Jamaica Bay. Note that nitrate and silicate are on the same scale.

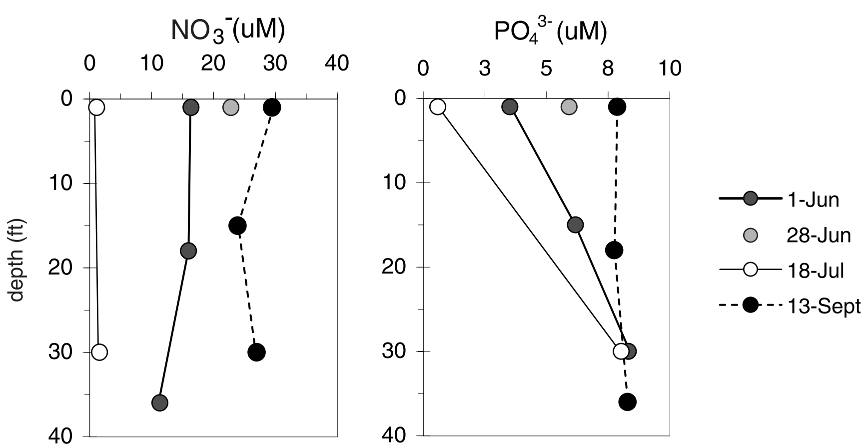

Figure 7.7-2. Changes in water column concentrations of nitrate and phosphate throughout the summer in Grassy Bay.

Table 7.7-1. Summer time series of surface and water column nutrient concentrations in West Beach Channel (WB), at the mouth of Fresh Creek (FC), in Grassy Bay (GB), and in the East Beach Channel (EB). n.d. indicates concentrations were below the measurable detection limit.

	depth	P (µM)	N (µM)	Si (µM)
1 June 2000				
WB	surface	2.97	20.32	8.84
	mid	2.91	19.93	12.54
	bottom	2.40	16.70	8.27
FC	surface	6.14	28.64	15.89
	mid	5.38	27.61	15.47
	bottom	5.06	26.09	13.11
GB	surface	3.52	29.46	20.41
	mid	6.18	23.91	15.36
	bottom	7.75	26.99	20.17
EB	surface	3.11	21.02	6.74
	mid	3.12	21.03	7.53
	bottom	3.04	20.66	7.37
28 June 2000				
WB	surface	3.73	11.86	0.82
FC	surface	6.44	17.58	0.60
GB	surface	5.92	22.83	n.d.
EB	surface	4.69	16.16	n.d.
18 July 2000				
WB	surface	2.29	0.92	14.80
FC	surface	3.22	1.72	32.52
GB	surface	0.59	1.14	35.47
	bottom	8.04	1.60	40.56
EB	surface	2.85	1.96	13.75
13 September 2000				
WB	surface	4.13	14.12	11.25
	mid	3.46	12.02	10.92
FC	surface	6.53	19.23	20.19
	mid	5.16	16.65	22.20
GB	surface	7.87	16.37	19.86
	mid	7.75	15.97	19.60
	bottom	8.29	11.35	24.96
EB	surface	4.68	15.50	10.33
	mid	4.65	14.55	10.54

Table 7.7-2. ***September 11, 2000:*** **high resolution depth profile in Grassy Bay.** ***September 12, 2000:*** **changes in nutrient concentrations in Grassy Bay (GB), Fresh Creek (FC), and the West Beach Channel (WB) over half a tidal-cycle (high-low-slack tide).** ***September 13, 2000:*** **nutrient concentrations in Bergen Basin (BB), Paerdegat Basin (PB), Broad Channel (BC), Grass Hassock Channel (B19), and at the Rockaway Treatment Plant (RTP).**

	time	depth (ft)	P (µM)	N (µM)	Si (µM)
September 11, 2000					
GB	16:30	27	10.23	9.39	31.88
		24	8.98	13.55	24.14
	16:37	21	8.74	14.29	22.61
	16:41	18	8.77	14.56	22.68
	16:45	15	8.67	15.63	22.89
	16:49	12	8.69	15.76	24.22
	16:57	12	8.95	16.51	23.37
	17:01	9	9.63	16.48	23.36
	17:04	6	10.17	17.62	25.29
	17:08	3	11.08	17.64	27.55
	17:13	1.5	9.58	16.55	25.11
GB	17:51	36	8.06	12.20	23.36
	17:55	1	6.94	15.70	18.02
September 12, 2000					
GB	8:09	36	9.32	9.38	30.21
	8:14	18	7.82	14.68	19.62
	8:19	1	8.11	15.51	19.10
GB	8:15	33	8.62	11.80	24.42
		15	7.47	14.77	17.32
	8:28	1	9.42	17.45	22.67
		0	10.20	18.02	25.56
GB	11:10	36	8.29	11.35	24.96
	11:13	18	7.75	15.97	19.60
	11:19	1	7.87	16.37	19.86
GB	14:30	30	9.03	8.50	29.49
	14:38	27	8.28	11.34	24.10
	14:44	15	7.72	15.79	18.84
	14:47	0	7.37	16.41	17.04
GB	16:13	30	8.64	9.65	26.35
	16:22	10	7.63	15.45	18.67
	16:26	0	8.01	18.76	22.33
FC	11:59	0	6.61	30.37	11.11
FC	9:04	9	5.21	17.01	15.40
	9:10	1	6.68	24.21	17.03
FC	11:45	6	5.16	16.65	22.20
	11:50	1	6.53	19.23	20.19

FC	15:12	3	6.48	22.24	16.28
FC	16:48	5	6.95	21.86	17.52
WB	10:05	24	1.84	4.34	3.25
	10:11	0	3.13	8.86	7.50
WB	12:10	24	3.46	12.02	10.92
	12:21	0	4.13	14.12	11.25
WB	15:38	27	4.09	13.43	10.63
	15:45	0	4.82	16.04	12.91
WB	17:12	24	3.68	11.69	9.34
	17:18	0	3.68	11.89	9.44
September 13, 2000					
BB	9:00	0.5	9.90	25.44	12.50
BB	9:07	1	26.13	68.53	18.77
BB	9:17	2	19.00	49.56	14.83
BB		1	8.87	21.83	16.85
BB	9:43	7	9.97	24.97	12.51
BB	9:52	0	14.89	38.40	15.16
BB		15	9.14	24.74	11.28
PB		1	5.30	64.96	24.34
PB	12:53	8	6.28	22.04	17.28
PB		1	2.92	66.37	28.12
PB	13:32	1	3.89	21.56	19.30
PB	13:32	1	5.10	21.19	19.86
BC	15:35	27	6.79	16.30	14.97
BC		1	6.85	14.24	15.01
BC	16:13	17	4.65	10.54	14.55
BC		1	4.68	10.33	15.50
BC		1	4.66	10.17	15.60
B19	16:34	36	4.94	14.12	14.68
B19		1	3.84	7.53	13.14
RTP	10:45	9	6.56	16.37	38.55
RTP		0	4.57	12.02	14.81

7.8 Trophic Status of Jamaica Bay: Spatial and Temporal Patterns

Chris Langdon

7.8.1 SUMMARY

Oxygen data indicate that there are two periods of intense phytoplankton production during the year. There is a winter/spring bloom (February-March) and a second weaker bloom in summer (June-July). Rates of net production during the winter/spring bloom ranged from 220-250 mmol O_2 m^{-2} d^{-1} in the Beach Channel to 500 mmol O_2 m^{-2} d^{-1} in North Channel in the vicinity of Fresh Creek and in Grassy Bay. The summer bloom is more spatially variable. Grassy Bay had the highest rates (79-469, avg. 267 mmol O_2 m^{-2} d^{-1}) followed by the eastern end of Beach Channel (17-234, avg. 105 mmol O_2 m^{-2} d^{-1}). Production at the west end of Beach Channel near the entrance to the bay and North Channel in the vicinity of Fresh Creek was highly variable ranging from –184 to 257 mmol O_2 m^{-2} d^{-1} near Fresh Creek and –86 to 10 mmol O_2 m^{-2} d^{-1} near the entrance to the bay. Between the summer and winter/spring blooms is a period when production is uniformly negative (net heterotrophic) throughout the bay (-13 to –119 mmol O_2 m^{-2} d^{-1}). The cause of the drop in production between the winter/spring and summer blooms was not determined. Nutrient concentrations drop but not to levels that would be limiting. We did find evidence that the decline of the summer bloom and the period of heterotrophy that followed could be the result of carbon limitation. Concentrations of $CO_{2\,aq}$, the form of inorganic carbon utilized by the photosynthetic enzyme Rubisco carboxylase, drops over the summer. The lowest concentration in surface waters were observed in Grassy Bay (2.4-4.0 µmol kg^{-1}) but concentrations were also low in North Channel (3.5-9.7 µmol kg^{-1}) and the eastern end of Beach Channel (4.8-6.8 µmol kg^{-1}). The $\delta^{13}C$ of the particulate carbon was –16 to –12 per mil in the areas where low $CO_{2\,aq}$ was found. Phytoplanktons growing under carbon replete conditions have a $\delta^{13}C$ of –24 to –20 per mil. Laboratory studies have shown that $\delta^{13}C$ becomes more positive (heavier) as inorganic carbon becomes limiting. An isotopic shift of +6 to +10 per mil is an indication of severe carbon limitation.

7.8.2 INTRODUCTION

Jamaica Bay receives huge inputs of inorganic nutrients and organic matter from the New York City sewage treatment plants that discharge into the bay. As a result of these inputs Jamaica Bay can be classified as a hypereutrophic system. Chlorophyll concentrations are regularly in the range of 45-65 µg L^{-1} and can go as high as 120 µg L^{-1}. All this chlorophyll strongly attenuates the intensity of light as it passes through the water column. As a result only the shallowest regions of the bay receive enough light to support net production of oxygen. Below this depth the oxygen consuming process of respiration and degradation of organic matter dominates. To maintain a healthy ecosystem the oxygen consumed in the sediments and water column must be replaced by oxygen diffusing into the water from the overlying air, oxygen advected into the bay from the coastal ocean and oxygen produced by phytoplankton in the surface layer. The rapid flushing of the bay is the most important factor keeping the bay well oxygenated. However, the rates of biological activity in the bay are very high and an imbalance between rates of photosynthesis and respiration could easily result in certain areas in the bay becoming hypoxic or anoxic, particularly during the summer when high temperatures elevate respiration rates and low wind speed and thermal stratification combine to reduce the flux of oxygen from the air into the water column. Low oxygen levels and the associated low pH and $[CO_3^{2-}]$ can seriously upset an ecosystem stressing the fauna living in the sediments that need oxygen to metabolize their food and CO_3^{2-} to build their shells. The purpose of this study was to characterize the temporal and spatial variability of oxygen and the parameters of the carbonate system (pH, $CO_{2\,aq}$, pCO_2 and CO_3^{2-}) in the bay and estimate the biological rates of production and consumption in the water column.

7.8.3 METHODS

Sampling was conducted from the US Park Police Marine Unit vessel, Herbert Johnson operated by the NPS or the Fairbanks operated by LDEO depending on availability. Due to the fact that it was not feasible to sample all twelve JBERRT sites because of budgetary and boat time constraints we settled on four stations that we felt would be adequate to characterize the spatial variability of Jamaica Bay. These stations were East and West Beach Channel, Fresh Creek and Grassy Bay (Table 7.8-1). Water samples were collected near the surface and bottom of the water column using a Niskin water sampler. Oxygen samples were collected in triplicate, fixed immediately with the Winkler reagents ($MnSO_4$ and NaOH/NaI) and were titrated back at LDEO within 48 hours. Typical accuracy and precision was ±0.3 µM. Samples for total dissolved inorganic carbon (DIC) and total alkalinity (TA) were collected 250 ml PET plastic bottles and fixed with 25 µL of saturated $HgCl_2$. DIC was determined by coulometry and TA by Gran titration. Typical accuracy and precision of the DIC analyses was ±1-3 µmol kg^{-1}. Typical precision of the TA analysis was 3 µequiv kg^{-1} and the accuracy was ±10 µequiv kg^{-1}. pCO_2, $CO_{2\,aq}$ and pH were computed at *in situ* temperature and salinity using the measured DIC and TA and Mehrbach measured values for K1 and K2. Salinity was measured on a Guildline salinometer.

Two sensor packages were deployed 9/11/01 – 9/15/01 in Grassy Bay, to monitor the diel fluctuations in dissolved oxygen and to attempt to derive an estimate of the rate of primary production at this location. One package deployed near the bottom measured oxygen and temperature and the second deployed near the surface measured oxygen, temperature and salinity. Oxygen sensors were of the pulsed potential variety and were built in the shop at LDEO. The raw sensor readings where calibrated against Winkler data that were collected at the mooring several times during the deployment. The accuracy of the calibrated oxygen sensor data is estimated to be ±5 µM. Temperature was measured with a YSI thermistor and salinity was measured with a Seabird (SBE 4). The accuracy is estimated to be ±0.05C and ±0.02 psu, respectively.

Table 7.8-1Station Locations

Station	Lat, °N	Lon, °W
West Beach Channel	40° 34.7'	73° 52.3'
East Beach Channel	40° 35.2'	73° 49.7'
Fresh Creek	40° 38.2'	73° 52.6'
Grassy Bay	40° 37.5'	73° 48.2'

7.8.4 RESULTS

7.8.4.1 Oxygen levels

The bottle data for the surface and bottom depths are given in Table 7.8-2 and Table 7.8-3. The main finding is that the surface waters of the bay are generally well oxygenated throughout the year (Figure 7.8-1). The lowest oxygen concentration we observed was 59% of saturation at the Fresh Creek station in September 2000. The average percent saturations for the period of June 2000 to March 2001 are 120, 101, 118 and 99 for E. Beach Channel, Fresh Creek, Grassy Bay and W. Beach Channel, respectively. Figure 7.8-2 shows the oxygen saturation in the layer of water closest to the bottom of the bay. Levels drop during the summer as expected due the combination of increased water column stratification and increased oxygen demand due to the increase in temperature. The lowest oxygen concentration observed was 26 µM at the deepest part of Grassy Bay in July. This was probably low enough to deter fish from the area but would not be injurious to the invertebrates living in the sediments. By September the oxygen levels at this site had increased to 39-105 µM. The rest of the bay maintains bottom oxygen levels that would not cause any stress to aquatic organisms. The averages are 120, 73, and 95 percent for E. Beach Channel, Fresh Creek, and W. Beach Channel, respectively.

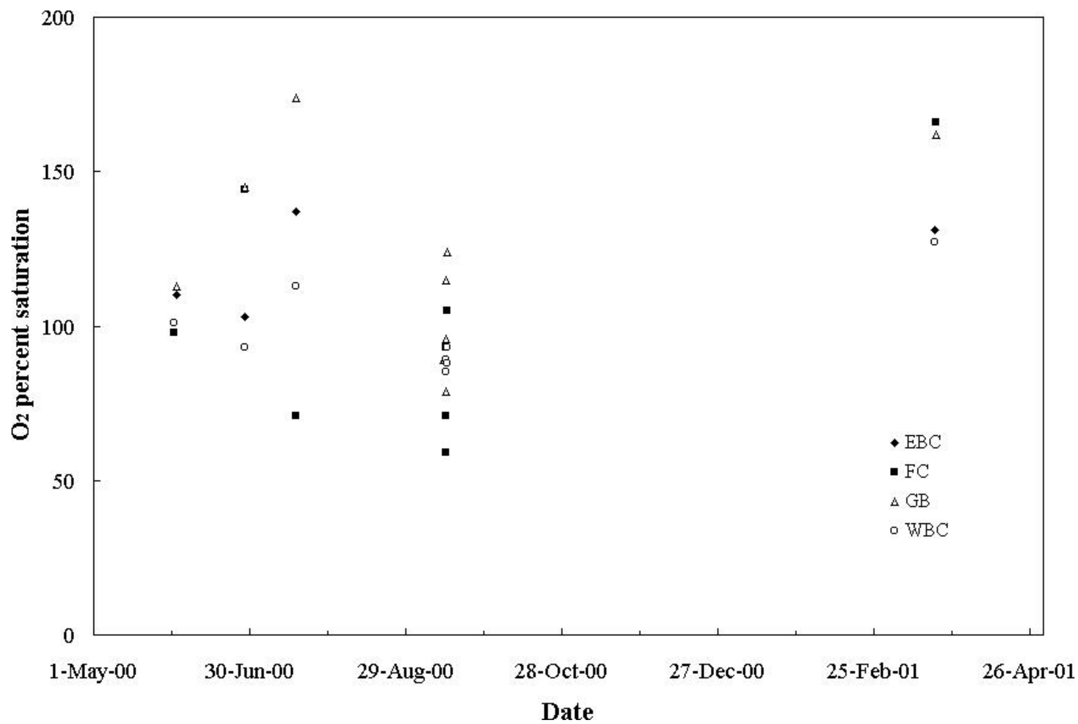

Figure 7.8-1 Oxygen percent saturation in the surface layer.

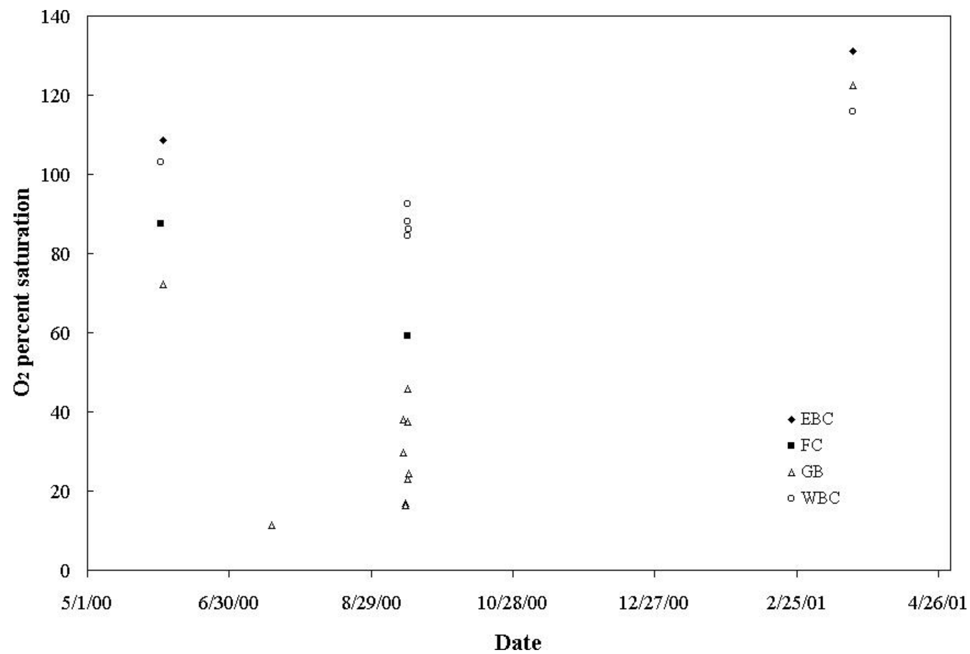

Figure 7.8-2 Oxygen percent saturation in the bottom layer.

In September 2000 we conducted sampling to characterize the variability of oxygen over the course of tidal cycle and in Grassy Bay moored oxygen sensors were deployed for five days to further characterize the diel variability. Variability over a tidal cycle ranged from 18 µM at the west Beach Channel station to 101-104 µM at Grassy Bay and Fresh Creek, respectively (Table 7.8-2). A more detailed picture of the short-term variability of oxygen that occurs in the bay is provided by the mooring time series (Figure 7.8-3). Approximately 50% of the variability in oxygen was explained by variations in temperature. The other 50% is presumably due to oxygen production during the day by photosynthesis and consumption of oxygen at night by respiration. There was a concern that the regular sampling by the Park Service might miss very low oxygen levels at night. It is clear that this is not the case.

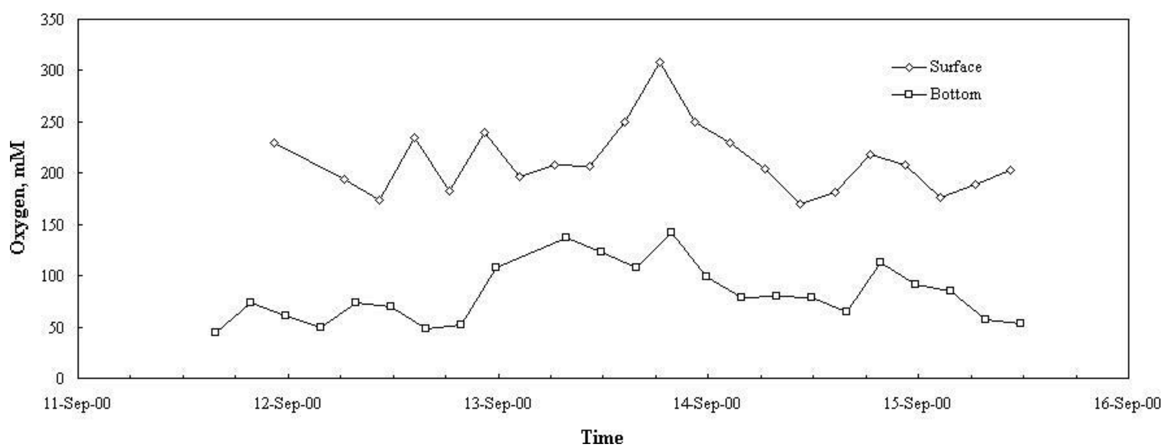

Figure 7.8-3 Time series of oxygen from the mooring deployed in Grassy Bay.

7.8.4.2 $CO_{2\ aq}$ levels

Only a few of the TA samples have been run because of a problem with the titrator, however, based on the data we have we have computed the concentration of $CO_{2\ aq}$. This is the form of inorganic carbon that is used by many aquatic plants. Levels range from 8.5 µmol kg^{-1} near the entrance to the bay (W. Beach Channel) to 4.8-6.8 at Fresh Creek to 2.4-4.0 at Grassy Bay. The decrease reflects increasing spatial isolation from the main source of inorganic carbon to the bay, which is tidal exchange with the coastal ocean. Levels of $CO_{2\ aq}$ less than 10 µmol kg^{-1} have been found to be limiting to some species of phytoplankton. It is interesting that in Jamaica Bay with its virtually inexhaustible supply of nutrients it may be carbon that eventually becomes the limiting element controlling the overall rate of primary production.

7.8.5 Calcite saturation state

The calcite saturation state (Ω_c) for the bottom of Grassy Bay on July 18, 2000 was 1.9. This is approximately one-third of the normal Ω_c of seawater but it still represents a condition that is 190% supersaturated with respect to the mineral calcite produced by bivalves and gastropods. The possibility exists that this may be stressful to the organisms. The reason is that the Ω_c of the pore waters in the sediments are typically lower than in the overlying water because of the production of respiratory CO_2.

The TA samples for September 2000 have not been run yet but if I make the assumption that TA does not change much seasonally then I can estimate Ω_c during the period of the year that surface Ω_c might be the lowest. I find that Ω_c might be on the order of 1.7 to 2.3 at Fresh Creek, Grassy Bay and west Beach Channel. This is similar to the level observed at the bottom of Grassy and the same comments apply as the possible stress this might impose on bivalves and gastropods.

7.8.5.1 pCO_2 levels

The partial pressure of CO_2 gas in the surface waters of the water were significantly under saturated with respect to the atmosphere, which has a concentration of 368 µatm at present. The only process likely to lower the pCO_2 of the water is the photosynthetic draw down of DIC. The pCO_2 was lowest in Grassy Bay (73-114 µatm), followed by east Beach Channel (157-204 µatm), Fresh Creek (105-315 µatm) and west Beach Channel (215-256 µatm). These data indicate that net production of organic matter is occurring across the bay during June and July 2000 and that the highest rates are in Grassy Bay followed by east Beach Channel, Fresh Creek and west Beach Channel.

7.8.6 Rates of net community production

I have estimated rates of net community production (NCP) by the oxygen disequilibria method. The method is based on a simple mass balance of oxygen in the water column. NCP is assumed to be equal to the flux of oxygen across the air-sea interface. The gas exchange flux can be computed from knowledge of water temperature, wind speed and the oxygen concentration gradient across the air-sea interface.

$$NCP = k_{O2}(C_w - C^*)$$

Where NCP is in units of mmol O_2 m^{-2} d^{-1}, k_{O2} is the oxygen gas exchange coefficient computed from a parameterization of temperature and wind speed (Wanninkhof, 1992) in units of m d^{-1}, C_w is the oxygen concentration of the water in µM or mmol m^{-3} and C^* is the oxygen concentration of water equilibrated with air computed as a function of temperature and salinity (Benson and Krause, 1984). The method assumes that oxygen concentration on the time scale of a few days is in steady state and that no net oxygen is transported into or out of the water column. These assumptions are difficult to test without a great deal of information about the temporal and spatial variability of oxygen and the currents in the region. However, in a very productive area like Jamaica Bay I believe but cannot prove that the other terms on the oxygen budget are probably small relative to the gas exchange term so that the accuracy of the method is on the order of 10-20%.

The highest rates of NCP averaged over the four sample locations were July 18, 2000 (128 mmol O_2 m^{-2} d^{-1}) and March 20, 2001 (367 mmol O_2 m^{-2} d^{-1}). This is consistent with the historical chlorophyll data that indicates that there are two phytoplankton blooms in Jamaica Bay. A winter/spring bloom that can reach peak chlorophyll concentrations of 120 μg L^{-1} and a second weaker bloom during the summer. Separating the summer bloom and the winter/spring bloom is a period in September when NCP becomes negative (-71 mmol O_2 m^{-2} d^{-1}). Spatially NCP is quite variable. NCP is highest in Grassy Bay averaging 257 mmol O_2 m^{-2} d^{-1} over the study. Ranked in order of decreasing NCP, Grassy Bay is followed by east Beach Channel, Fresh Creek and west Beach Channel. Interestingly, this is the same order that the draw down in pCO_2 would rank the productivity of the stations. I suspect that in a system like Jamaica Bay that has an inexhaustible nutrient supply that the level of plant biomass and hence NCP becomes dependent on residence time of the water. The west Beach Channel station is closest to the entrance to the bay and the water there will be exchanged on almost a daily basis resulting in little time for biomass to accumulate. Grassy Bay is the furthest removed from the entrance of the bay and therefore the residence time of the water is the longest. Houghton et al. (this report) based on a dye injection study estimate that the residence of water shallower than 5 m in Grassy Bay is on the order of 7 days. This is sufficient time for biomass to build up to the highest level in the bay and for DIC to be pulled down to the lowest level. The east Beach Channel and Fresh Creek stations are intermediate in their distances from the entrance to the bay and are intermediate in terms of all measured parameters, i.e. oxygen saturation, pCO_2 draw down, and NCP.

Our sampling does not cover the period between the winter/spring bloom and the summer so I cannot make any conjectures about why the winter/spring bloom collapses. I can comment on why the summer bloom may collapse. I observed that the concentration of $CO_{2\,aq}$, the form of inorganic carbon utilized by the photosynthetic enzyme Rubisco, declines over the summer and by July 18, 2000 had reached a concentration of 2.4 μmol kg^{-1} in the surface waters of Grassy Bay. This is less than 25% of the concentration available in normal seawater and laboratory studies have shown that it would be strongly limiting to phytoplankton (Riebesell et al., 1993). Further support for carbon limitation comes from the $\delta^{13}C$ composition of the particulate matter. Sambrotto (this report) found a significant positive relationship between $\delta^{13}C$ and the concentration of particulate carbon (POC) in Jamaica Bay. It is well known from both laboratory and field studies that as CO_2 becomes limiting the $\delta^{13}C$ of phytoplankton becomes progressively heavier. Sambrotto observed an isotopic shift of +6 to +10 per mil. This is very conclusive evidence of carbon limitation. I hypothesize that sometime after July 18, 2000 carbon limitation caused the crash of the summer bloom in Jamaica Bay. Subsequently CO_2 levels recovered once the demand was reduced but the phytoplankton do not recover until the following winter/spring. The explanation may be that carbon limitation reduced the phytoplankton population to a level that the zooplankton community could keep a lid on them until cold winter temperatures caused a collapse of the zooplankton population. This is only conjecture because no one quantified zooplankton abundance and grazing rate in this study.

7.8.7 REFERENCES

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7.8.8 TABLES

Table 7.8-2 Surface Bottle Data

Table 1. Surface bottle data

Date	Station	Temp	Salinity, psu	O_2, μM	%O_2 sat	C*, μM	TA, μequiv kg^{-1}	DIC, μmol kg^{-1}	pCO_2, μatm	pH	$CO_{2\,aq}$, μmol kg^{-1}
6/2/00	EBC	17.1	26.5	284	110	257	nd	nd	nd	nd	nd
6/28/00	EBC	20.6	27.0	247	103	240	1876	1608	204	8.23	6.8
7/18/00	EBC	23.2	27.6	312	137	228	1866	1530	157	8.31	4.8
3/20/01 12:43	EBC	7.0		423	131	322					
6/1/00	FC	16.5	25.0	257	98	262	nd	nd	nd	nd	nd
6/28/00	FC	20.4	25.8	350	144	242	1908	1517	105	8.47	3.5
7/18/00	FC	23.3	26.5	163	71	229	1946	1722	315	8.09	9.7
9/13/00 9:10	FC	24.0	26.6	160	71	226		1840			
9/13/00 11:50	FC	24.0	25.5	135	59	227		1871			
9/13/00 15:12	FC	24.0	25.5	213	93	227		1852			
9/13/00 16:48	FC	24.0	25.6	239	105	227		1758			
3/20/01 14:12	FC	9.3		506	166	305					
6/2/00	GB	17.0	24.9	293	113	260	nd	nd	nd	nd	nd
6/28/00	GB	22.4	24.2	342	145	236	1865	1495	114	8.44	4.0
7/18/00	GB	24.3	25.5	394	174	226	1868	1388	73	8.57	2.4
9/12/00 8:19	GB	24.0	25.4	202	89	227		1723			
9/12/00 17:08	GB	23.8	25.4	199	87	229.7		1783			
9/13/00 8:28	GB	24.2	24.3	181	79	228		1854			
9/13/00 11:19	GB	24.2	25.3	217	96	227		1773			
9/13/00 14:47	GB	24.2	25.2	261	115	227		1745			
9/13/00 16:26	GB	24.2	24.9	282	124	227		1786			
3/20/01 13:22	GB	6.7		523	162	324					
6/1/00	WBC	17.0	25.5	263	101	259	nd	nd	nd	nd	nd
6/28/00	WBC	20.2	26.8	225	93	261	1863	1637	215	8.16	8.5
7/18/00	WBC	22.5	28.0	259	113	261	1907	1653	256	8.15	8.0
9/13/00 10:11	WBC	23.6	28.0	191	89	224		1829			
9/13/00 12:24	WBC	23.6	27.3	192	85	225		1802			
9/13/00 15:45	WBC	23.6	27.1	209	93	225		1839			
9/13/00 17:18	WBC	23.6	27.6	198	88	225		1807			
3/20/01 12:12	WBC	7.1		409	127	321					

Table 7.8-3 Bottom Bottle Data

Table 2. Bottom bottle data.

Date	Station	Depth, m	Temp	Sal, psu	O_2, μM	%O_2 sat	C*, μM	TA, μequiv kg^{-1}	DIC, μmol kg^{-1}	pCO_2, μatm	pH
6/2/00	EBC	10.0	17.1	26.50	279	109	257	nd	nd	nd	nd
3/20/01 12:43	EBC	7.0	7.0		418	131	319				
6/1/00	FC	10.0	17.1	24.70	227	87	260	nd	nd	nd	nd
9/13/00 11:45	FC	1.8	23.3	26.37	135	59	229				
6/2/00	GB	15.0	19.7	23.00	180	72	250	nd	nd	nd	nd
7/18/00	GB	15.0	22.9	26.79	26	11	230	1938	1852	830	7.72
9/11/00 16:30	GB	8.2	22.4	25.94	70	30	233		1920		
9/11/00 17:51	GB	11.0	22.6	26.22	89	38	232		1868		
9/12/00 8:09	GB	11.0	22.7	26.02	39	17	232		1917		
9/12/00 16:34	GB	10.0	22.5	26.20	38	17	233		1826		
9/13/00 8:15	GB	10.1	23.2	25.96	105	46	230		1881		
9/13/00 11:10	GB	9.1	23.2	25.90	86	37	230		1870		
9/13/00 14:30	GB	9.1	23.1	26.03	53	23	230				
9/13/00 16:13	GB	9.1	23.1	26.01	56	24	230				
3/20/01 13:22	GB	10.0	6.7		394	122	322				
6/1/00	WBC	9.0	16.7	25.00	269	103	261	nd	nd	nd	nd
9/13/00 10:05	WBC	7.3	23.3	28.52	199	88	226				
9/13/00 12:10	WBC	7.3	23.3	27.55	192	84	228		1818		
9/13/00 15:38	WBC	8.2	23.3	27.33	211	92	228		1800		
9/13/00 17:12	WBC	7.6	23.3	27.60	196	86	227		1799		
3/20/01 12:12	WBC	7.0	6.6		372	116	321				

Table 7.8-4 Calculated rates of net community production

Table 3. Calculated rates of net community production based on oxygen disequilibria with atmosphere.

Date	Avg. Wind Speed	kO_2	EBC	FC	GB	WBC	
	m s^{-1}	m d^{-1}		mmol O_2 m^{-2} d^{-1}			Avg
6/2/00	4.5	2.4	64	-12	79	10	35
6/28/00	4.5	2.4	17	257	252	-86	110
7/18/00	4.7	2.8	234	-184	469	-6	128
9/13/00	4.9	3.0	nd	-119	-13	-81	-71
3/20/01	6.1	2.5	251	500	496	219	367
		Avg	142	88	257	11	

7.9 Nitrogenous Nutrients and Plankton Production in Jamaica Bay, NY

Ray Sambrotto

7.9.1 SUMMARY

Two blooms characterize phytoplankton growth in Jamaica Bay: the winter/spring bloom, between February and April; and the summer bloom between June and September. The winter/spring bloom is more productive with chlorophyll α concentration ranging between 45 and 65 µg/l. Nitrate and nitrite levels decrease in summer and over the ten year period of the 1990s, concentrations never exceeded 4.5 µmoles/l between the months of March and August. Ammonia exhibits a similar trend to that seen for nitrate + nitrite. Throughout the summer bloom, concentrations also decrease but remain above an average of 25 µmoles/l for the duration. Phosphate concentrations never decreased below 0.25 µmoles/l. Unlike inorganic nitrogen, phosphate depletion only occurs during the winter/spring phytoplankton blooms. Dissolved organic nitrogen (DON) levels equal those of dissolved inorganic nitrogen (DIN) in summer and provide a significant pool of combined nitrogen for plant and bacterial growth. The isotopic composition of organic carbon ($\delta^{13}C$) suggests that phytoplankton experience periods of carbon limitation during intense blooms.

7.9.2 INTRODUCTION

Estuarine environments are typically productive and provide food and habitat for a large number of birds, mammals, fish and other wildlife. Jamaica Bay is a eutrophic coastal lagoon that is a goods example of such a system that that has, and is currently, undergoing significant biogeochemical modification in response to the changing level and nature of anthropogenic inputs. Much of the food supply is derived from the primary production of phytoplankton (Simpson *et al.* 1977). Because of this, variations in the amount and type of phytoplankton production brought about by changes in nutrient levels such as phosphorus or nitrogen can impact the larger estuarine food web. One of the human activities that has most altered coastal ecosystem is the use of estuaries and other coastal areas for sewage disposal and fresh water runoff of Jamaica Bay is dominated by outflow from sewage treatment plants. When nitrogen and phosphorus become overabundant, it can lead to an increased growth of nuisance algae. Such eutrophication can cause coastal waters to become anoxic or hypoxic, effectively choking the marine organisms living there, disrupting the food chain, reducing fishery harvests and decreasing biodiversity (Howarth *et al.* 2000).

This report summarizes the results of recent work that examines the nutrients and particulate organic matter of Jamaica Bay. These data were designed to address the eutrophication status of the Bay and look for biological and/or chemical indexes that could be used to follow future changes. The measurement suite includes dissolved inorganic nitrogen (DIN), selected dissolved organic nitrogen pools such as amino acids and urea, particulate carbon and nitrogen and their corresponding isotopic enrichment. Most of the new measurements were collected during the spring and summer of 2000 and March, 2001. The report is organized into three sections. The first deals with a synthesis of the historical data compiled during the 1990s by the New York City Dept. of Environmental Conservation. The second presents the results of the 2000-2001 field work on nutrients. Finally, the third section summarizes the isotopic results.

7.9.3 Results I: Synthesis of nutrient and production data from the 1990s

The New York City Dept. of Environmental Conservation has measured the major nutrients and chlorophyll levels at several sites in Jamaica Bay for more than a decade as part of a long-standing program of water quality assessment. One of the first tasks for this project was the compilation and analysis of the high-quality data collected at ten sites in the Bay by the NYC-DEP and provided to us from the NY Harbor Water Quality Regional Reports (Figure 7.9-1).

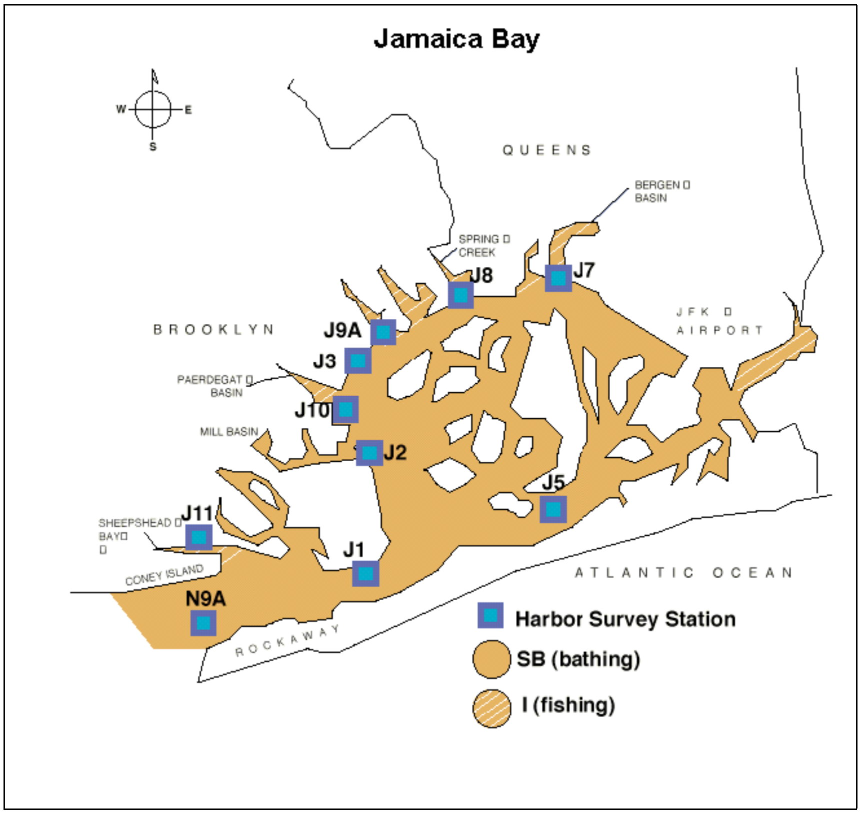

Figure 7.9-1: Jamaica Bay and the 10 monitoring stations used by the New York City Department of Environmental Protection (NYC DEP 1999).

With these data, we were able to address the following questions: 1) What are the typical seasonal patterns of nutrients and production? 2) How have nutrient and production levels in the Bay changed in recent years?; and finally, 3) Has there been any correlation between changes in nutrients and production levels?

There is a clear seasonal trend in DIN and phosphate levels in the Bay (Figure 7.9-2 and Figure 7.9-3). Combined nitrate + nitrite is generally lower from March to September, but there is a consistent rise in May of each year. In contrast, phosphate levels are lowest in February and March, and generally high and invariant for much of the rest of the year. Both of these elements are primary macronutrients needed for phytoplankton production. Nitrogen enrichment is common in coastal waters where sewage and treated effluent water is disposed. An increase in nitrogen, which has been shown to limit production, could lead to eutrophication in coastal ecosystems.

The difference in the seasonal trends may reflect seasonal differences in nutrient loading. However a more likely interpretation is that the succession of phytoplankton species in the Bay influence the utilization of nutrients. Thus, although at this point, the effect of seasonal changes in the mix of nutrients discharged cannot be ruled out, the biology of the Bay itself is more likely the cause of the difference. This is supported by the fact that the changes in nitrogen were more similar to the seasonal changes in chlorophyll (Figure 7.9-4). A correlation analysis showed that dissolved inorganic nitrogen (nitrate + nitrite + ammonium) accounted for much more of the variance in chlorophyll levels than did phosphate (r^2=0.89 vs. r^2=0.31).

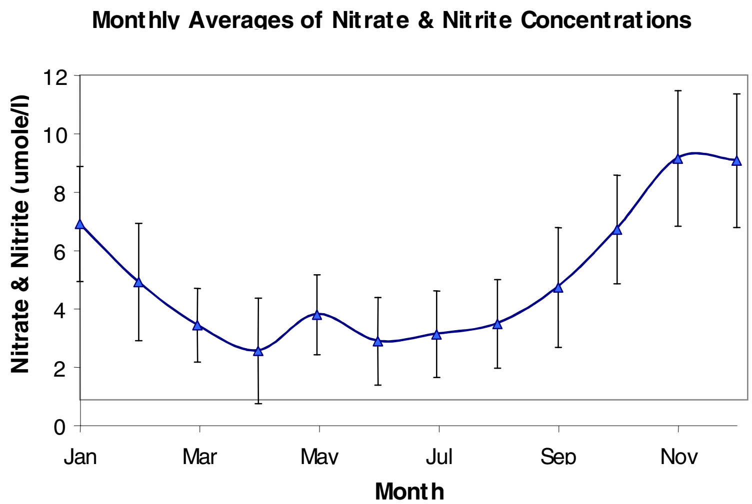

Figure 7.9-2: Monthly averages for nitrate and nitrite concentrations in Jamaica Bay, show seasonal trends in nutrient levels. Nitrate and nitrite levels range from 2.55 µmole/l to 9.14 µmole/l with peaks in May and November through January.

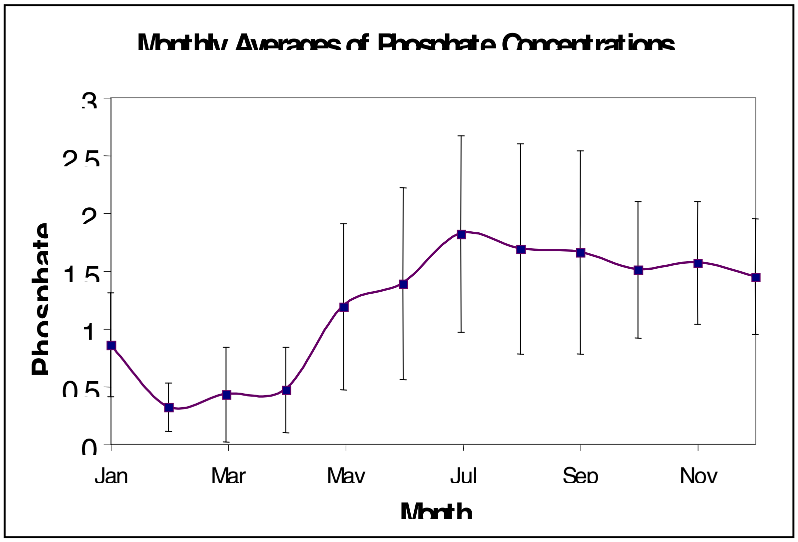

Figure 7.9-3: **The monthly averages for phosphate concentration in Jamaica Bay, showing seasonal trends in nutrient levels. Phosphate levels range from 0.32 μmole/l to 1.82 μmole/l with high levels in May though November.**

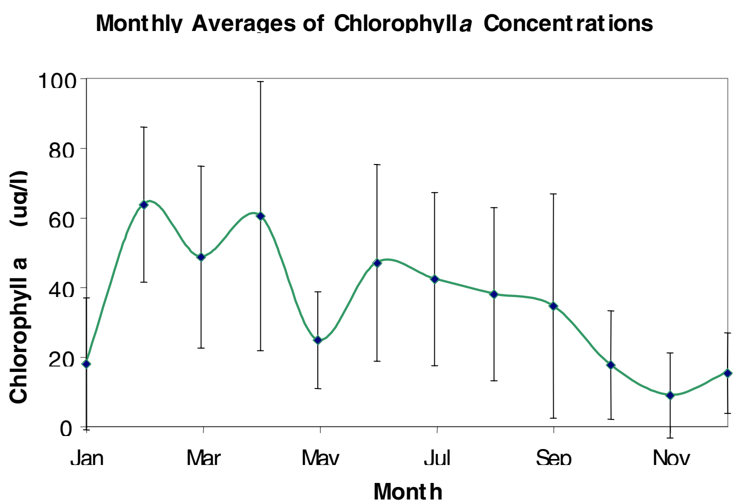

Figure 7.9-4: Monthly averages of chlorophyll α concentration in Jamaica Bay, showing seasonal trends in production. Chlorophyll α levels range from 8.90 μg/l to 63.69 μg/l with peaks in February through April, and June through August.

7.9.4 RESULTS II – NITROGENOUS NUTRIENTS DURING 2000.

During 2000, a survey of nitrogenous nutrients was conducted in Jamaica Bay that concentrated on a more detailed analysis of the organic components. Although these components can be present at significant levels, they are rarely measured and may have diagnostic values in assessing the health of the Bay. The measurements were made at four sites in the Bay (Figure 7.9-5). In Grassy Bay, levels of dissolved organic nitrogen (DON) were equal to the DIN at most sampling times (Figure 7.9-6). In the west Channel (Figure 7.9-7) levels of DON were lower, but remained a significant part of the dissolved nitrogen pool. The gradient in dissolved organic nitrogen compounds between Grassy bay and the more rapidly flushed west Channel station suggests that the organic constituents originate in the Bay or its tributaries and are flushed out through the mouth of the Bay.

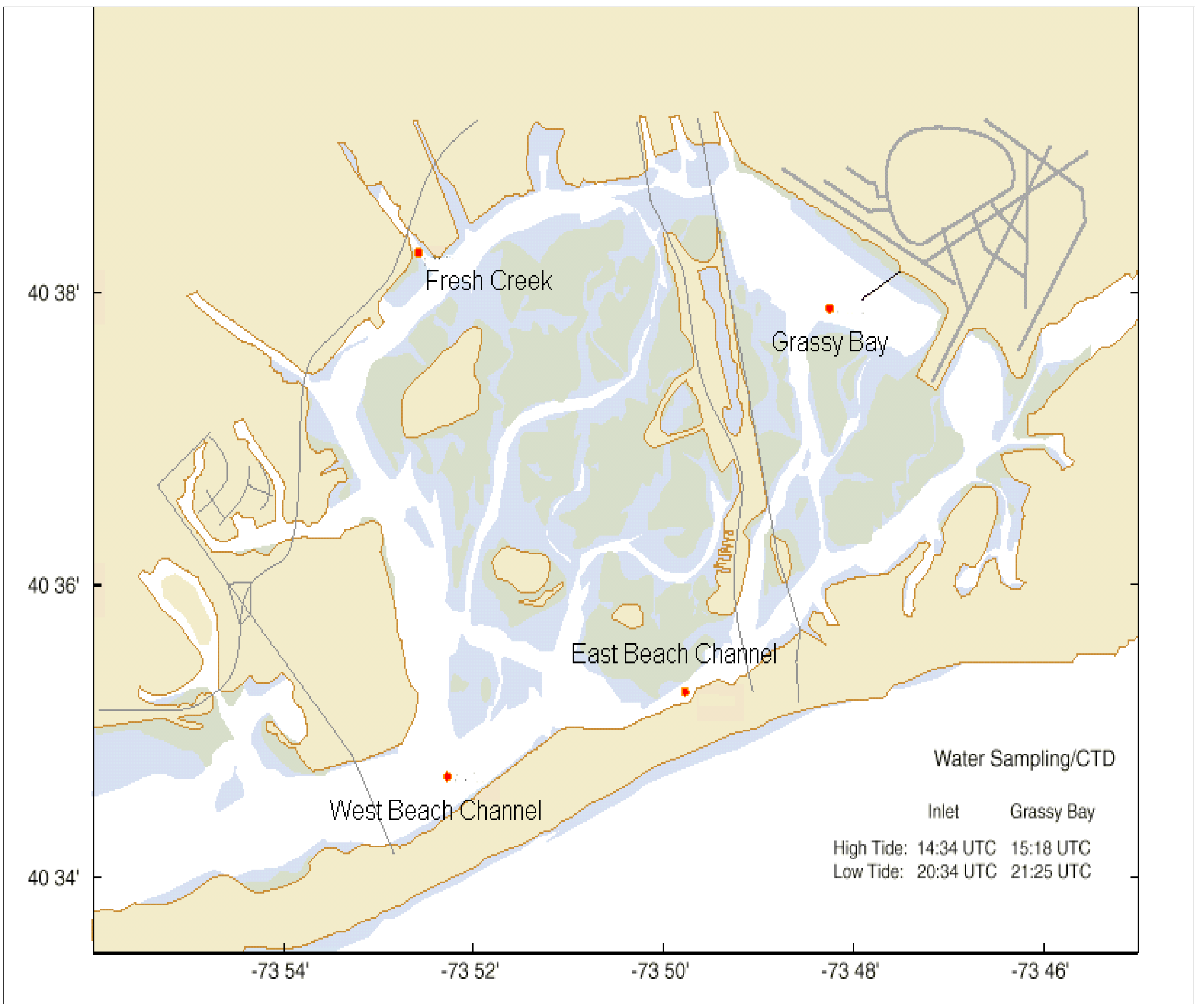

Figure 7.9-5. Sampling sites in Jamaica Bay

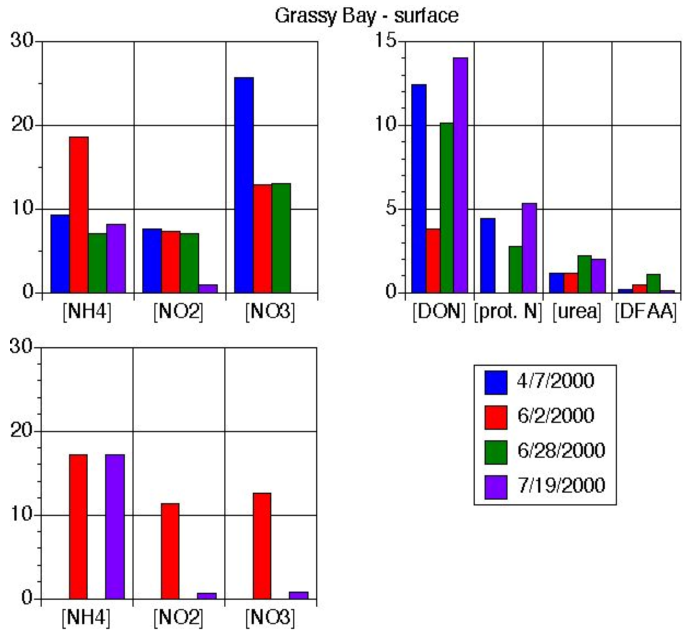

Figure 7.9-6

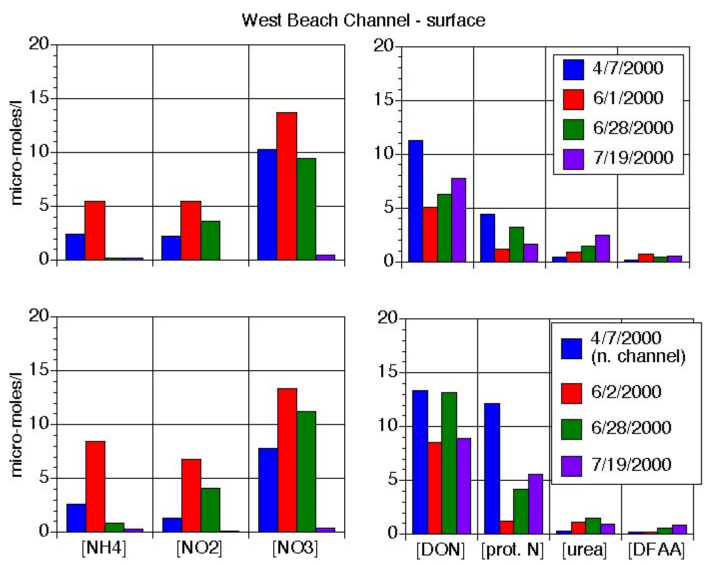

Figure 7.9-7

7.9.5 RESULTS III – ISOTOPIC EV IDENCE FOR CARBON LIMITATION DURING PEAK PRODUCTIVITY TIMES.

The importance of nitrogen and phosphorus levels are due to the fact that in many aquatic systems, these elements limit production. However, in estuarine conditions where an abundance of these nutrients are present year-round in either inorganic or organic form, perhaps other factors limit the rate of organic matter synthesis at certain times. In addition to the levels of nutrients, the amount of particulate organic matter suspended in Bay waters was also measured.

Like chlorophyll, particulate carbon reached extraordinary levels during phytoplankton bloom periods. At the greatest levels, a significant increase in the isotopic composition of the organic carbon was observed (Figure 7.9-8).

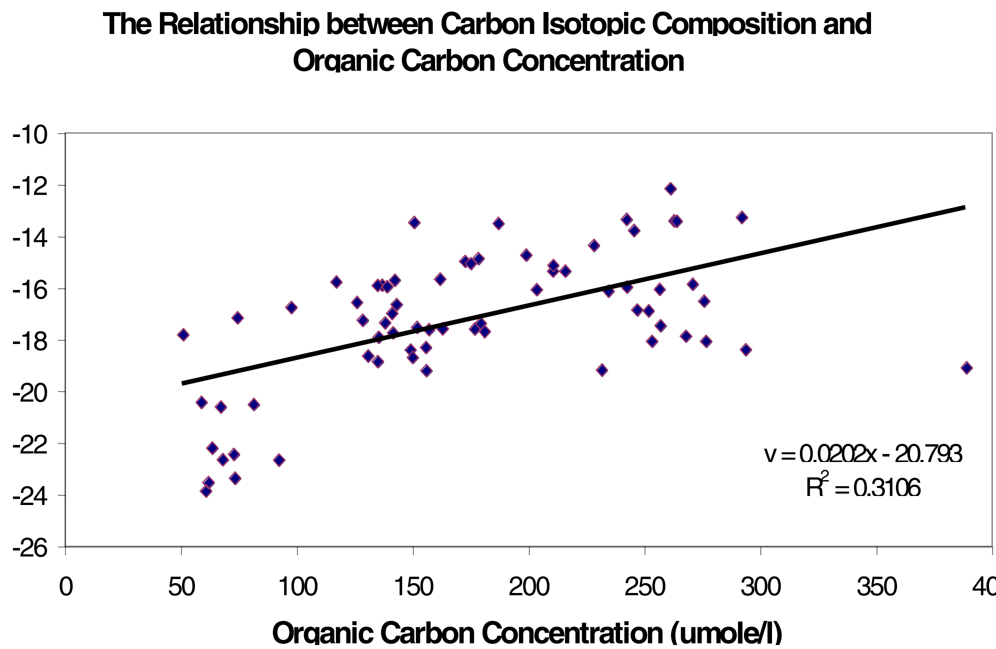

Figure 7.9-8: The relationship between organic carbon concentration and carbon isotopic composition ($\delta^{13}C$) in surface waters. $\delta^{13}C$ values range from –23.86 to –12.16. Carbon concentration ranges from 51.10 to 389.09 µmole/l. A positive correlation exists between the two variables with an R^2 value of 0.3106. Note that the $\delta^{13}C$ of inorganic carbon in the atmosphere is between –7.0 and –8.0.

Phytoplankton assimilate inorganic carbon during photosynthesis and normally discriminate against the heavier isotope when carbon dioxide is abundant. The isotopic data suggest that during bloom periods in Jamaica Bay, phytoplankton grow so rapidly that they deplete the amount of carbon dioxide. This scarcity is reflected in their isotopic signature because the discrimination against the heavy isotope decreases and the resulting organic carbon is heavier.

There are several other variables that affect fractionation to a different degree (Table 7.9-1). Although all these factors influence carbon fractionation by marine phytoplankton, there is still an overriding correlation between fractionation and pCO_2 concentration. Thus, it may be able to follow the changing trophic status of the Bay by measuring the isotopic signature of the organic carbon produced during bloom periods.

Variable	Range
PCO_2 concentration	20%0
Species	8–10%0
pH	9%0
Temperature	8%0
Light	2-3%0

Table 7.9-1: The ranges in fractionation factors (ε_p) caused by changes in specific variables. Although many different things affect fractionation, pCO_2 concentration has the largest impact. It is followed by: species-related differences, pH, temperature and light.

7.9.6 References

Howarth, R.W. Swaney, D.P., Butler, T.J., Marino, R. (2000) Climatic control on eutrophication of the Hudson River Estuary. *Ecosystems*, 3: 210-215.

Simpson H.J., Williams, S.C., Olsen C.R., Hammond, D.E. (1997) Nutrient and particulate matter budgets in urban estuaries. *Estuaries, Geophysics and the Environment*, National Academy of Sciences, Washington D.C., pp. 94-103.

8.0 Acknowledgements

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9.0 Appendices

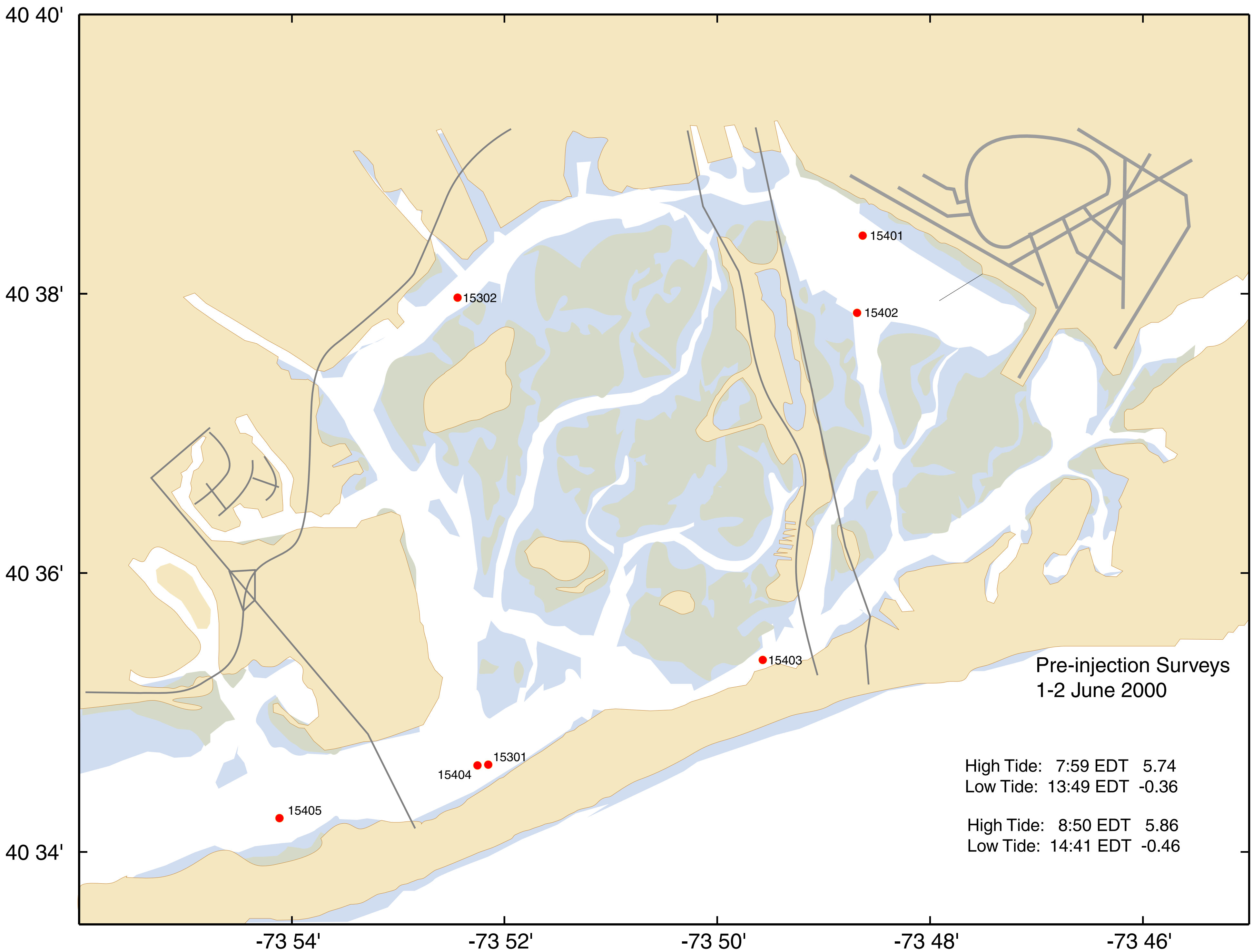
9.1 Appendix 1 - Jamaica Bay $\delta^{18}O$ and salinity measurements, June-July September 2000

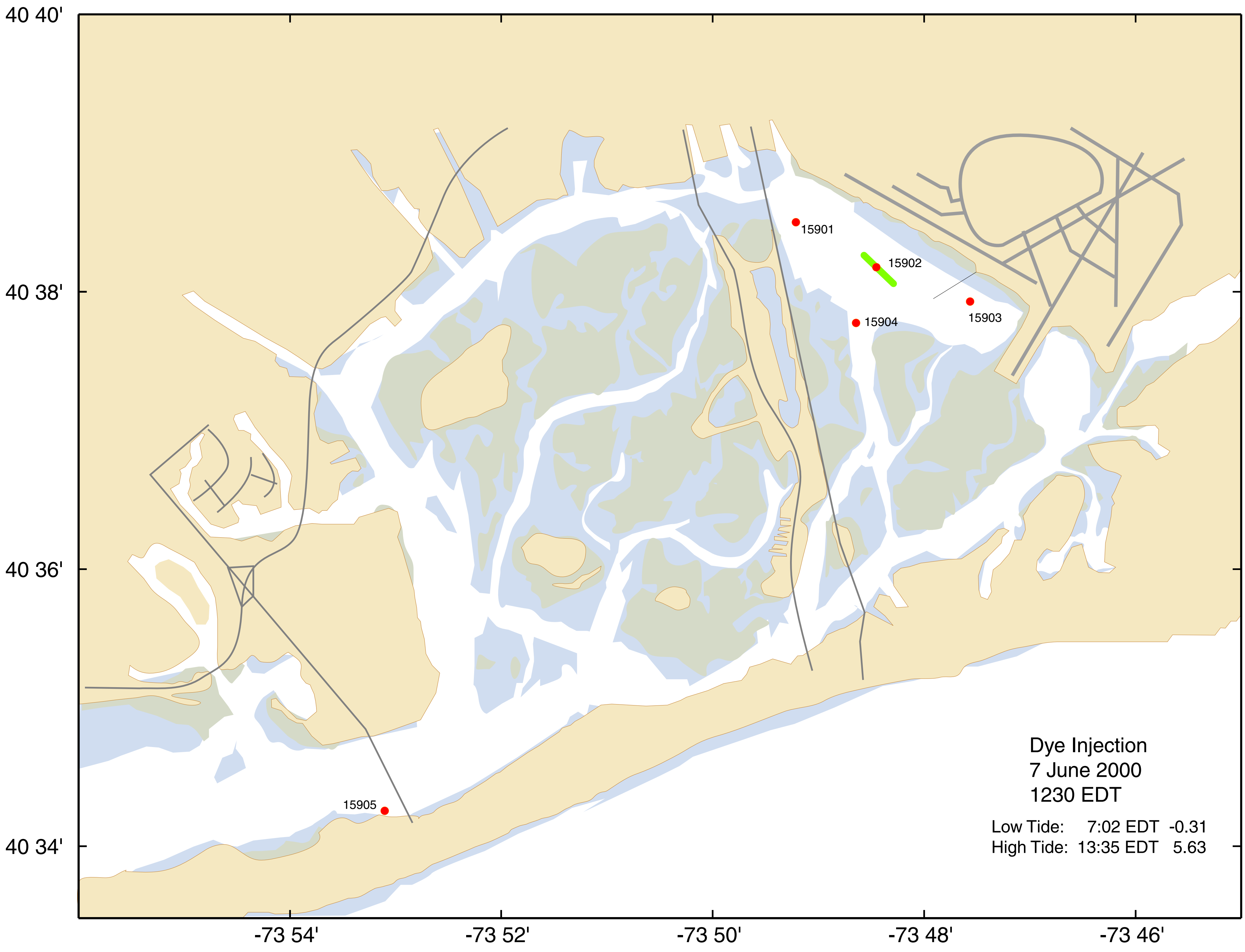
Date	Time (L)	Sta	Locale	Lat (°N)	Lon (°W)	Bottle #	Depth (m)	δ^{18}O (VSMOW)	Salinity	Delta
6/2/00	12:15	4	Beach Chan E	40.5867	73.8283	O-59	-0.30	-2.2462	24.984	-2.190
6/2/00	12:15	4	Beach Chan E	40.5867	73.8283	O-60	-4.57	-2.2183	25.282	-2.162
6/2/00	12:15	4	Beach Chan E	40.5867	73.8283	O-52	-8.53	-2.2043	25.303	-2.149
6/28/00		4	Beach Chan E	40.5867	73.8283	O-51	-0.30	-2.4755	25.097	-2.413
7/19/00	11:39	4	Beach Chan E	40.5867	73.8283	O-69	-0.30	-1.8425	27.514	-1.792
6/1/00	12:15	1	Beach Chan W	40.5783	73.8717	2	-0.30	-2.1560	25.529	-2.101
6/1/00	12:15	1	Beach Chan W	40.5783	73.8717	O-56	-4.27	-2.2033	24.492	-2.149
6/1/00	12:15	1	Beach Chan W	40.5783	73.8717	O-58	-8.53	-2.2253	24.633	-2.170
6/28/00		1	Beach Chan W	40.5783	73.8717	O-53	-0.30	-2.2435	25.772	-2.186
7/19/00	13:10	1	Beach Chan W	40.5783	73.8717	O-63	-0.30	-1.7772	28.022	-1.727
6/1/00	13:07	2	Fresh Creek	40.6367	73.8767	5	-0.30	-2.6612	23.355	-2.599
6/1/00	13:07	2	Fresh Creek	40.6367	73.8767	O-57	-4.88	-2.3909	24.461	-2.332
6/1/00	13:07	2	Fresh Creek	40.6367	73.8767	O-55	-10.06	-2.3939	24.647	-2.335
6/28/00		2	Fresh Creek	40.6367	73.8767	O-68	-0.30	-2.4700	24.858	-2.409
7/19/00	12:45	2	Fresh Creek	40.6367	73.8767	O-62	-0.30	-2.0086	26.736	-1.955
6/2/00	10:40	3	Grassy Bay	40.6250	73.8033	4	-0.30	-2.6727	23.140	-2.611
6/2/00	10:40	3	Grassy Bay	40.6250	73.8033	O-54	-4.27	-2.3575	24.575	-2.300
6/2/00	10:40	3	Grassy Bay	40.6250	73.8033	3	-8.53	-2.2672	24.799	-2.211
6/28/00		3	Grassy Bay	40.6250	73.8033	O-67	-0.30	-2.5807	24.246	-2.518
7/19/00	12:03	3	Grassy Bay	40.6250	73.8033	O-70	-0.30	-2.1483	25.704	-2.093
7/19/00	12:20	3	Grassy Bay	40.6250	73.8033	O-61	-11.34	-1.8490	26.703	-1.800
9/12/00	9:00	BB	Bergen Basin	40.6647	73.8230	16	0.00	-2.586	24.282	-2.524
9/12/00	9:07	BB	Bergen Basin	40.6633	73.8233	17	0.00	-4.393	15.794	-4.323
9/12/00	9:27	BB	Bergen Basin	40.6603	73.8240	21	0.00	-3.232	21.142	-3.164
9/12/00	9:32	BB	Bergen Basin	40.6603	73.8240	22	-0.89	-2.603	23.984	-2.541
9/12/00	9:38	BB	Bergen Basin	40.6603	73.8240	23	-1.19	-2.644	24.042	-2.581
9/12/00	9:43	BB	Bergen Basin	40.6603	73.8240	24	-2.13	-2.498	24.897	-2.436
9/12/00	9:12	BB	Bergen Basin	40.6592	73.8238	18	0.00	-3.927	18.185	-3.856
9/12/00	9:17	BB	Bergen Basin	40.6581	73.8240	19	0.00	-3.370	20.510	-3.301
9/12/00	9:52	BB	Bergen Basin	40.6575	73.8225	25	0.00	-3.209	21.043	-3.141
9/12/00		BB	Bergen Basin	40.6575	73.8225	26	-3.05	-2.237	25.642	-2.179
9/12/00	9:20	BB	Bergen Basin	40.6508	73.8235	20	-2.74	-2.295	25.449	-2.237
9/12/00	11:59	FC	Fresh Creek	40.6349	73.8820	27	0.00	-2.541	24.595	-2.478
9/14/00		TB	Thurston Basin	40.6426	73.7478	71	-3.05	-2.129	25.445	-2.075
9/14/00		TB	Thurston Basin	40.6426	73.7478	72	0.00	-2.211	25.184	-2.155
9/14/00	13:32	TB	Thurston Basin	40.6376	73.7478	69	-4.27	-2.068	26.086	-2.014
9/14/00		TB	Thurston Basin	40.6376	73.7478	70	0.00	-2.118	25.514	-2.064
9/13/00	9:04	FC	Fresh Creek	40.6366	73.8769	42	-2.74	-1.978	26.809	-1.925
9/13/00	9:10	FC	Fresh Creek	40.6366	73.8769	43	0.00	-2.064	26.605	-2.009
9/13/00	15:12	FC	Fresh Creek	40.6366	73.8760	60	0.00	-2.245	25.463	-2.188
9/13/00	16:48	FC	Fresh Creek	40.6365	73.8757	66	0.00	-2.249	25.580	-2.192

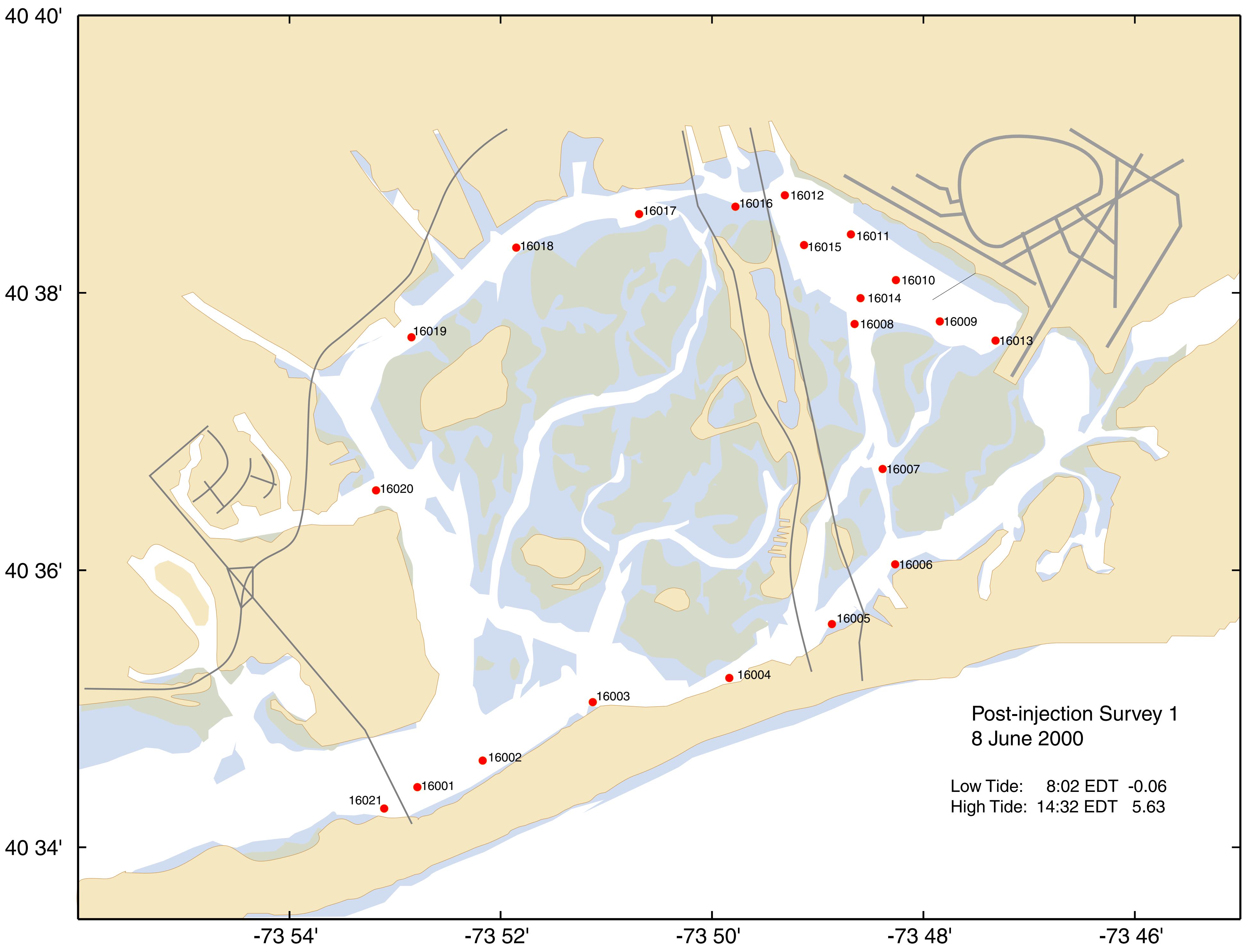
9/13/00	11:45	FC	Fresh Creek	40.6340	73.8738	52	-1.83	-2.128	26.365	-2.072
9/13/00	11:50	FC	Fresh Creek	40.6340	73.8738	53	0.00	-2.232	25.512	-2.175
9/12/00	12:53	PB	Paerdegat Basin	40.6314	73.9134	28	0.00	-2.983	22.504	-2.916
9/11/00	16:30	GBM	Grassy Bay	40.6312	73.8067	1	-8.23	-2.264	25.937	-2.205
9/11/00	16:37	GBM	Grassy Bay	40.6312	73.8067	2	-6.40	-2.199	25.678	-2.143
9/11/00	16:41	GBM	Grassy Bay	40.6312	73.8067	3	-5.49	-2.219	25.592	-2.163
9/11/00	16:45	GBM	Grassy Bay	40.6312	73.8067	4	-4.57	-2.207	25.537	-2.151
9/11/00	16:49	GBM	Grassy Bay	40.6312	73.8067	5	-3.66	-2.444	24.672	-2.384
9/11/00	16:57	GBM	Grassy Bay	40.6312	73.8067	6	-3.66	-2.195	25.571	-2.139
9/11/00	17:01	GBM	Grassy Bay	40.6312	73.8067	7	-2.74	-2.369	25.082	-2.310
9/11/00	17:04	GBM	Grassy Bay	40.6312	73.8067	8	-1.83	-2.393	24.793	-2.334
9/11/00	17:08	GBM	Grassy Bay	40.6312	73.8067	9	-0.91	-2.538	24.332	-2.476
9/11/00	17:13	GBM	Grassy Bay	40.6312	73.8067	10	-0.46	-2.397	24.732	-2.338
9/11/00	17:51	GBM	Grassy Bay	40.6312	73.8067	11	-10.97	-2.126	26.223	-2.070
9/11/00	17:55	GBM	Grassy Bay	40.6312	73.8067	12	-0.30	-2.198	25.584	-2.142
9/13/00	11:10	GBM	Grassy Bay	40.6307	73.8058	49	-9.14	-2.121		-2.121
9/13/00	11:13	GBM	Grassy Bay	40.6307	73.8058	50	-4.57	-2.182	25.663	-2.126
9/13/00	11:19	GBM	Grassy Bay	40.6307	73.8058	51	0.00	-2.298	25.308	-2.240
9/13/00	16:13	GBM	Grassy Bay	40.6307	73.8058	63	-9.14	-2.166	26.013	-2.110
9/13/00	16:22	GBM	Grassy Bay	40.6307	73.8055	64	-4.57	-2.169	25.709	-2.114
9/13/00	16:26	GBM	Grassy Bay	40.6307	73.8055	65	0.00	-2.288	24.923	-2.231
9/13/00	14:38	GBM	Grassy Bay	40.6307	73.8058	57	-9.14	-2.130	26.026	-2.074
9/13/00	14:30	GBM	Grassy Bay	40.6307	73.8058	56	-8.23	-2.135	25.985	-2.079
9/13/00	8:15	GBM	Grassy Bay	40.6302	73.8058	39	-10.06	-2.120	25.958	-2.065
9/13/00		GBM	Grassy Bay	40.6302	73.8058	40	-4.57	-2.260	25.659	-2.202
9/13/00	8:28	GBM	Grassy Bay	40.6302	73.8058	41	0.00	-2.560	24.330	-2.498
9/13/00	14:44	GBM	Grassy Bay	40.6300	73.8058	58	-4.57	-2.274	25.254	-2.217
9/13/00	14:47	GBM	Grassy Bay	40.6300	73.8058	59	0.00	-2.304	25.212	-2.246
9/12/00	8:09	GBM	Grassy Bay	40.6300	73.8100	13	-10.97	-2.123	26.018	-2.067
9/12/00	8:14	GBM	Grassy Bay	40.6300	73.8100	14	-5.49	-2.168	25.777	-2.113
9/12/00	8:19	GBM	Grassy Bay	40.6300	73.8100	15	0.00	-2.294	25.411	-2.235
9/12/00		PB	Paerdegat Basin	40.6286	73.9106	29	-2.44	-2.105	26.332	-2.049
9/12/00		PB	Paerdegat Basin	40.6286	73.9106	30	0.00	-2.987	22.423	-2.920
9/12/00		PB	Paerdegat Basin	40.6277	73.9080	31	0.00	-2.836	23.214	-2.770
9/14/00	14:13	HB	SE Head of Bay	40.6255	73.7648	73	-5.49	-2.063	26.286	-2.009
9/14/00		HB	SE Head of Bay	40.6255	73.7648	74	-2.74	-2.076	26.123	-2.022
9/14/00		HB	SE Head of Bay	40.6255	73.7648	75	0.00	-2.069	26.049	-2.015
9/14/00	14:28	EGB	East Grassy Bay	40.6222	73.7785	76	-10.67	-2.089	26.517	-2.034
9/14/00		EGB	East Grassy Bay	40.6222	73.7785	77	-6.40	-2.047	26.313	-1.993
9/14/00		EGB	East Grassy Bay	40.6222	73.7785	78	-3.66	-1.993	26.289	-1.940
9/14/00		EGB	East Grassy Bay	40.6222	73.7785	79	-1.83	-2.015	26.265	-1.962
9/14/00		EGB	East Grassy Bay	40.6222	73.7785	80	0.00	-2.017	26.259	-1.964

9/12/00	13:32	PB	Paerdegat Basin	40.6218	73.8925	32	0.00	-2.314	25.618	-2.255
9/12/00	15:35	BC	Broad Chan N	40.6169	73.8079	33	-5.49	-2.093	26.298	-2.038
9/12/00		BC	Broad Chan N	40.6169	73.8079	34	0.00	-2.234	25.675	-2.176
9/12/00	16:34	B19	Grass Hass Ch.	40.6063	73.7879	37	-10.97	-2.029	26.556	-1.975
9/12/00		B19	Grass Hass Ch.	40.6063	73.7879	38	0.00	-2.064	26.372	-2.010
9/12/00	16:13	BC	Broad Chan S	40.6055	73.8050	35	-4.57	-2.015	26.501	-1.962
9/12/00		BC	Broad Chan S	40.6055	73.8050	36	0.00	-2.100	26.461	-2.044
9/14/00	15:00	B2	The Raunt	40.5972	73.8477	81	-3.66	-1.925	26.926	-1.873
9/14/00		B2	The Raunt	40.5972	73.8477	82	0.00	-1.905	26.905	-1.854
9/13/00	10:45	RTP	S. Beach Chan	40.5855	73.8310	46	-7.32	-2.010	26.742	-1.956
9/13/00	10:48	RTP	S. Beach Chan	40.5855	73.8310	47	-2.74	-2.022	27.098	-1.967
9/13/00	10:55	RTP	S. Beach Chan	40.5855	73.8310	48	0.00	-1.961	27.018	-1.908
9/13/00	17:18	WBC	W. Beach Chan	40.5786	73.8674	68	0.00	-1.853	27.643	-1.802
9/13/00	17:12	WBC	W. Beach Chan	40.5777	73.8688	67	-7.62	-1.904	27.600	-1.852
9/13/00	15:45	WBC	W. Beach Chan	40.5777	73.8699	62	0.00	-1.916	27.131	-1.864
9/13/00	15:38	WBC	W. Beach Chan	40.5776	73.8697	61	-8.23	-1.880	27.333	-1.828
9/13/00	10:05	WBC	W. Beach Chan	40.5773	73.8682	44	-7.32	-1.780	28.519	-1.730
9/13/00	10:11	WBC	W. Beach Chan	40.5773	73.8682	45	0.00	-1.829	27.975	-1.778
9/13/00	12:10	WBC	W. Beach Chan	40.5771	73.8686	54	-7.32	-1.880	27.547	-1.828
9/13/00	12:21	WBC	W. Beach Chan	40.5770	73.8692	55	0.00	-1.957	27.255	-1.904
9/14/00	15:24	CISO	Rockaway Inlet	40.5657	73.9305	83	-2.74	-1.768	28.049	-1.718
9/14/00		CISO	Rockaway Inlet	40.5657	73.9305	84	-1.83	-1.821	27.729	-1.770
9/14/00		CISO	Rockaway Inlet	40.5657	73.9305	85	-0.91	-1.876	27.630	-1.825
9/14/00		CISO	Rockaway Inlet	40.5657	73.9305	86	0.00	-1.855	27.643	-1.804
9/22/00	11:14	BP	W. Breezy Point	40.5375	73.9613	O-1	-9.14	-1.148	31.486	-1.112
9/22/00		BP	W. Breezy Point	40.5375	73.9613	O-2	-7.32	-1.146	31.281	-1.110
9/22/00	11:19	BP	W. Breezy Point	40.5375	73.9613	O-3	-5.49	-1.292	30.581	-1.253
9/22/00	11:33	BP	W. Breezy Point	40.5375	73.9613	O-4	-3.66	-1.163	31.358	-1.127
9/22/00		BP	W. Breezy Point	40.5375	73.9613	O-5	-1.83	-1.107	31.359	-1.072
9/22/00	11:40	BP	W. Breezy Point	40.5375	73.9613	O-6	0.00	-1.192	31.274	-1.155

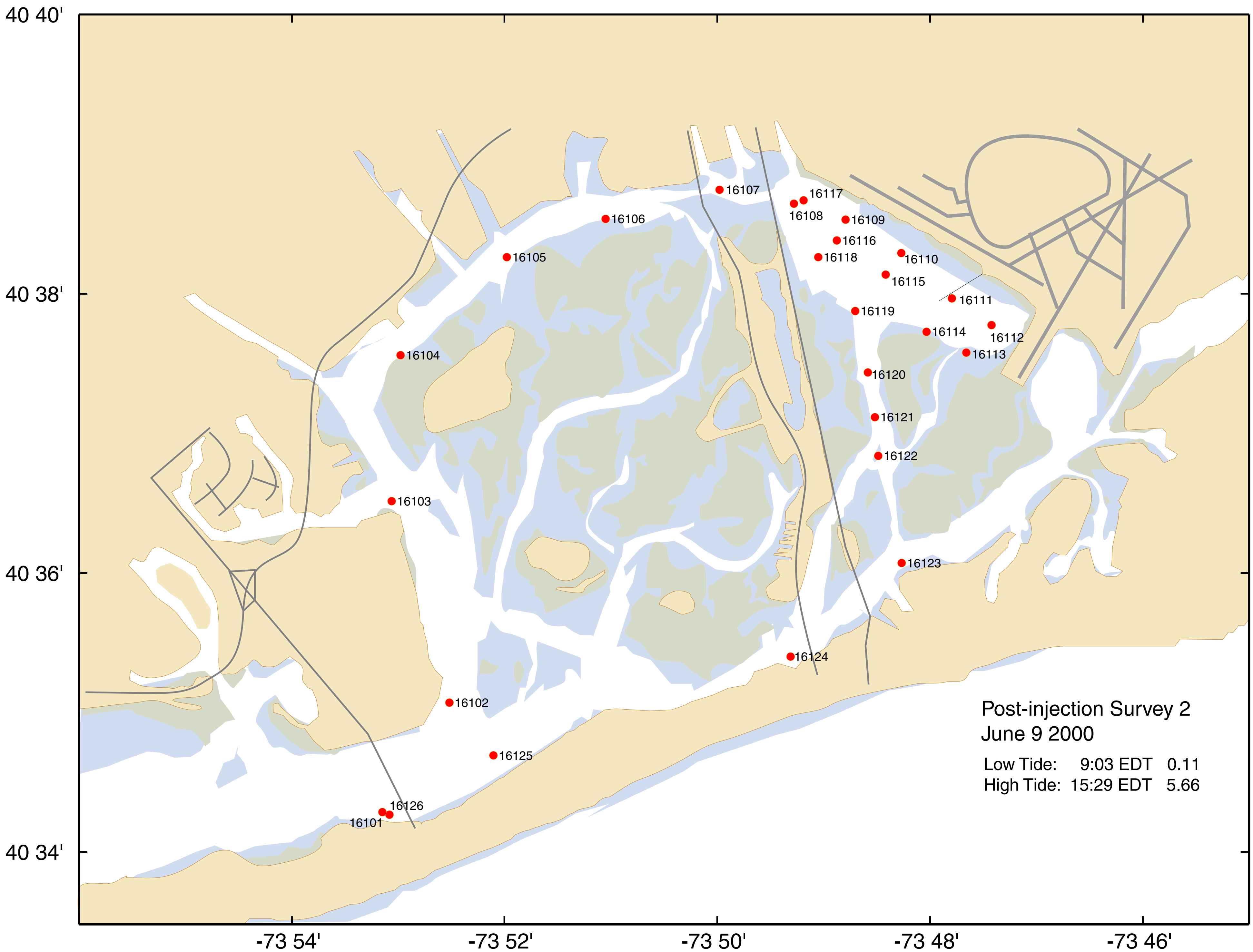
9.2 Appendix 2- CTD sampling sites and profiles


40 40'
40 38'
40 36'
40 34'
-73 54'
-73 52'
-73 50'
-73 48'
-73 46'
15401
15302
15402
15403
15301
15404
15405
Pre-injection Surveys
1-2 June 2000
High Tide: 7:59 EDT 5.74
Low Tide: 13:49 EDT -0.36
High Tide: 8:50 EDT 5.86
Low Tide: 14:41 EDT -0.46


40 40'
40 38'
40 36'
40 34'
-73 54'
-73 52'
-73 50'
-73 48'
-73 46'
15901
15902
15903
15904
15905
Dye Injection
7 June 2000
1230 EDT
Low Tide: 7:02 EDT -0.31
High Tide: 13:35 EDT 5.63

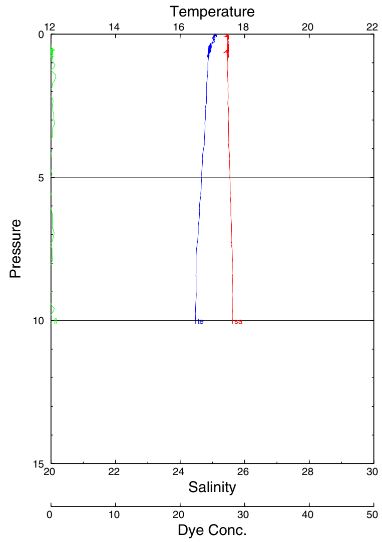


40 40'
40 38'
40 36'
40 34'
-73 54'
-73 52'
-73 50'
-73 48'
-73 46'
16001
16002
16003
16004
16005
16006
16007
16008
16009
16010
16011
16012
16013
16014
16015
16016
16017
16018
16019
16020
16021
Post-injection Survey 1
8 June 2000
Low Tide: 8:02 EDT -0.06
High Tide: 14:32 EDT 5.63



40 40'
40 38'
40 36'
40 34'
-73 54'
-73 52'
-73 50'
-73 48'
-73 46'
16101
16102
16103
16104
16105
16106
16107
16108
16109
16110
16111
16112
16113
16114
16115
16116
16117
16118
16119
16120
16121
16122
16123
16124
16125
16126
Post-injection Survey 2
June 9 2000
Low Tide: 9:03 EDT 0.11
High Tide: 15:29 EDT 5.66

40 35.70 N 73 53.20 W
2000/06/01 16:23
15301



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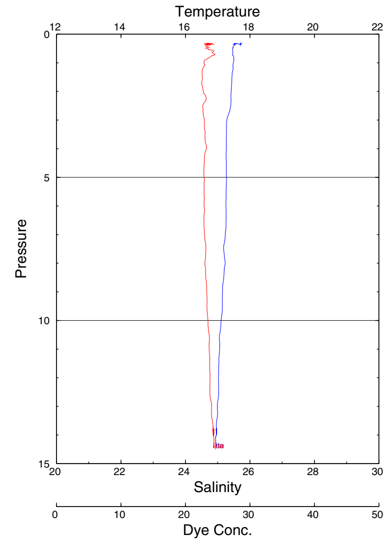

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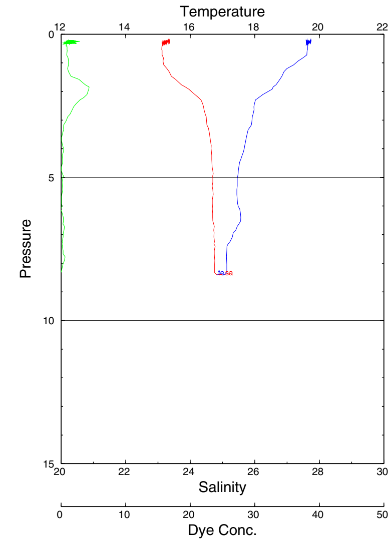
15401



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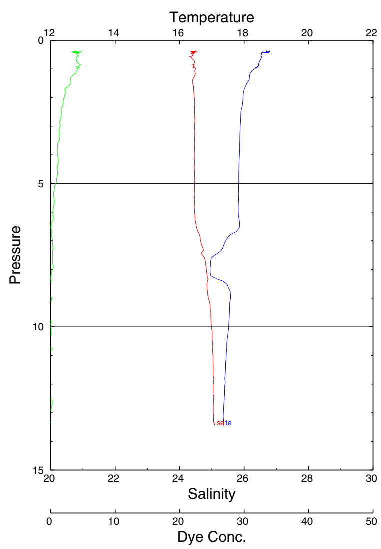

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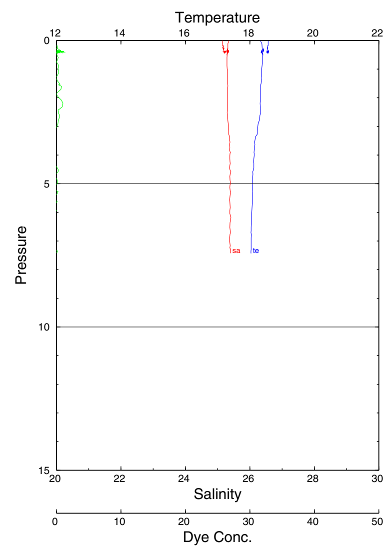

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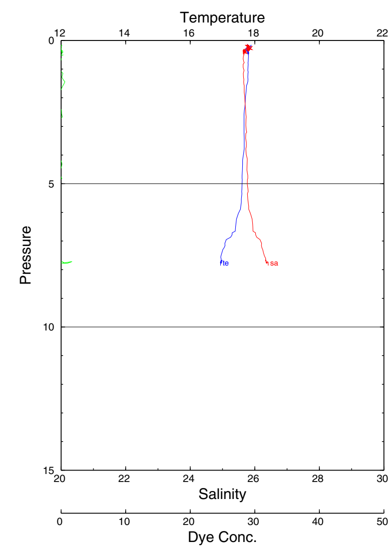

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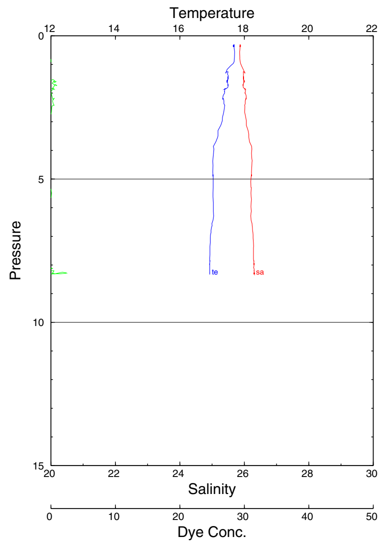

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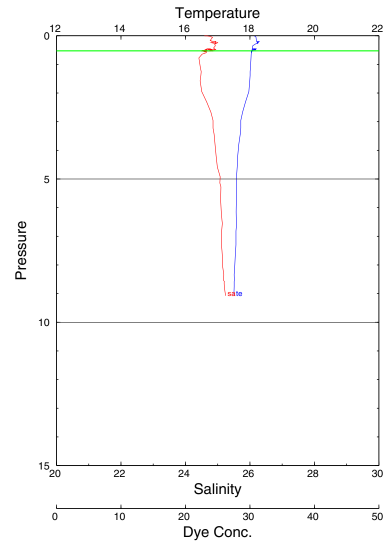

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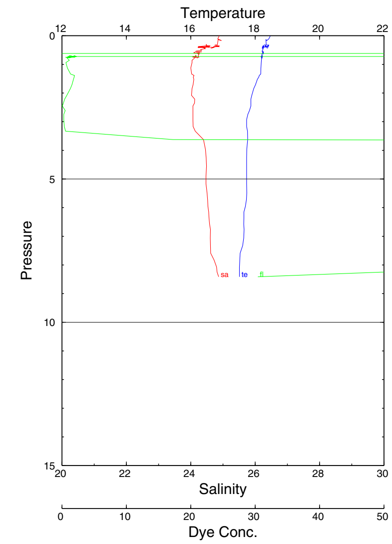

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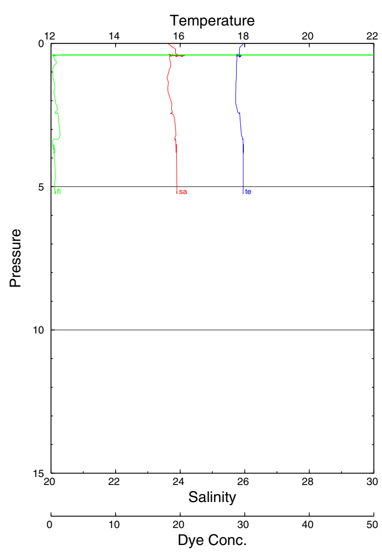

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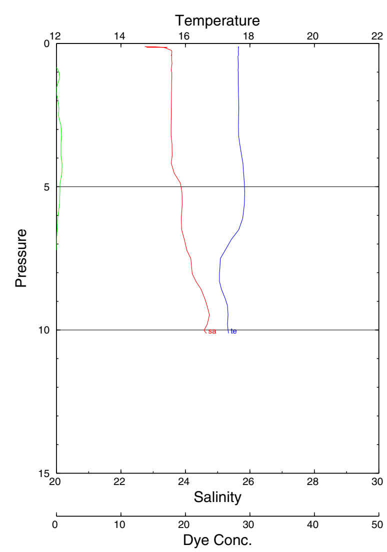

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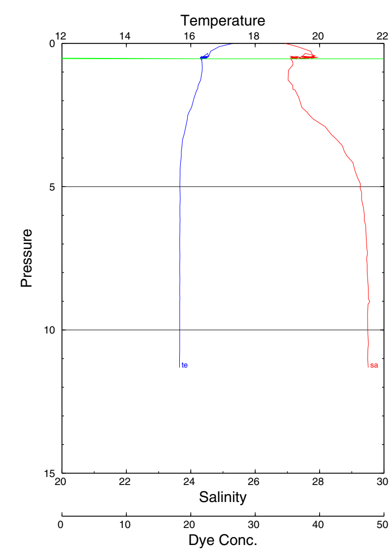

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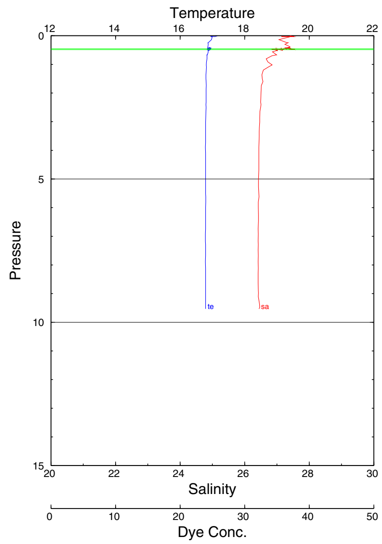

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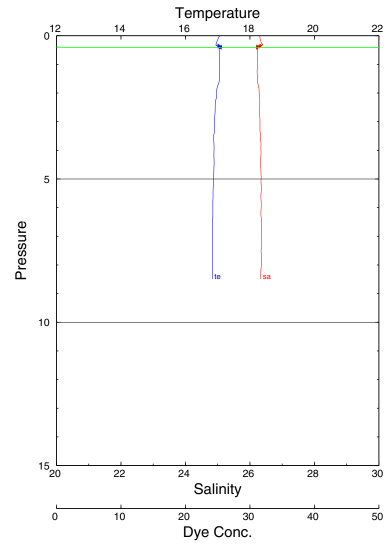

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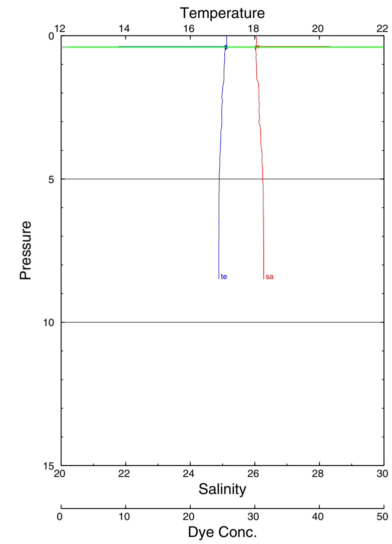

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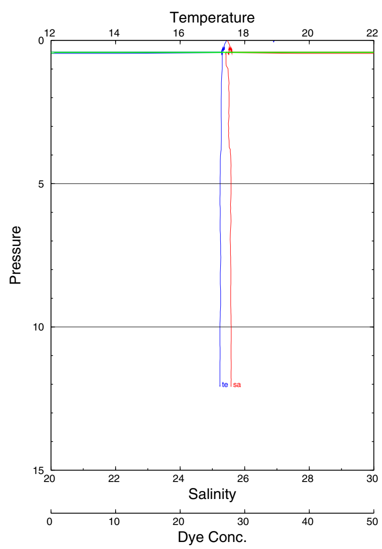

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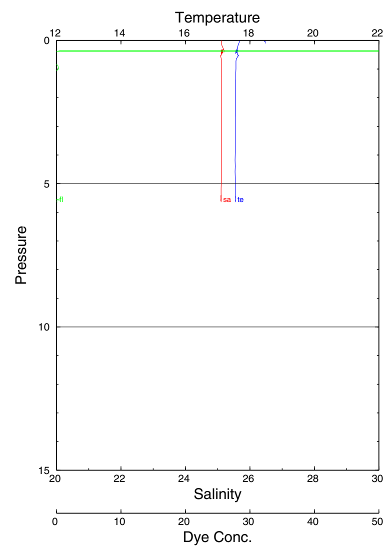

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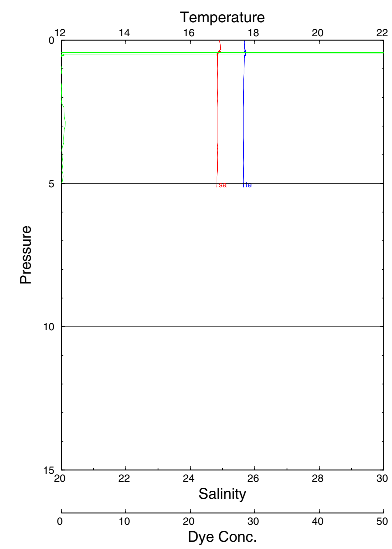

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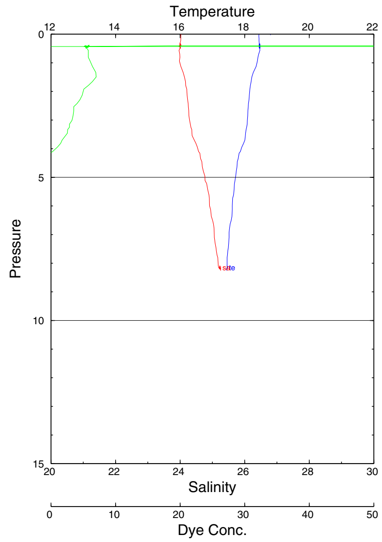

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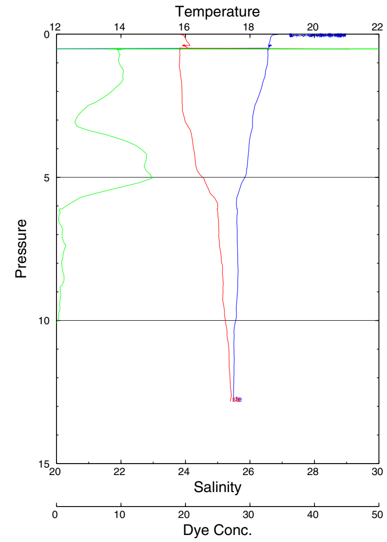

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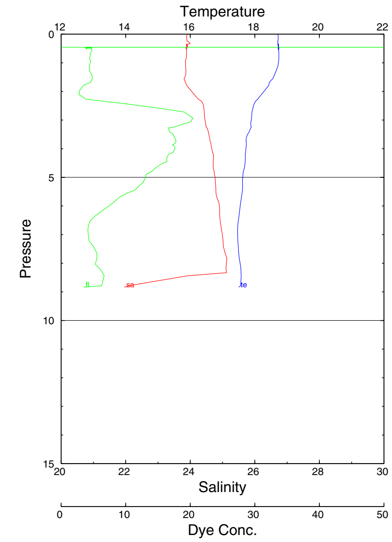

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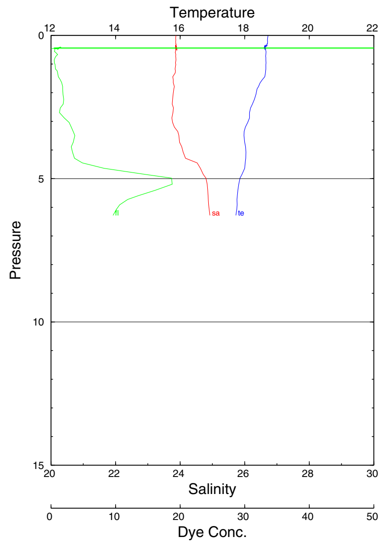

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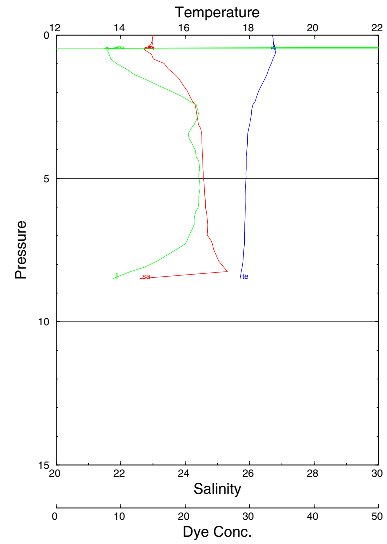

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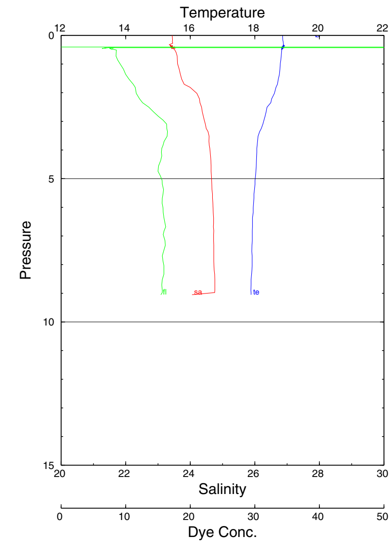

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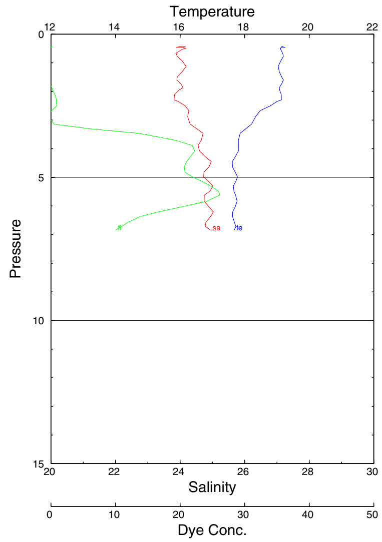

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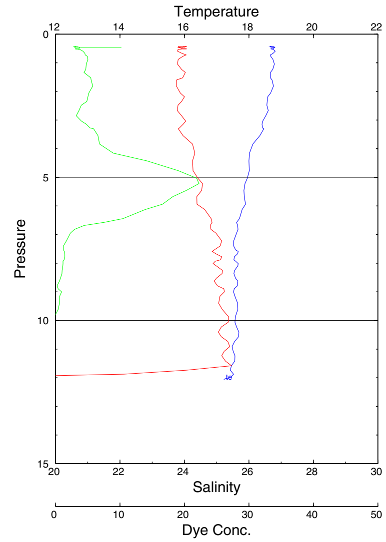

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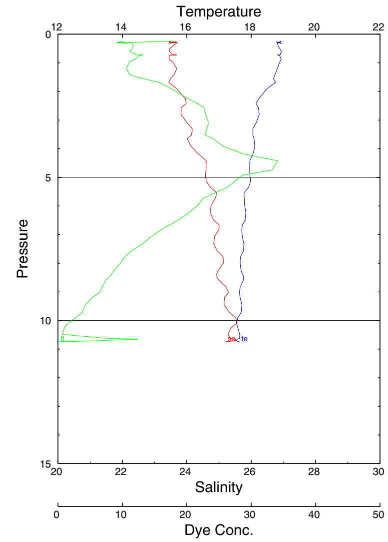

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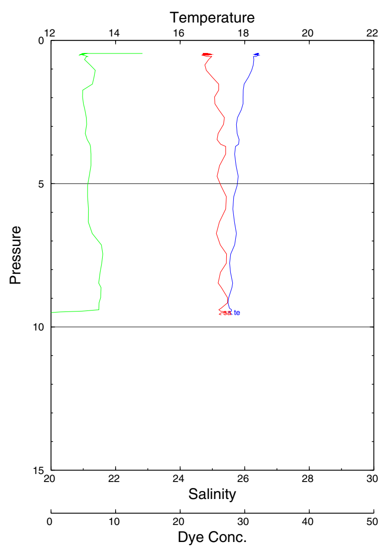

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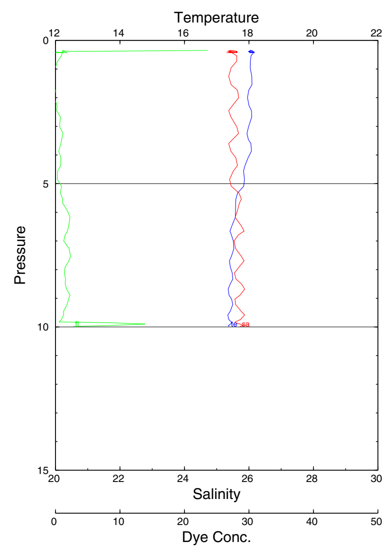

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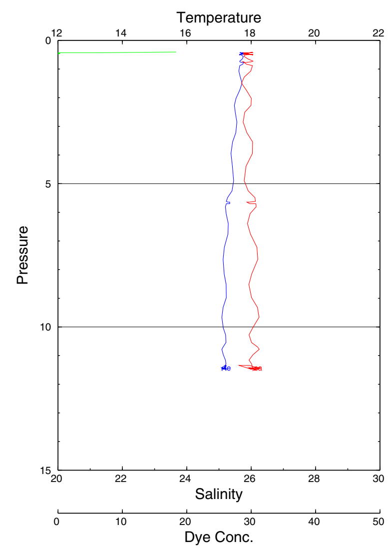

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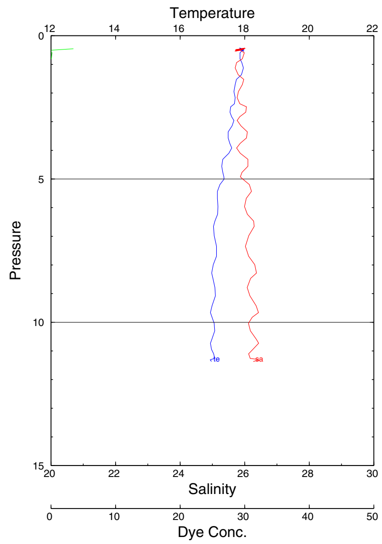

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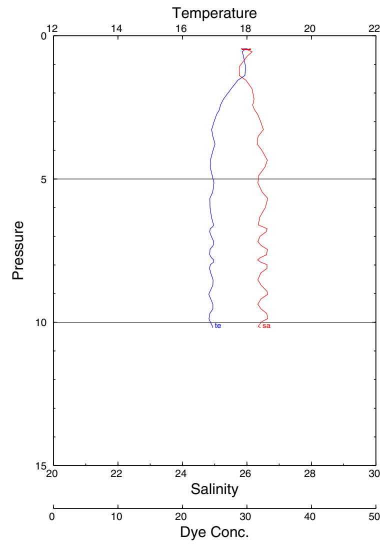

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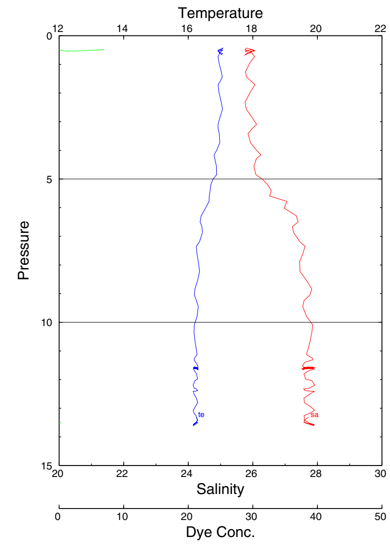

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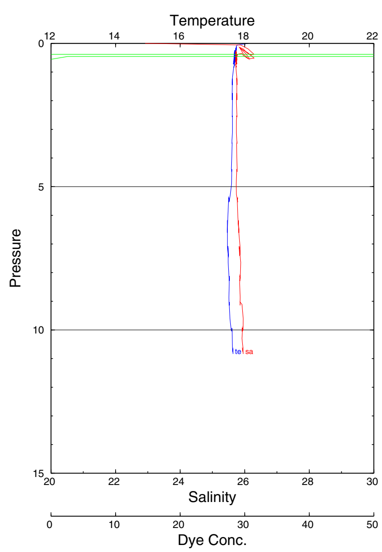

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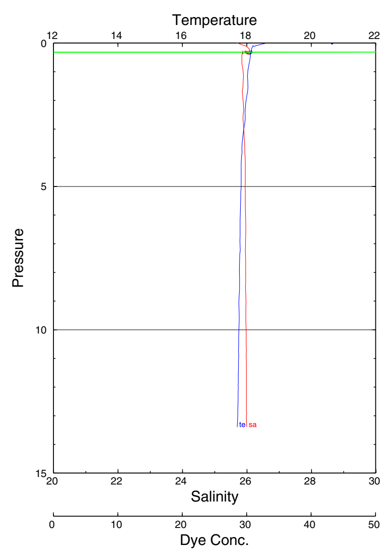

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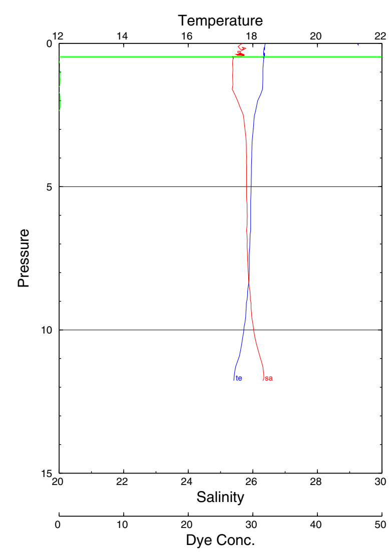

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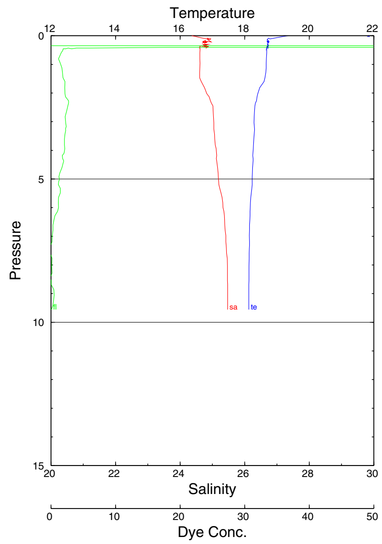

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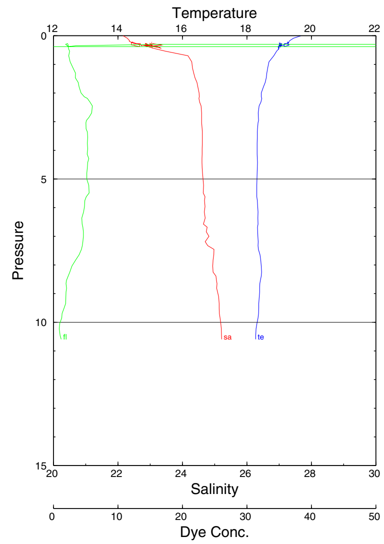

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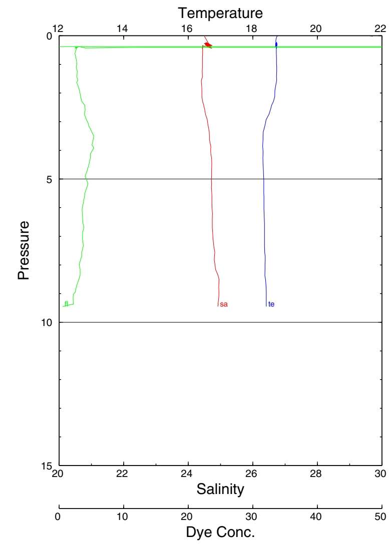

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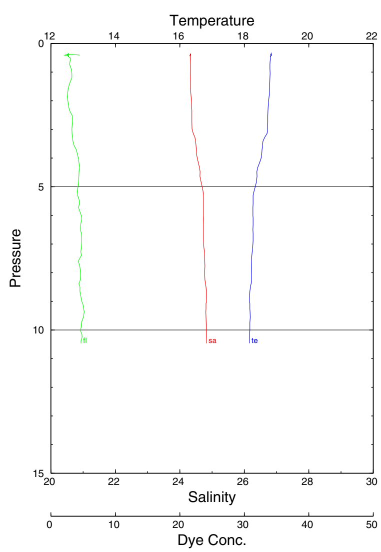

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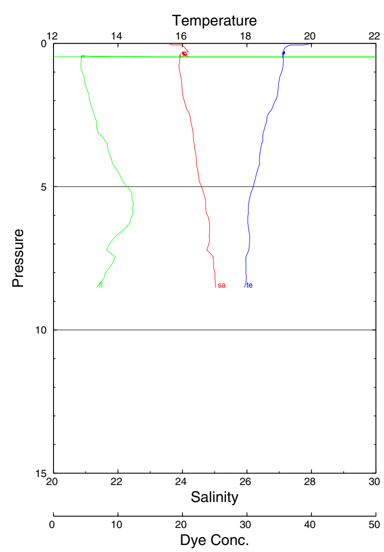

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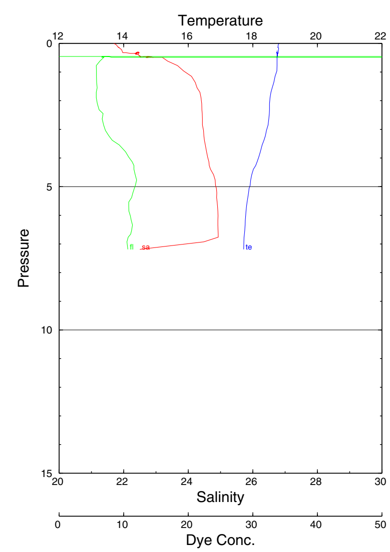

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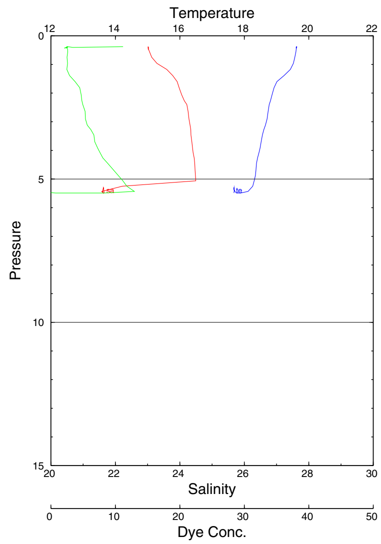

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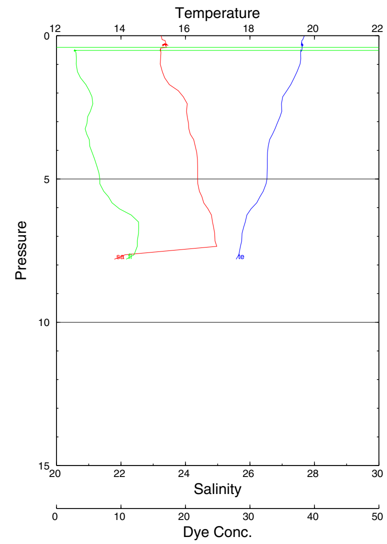

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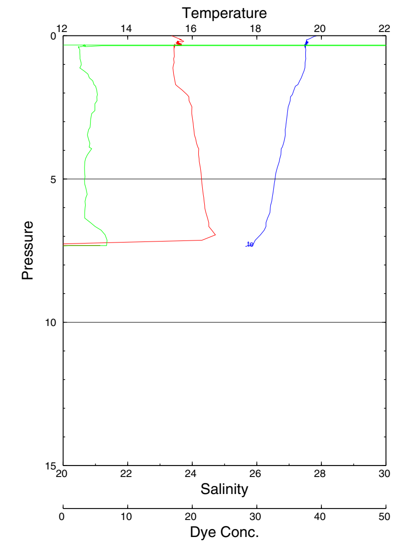

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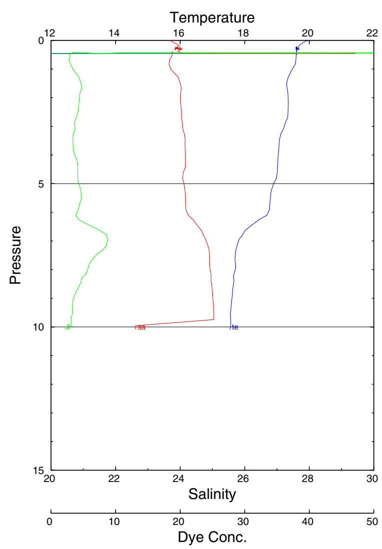

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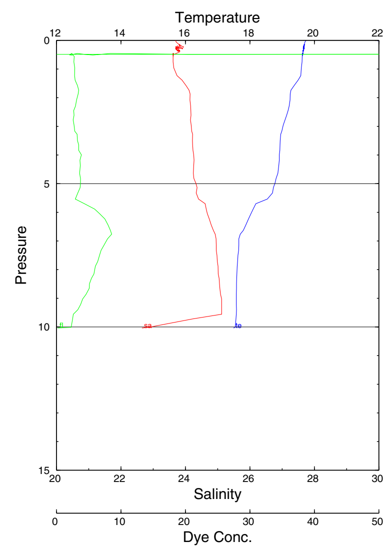

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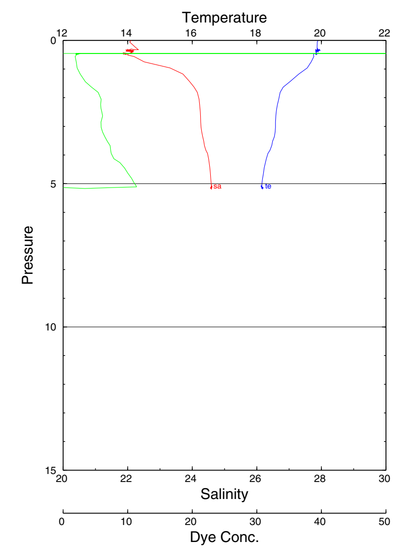

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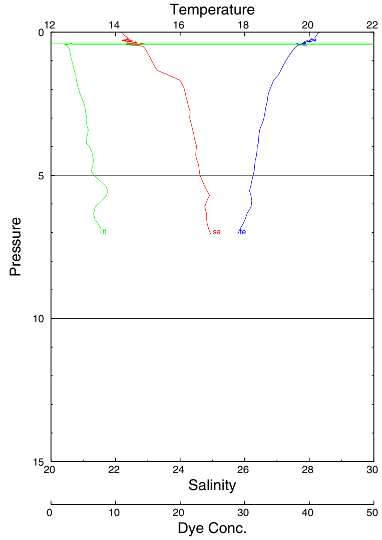

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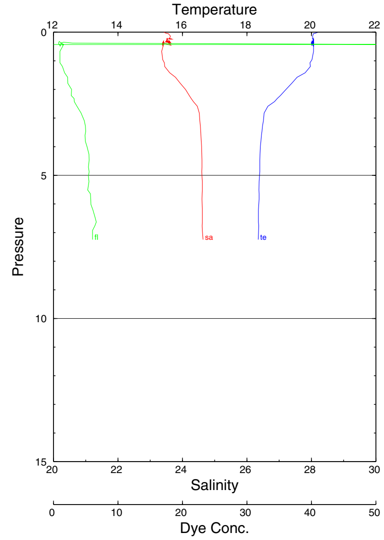

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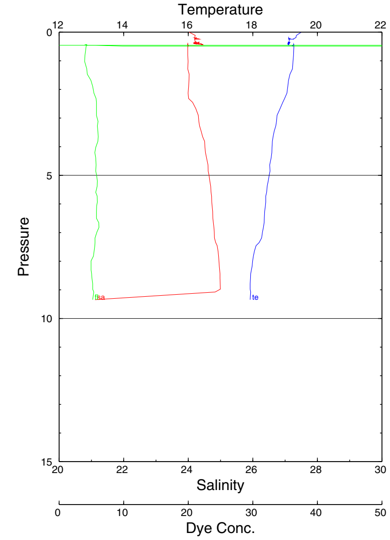

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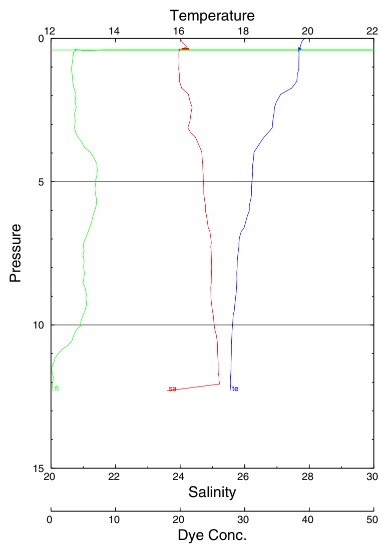

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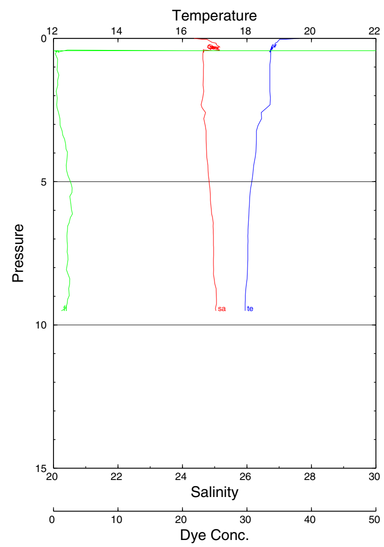

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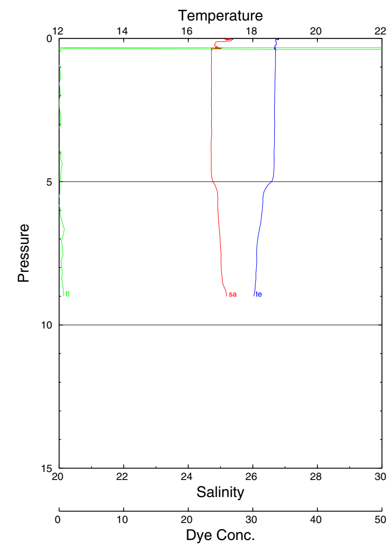

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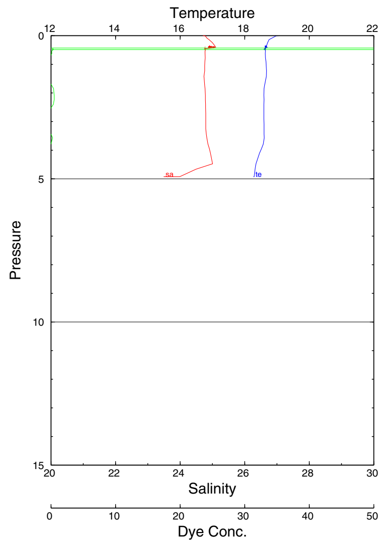

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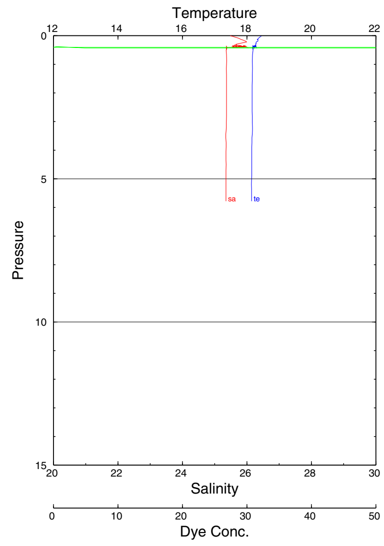

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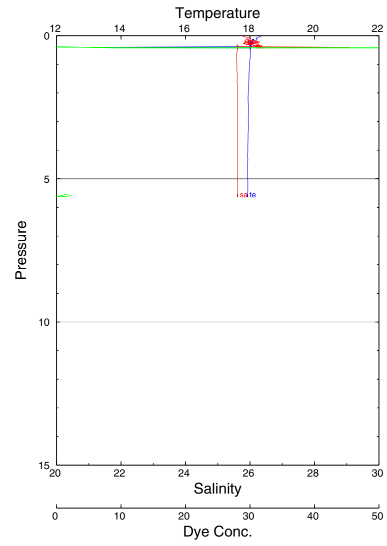

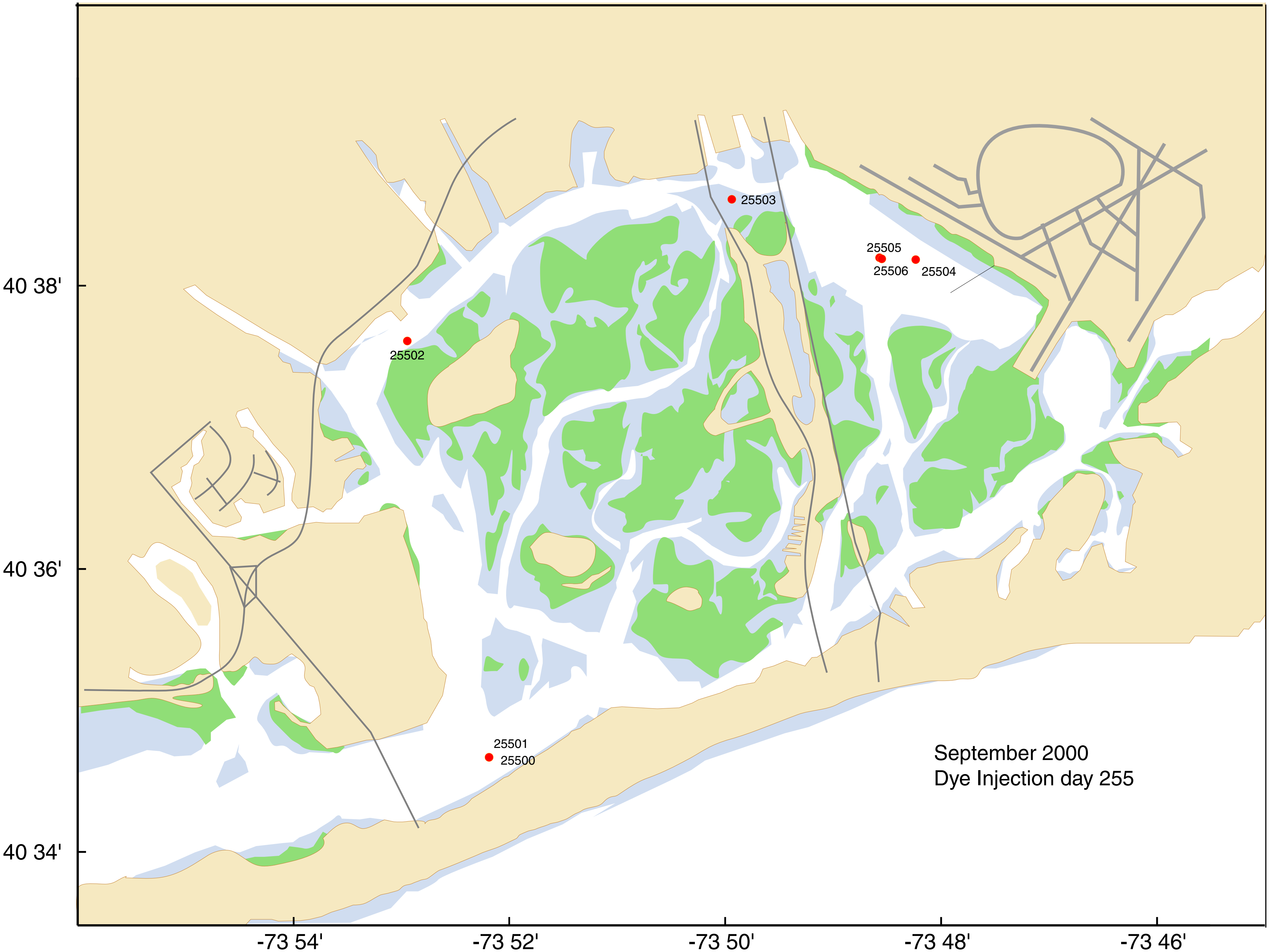

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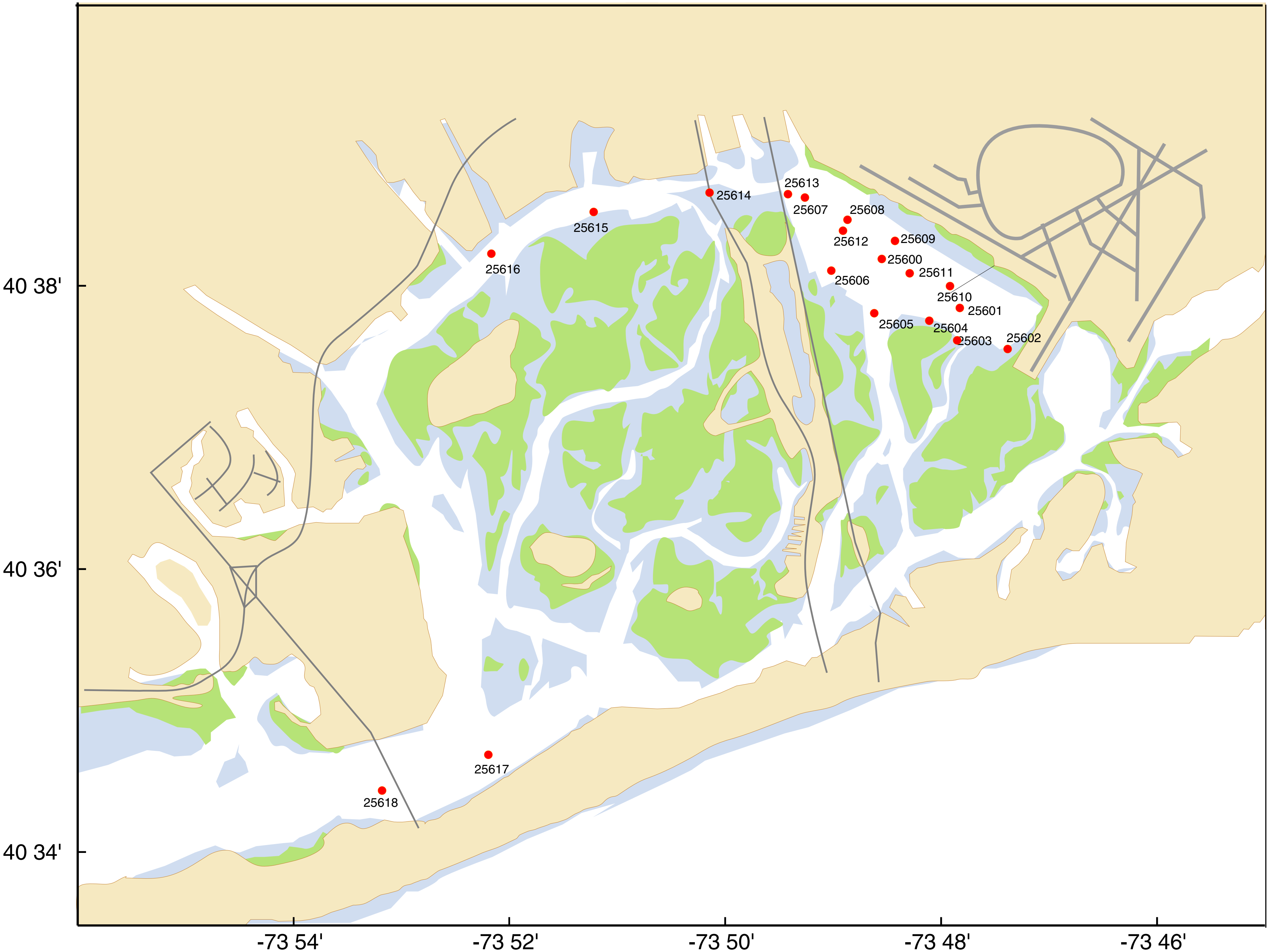

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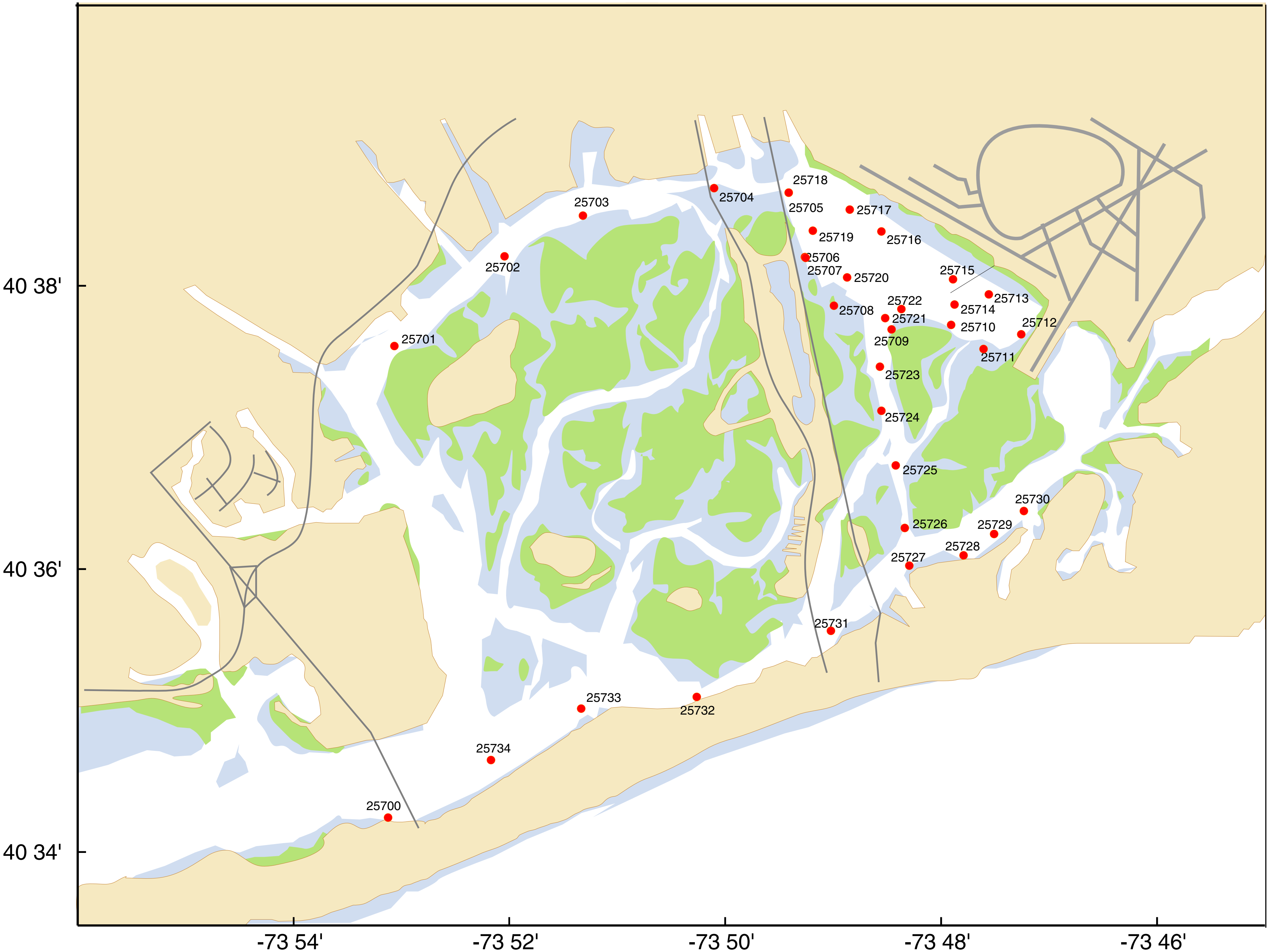
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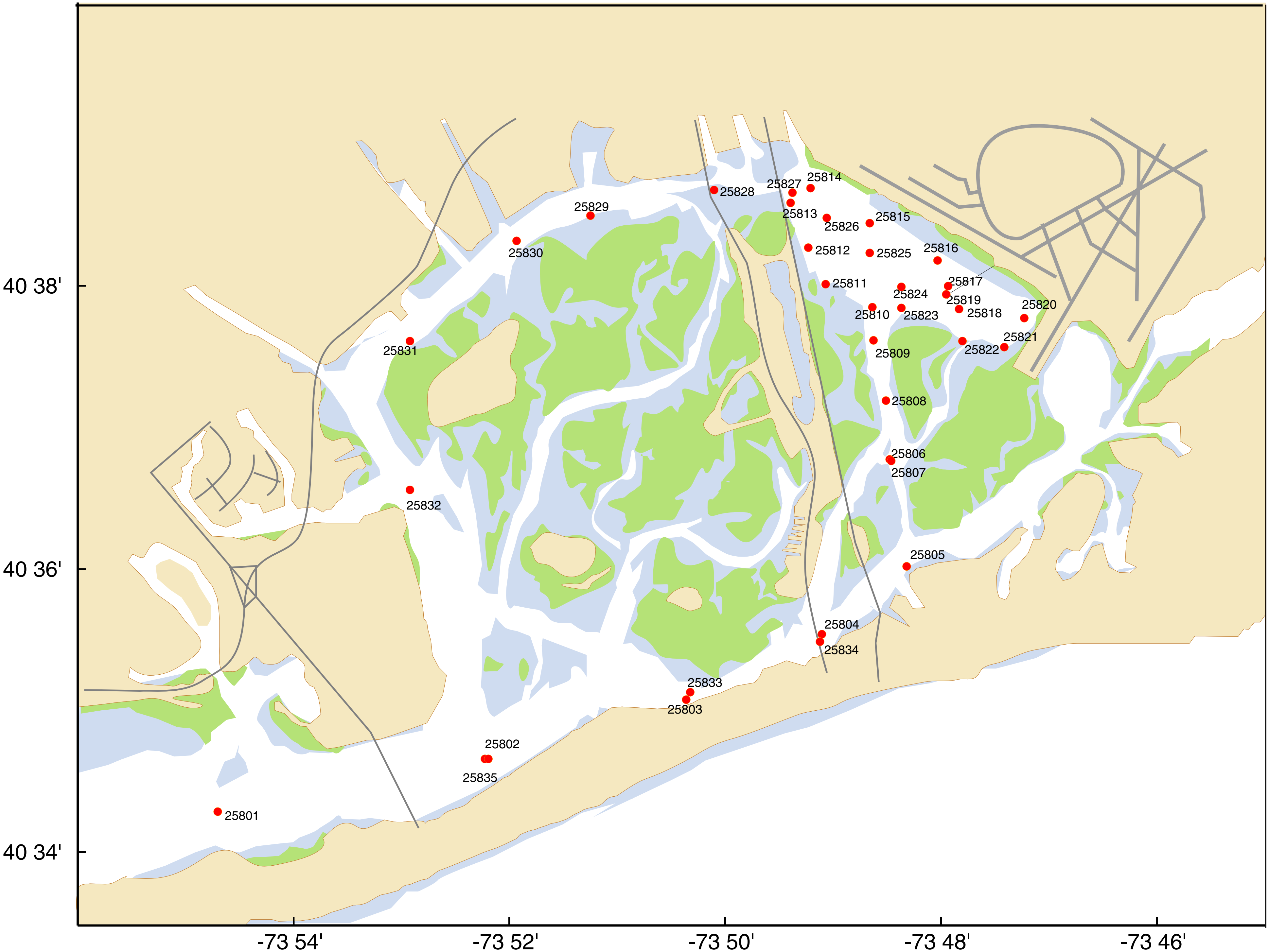

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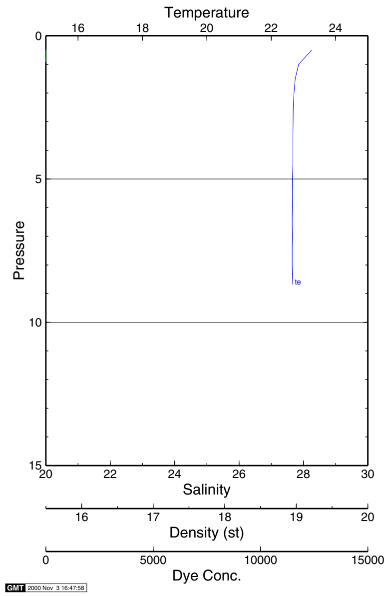

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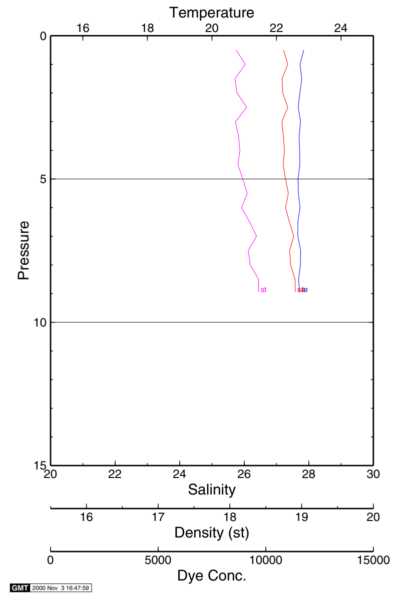

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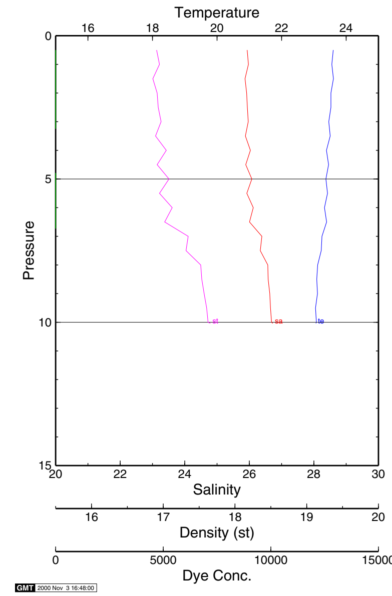

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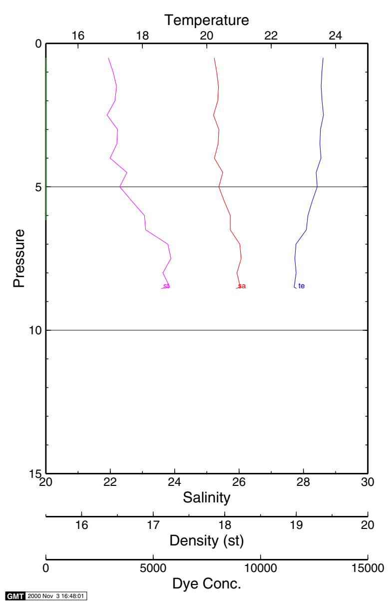

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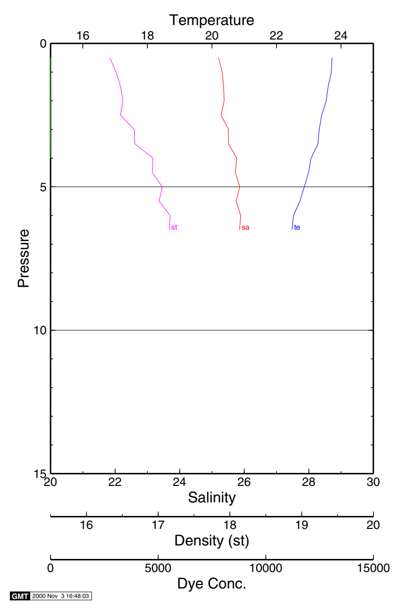

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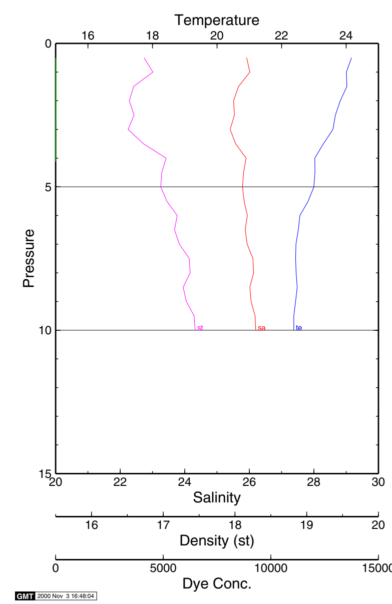

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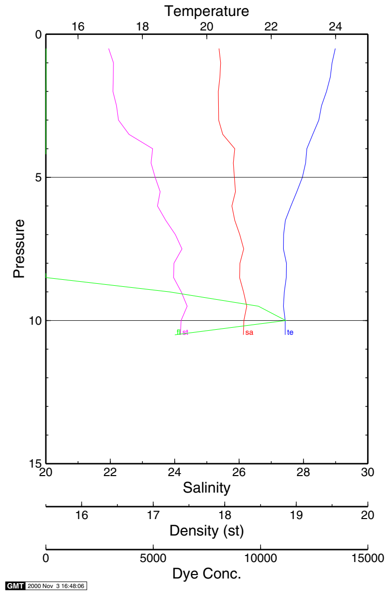

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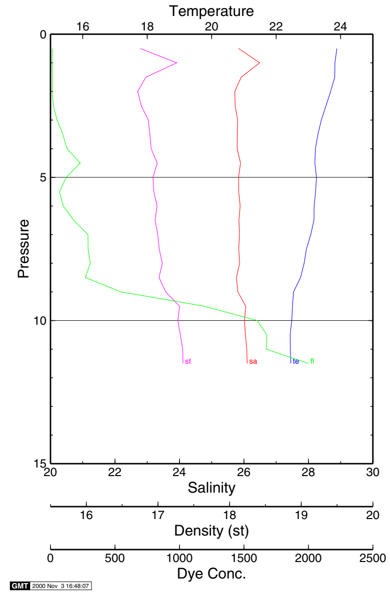

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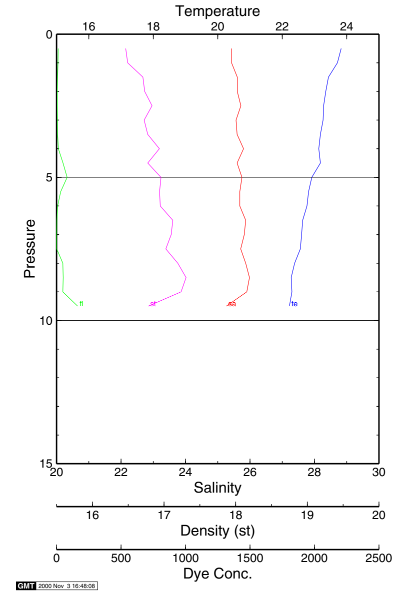

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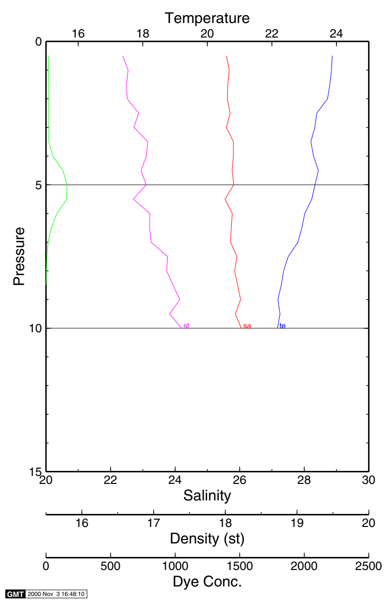

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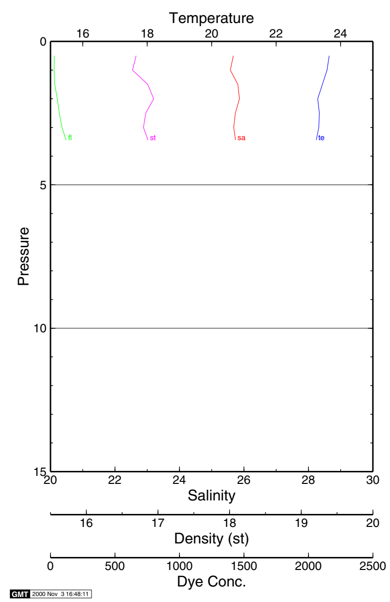

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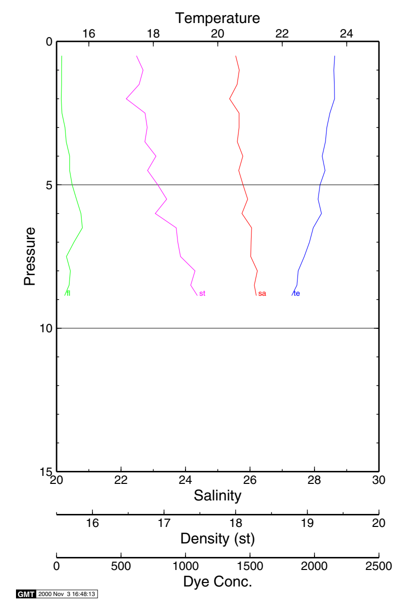

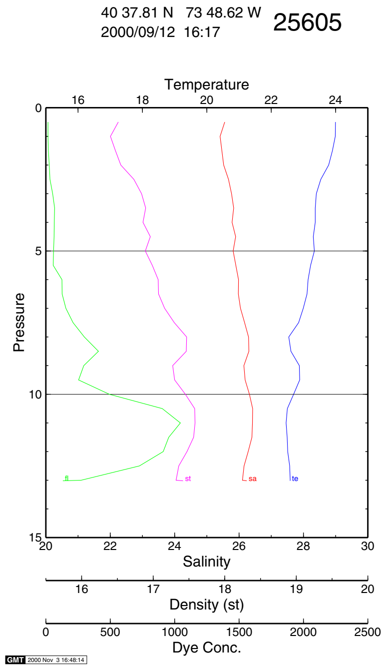
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Salinity
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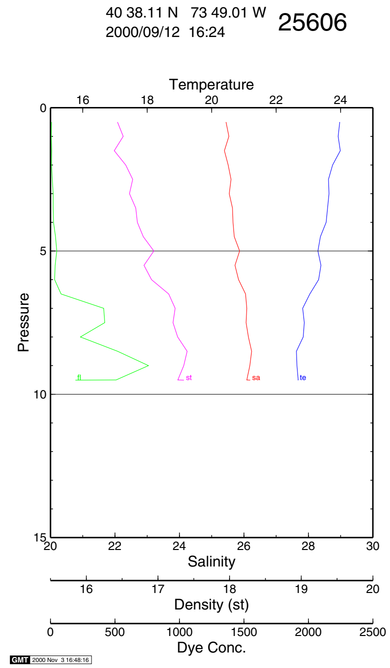
Dye Conc.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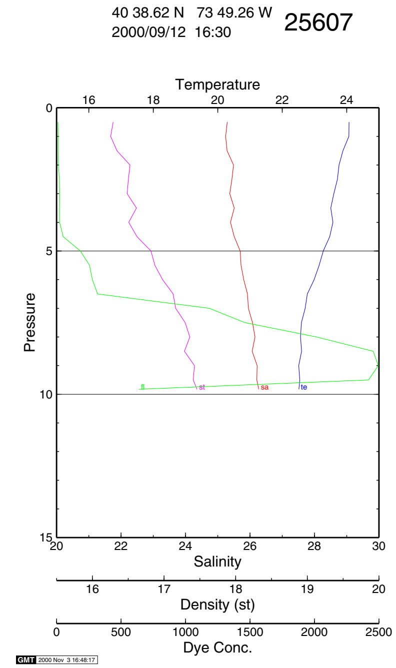
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Density (st)
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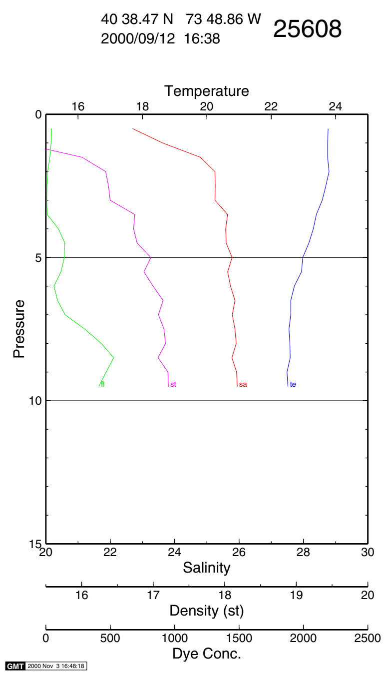
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Salinity
Density (st)
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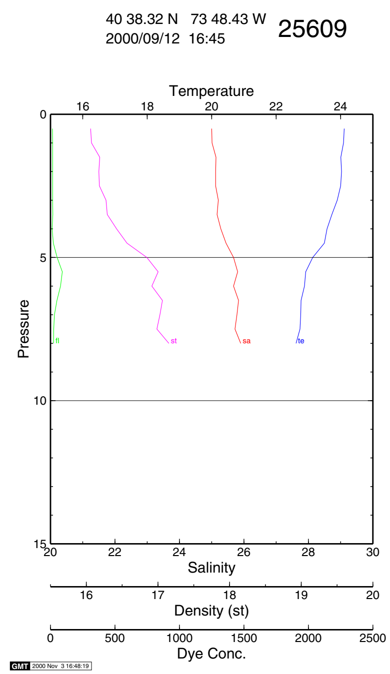
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Density (st)
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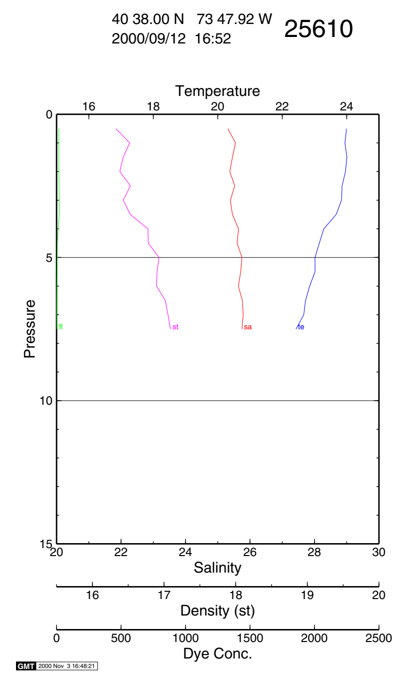
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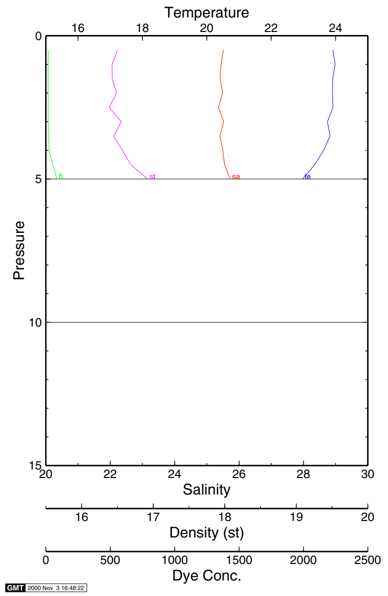

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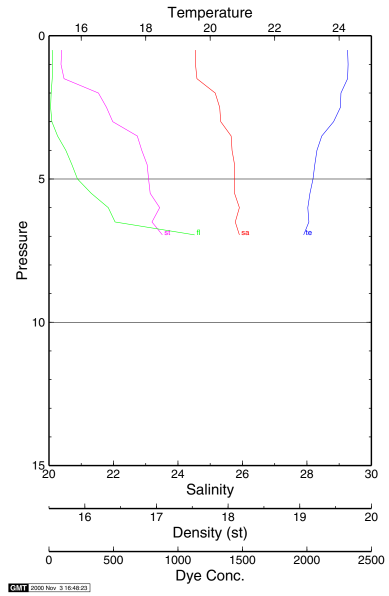

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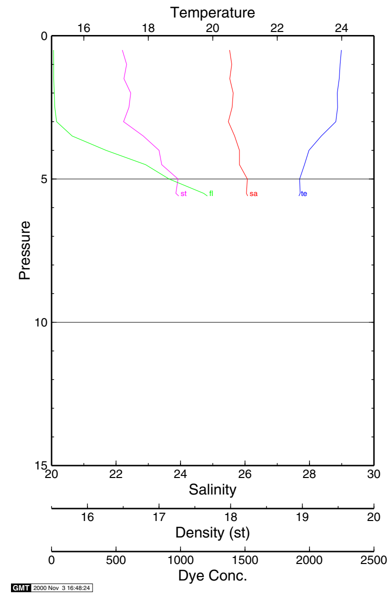

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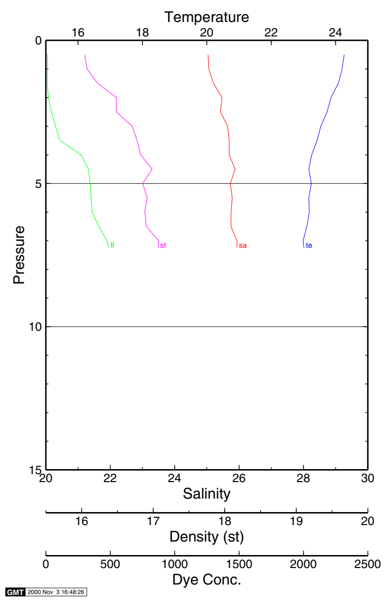

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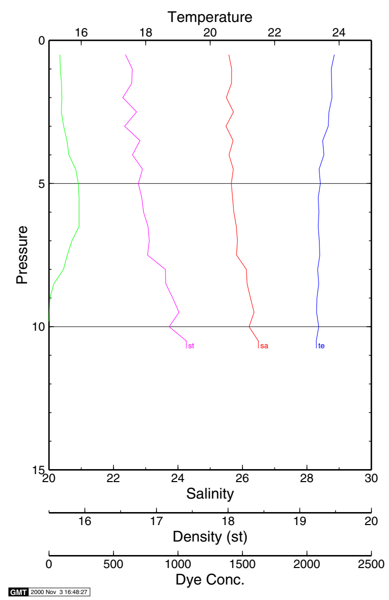

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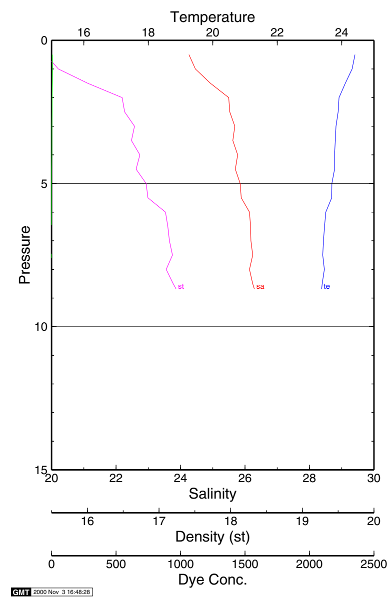

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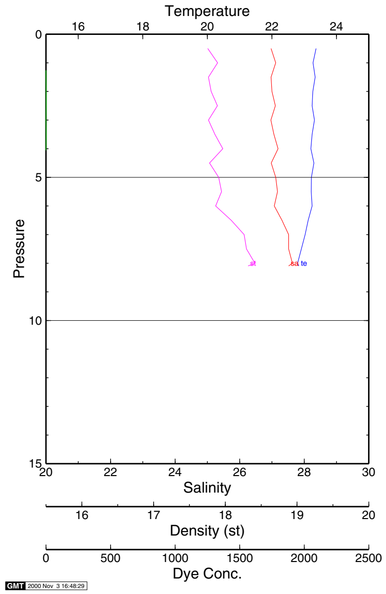

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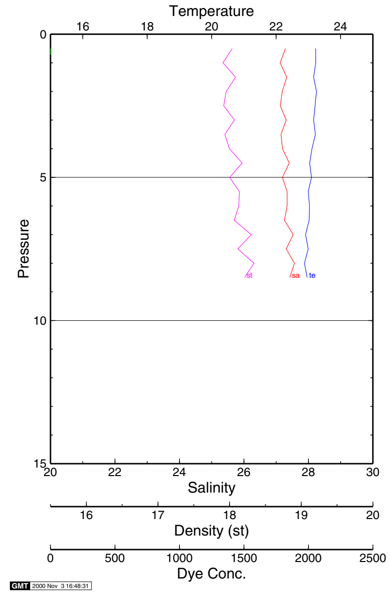

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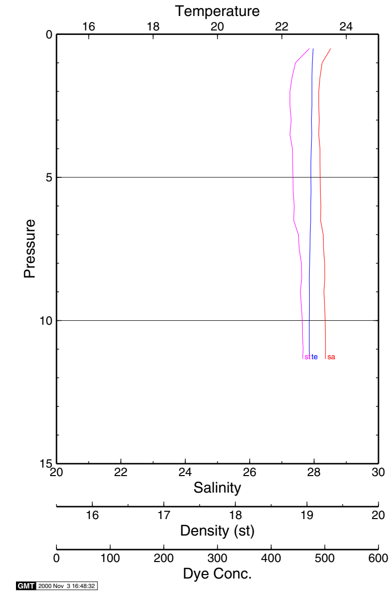

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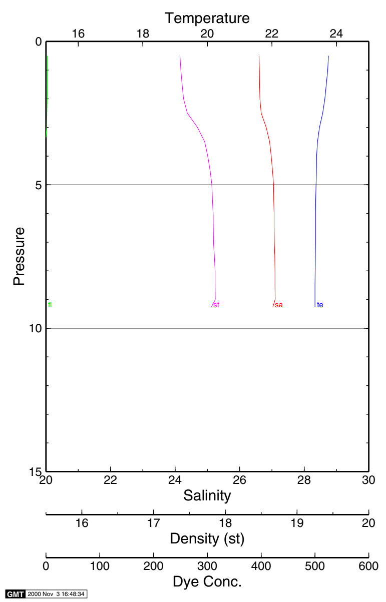

40 38.21 N 73 52.04 W
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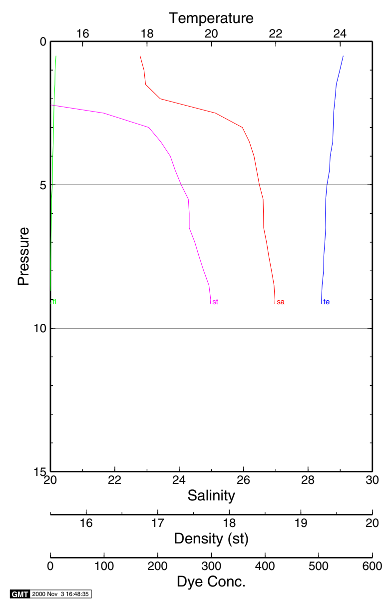
25702



40 38.50 N 73 51.32 W
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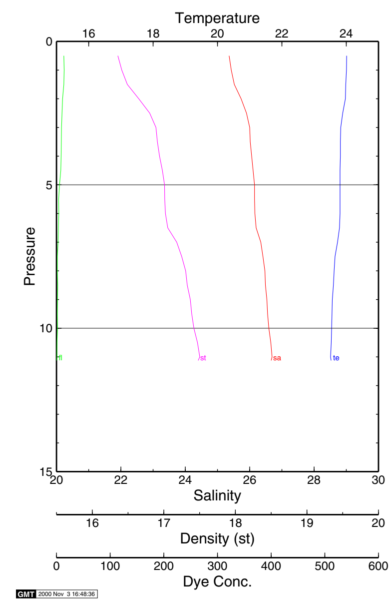

40 38.69 N 73 50.10 W
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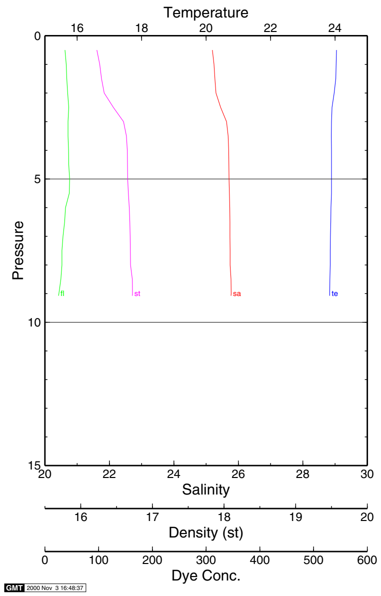

40 38.66 N 73 49.41 W
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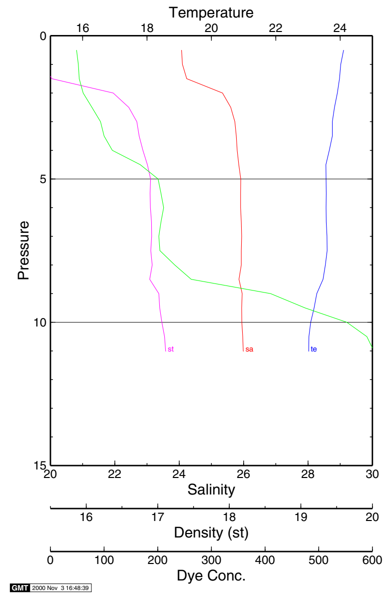

40 38.20 N 73 49.26 W
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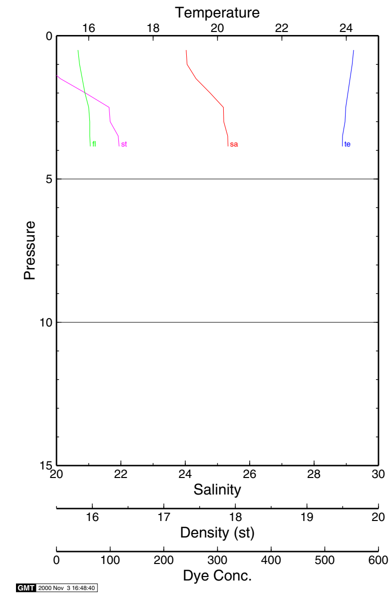

40 38.20 N 73 49.25 W
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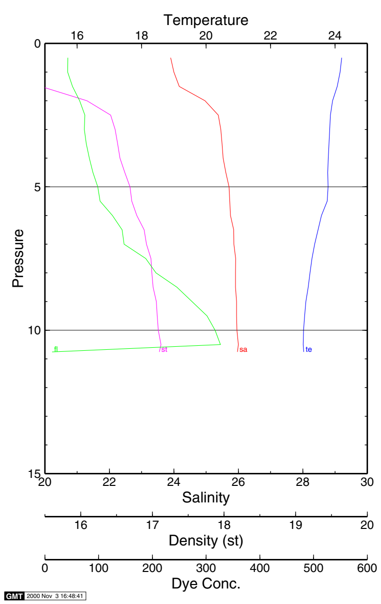

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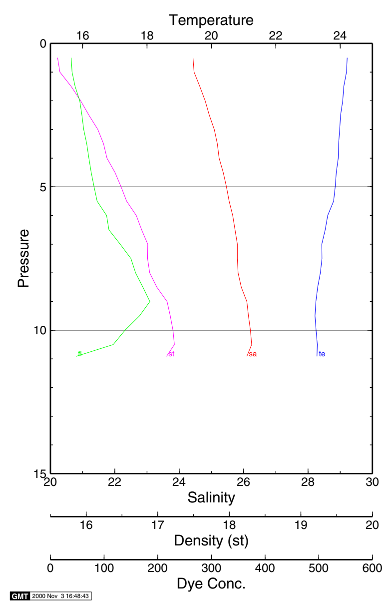

40 37.69 N 73 48.46 W
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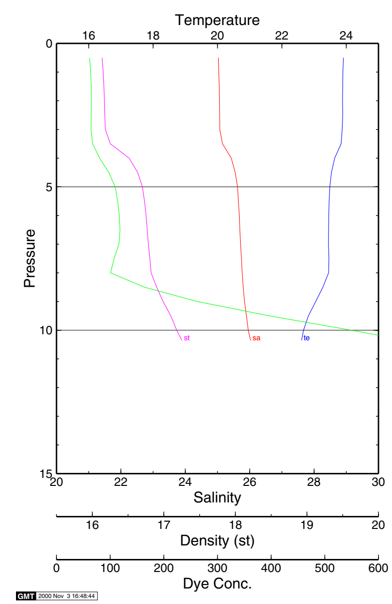

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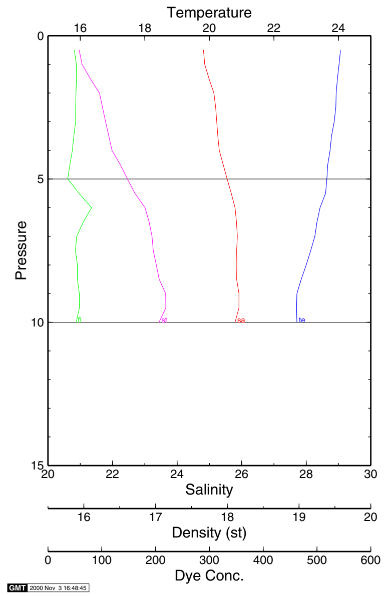

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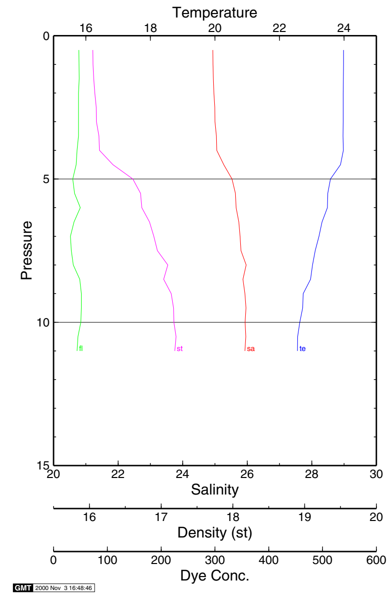

40 37.66 N 73 47.26 W
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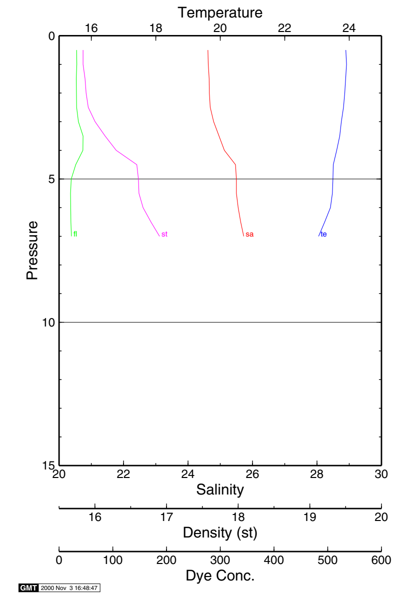

40 37.94 N 73 47.56 W
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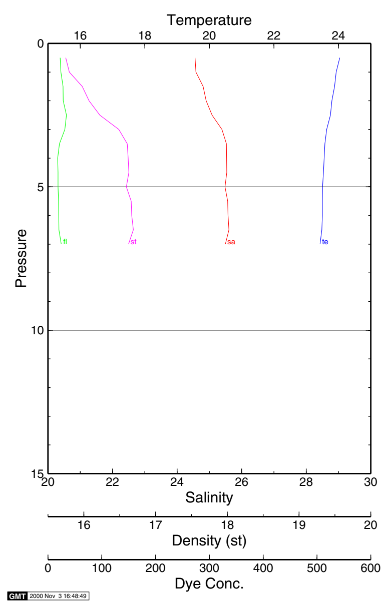

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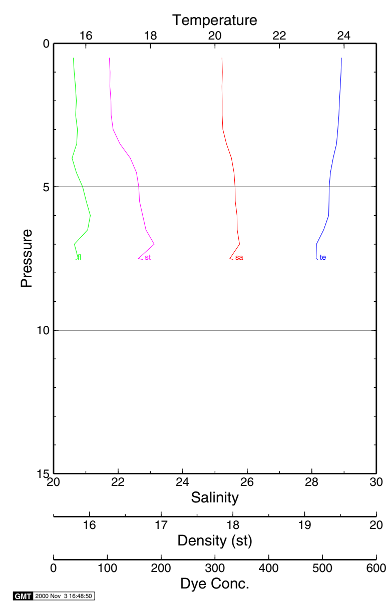

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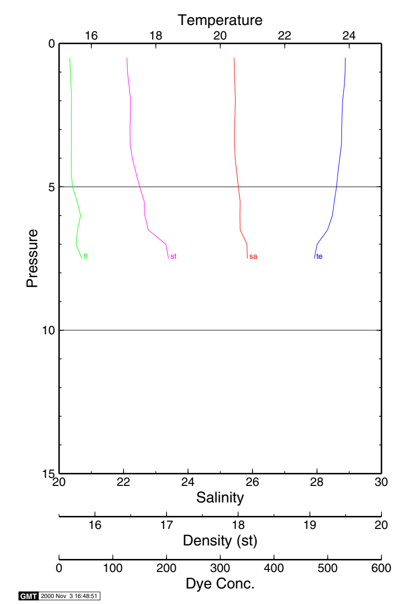

40 38.38 N 73 48.55 W
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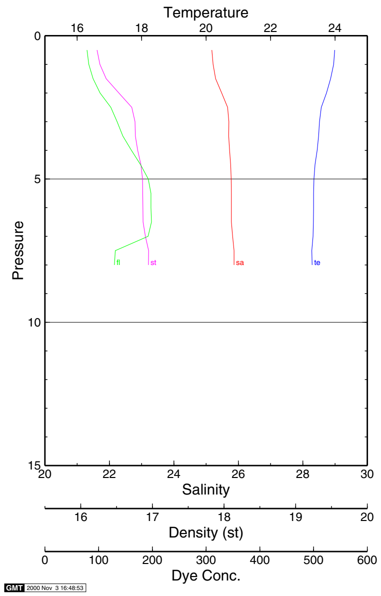

40 38.54 N 73 48.85 W
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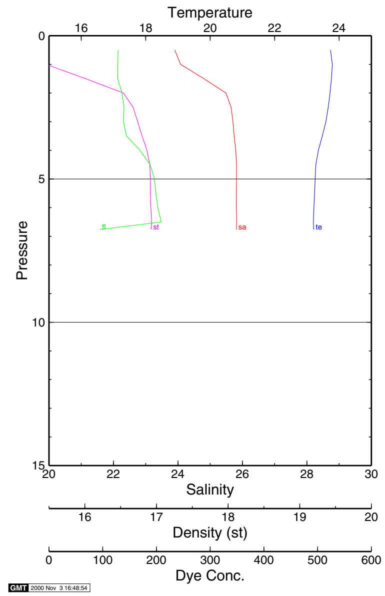

40 38.66 N 73 49.41 W
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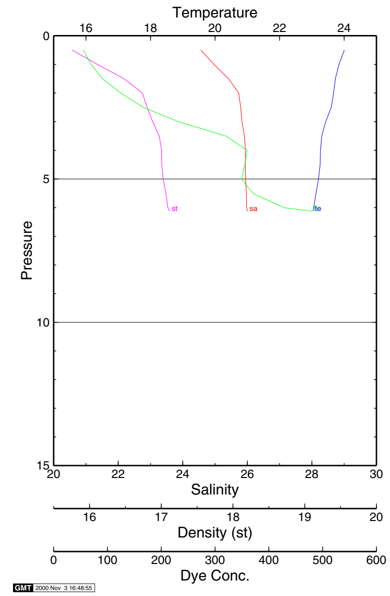
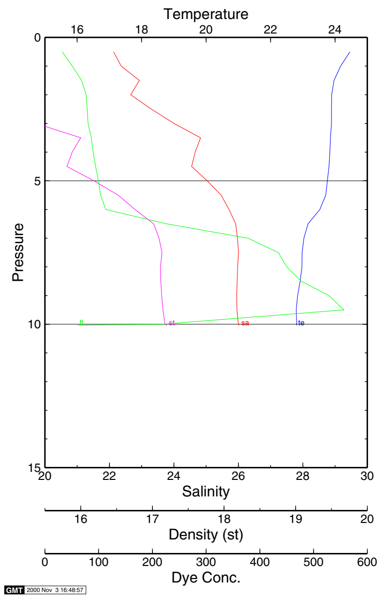
25718



40 38.39 N 73 49.19 W
2000/09/13 16:16
25719



40 38.06 N 73 48.87 W
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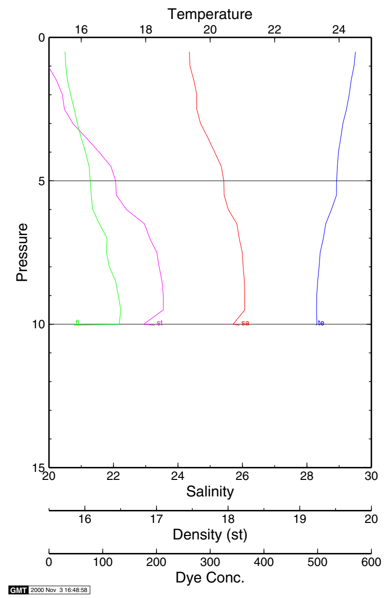

40 37.77 N 73 48.52 W
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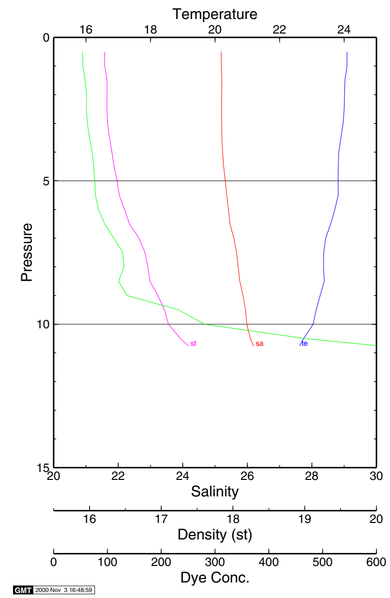

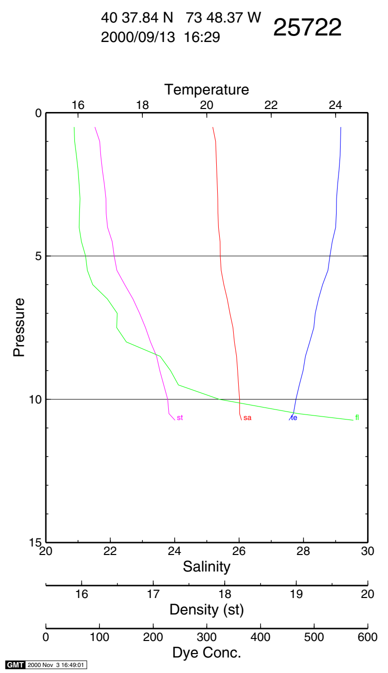
40 37.84 N 73 48.37 W
2000/09/13 16:29
25722
Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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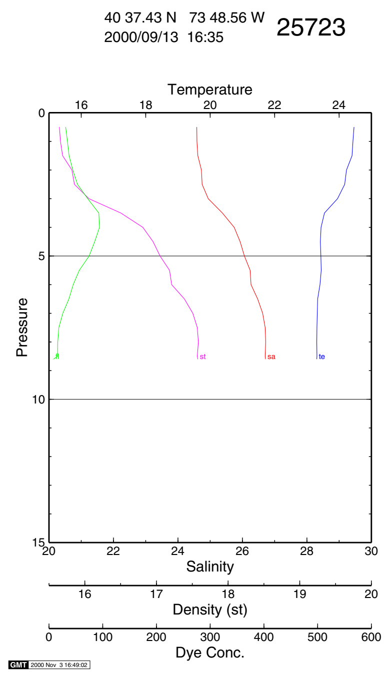
40 37.43 N 73 48.56 W
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Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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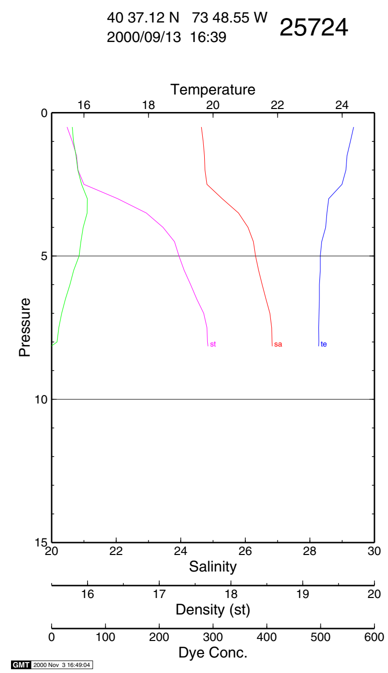
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Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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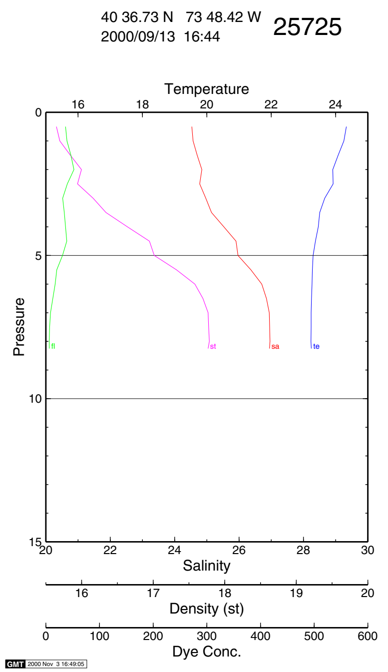
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25725
Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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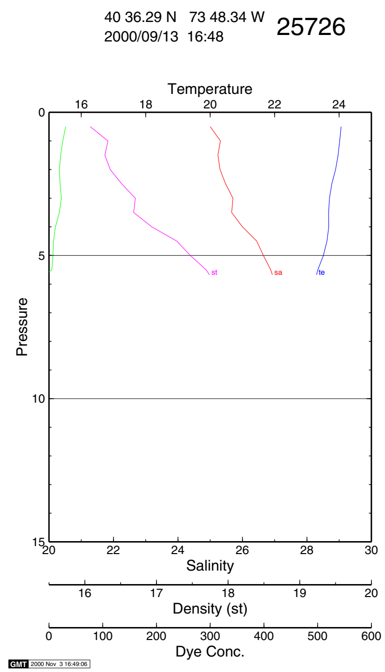
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Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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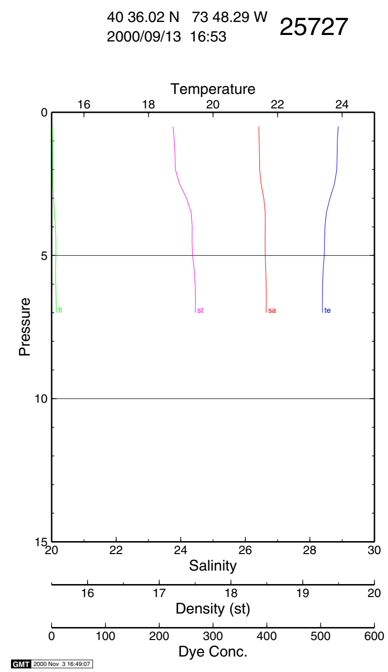
40 36.02 N 73 48.29 W
2000/09/13 16:53
25727
Temperature
Pressure
Salinity
Density (st)
Dye Conc.
fl
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sa
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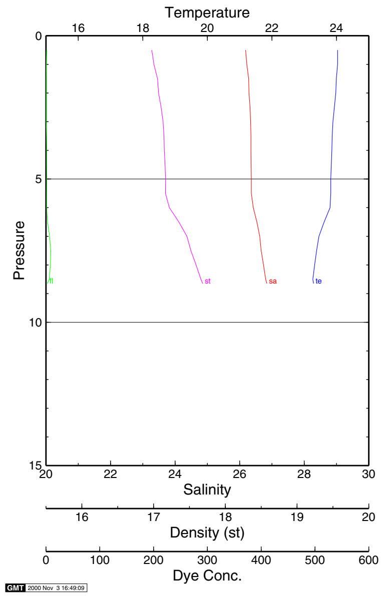
40 36.07 N 73 47.79 W
2000/09/13 16:57
25728



40 36.25 N 73 47.51 W
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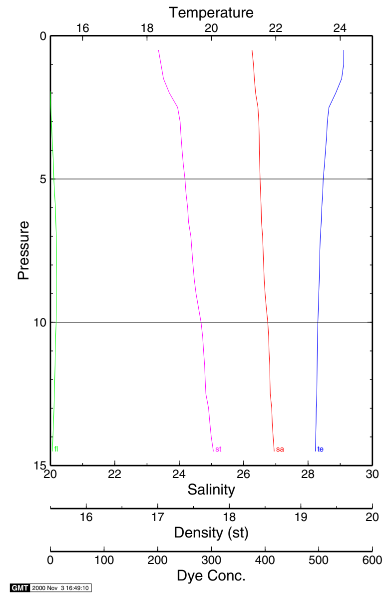
25729



40 36.41 N 73 47.23 W
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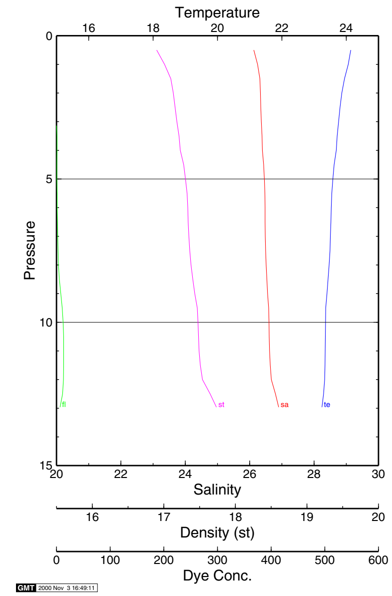

40 35.56 N 73 49.02 W
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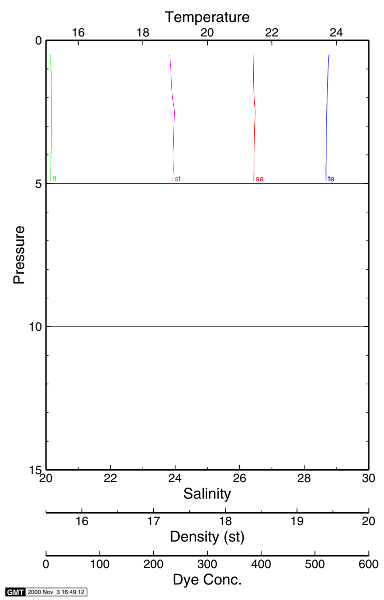
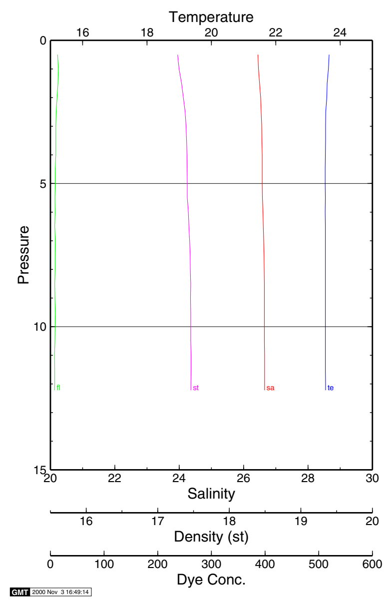


40 35.05 N 73 50.26 W
2000/09/13 17:22
25732



40 34.96 N 73 51.32 W
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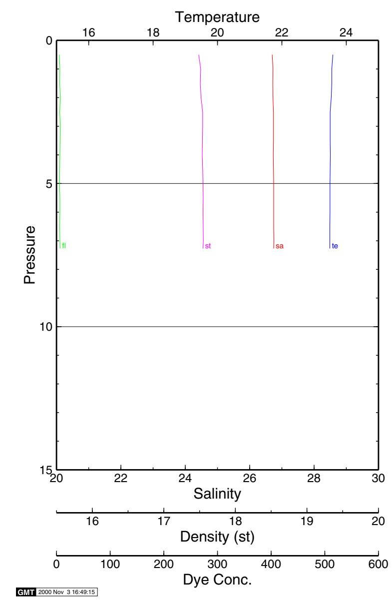

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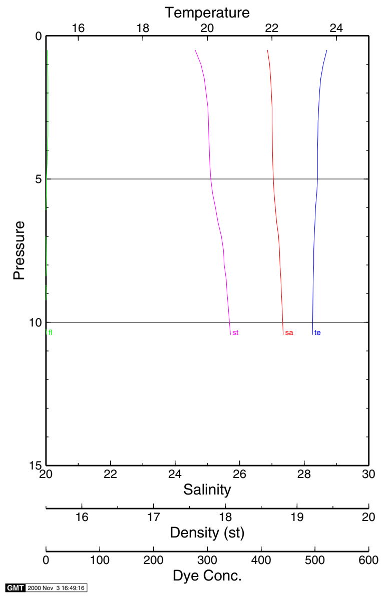

40 34.28 N 73 54.70 W
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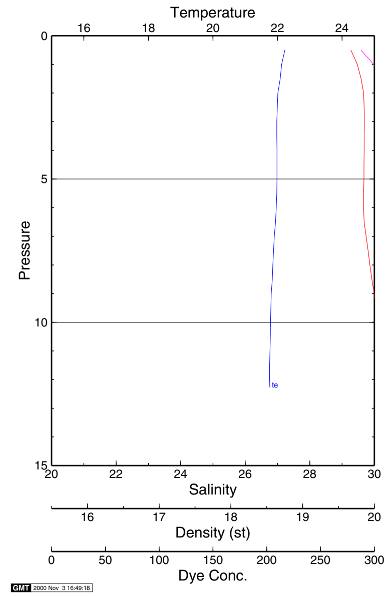
25801



40 34.66 N 73 52.22 W
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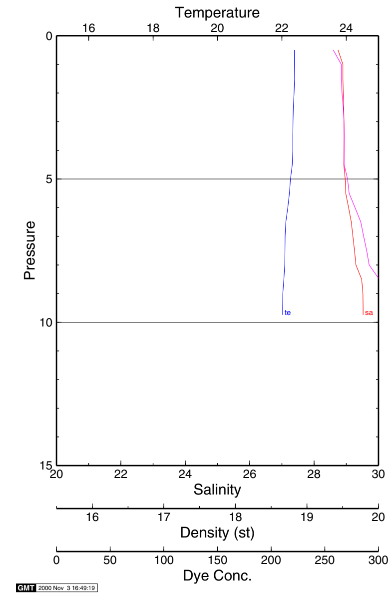

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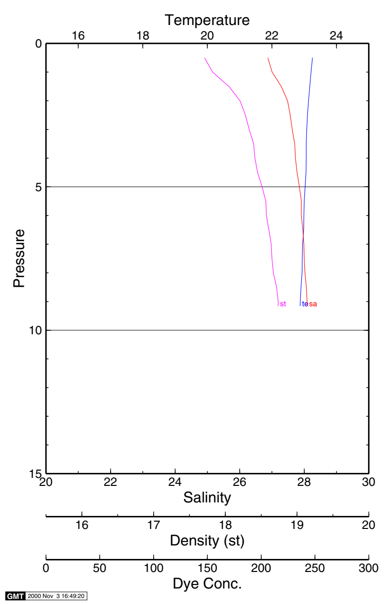

40 35.54 N 73 49.10 W
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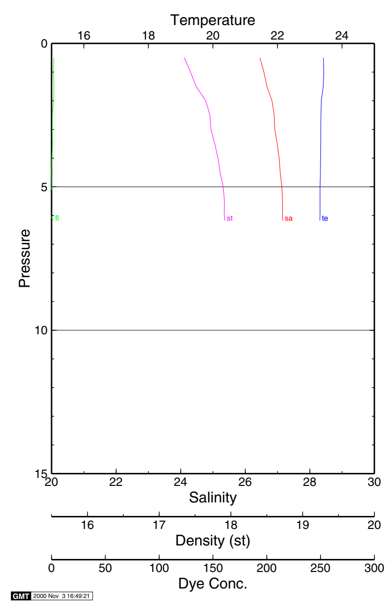

40 36.02 N 73 48.32 W
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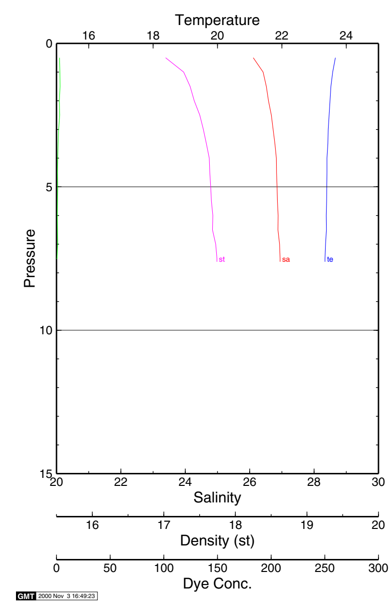

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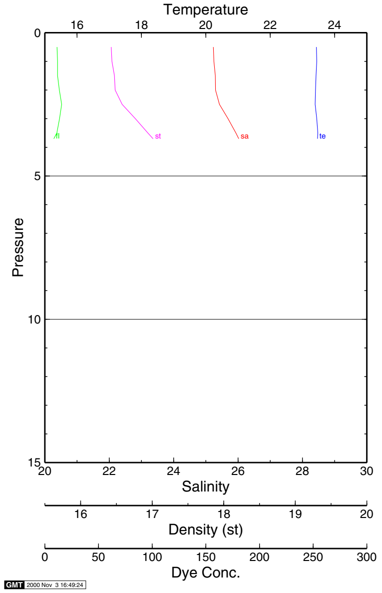

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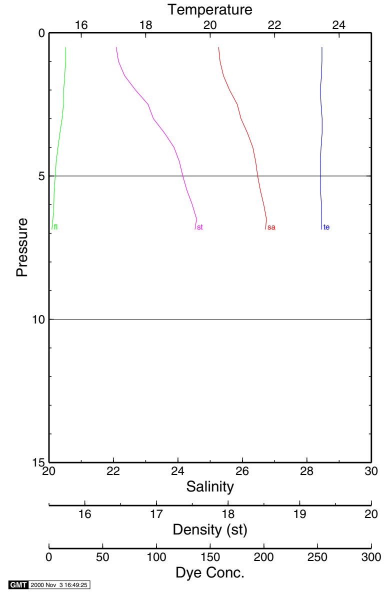

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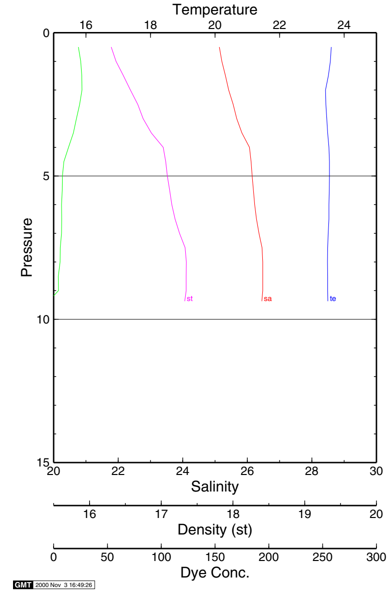

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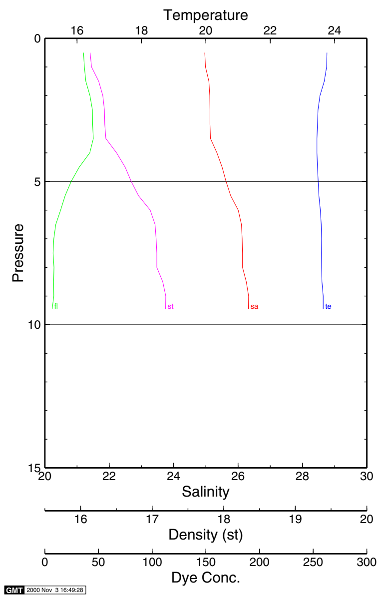

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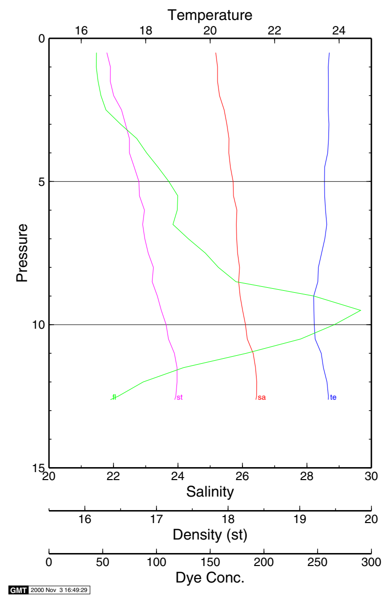

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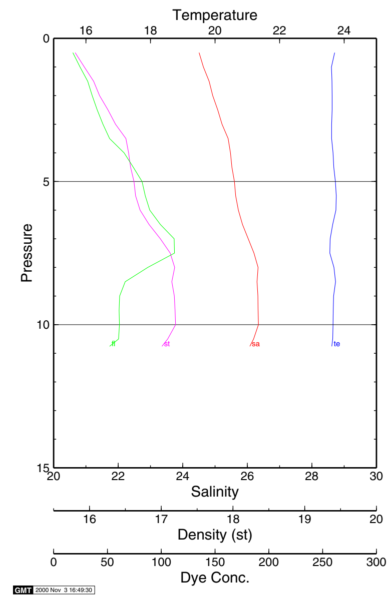
2000/09/14 15:01
25811



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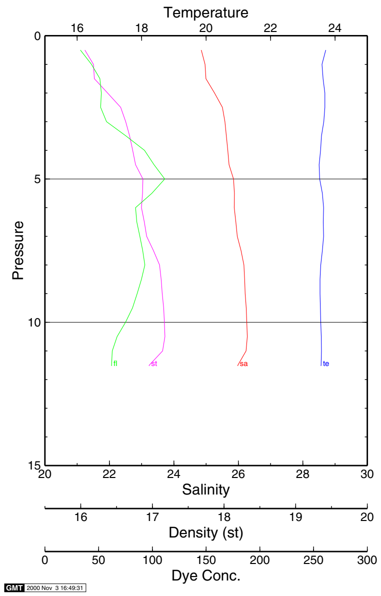

40 38.59 N 73 49.39 W
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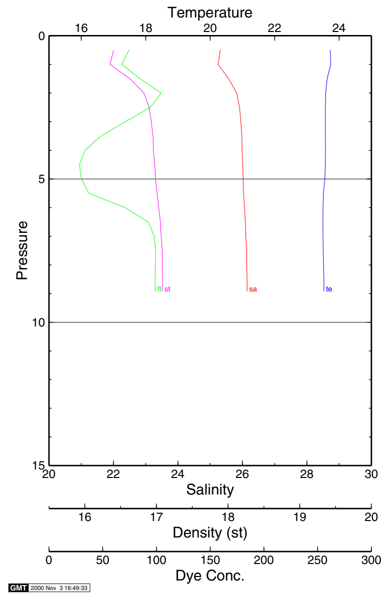

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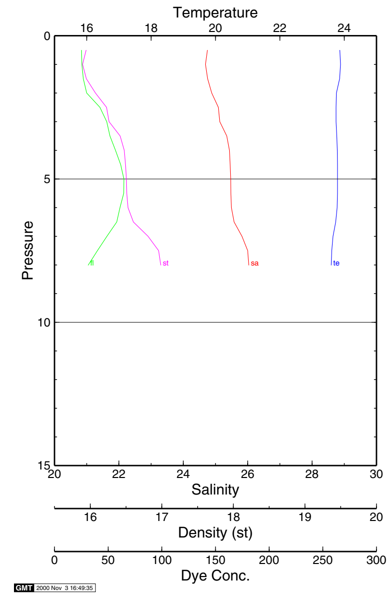

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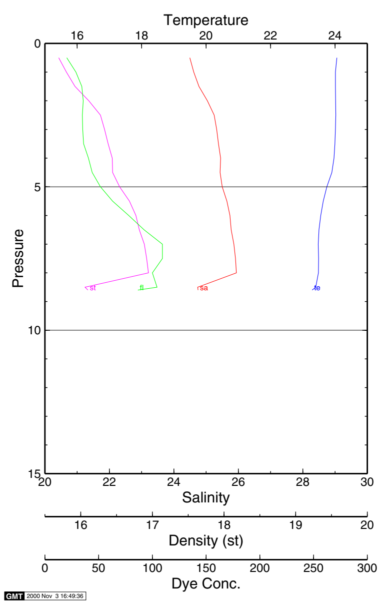

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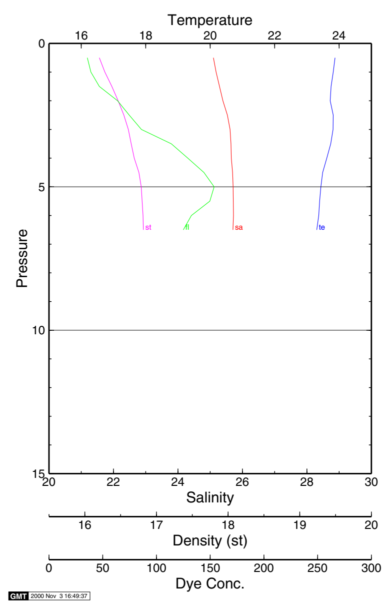

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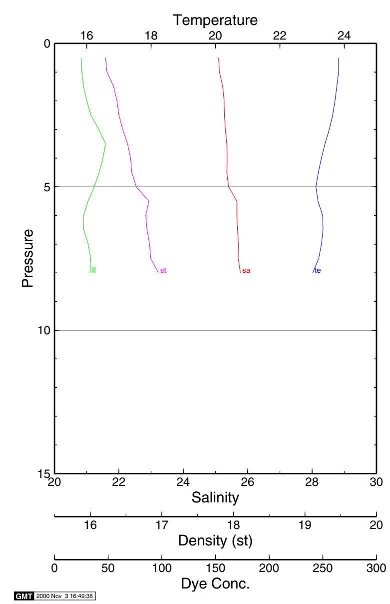

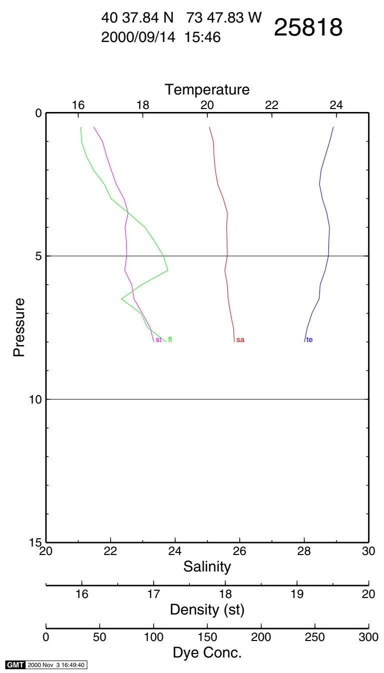
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0 5 10 15
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
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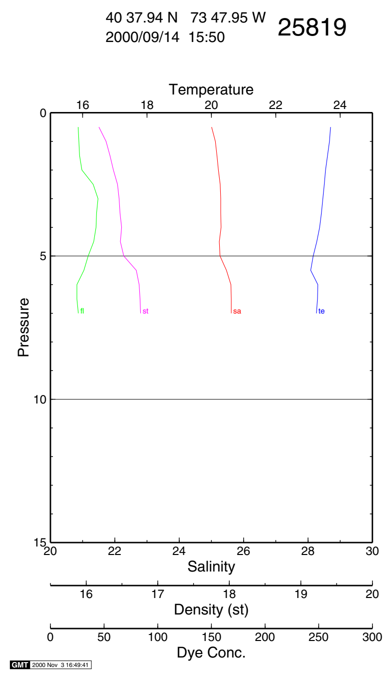
Dye Conc.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Salinity
16 17 18 19 20
Density (st)
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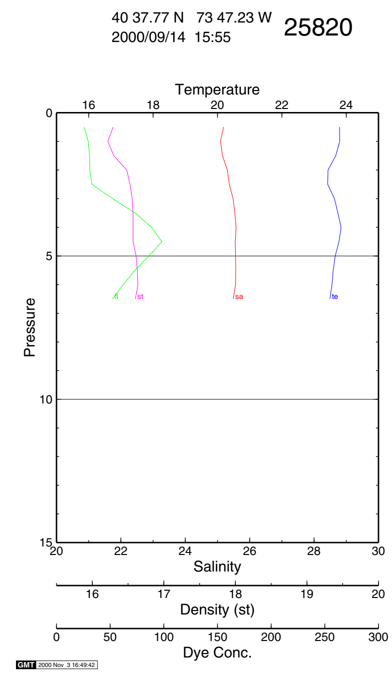
Dye Conc.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2000/09/14 15:55
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Pressure
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Salinity
16 17 18 19 20
Density (st)
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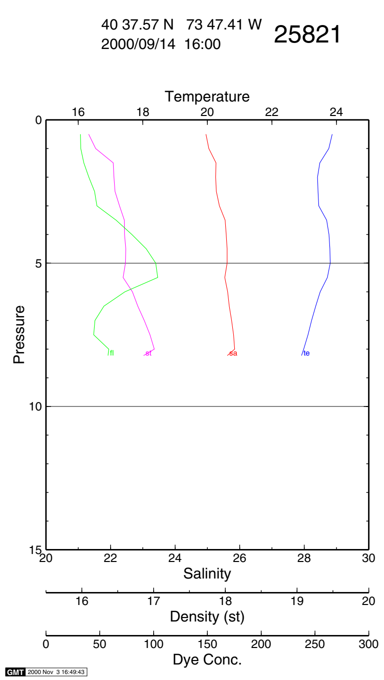
Dye Conc.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Salinity
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Density (st)
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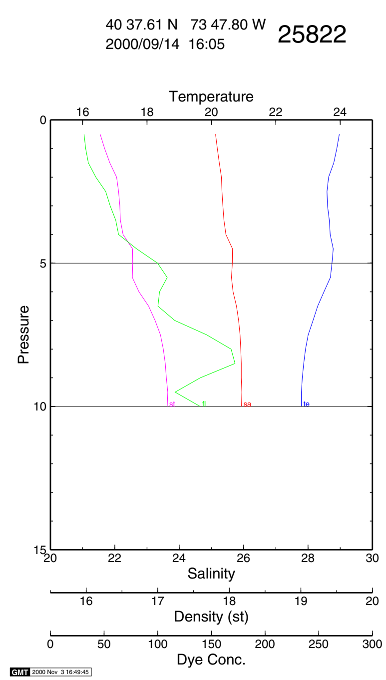
Dye Conc.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0 5 10 15
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
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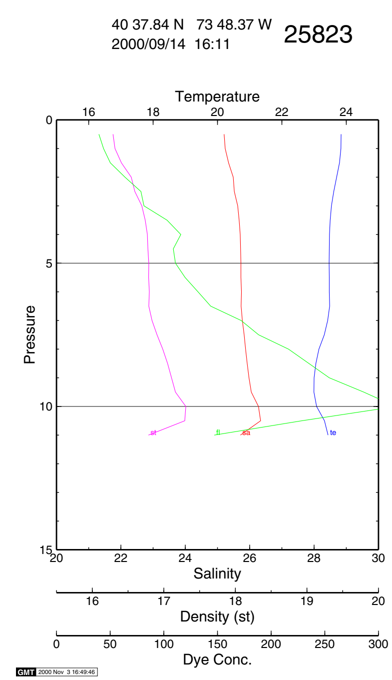
Dye Conc.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Pressure
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Salinity
16 17 18 19 20
Density (st)
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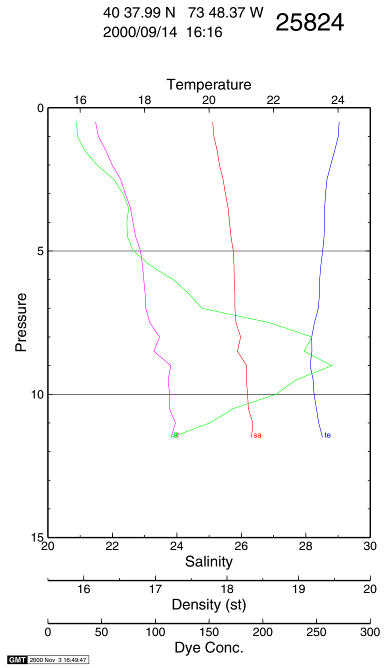
Dye Conc.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2000/09/14 16:16
25824
Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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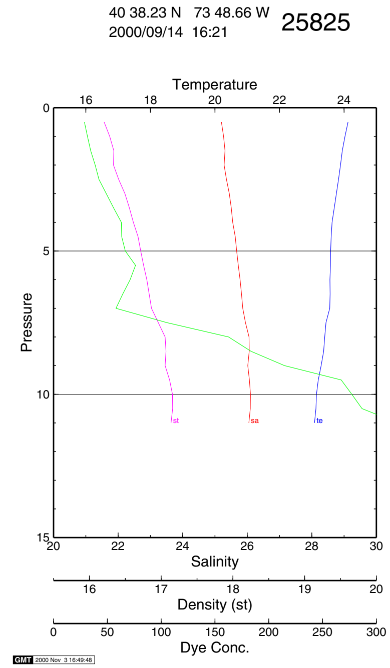
GMT 2000 Nov 3 16:49:47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Temperature
Pressure
Salinity
Density (st)
Dye Conc.
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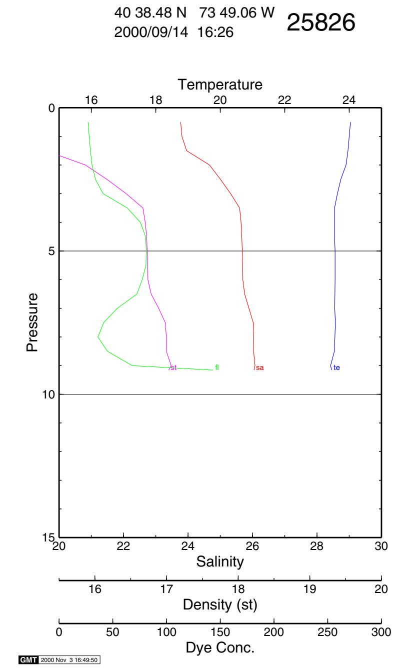
GMT 2000 Nov 3 16:49:48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Salinity
Density (st)
Dye Conc.
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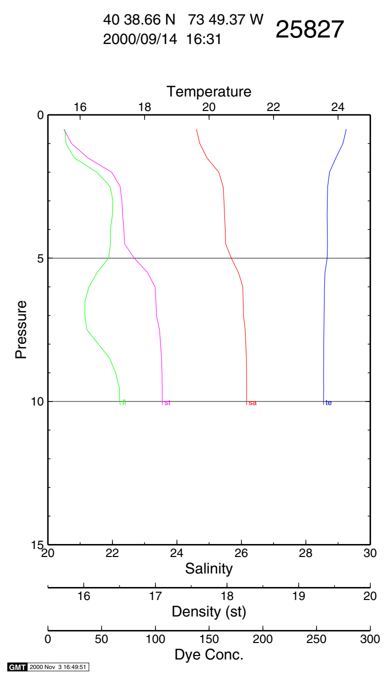
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Pressure
Salinity
Density (st)
Dye Conc.
fl
st
sa
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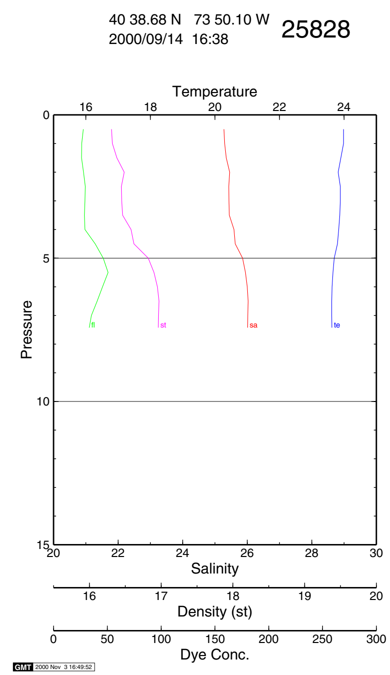
GMT 2000 Nov 3 16:49:51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Pressure
Salinity
Density (st)
Dye Conc.
fl
st
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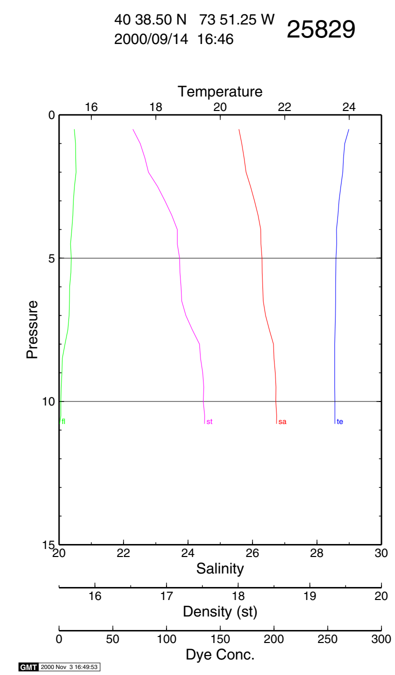
GMT 2000 Nov 3 16:49:52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25829
Temperature
Pressure
Salinity
Density (st)
Dye Conc.
fl
st
sa
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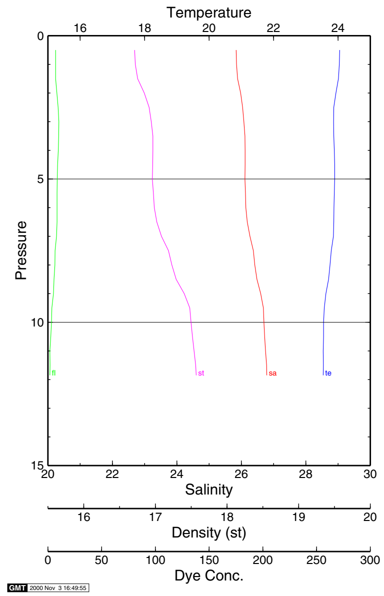
GMT 2000 Nov 3 16:49:53

40 38.32 N 73 51.93 W
2000/09/14 16:51
25830



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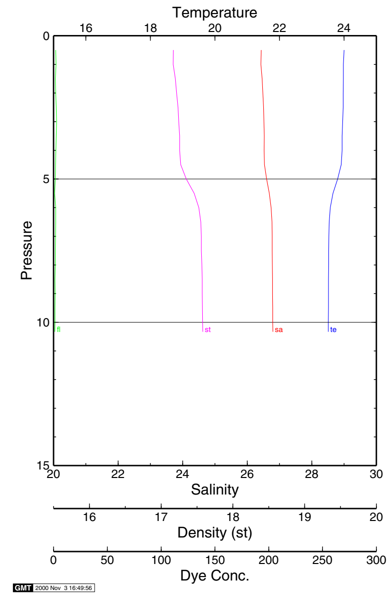

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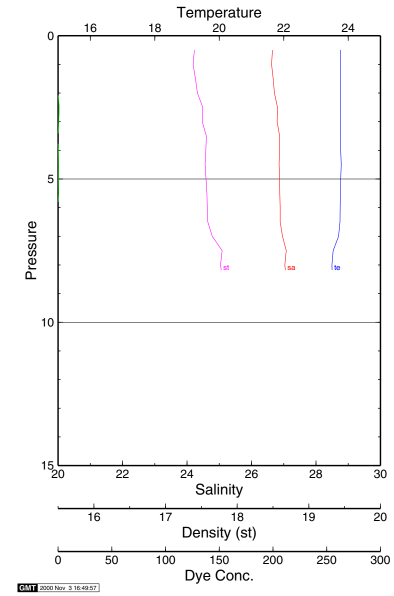
25832



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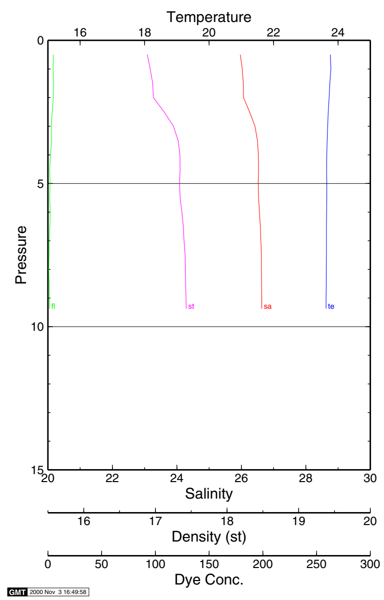

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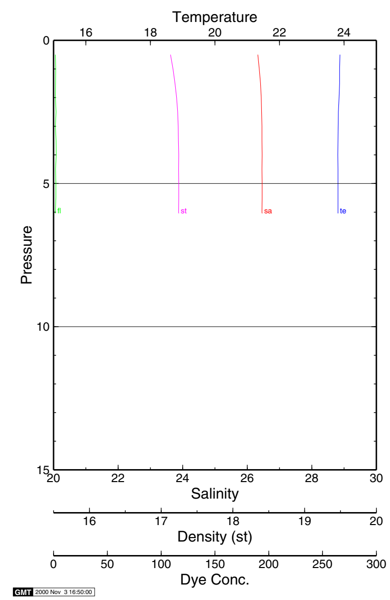
25834



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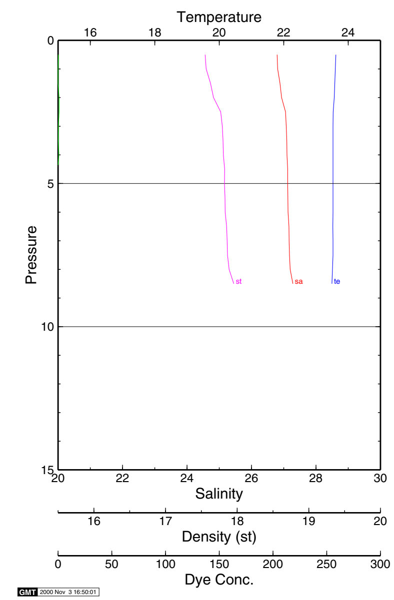
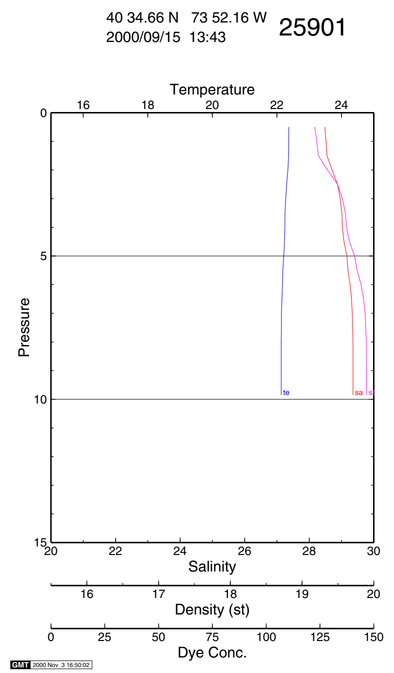
25835

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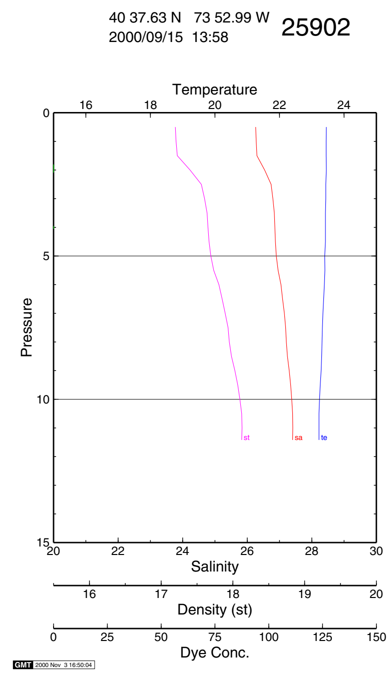
Temperature
Pressure
Salinity
Density (st)
Dye Conc.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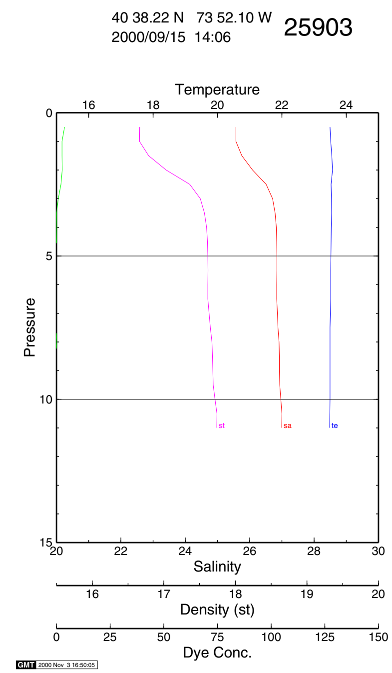
Pressure
Salinity
Density (st)
Dye Conc.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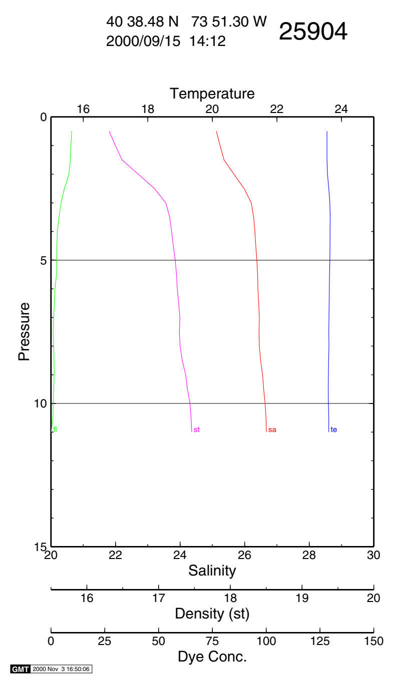
Pressure
Salinity
Density (st)
Dye Conc.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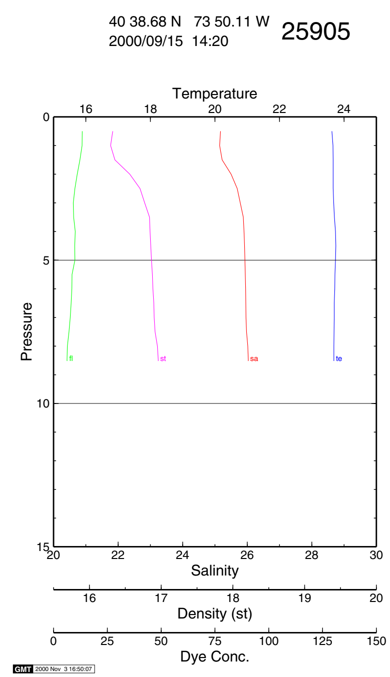
Pressure
Salinity
Density (st)
Dye Conc.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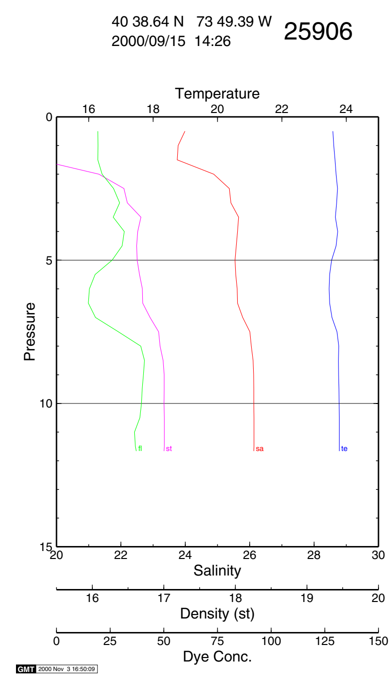
Pressure
Salinity
Density (st)
Dye Conc.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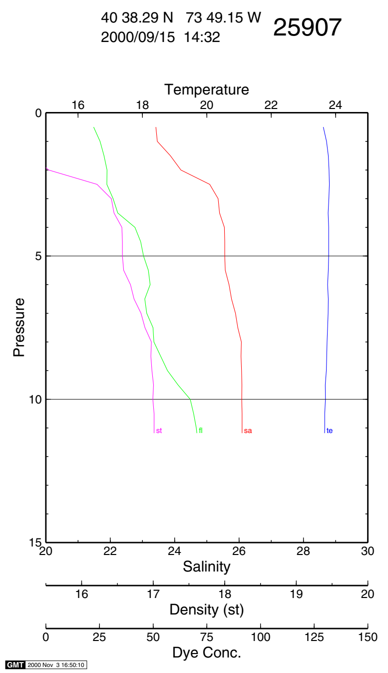
Temperature
Pressure
Salinity
Density (st)
Dye Conc.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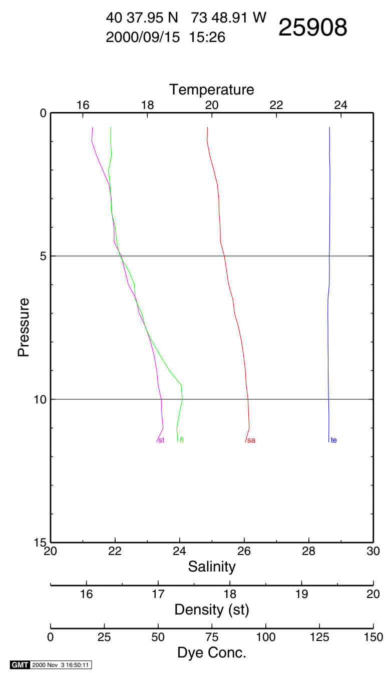
Temperature
16 18 20 22 24
Pressure
0 5 10 15
st fl sa te
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
0 25 50 75 100 125 150
Dye Conc.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st fl sa te
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
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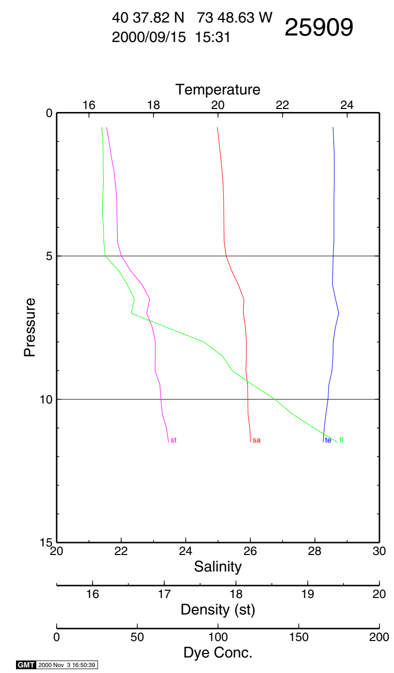
Dye Conc.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Pressure
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st sa te fl
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Salinity
16 17 18 19 20
Density (st)
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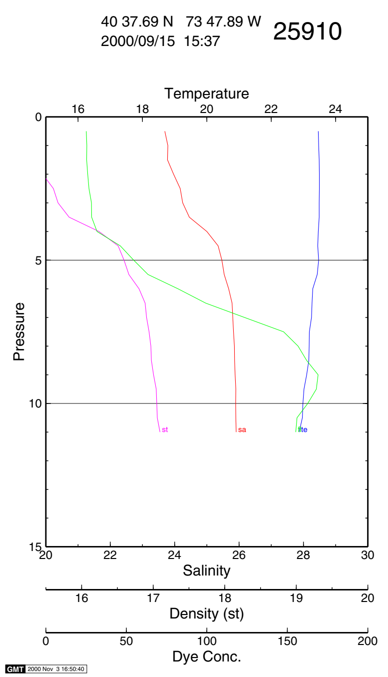
Dye Conc.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Pressure
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st sa te
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Salinity
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Density (st)
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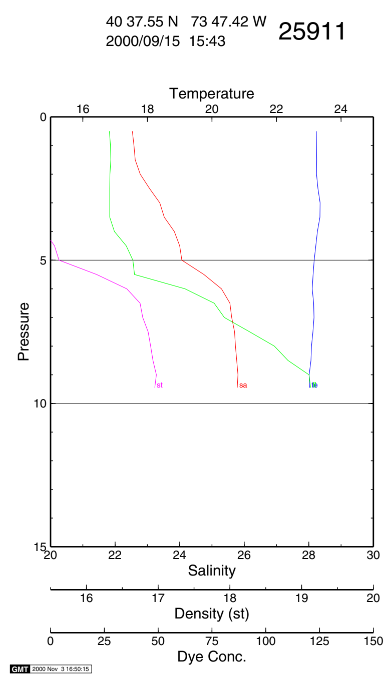
Dye Conc.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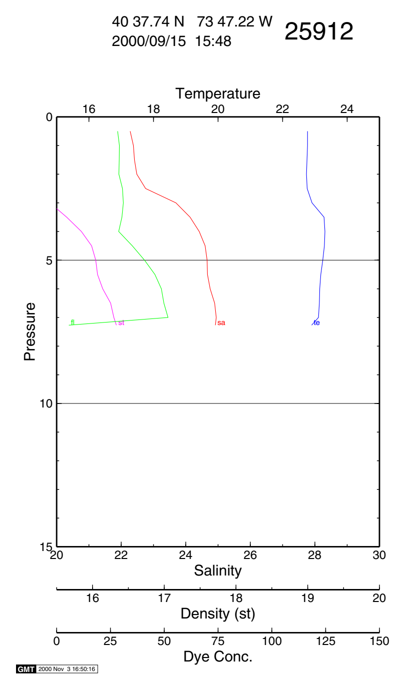
16 18 20 22 24
Pressure
0 5 10 15
st sa te
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
0 25 50 75 100 125 150
Dye Conc.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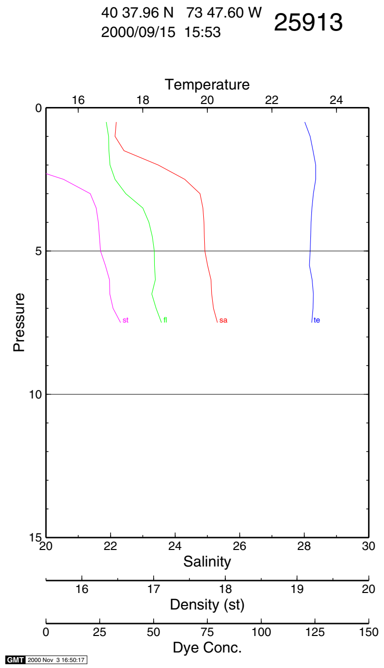
16 18 20 22 24
Pressure
0 5 10 15
fl st sa te
20 22 24 26 28 30
Salinity
16 17 18 19 20
Density (st)
0 25 50 75 100 125 150
Dye Conc.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16 18 20 22 24
Pressure
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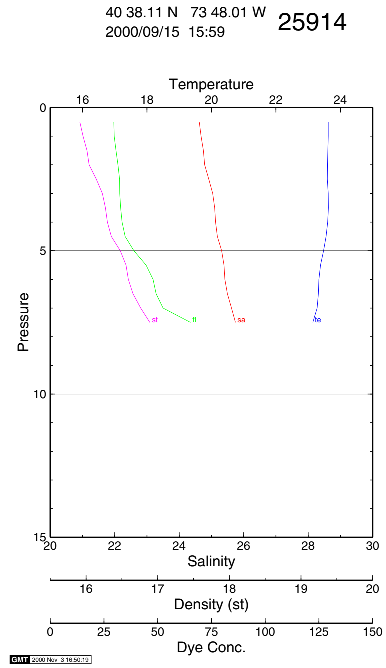
Salinity
20 22 24 26 28 30
Density (st)
16 17 18 19 20
Dye Conc.
0 25 50 75 100 125 150
st fl sa te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16 18 20 22 24
Pressure
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Salinity
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Density (st)
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Dye Conc.
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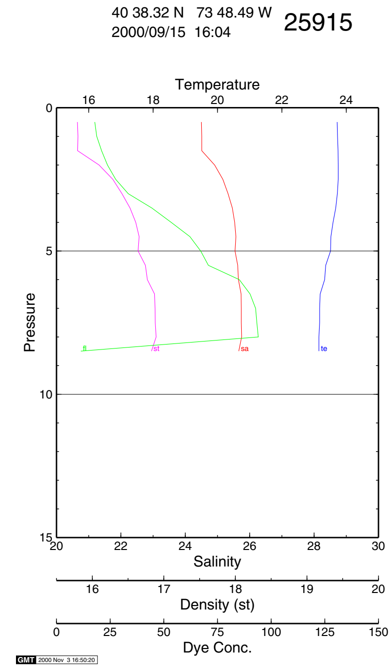
st fl sa te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2000/09/15 16:04
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Temperature
16 18 20 22 24
Pressure
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Salinity
20 22 24 26 28 30
Density (st)
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Dye Conc.
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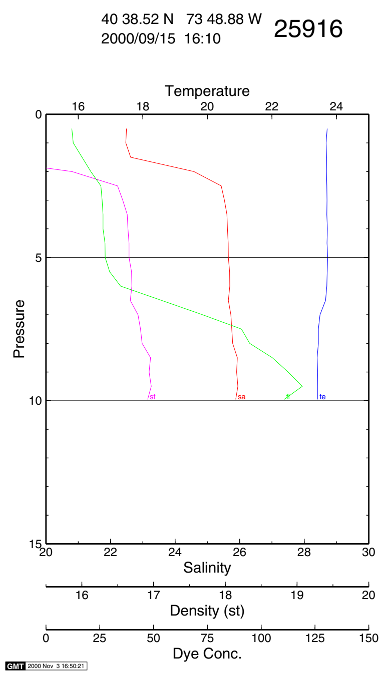
fl st sa te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Pressure
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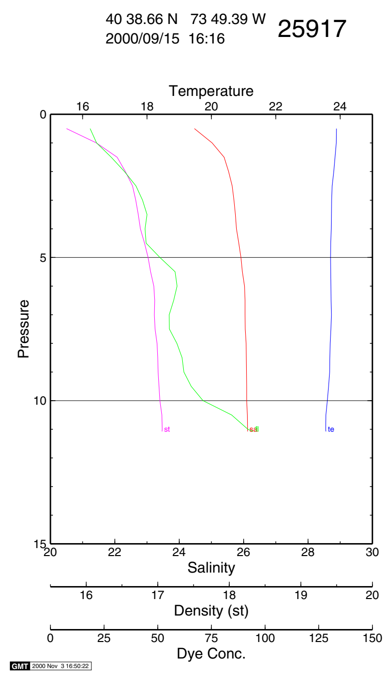
Salinity
20 22 24 26 28 30
Density (st)
16 17 18 19 20
Dye Conc.
0 25 50 75 100 125 150
st sa fl te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Temperature
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Pressure
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Salinity
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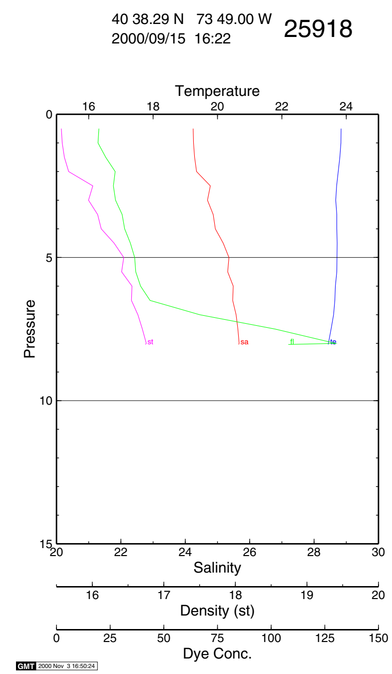
Density (st)
16 17 18 19 20
Dye Conc.
0 25 50 75 100 125 150
st te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Pressure
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Salinity
20 22 24 26 28 30
Density (st)
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Dye Conc.
0 25 50 75 100 125 150
st sa fl te

40 38.00 N 73 48.47 W
2000/09/15 16:27
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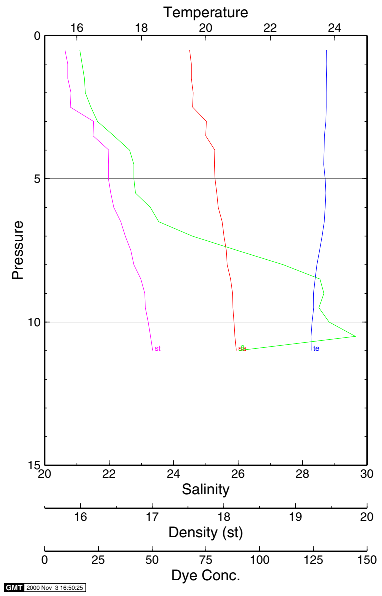

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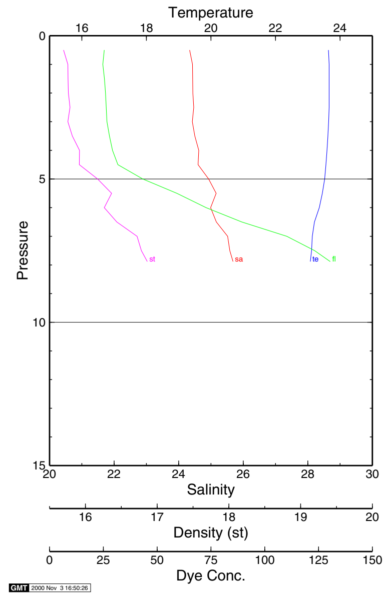

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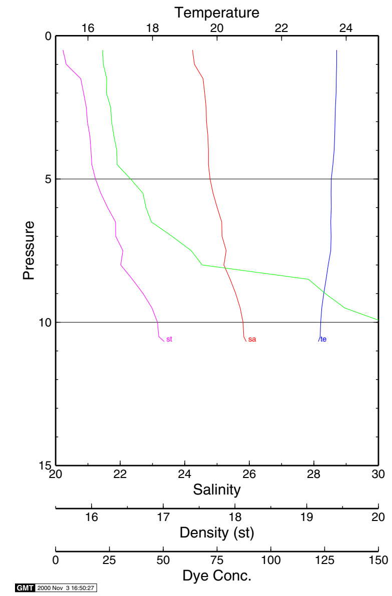

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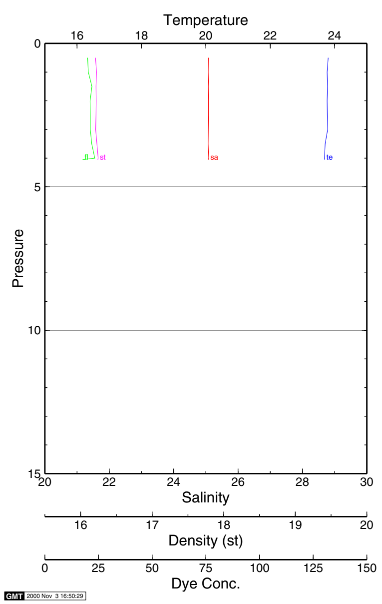

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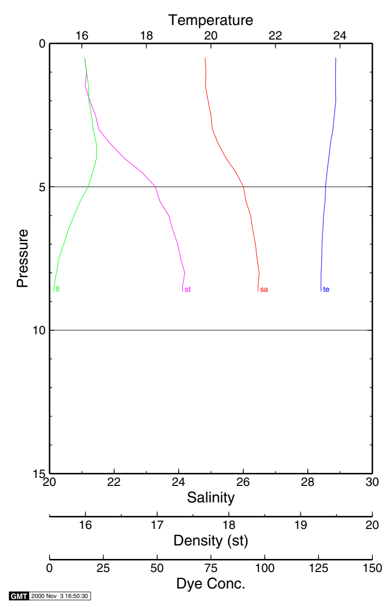

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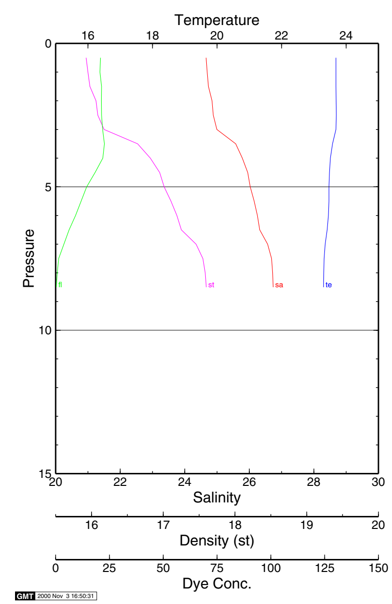

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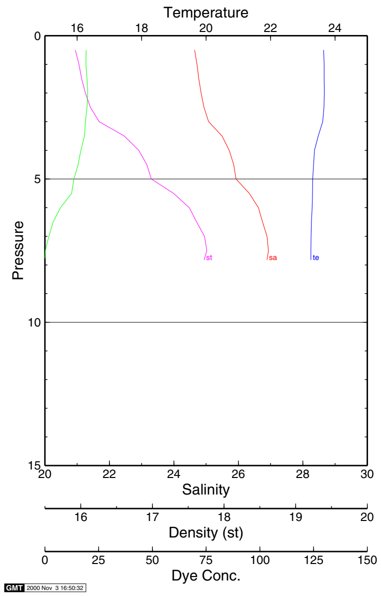

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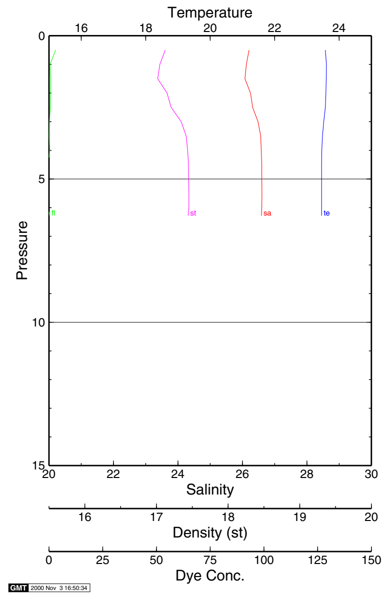

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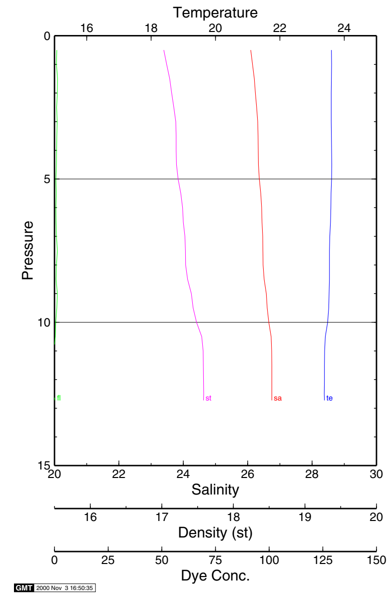

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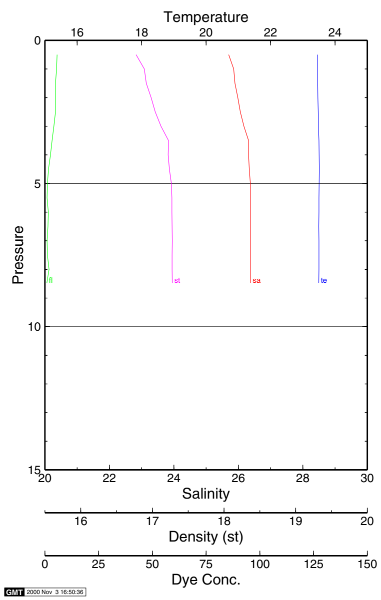

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