AN INVESTIGATION OF SEDIMENTATION INDUCED BY GAS PIPELINE LAYING OPERATIONS IN THE VICINITY OF THE OYSTER BED LEASE AREAS, MILFORD, CONNECTICUT

FINAL REPORT

Prepared For

Iroquois Gas Transmission System
Shelton, Connecticut 06484

By

W. Frank Bohlen
D. Cohen
K.H. Strobel

University of Connecticut
Department of Marine Sciences
Avery Point
Groton, Connecticut 06340

March 17, 1992

TABLE OF CONTENTS

Introduction

In March,1991 Iroquois Gas Transmission System initiated field operations associated with the placement of a 24in o.d.(0.576in-wall thickness) concrete cased pipeline across Long Island Sound. These operations involved excavation of a trench in the near-shore area adjoining Milford, Connecticut, pipeline placement, and final trench infilling and bottom grading. Since the pipeline route crossed an area of leased oyster and clam beds the dredging and grading associated with trenching operations was considered to have the potential to alter both near and far-field suspended material concentrations sufficient to affect the viability and ultimate yield of the shellfish beds. In order to permit assessment of the spatial scale of these impacts and to provide a quantitative measure of the mass of sediment suspended by the construction activities, three bottom mounted instrument arrays were deployed in and adjacent to the project area. These arrays were placed prior to the initiation of dredging and remained on-station throughout the construction period and for approximately 30 days after the completion of bottom grading. This extended deployment permitted evaluation of project associated sediment resuspension under a variety of meteorological and hydrographic conditions. The following report provides a summary of the results of these evaluations.

Study Area

a. Location and Hydrographic Conditions

The Iroquois Gas Transmission System pipeline enters Long Island Sound on the Connecticut shoreline within the City of Milford at a point approximately 3nm to the east of the entrance to the Housatonic River and 7nm to the west of the entrance to New Haven Harbor. The pipeline route crosses Silver Beach and proceeds initially along a southeasterly path passing north and east of Charles Island to a point approximately 4000ft offshore where it begins a progressive clockwise rotation to a southwest tending track (Fig.1). On entry to the Sound the pipeline immediately crosses an area of active, leased, shellfish beds (Fig.2).

Circulation throughout the area of the central Sound adjoining the pipeline route is dominated by the semi-diurnal lunar tide (M2). Tidal range in the vicinity of Milford Harbor averages approximately 6.6ft increasing to 7.6ft during springs (NOAA,1991). Currents in the area are expected to display significant spatial variability as a result of the regional variations in bathymetry and impediments to flow introduced by protruding headlands and partial submergence of the Bar extending landwards from the northwest corner of Charles Island (Fig.1). Measurements conducted during pre-project site investigations show near-bottom currents to the south of Charles Island, in 34ft of water, to be essentially shoreline parallel with the flood proceeding to the southwest and

This document involves pipeline location information and is not available at this Internet site due to homeland security-related considerations. This portion of the Islander East consistency appeal administrative record may be reviewed at NOAA's Office of General Counsel for Ocean Services, 1305 East-West Highway, Silver Spring, Maryland.

the ebb to the northeast. Maximum speed during the observation period (November 2 - December 15,1986) approached 1.5 nm/hr (knots) (Alpine Ocean Seismic Survey,Inc,1987).

The tidal currents in the area are aperiodically supplemented by density driven flows, dominated by water temperature, salinity, and local winds. Water column temperatures display a regular seasonal cycle with maxima occurring during the late summer and minima during the late winter. Values are clearly correlated with concurrent air temperatures and wind associated energies acting to mix the water column over the vertical. Salinities vary in response to regional streamflows and can be particularly variable in the Milford area due to the close proximity of the discharge region of the Housatonic River. Average discharge from this tributary stream displays a regular seasonal pattern with peak flows typically occurring during the late winter-early spring. Gage data obtained at Stevenson, Connecticut, approximately 20 mi upstream from the Sound, indicate an average discharge over the 61 year period of record of approximately 2600 ft^3/sec (USGS,1989). The peak discharge observed during the period was 75,800 ft^3/sec on October 16,1955. Minima have been observed to approach zero as a result of commercial diversions and demands associated with hydroelectric generation.

The surface wind field affecting the study area displays a regular seasonal variability with southwesterly winds dominating during the summer and west to northwesterly winds dominant during the winter. Short-term high energy storm events, rich in easterly components, can occur at any time during the year but are most common during the spring and fall transition periods. Sheltering provided by the adjoining land mass makes the region of the Gulf and the areas around Charles Island particularly sensitive to winds from the southerly quadrant ranging from the southeast clockwise to the southwest. Only from these directions is the over-water distance, or fetch, sufficient to permit generation and inshore propagation of an energetic surface wave field. Such energies serve both to mix the water column over the vertical, modifying the density distributions, and to produce near-bottom velocities and associated boundary shear sufficient to disturb the sediment-water interface and transport the resuspended sediments.

The combination of wind induced mixing and concurrent cycling of water temperature and salinity favors the development of horizontal and vertical density gradients which in turn serve to generate small, but measureable, currents. On average, these gradients tend to favor the seaward movement of the fresher, near-surface waters, and landward migration of the more saline bottom waters. This simple estuarine circulation pattern can be significantly modified, however, by local factors including the shape and form of the bottom and local streamflows. In the Milford area, the field measurements obtained in 1986 indicate that the net, near-bottom, residual flow does not proceed simply to the west into the Sound or towards the entrance to the Housatonic River but rather flows to the northeast towards Welches Point at speeds of approximately 3cm/sec. These data are reasonably consistent with previous observations showing the non-tidal drift along the Milford shoreline to be easterly and part of a larger scale clockwise gyre encompassing much of central Long Island Sound, at least for some portions of the year (Riley,1956). The factors governing this system are complex and still cannot be accurately defined in the absence of data providing improved spatial and temporal coverage.

b. Bathymetry and Surficial Geology

Water depths in the vicinity of the pipeline route adjoining Milford increase progressively with distance offshore. The associated lines of equal depth throughout the area are essentially shore parallel except in the vicinity of some rocky shoals to the southwest of Charles Island (Fig.1). This distribution favors the refraction of incoming waves resulting in nearly shore-normal angles of approach and minimal alongshore transport energy. These factors in combination with the exposure of the area to the dominant southwesterly wind field complicates maintenance of the dredged navigational channel entering Milford Harbor and favors a persistent cycle of resuspension and deposition of the surficial materials residing along the local sediment-water interface and minimal far-field transport. This sediment cycling is expected to be particularly pronounced during the higher energy spring and fall transition periods and may affect the viability of the shellfish resources in the area.

The variety of geophysical and geotechnical studies conducted as part of the pre-construction site investigation indicate that the sediments along and adjacent to the pipeline route consist primarily of medium sands with occasional intrusions of coarse sands and gravels and mixtures of silt (Jacques/McClelland Geosciences Inc,1988; Alpine Ocean Seismic Survey,Inc,1987) The majority of these data were obtained by analysis of split-spoon samples from a mechanical drilling system and/or small volume grabs. As a result, details of the immediate sediment-water interface were often obscured. Diver observations obtained during the late winter and spring, intended to supplement this investigation of pipeline associated sediment resuspension, indicate that the region of the interface, throughout the study area, is dominated by a layer of relatively high water content, organic rich, fine-grained materials which grade progressively into the more resistant sands forming the remainder of the sediment column. This layer is easily disturbed by low velocity currents resulting in generally high near-bottom concentrations of suspended materials. The materials forming this layer appear to be supplied by winnowing from the underlying sands during wave-induced cycles of resuspension/deposition. As a result, the layer may be most prevalent during the higher energy periods of the year, when the majority of the observations provided by this investigation were obtained, and slowly dissipate during the summer months under the combined effects of decreasing physical energy and increasing biological activity. The latter factor, including suspension feeding by resident oysters, favors aggregation and settling of fine-grained materials and a general increase in the erosion resistance of the sediment-water interface.

Project Characteristics

To provide reasonable protection through the nearshore zone, designs called for the gas pipeline to be covered by a minimum 3ft of sediment through the area extending from the beach crossing to the vicinity of the 30ft isobath, a distance of approximately 2.7 statute miles. Excavation of the required trench by a mechanical clamshell dredge, using large volume buckets (13-22 yds^3), began on March 9,1991 in the vicinity of the northeast corner of Charles Island (Fig.3) and proceeded inshore to the shallow water immediately adjacent to the beach. Following completion of this section, on or about March 28th, the dredge was moved offshore to the vicinity of the 30ft isobath and again proceeded to work shorewards excavating the deeper water section of the trench. Dredged sediments in both the nearshore and deeper water areas were placed along the western margin of the trench forming a subaqueous deposit for subsequent use as infill material. Placement typically involved release of dredged sediments at or near the water surface and subsequent gravitational settling to the bottom. Attempts to place materials directly by opening of the dredge bucket just above the bottom were not successful.

Dredging of the majority of the trench was completed by April 8,1991 and pipeline laying commenced on April 9,1991. The pipelaying barge was first positioned at a point to permit pulling of the pipe from the barge to shore. When this section was complete the barge proceeded to winch itself offshore along the route of the trench using a network of anchors. As the barge proceeded the pipeline was continuously fabricated aboard and progressively laid in the trench. Pipelaying in the region of the trench was completed on April 13,1991. Beyond this point, south and west to the nearshore region adjoining Long Island, pipelaying operations continued to bury the line using a trenching sled. The combination of dredging and towed trenching resulted in the burial of the entire line from the Connecticut shore across the Sound to Long Island.

Backfilling of the dredged trench adjoining Milford began on April 22,1991, immediately following the completion of pipelaying in the area, and continued until approximately May 22,1991. Operations employed the same dredges and dredging techniques used during the initial trench excavation. Clamshell buckets removed materials placed as a subaqeous deposit along the western margin of the trench and returned them to the trench as pipeline cover. Periodic bathymetric surveys were conducted throughout the operation to monitor the placement accuracy and to determine the need for additional fill materials.

Following completion of the infilling of the inshore sections of the trench on May 13,1991, mechanical grading operations intended to smooth the contours of the bottom in the area immediately over and adjoining the pipeline were initiated. Operations involved the use of a 40 ton steel box beam supported by the dredge crane and towed by a tug. These operations continued until June 23,1991. Again, there were frequent bathymetric surveys to detail the effects of smoothing and to define areas needing additional work. Positioning of the beam made use of the same precision navigational system employed during the dredging and pipelaying operations. It was intended that the beam working of the bottom be confined to a 300ft wide corridor centered on the pipeline.

Methods and Procedures

To detail the effects of the variety of pipeline construction activities on the ambient suspended material field three bottom mounted instrument arrays were deployed in the area of the Gulf on February 6,1991, approximately one month prior to the scheduled initiation of dredging. Two of the arrays were located immediately adjacent to the pipeline route (designated B and C) and one to the west (designated A), beyond the area of probable impact, to serve as a control monitoring average background conditions and the possible presence or absence of freshwater flows from the nearby Housatonic River (Fig.1). Each array was self contained and included an electromagnetic current meter, optical sensors monitoring suspended material concentrations, and water temperature and conductivity sensors. Instruments were positioned to monitor conditions approximately 1m above the sediment-water interface and were burst sampled for a period of 60 sec., four (4) times each

TABLE 1

Array Servicing Schedule

DATE	PURPOSE
06 February 1991	Deploy instrument arrays at Stations A,B & C
19 February	Retrieve data from Stations A,B & C
26 February	Retrieve data from Stations A,B & C; service the arrays
05 March	Retrieve data from Stations A,B & C
13 March	Retrieve data from Stations A,B & C; deploy wave gauge at Station C
26 March	Retrieve data from Stations A, B, C and wave gauge
02 April	Retrieve data from Stations A, B, C and wave gauge; service the arrays
09 April	Retrieve data from Stations B & C, move B & C arrays to the west of Charles Island
16 April	Retrieve data from Stations A, B', C' and wave gauge
01 May	Retrieve data from Stations A, B', C' and wave gauge
15 May	Retrieve data from Stations A, B' & C'; move B' & C' arrays back to original postions
22 May	Retrieve data from Stations A, B, C and wave gauge
05 June	Retrieve data from Stations A, B & C
17 June	Retrieve data from Stations A, B & C; fetch array from Station A
27 June	Retrieve data from Stations B & C
10 July	Retrieve data from Stations B & C
27 July	Retrieve data from Stations B, C & wave gauge; fetch wave gauge and instrument arrays from Stations B & C

hour. Data were recovered approximately every two weeks throughout the study period and returned to the laboratory for analysis. A summary of the array servicing schedule is shown in Table 1.

All instruments were calibrated in the laboratory prior to field deployment. For the electromagnetic current meters, voltage outputs were correlated with known flow characteristics by the manufacturer. Each optical sensor was calibrated against varying concentrations of suspended sediments. Sediment samples for these tests were obtained by surficial grab at various locations throughout the study area. The results of these tests for each of the instruments used in the field deployments are shown in Figures 4 and 5. The temperature and conductivity sensors were calibrated against laboratory standard thermometers and I.A.P.S.O. Standard Seawater, respectively. An example of the calibration checks for the conductivity probes is shown in Figures 6 and 7.

To supplement the primary array observations, a bottom mounted pressure gage (Sea-Data Model 635-11) was deployed at Station C on March 13,1991. This unit was intended to monitor near bottom pressure fluctuations associated with the surface wave field and tide induced alterations in water column height. Instrument specifications are listed in Table 2. This unit was added to the initial suite of instruments after review of the first data set indicated the relative importance of surface wind waves as a factor governing local suspended material concentrations.

In addition to the wave gage, the array systems were supplemented by selective deployments of two InterOcean S4

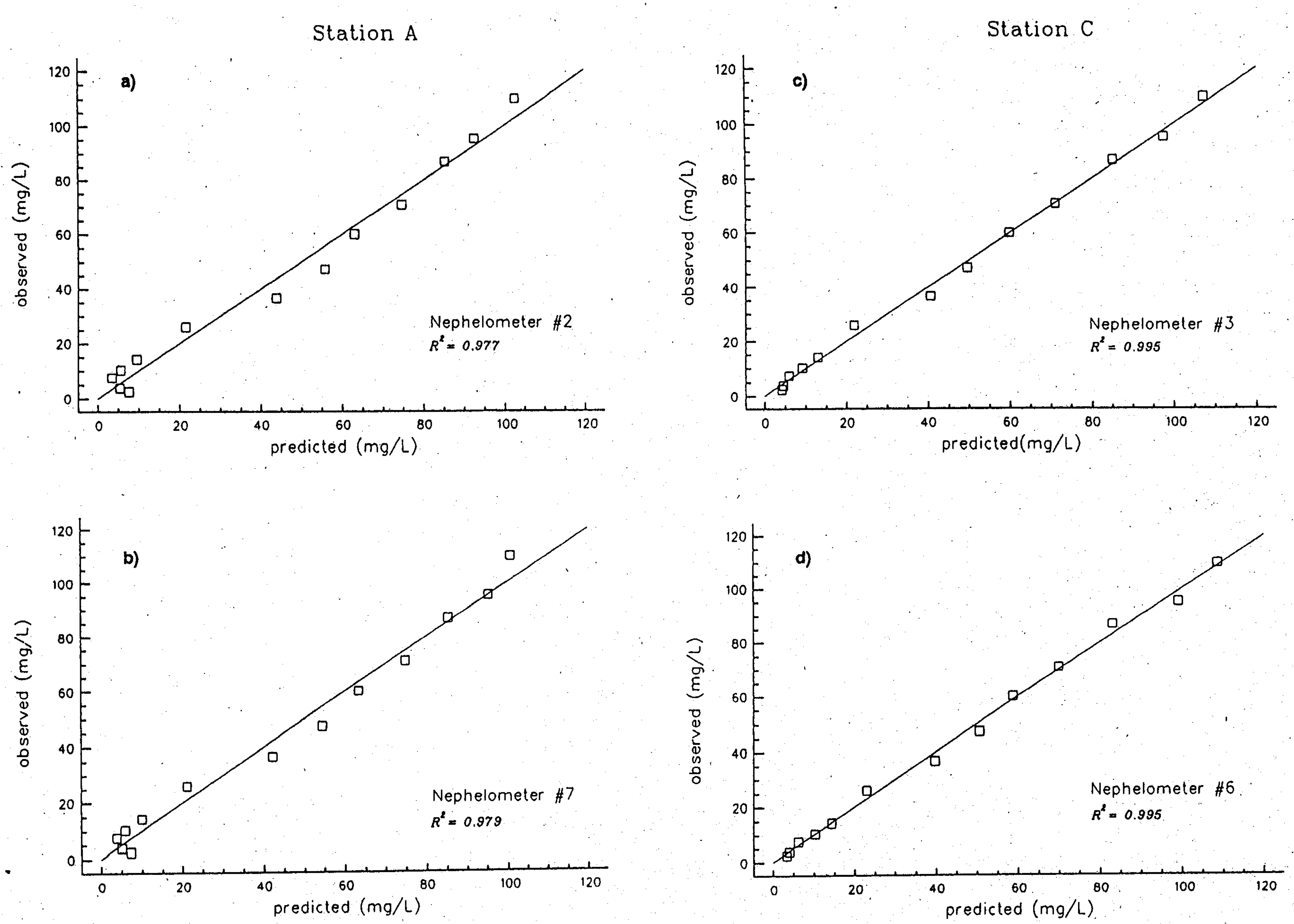


Figure 4 Instrument Calibrations - 1991 - Stations A & C
Optical Suspended Material Concentration Sensors

STATION B

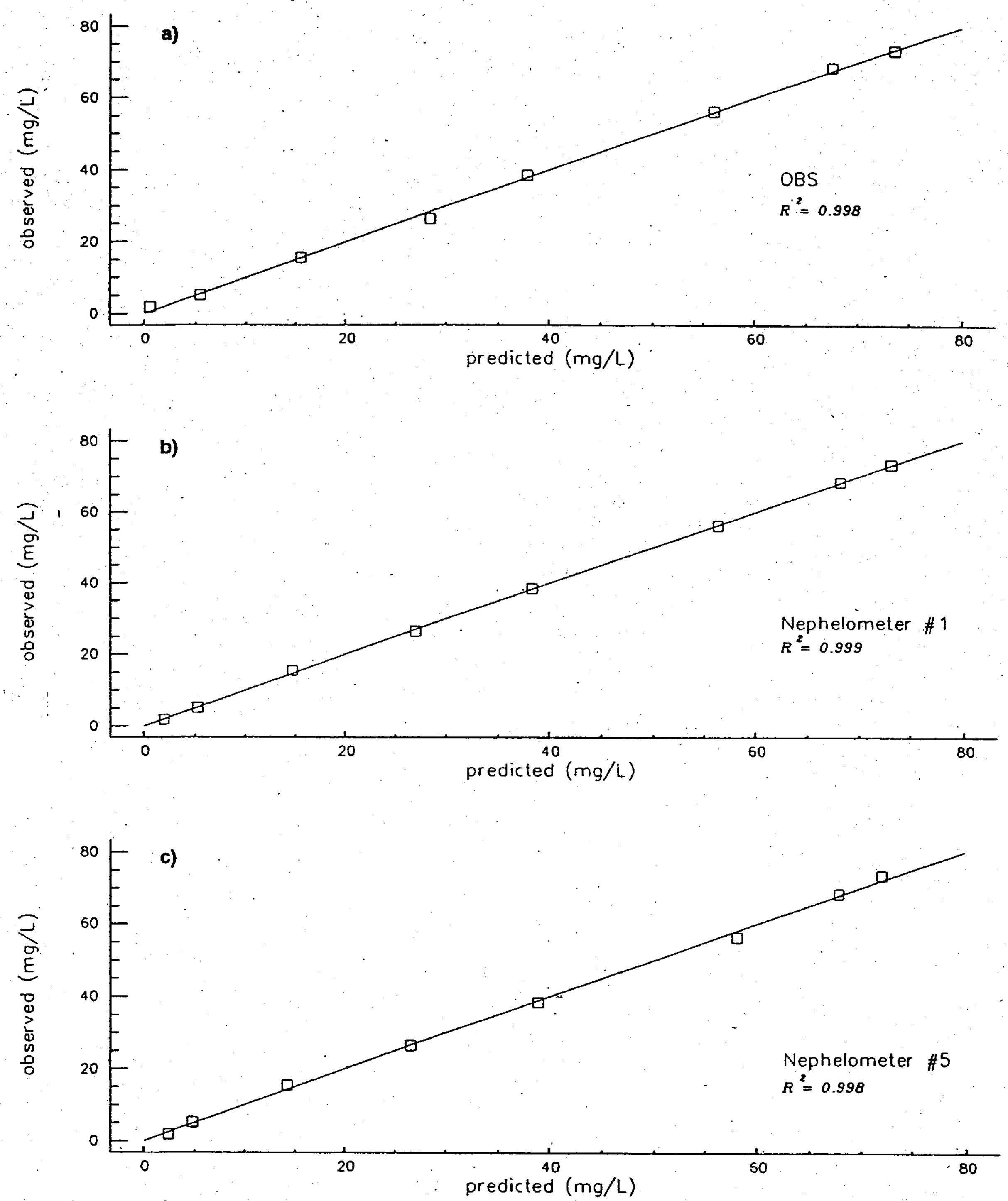


Figure 5 Instrument Calibrations - 1991 - Station B
Optical Suspended Material Concentration Sensors

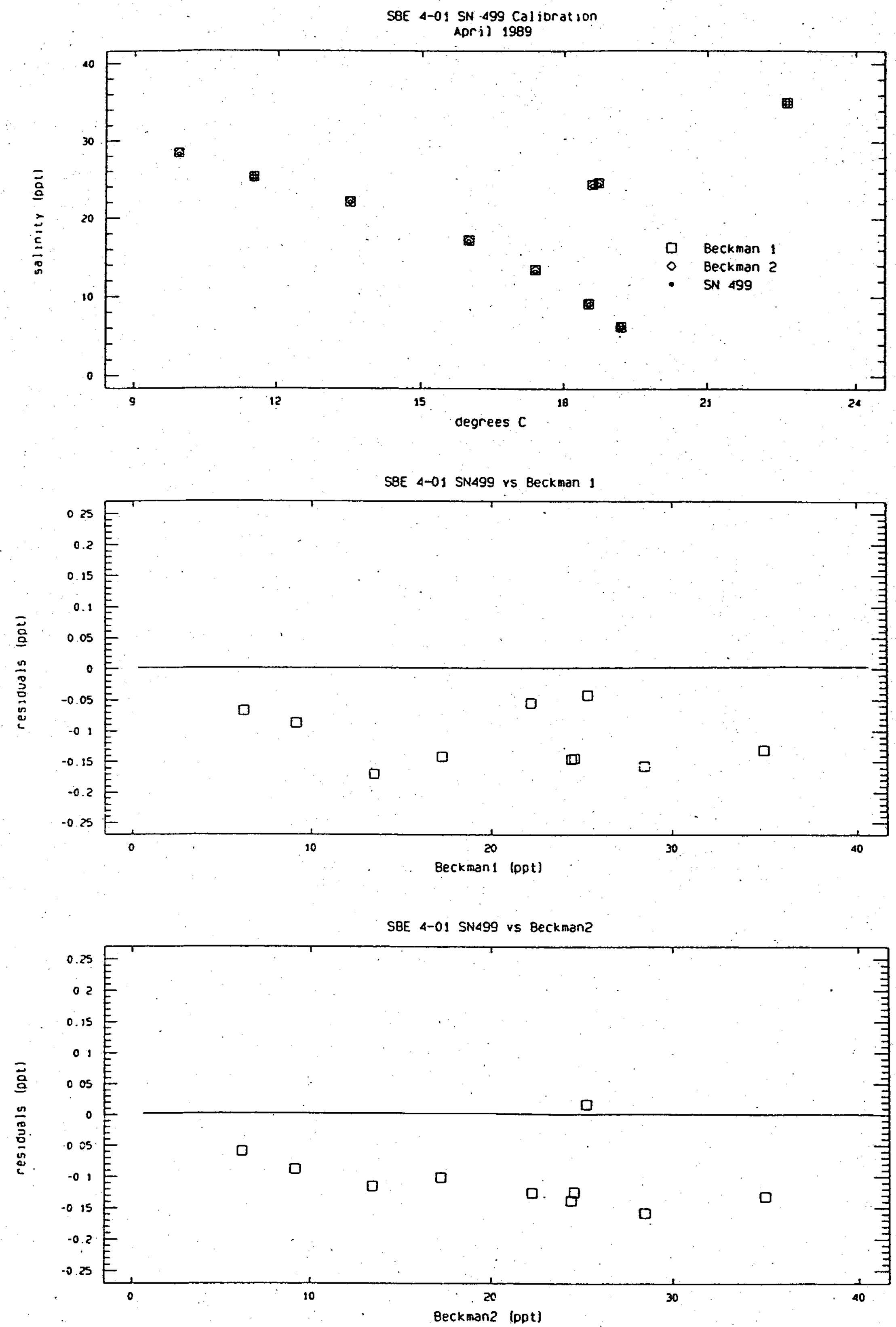


Figure 6 Laboratory Calibration Check - SN499 Conductivity Sensor versus Beckman RS-B7 Conductivity Bridge

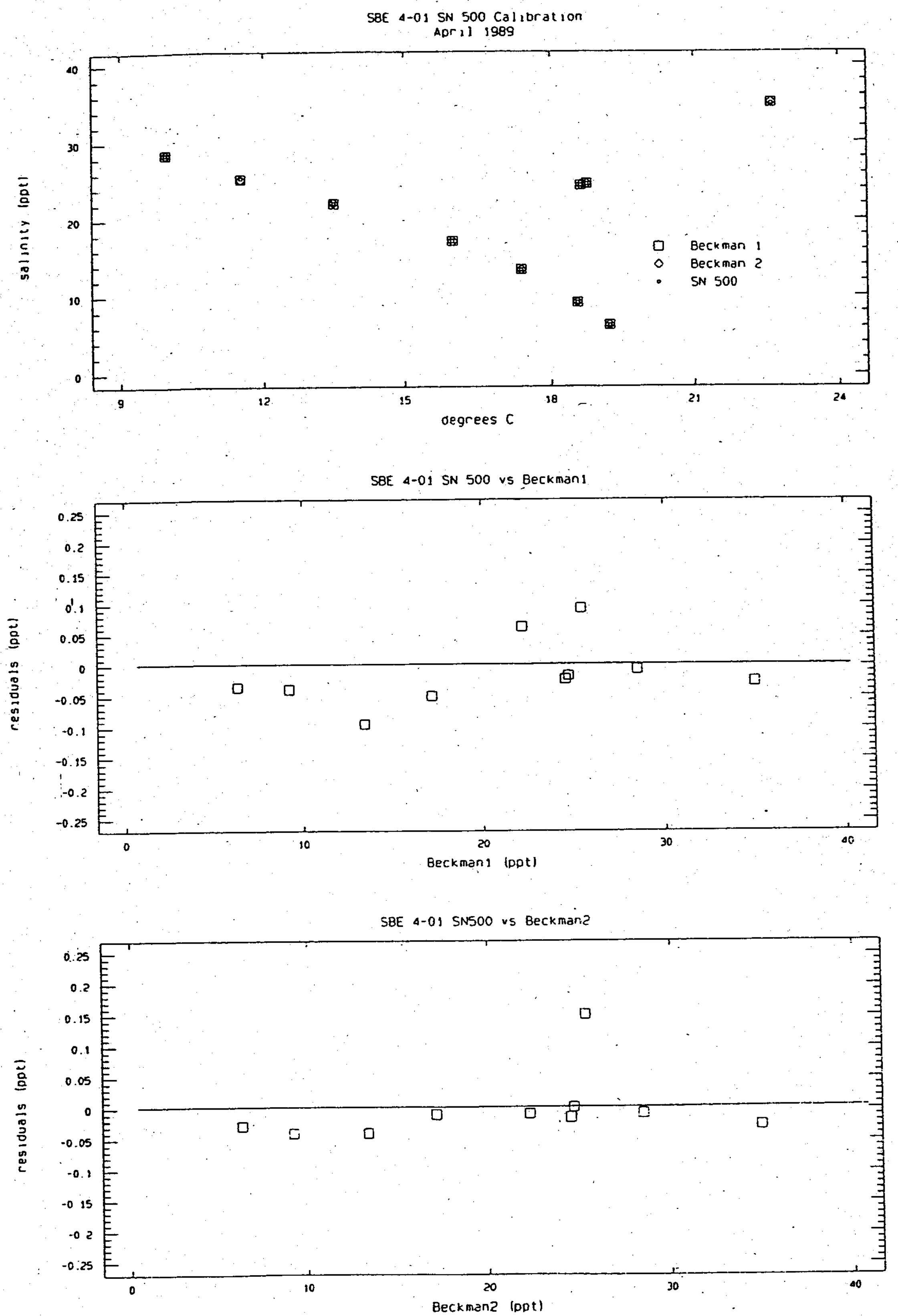


Figure 7 Laboratory Calibration Check - SN500 Conductivity Sensor versus Beckman RS-B7 Conductivity Bridge

electromagnetic current meters (Table 3). These units were supported by separate bottom mounts placed adjacent to the primary arrays and yielded an independent check on the accuracy of the current speed and direction provided by the array current meters.

On completion of the trench excavation phase of the project on April 8,1991 the instrument arrays deployed at Stations B and C were relocated to the west of Charles Island (Fig.1) to eliminate the possibility of damage by the up-coming pipe laying operations. They remained in these locations until the 15th of May,1991 and were then returned to their original positions. Deployments continued at Stations B and C until July 29,1991, approximately one month after termination of the the beam smoothing operations. The array deployment at Station A was terminated on June 17,1991 due to developing problems with biofouling of the array and confidence that the control on ambient suspended material concentrations and the presence of Housatonic River water provided by this array was no longer required. A summary of the instrument deployment schedule is provided in Table 4.

In addition to the time series observations provided by the fixed arrays, drawn water samples were obtained on many of the days on which the arrays were serviced. These data were intended to provide continuing checks on the in-situ instrument calibrations. Samples were obtained using five (5) liter Niskin samplers at two points on the vertical, near-surface and 1m above the bottom. Following recovery, samples were transferred to pre-rinsed plastic bottles and returned to the laboratory for analysis of salinity and

TABLE 2

Wave Gage Technical Specifications

PRESSURE SENSOR

Type:	Paros Scientific "Digi-Quartz"
Range:	100 psia: 0-70 meters
Resolution:	waves:0.1 cm, tides:0.12 cm
Accuracy:	0.03 ft@<80ft; 0.05 ft@>80 ft

TEMPERATURE

Type:	Thermistor
Range:	-4.5 to 34.5°C
Resolution:	0.003° C
Accuracy:	0.07°

TIMEBASE

Type:	4.194304 MHz quartz crystal
Stability:	1 ppm/year

CONTROL

Waves:	Burst Interval, Sample Interval, Samples per Burst, hours/sec switch, Scan Indicator
Tides:	Measurement Interval, Scan Indicator

DATA STŌRAGE

Type:	Cassette tapes, 300 & 450 ft
Format:	800 bpi bi-phase code on 4 tracks
Capacity:	30,800 data records, 300' tape 48,000 data records, 450' tape

DATA FORMAT

Time:	20 bit binary, 128 ticks/hr
Pressure:	tides: 20 bit binary; waves: 16 bit binary
Temperature:	16 bit binary

RECORD FORMAT

Type:	308 bits, 2 concurrent interleaving formats
Tides:	mode, header, time, 8 P&T samples, parity
Waves:	mode, burst record number, 16 P samples, parity

POWER SUPPLY

Type:	12 internal akaline "D" cells

MECHANICAL/ENVIRONMENTAL

Size:	7 inches diameter x 24 inches long
Weight:	14 lbs in air with battery; 12.5 lbs in water
Mounts:	2 - 0.5" bolt holes on 13" centers, 1.0" clearance
Material:	6061-T6 Aluminum
Finish:	Hard-coat anodixe with electrostatic epoxy overcoat
Depth:	1100 meters

TABLE 3

S4 Current Meter Specifications

SPEED SENSOR	
Type:	2-axis electromagnetic
Range:	0-350 cms/sec
Resolution:	0.2 cm/sec
Accuracy:	2% reading ±1 cm/sec
COMPASS	
Type:	Flux-Gate Magnetometer
Tilt:	±25 degrees
Resolution:	0.5 degrees
Accuracy:	2 degrees
CLOCK	
Type:	Quartz Oscillator
Power:	non-restricted lithium battery
Accuracy:	12 min/year
CONTROL	
Type:	EPROM Microprocessor
Format:	Vector average, burst adaptive, combination; Externally programmable or default
Memory:	64,000 bytes (optionally expandable)
POWER SUPPLY	
Type:	6 internal akaline "D" cells

PRESSURE	
Type:	Semiconductor Strain Gauge
Range:	0-70 meters
Resolution:	14 bit
TEMPERATURE	
Type:	Thermistor
Range:	-2.5 to 36° C
Resolution:	0.05° C
Response Time:	63% (1 minute)
CONDUCTIVITY	
Type:	Conductive
Range:	5-65 mSiemens
Resolution:	0.1 mSiemens
Accuracy:	± 0.2 mSiemens
TILT	
Type:	Fluid electrolyte
Range:	± 45 degrees
Resolution:	0.06 degrees
Accuracy:	Angle output: ±1 degree Speed Correction: ±1% of reading

MECHANICAL/ENVIRONMENTAL

Size:	10 inch diameter sphere
Weight:	24 lbs in air; 4 lbs in water
Mooring:	In-line
Through Load:	10,000 lbs working
Material:	glass-filled cycloaliaphalic epoxy sphere; Titanium 6
AL-4V mooring rod	
Drag:	18 lbs @ 250 cm/sec
Depth:	1000 meters
Temperature:	Storage: -40° to 70° C; Operating: -2.5° to 36° C

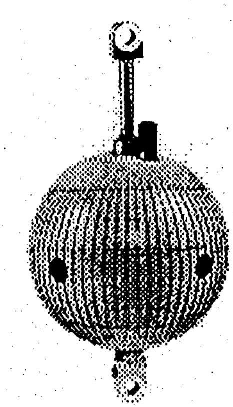
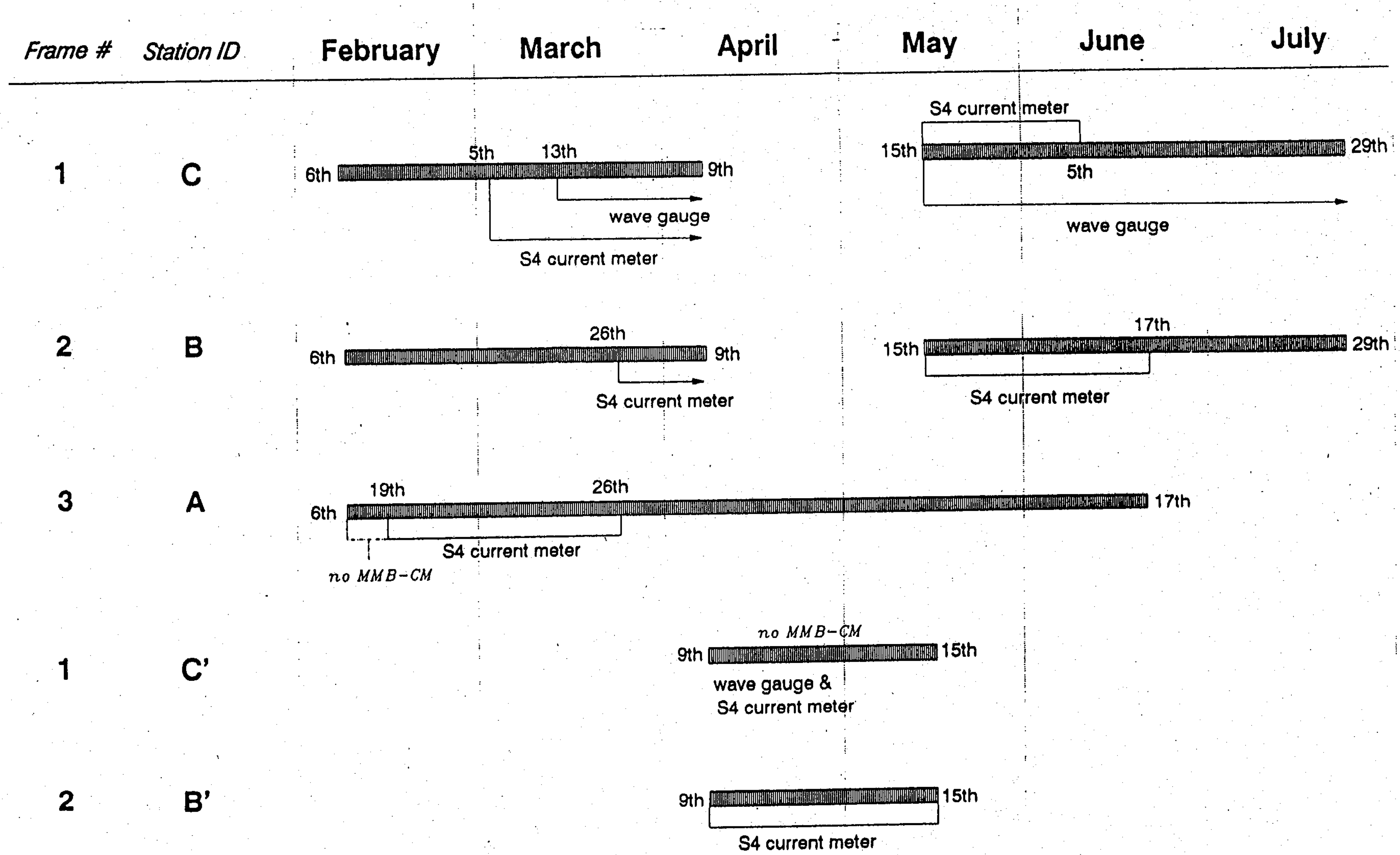


TABLE 4

Array Deployment Schedule



suspended material concentrations. Concurrent sample temperature was obtained immediately on recovery using a laboratory liquid-in-glass thermometer (± 0.1°C). Sample salinity was measured using a Beckman RS-7B conductivity bridge referenced to I.A.P.S.O. Standard Sea Water. By-weight suspended material concentrations were determined by vacuum filtration of a known volume of the sample through dried and pre-weighed Nuclepore filters (0.4 micron pore size-47mm diameter) mounted in a standard Millipore apparatus.

To provide some indication of the relationship between the time series current measurements, being obtained at discrete points by each of the bottom mounted arrays, and the associated spatial patterns of flow, Rhodamine WT dye (20% solution) was released on a number of occasions during the study period and tracked visually. All releases were near surface with horizontal positioning determined by triangulation on known land or navigational marks. On several days these dye releases coincided with aerial overflights being conducted by Iroquois Gas Transmission System. The presence of dye was observed in several of the photographic sequences obtained during these overflights (D'Amico, 1991).

Results and Conclusions

1. Hydrography and Circulation

Drawn water samples obtained at selected intervals throughout the study period indicate that the hydrographic structure in the region of the Gulf is reasonably uniform on the horizontal and well mixed over the vertical (Figs. 8-9). Water

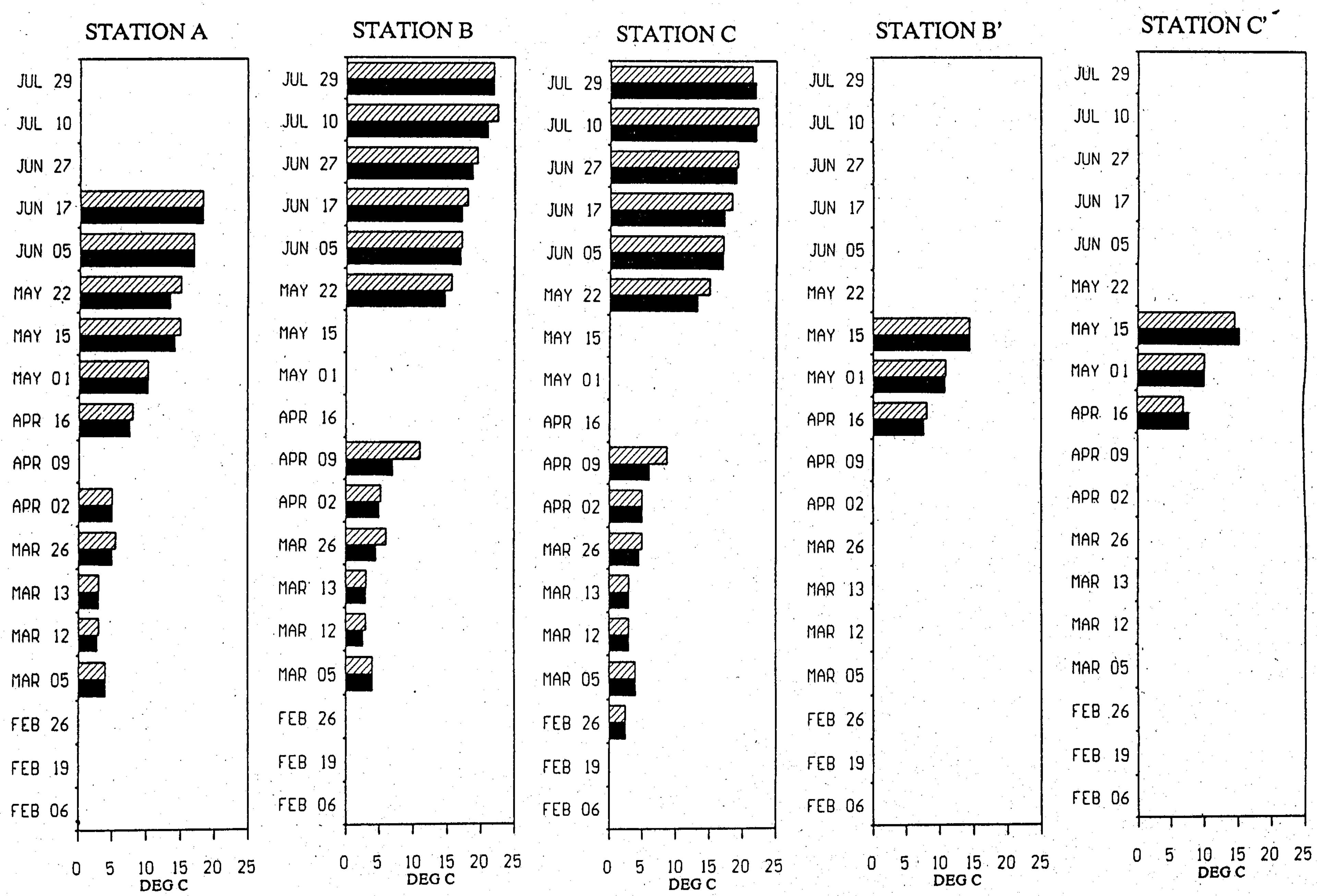


Figure 8 Water Temperatures - Drawn Water Samples
Iroquois Gas Transmission System - 1991

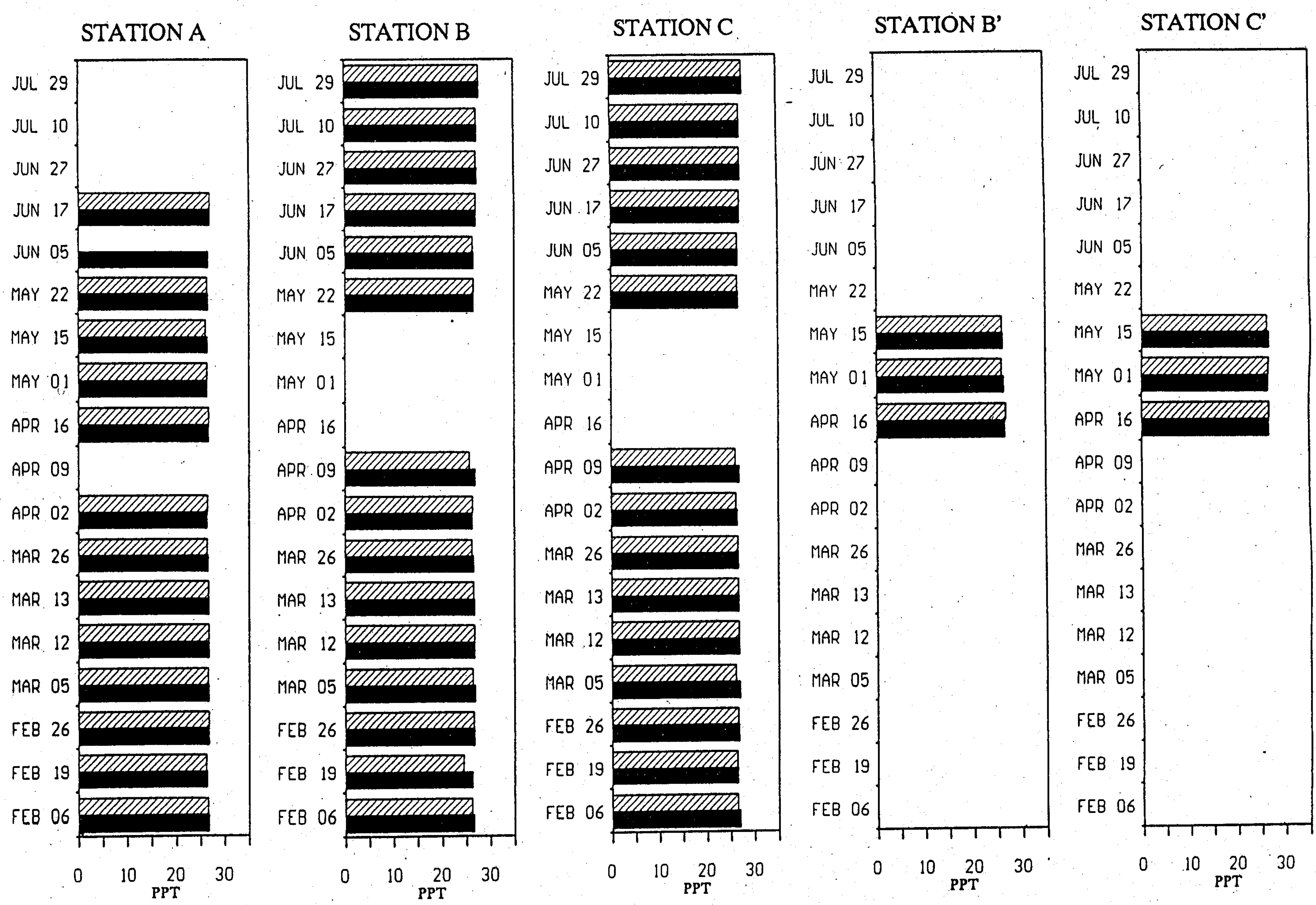


Figure 9 Salinity - Drawn Water Samples
Iroquois Gas Transmission System - 1991

Hatched - Surface
Solid - Bottom

temperatures progressively increased from a low of 2-3°C in February,1991 to highs of approximately 23°C in July (Table 5). During the winter months temperatures are essentially uniform over the vertical and there is limited evidence of thermal stratification. Warming of the surface waters during March favors the development of a weak thermocline that displays significant spatial and temporal varibility. With the onset of the lower energy, higher temperature, summer period this structure appears to break down and conditions over the vertical again become nearly uniform.

Salinities during the study period displayed relatively limited variability despite the seasonal variation in streamflow from the nearby Housatonic River. Observations in the vicinity of each of the monitoring stations indicate an average salinity value of approximately 26.6 ppt with maxima of 27.9 and minima of 24.4 ppt (Table 6). Conditions over the vertical were nearly constant throughout the period with freshening of near-surface waters confined to short-term events. Such variations can be expected to measureably modify the local density field and associated pressure gradients. Such gradients, in turn, may be sufficient to induce short term variations in near-bottom currents and associated mass transport.

The time series observations of near-bottom current speed and direction provided by the fixed arrays indicate significant spatial variability in the flow field affecting the study area. Within the Gulf, velocities are significantly lower than those observed to the

TABLE 5

Water Temperature - Drawn Water Samples

degrees-centigrade

	A		B		C		B'		C'	
DATE	SFC	BTM	SFC	BTM	SFC	BTM	SFC	BTM	SFC	BTM
FEB 06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FEB 19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
FEB 26	NA	NA	NA	NA	2.50	2.50	NA	NA	NA	NA
MAR 05	4.00	4.00	4.00	4.00	4.00	4.00	NA	NA	NA	NA
MAR 12	3.00	2.75	3.00	2.60	3.00	3.00	NA	NA	NA	NA
MAR 13	3.00	3.00	3.10	3.00	3.00	3.00	NA	NA	NA	NA
MAR 26	5.50	5.00	6.00	4.50	5.00	4.50	NA	NA	NA	NA
APR 02	5.00	5.00	5.25	5.00	5.00	5.00	NA	NA	NA	NA
APR 09	NA	NA	11.00	7.00	8.75	6.00	NA	NA	NA	NA
APR 16	8.00	7.50	NA	NA	NA	NA	8.00	7.50	7.00	7.75
MAY 01	10.25	10.25	NA	NA	NA	NA	10.80	10.70	10.00	10.00
MAY 15	15.00	14.20	NA	NA	NA	NA	14.40	14.40	14.40	15.00
MAY 22	15.10	13.50	15.70	14.70	15.00	13.20	NA	NA	NA	NA
JUN 05	17.00	17.00	17.20	17.00	17.10	17.00	NA	NA	NA	NA
JUN 17	18.30	18.30	18.05	17.20	18.30	17.20	NA	NA	NA	NA
JUN 27	NA	NA	19.50	18.75	19.25	19.00	NA	NA	NA	NA
JUL 10	NA	NA	22.55	21.00	22.25	22.00	NA	NA	NA	NA
JUL 29	NA	NA	21.94	21.94	21.38	21.90	NA	NA	NA	NA
mean	9.47	9.14	12.27	11.39	11.84	11.32	11.07	10.87	10.47	10.92
std dev	5.91	5.77	7.68	7.65	7.71	7.76	3.21	3.45	3.72	3.71
var	34.91	33.35	59.05	58.53	59.50	60.19	10.29	11.92	13.85	13.77
min	3.00	2.75	3.00	2.60	3.00	3.00	8.00	7.50	7.00	7.75
max	18.30	18.30	22.55	21.94	22.25	22.00	14.40	14.40	14.40	15.00

TABLE 6

Salinity - Drawn Water Samples

ppt

DATE	A SFC	A BTM	B SFC	B BTM	C SFC	C BTM	B' SFC	B' BTM	C' SFC	C' BTM
FEB 06	26.553	26.685	26.176	26.606	26.493	26.945	NA	NA	NA	NA
FEB 19	26.203	26.436	24.453	26.292	26.396	26.483	NA	NA	NA	NA
FEB 26	26.763	26.761	26.618	26.659	26.620	26.713	NA	NA	NA	NA
MAR 05	26.513	26.744	26.337	26.814	26.097	26.915	NA	NA	NA	NA
MAR 12	26.733	26.736	26.734	26.723	26.725	26.851	NA	NA	NA	NA
MAR 13	26.673	26.710	26.560	26.724	26.680	26.711	NA	NA	NA	NA
MAR 26	26.395	26.554	26.150	26.511	26.534	26.648	NA	NA	NA	NA
APR 02	26.484	26.407	26.353	26.264	26.243	26.493	NA	NA	NA	NA
APR 09	NA	NA	25.739	26.882	26.074	26.992	NA	NA	NA	NA
APR 16	26.727	26.678	NA	NA	NA	NA	26.716	26.577	26.632	26.603
MAY 01	26.355	26.424	NA	NA	NA	NA	25.896	26.379	26.356	26.374
MAY 15	26.088	26.496	NA	NA	NA	NA	26.043	26.197	26.046	26.324
MAY 22	26.416	26.583	26.530	26.611	26.521	26.693	NA	NA	NA	NA
JUN 05	NA	26.538	26.377	26.612	26.547	26.666	NA	NA	NA	NA
JUN 17	26.948	26.944	27.016	27.036	27.025	27.023	NA	NA	NA	NA
JUN 27	NA	NA	27.141	27.289	27.203	27.292	NA	NA	NA	NA
JUL 10	NA	NA	27.237	27.335	27.214	27.271	NA	NA	NA	NA
JUL 29	NA	NA	27.791	27.901	27.920	27.935	NA	NA	NA	NA
mean	26.527	26.628	26.481	26.817	26.686	26.909	26.22	26.38	26.34	26.43
std dev	0.241	0.160	0.757	0.428	0.485	0.374	0.44	0.19	0.29	0.15
var	0.058	0.026	0.572	0.183	0.236	0.140	0.19	0.04	0.09	0.02
min	26.088	26.407	24.453	26.264	26.074	26.483	25.90	26.20	26.05	26.32
max	26.948	26.944	27.791	27.901	27.920	27.935	26.72	26.58	26.63	26.60

west and southeast of Charles Island. A simple sorting of the data by speed (4 ranges- 5cm/sec each) and direction (22° bins) indicates that mean velocities at Station B, over the entire period of observation, remain below 10 cm/sec with the majority of speeds being below 5 cm/sec (Fig.10). Flows to the northwest dominate slightly with sufficient frequency of occurrence in other quadrants to make the flow field essentially omnidirectional.

In contrast to the conditions observed at Station B, flows at Station C and to the west of Charles Island at Stations A, B′ and C′ are evidently more energetic and less variable in direction. At C maximum mean speeds during the period of observation approach 20 cm/sec with the majority of flows proceeding along a northeast-southwest tending track (Fig.10). The frequency of occurrence of flows outside of these quadrants is low and associated mean speeds seldom exceed 5 cm/sec. To the west of Charles Island, maximum mean speeds approach 15 cm/sec. Flow directions in this area are evidently less oscillatory, or bi-directional, than those observed at C and there is clear dominance of higher speed flows to the east and southeast.

The degree of spatial variability characterizing the flow field in the area over or adjoining the pipeline corridor appears representative of a system dominated by the combination of bathymetry and coastal landforms. Charles Island and the associated Bar as well as Welches Point (Fig.10) clearly affect alongshore flows and favor the generation of wakes and eddies. Visual tracking of dye patches released at discrete points under a variety of tidal

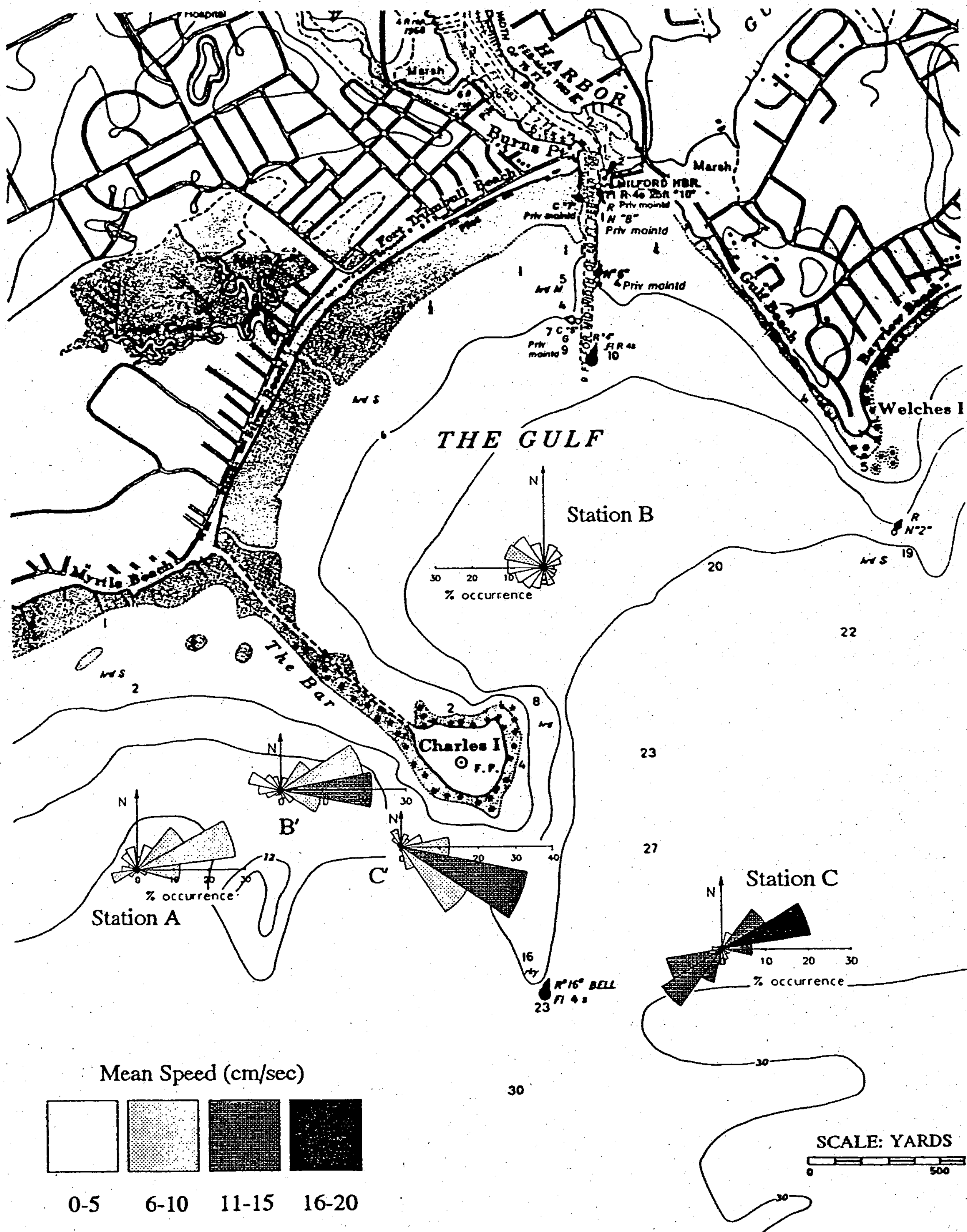


Figure 10 Near-Bottom Currents - Sorted Data
Iroquois Gas Transmission System - 1991

conditions and minimal wind speeds indicates that waters entering the Gulf from the east at the beginning of the flood, when the Bar is exposed, enter from the northeast and form a divergent stream in the vicinity of Welches Point (Fig.11). The northerly arm of the divergence proceeds to the north and west along Gulf Beach towards the entrance to Milford Harbor. The southerly component continues along a more westerly track towards Charles Island and displays a progressive clockwise rotation through west to northwest, on approach to Charles Island, to the north, near the northeast corner of the Island, and then northeast, towards the entrance of Milford Harbor. This clockwise gyre, favoring the transport of materials from the offshore areas into the Gulf persists until tidal levels exceed the elevation of the Bar. Beyond this period, for the remainder of the flood tide, the southerly limb of the flow from Welches Point proceeds along a more westerly track, crossing the Bar, and the gyre breaks down.

The flood flow across the submerged bar proceeds first to the southwest along a nearly shore parallel track but within 1000 to 1500 yds encounters an east going nearshore current. The current meter observations at Station A and the limited dye data suggest that this current is persistent throughout much of the year and displays limited dependence on streamflow conditions. The convergence of these two flows results in a southerly migration and reduction in energy of both streams with the combined flow proceeding along a south-southwesterly track towards Stratford Point, beyond the western limit of the entrance to the Housatonic

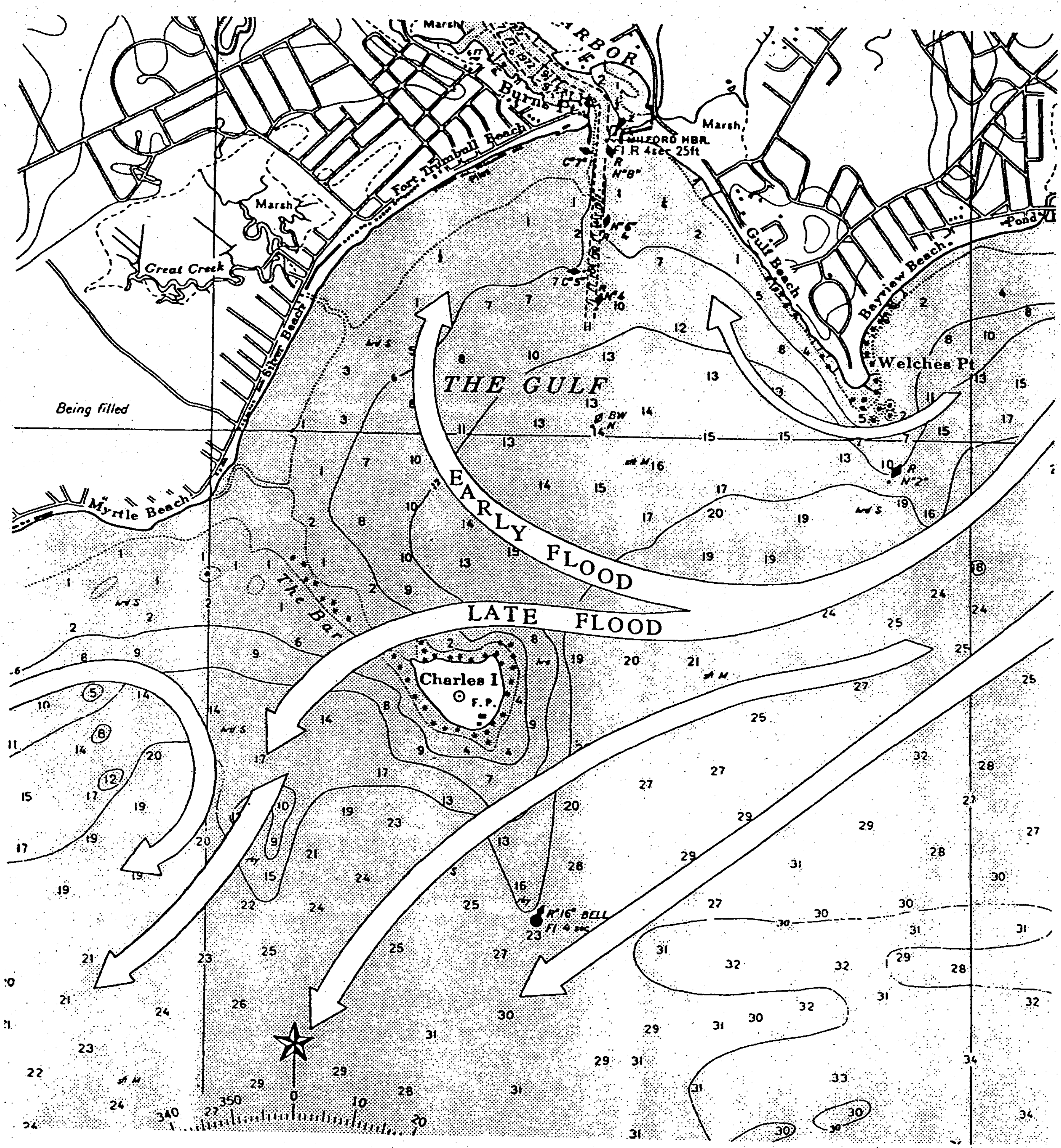


Figure 11 Mean Flow Schematic - Flood Tide
Offshore Area Adjoining Milford,Ct.

River.

With the onset of the ebb tide the velocity of the east going current on the west side of Charles Island increases with flows following a shore parallel track. Along the western limit of the Island the flow splits with a northerly component crossing the bar and proceeding easterly towards Welches Point (Fig.12). In the vicinity of Welches Point this flow combines with the water mass exiting Milford Harbor and continues around the Point alongshore towards New Haven. The southerly component is blocked by the presence of Charles Island, abruptly alters its course to the southeast and follows the margin of the Island through a progressive counterclockwise rotation to a northeast tending track. On departure from the shallows adjoining Charles Island this component of the original nearshore flow also proceeds towards Welches Point and progressively rejoins the northerly limb of the current.

The divergent east going current continues for a portion of each ebb tidal cycle until decreasing tidal elevation serves to expose the Bar. Bar exposure, during the late ebb, blocks the flow and forces all of the nearshore current to the south and east around Charles Island. Following a track around the Island and then eastward towards Welches Point, the northern margin of this flow is progressively slowed by the shallows within the Gulf and turned to the north forming a low energy counterclockwise gyre. For the remainder of the ebb this gyre persists and displays many of the characteristics shown by the clockwise gyre observed during the record are supplemented on occasion by higher frequency perturbations induced by the passage of energetic wind stress events. These events typically persist for periods shorter than one day and induce variations in local flows which vary as a function of the wind speed and direction and the duration of storm passage. Several storms sufficient to perturb circulation in the vicinity of Milford occurred during the study period. Each event was dominated by winds rich in east to southeasterly components. On March 23,1991 a developing low pressure system resulted in east to southeasterly winds and significant rainfall. The system produced an evident perturbation in the current field in the vicinity of Station C (Fig.19) increasing the duration and maximum speed of the late day flood tide and effectively suppressing the associated ebb. Speed during this period of neap tides was increased by storm passage to levels approaching those observed during the preceeding spring tidal period.

On April 21,1991 another low pressure system passed the study area producing high energy southeasterly winds over a period of approximately 20 hours. The system evidently perturbed the flow field in the vicinity of Station C' altering both speed and direction. Variations in this case however, were not as pronouced as those observed during the March 23,1991 event (Fig.20). The differences in response produced by these two storm events appear to be primarily associated with the difference in location of the observing stations and the associated water depths.

observing stations and the associated water depths.

2. Suspended Material Concentrations

During the pre-project period of observation, beginning in February,1991, the concentration of suspended materials in the area over and adjoining the pipeline corridor averaged between 5 and 10 mg/l (Fig.21). Concentrations at all stations displayed periodic variations over the course of each tidal cycle with values varying by as much as 30 to 50% in phase with local current speed. Concentrations were highest, and variability most pronounced, in the vicinity of Station B. These variations appear to be the result of the alternate resuspension and deposition of the high-water content layer of fine grained materials observed by divers along the sediment-water interface in this area. In contrast to Station B conditions, material concentrations and associated variability were lowest at Station A with values displaying minimal tidal cycle deviation (Fig.21). The response is representative of an area dominated by erosion resistant sediments and flows favoring the dispersal of finer grained materials winnowed from the bed during high energy storm events. Diver observations, obtained during array servicing intervals, and the near-bottom current meter data, indicate that such conditions exist in the vicinity of Station A.

The temporal distribution of high frequency, aperiodic, variations in suspended material concentrations is essentially similar at each of the observing stations. Perturbations are evident on February 6,13,and 20, and for the period from March 2

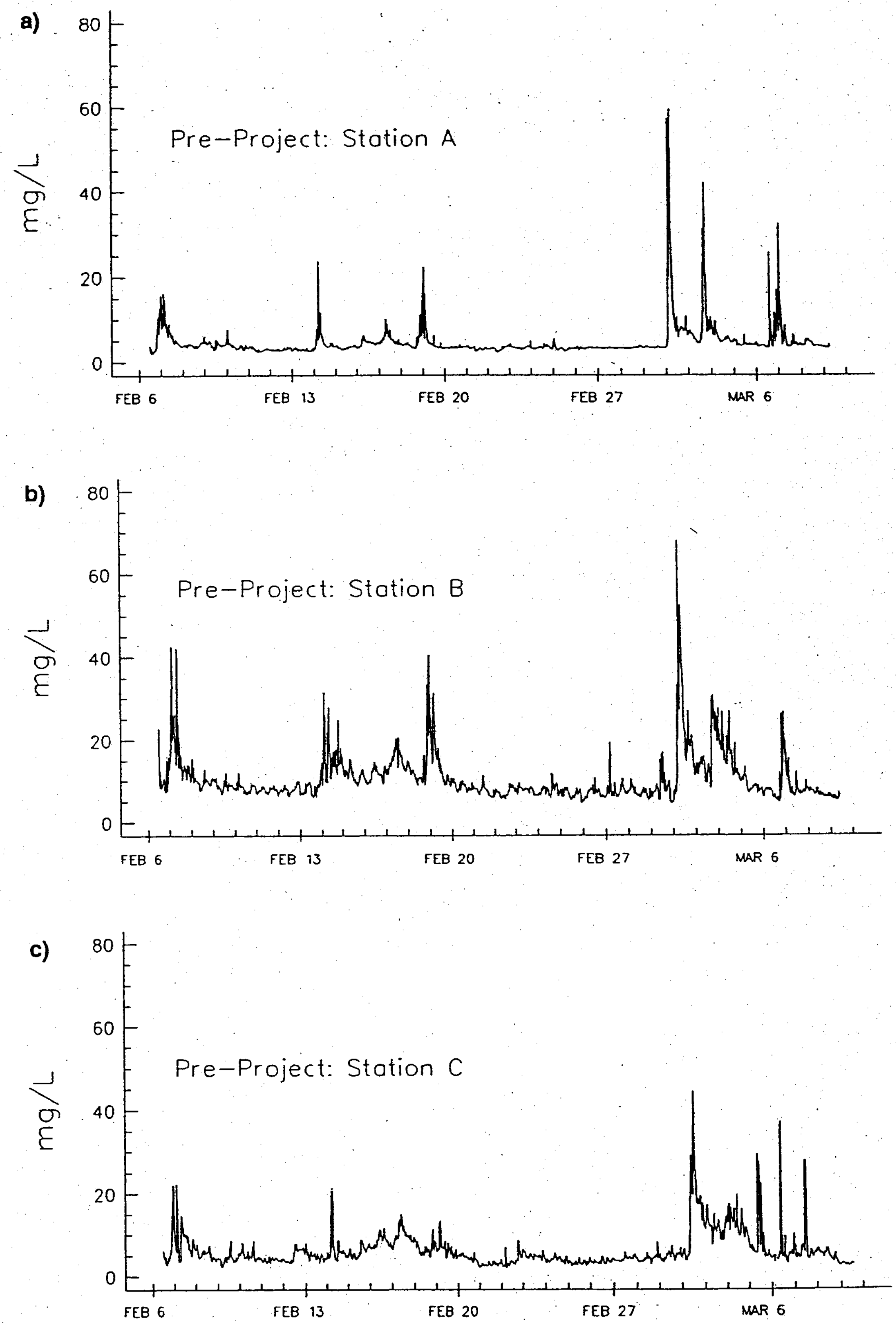


Figure 21 Time Series Suspended Material Concentrations
Pre-Project Period - 1991

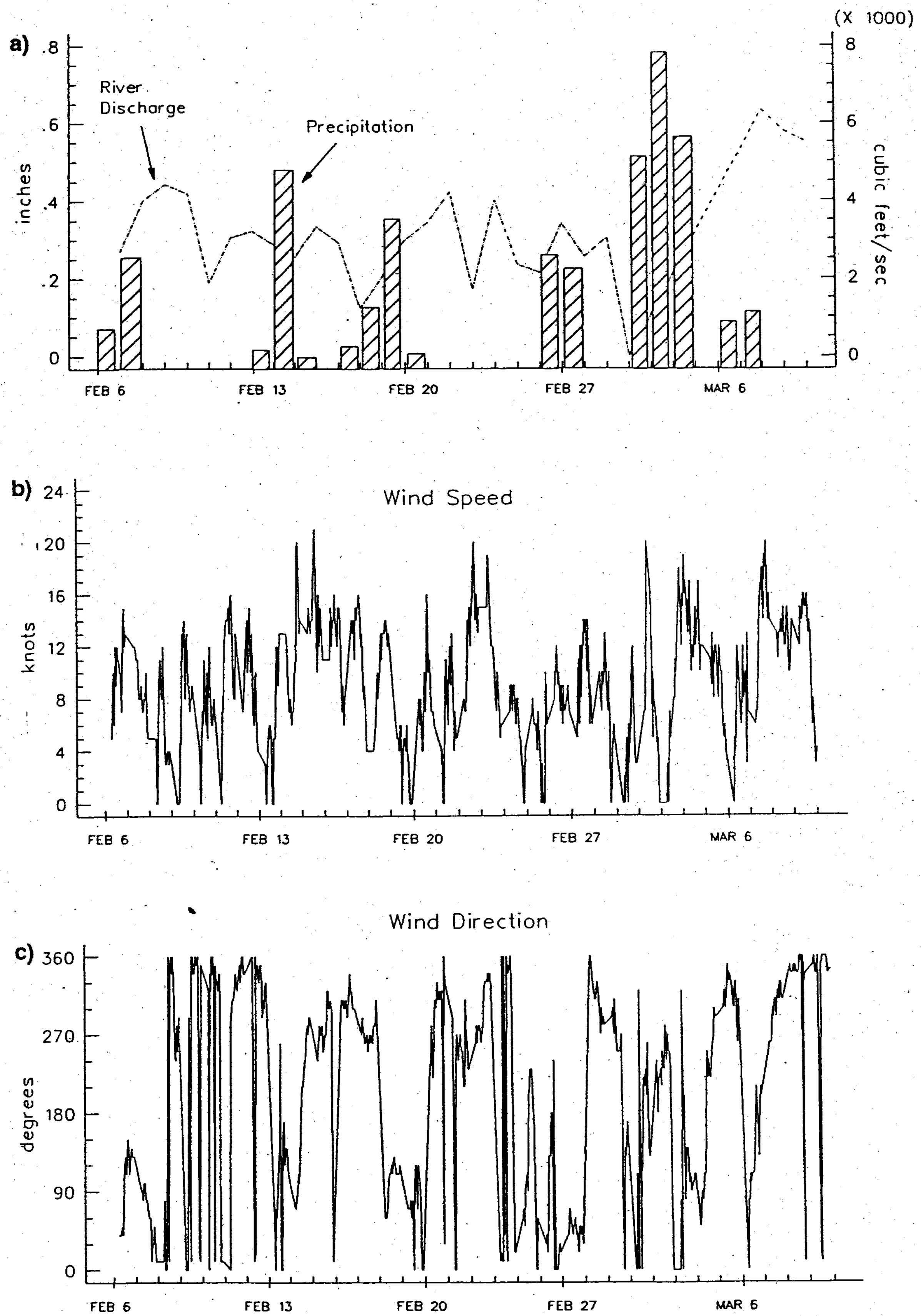


Figure 22 Meteorological and Streamflow Conditions
Pre-Project Period - 1991

through March 7,1991 with maximum concentrations approaching 60 mg/l (Fig.21). As in the case of the average ambient concentrations, the short-term variations are most pronounced at Station B and least well-defined at Station A. Reviews of the available climatological data including wind speed and direction and precipitation from the U.S. National Weather Service station at Sikorsky Field in Stratford, Connecticut and Housatonic River streamflow monitored at the U.S. Geological Survey gaging station at Stevenson, Connecticut (USGS,1991) indicate that each of the short-term variations in suspended material concentration were associated with significant short-term increases in rainfall-runoff and above average wind speeds (Fig.22). Sheltering provided by the adjoining land masses clearly favors winds from the east clockwise through the south to southwest with the major resuspension events ,at all stations, occurring during periods dominated by south to southeasterly winds. The evident correlation with local precipitation and the correspondingly weak correlation with measured streamflow suggests that rainfall-runoff along the lower Housatonic River valley below the gaging station and within ungaged tributary waterways entering Milford Harbor (i.e. Indian River and the Wepawaug River) can represent a significant factor affecting supplies of sediment to the coastal waters adjoining Milford. Subsequent distribution of these materials appears governed by the combination of local tidal currents and surface wind wave associated velocities. Detailing of the influence of this latter factor was not possible during the pre-project deployment period due to the absence of a wave gage on the monitoring arrays.

The initiation of dredging on March 9,1991 served to increase the tidal cycle variability in suspended material concentrations in the vicinity of Station B (Fig.23). Average background concentrations increased slightly relative to those observed during the pre-project period with values approaching 10 mg/l. During the initial phase of the project from March 9 to March 14,1991, and during the final stage between April 6 and April 8,1991, as the dredge worked the area inshore of the 25ft isobath (Fig.3), material concentrations at Station B varied by approximately 125% (Fig.23). Variations were most pronounced during the flood phase of the tide although smaller perturbations were observed during the ebb. This response appears to be the result of the advection of fine grained materials suspended by the dredging operation, to and past the monitoring site, by the counterclockwise current gyre present during the early stages of each flood tide cycle. Additional evidence of the effect of this gyre is provided by the relatively abrupt change in the degree of variability of the material concentration field on March 13,1991, as the dredge passed and moved to the northwest of Station B (Fig.3) and on April 7,1991 as the dredge returned to the outer limits of the Gulf (Fig. 23).

The array data indicate that the influence of dredging operations on the inshore suspended material field is principally confined to the region of the Gulf. Material concentrations at Station A displayed characteristics that were essentially identical to those observed during the pre-dredge period (Fig.23) and there

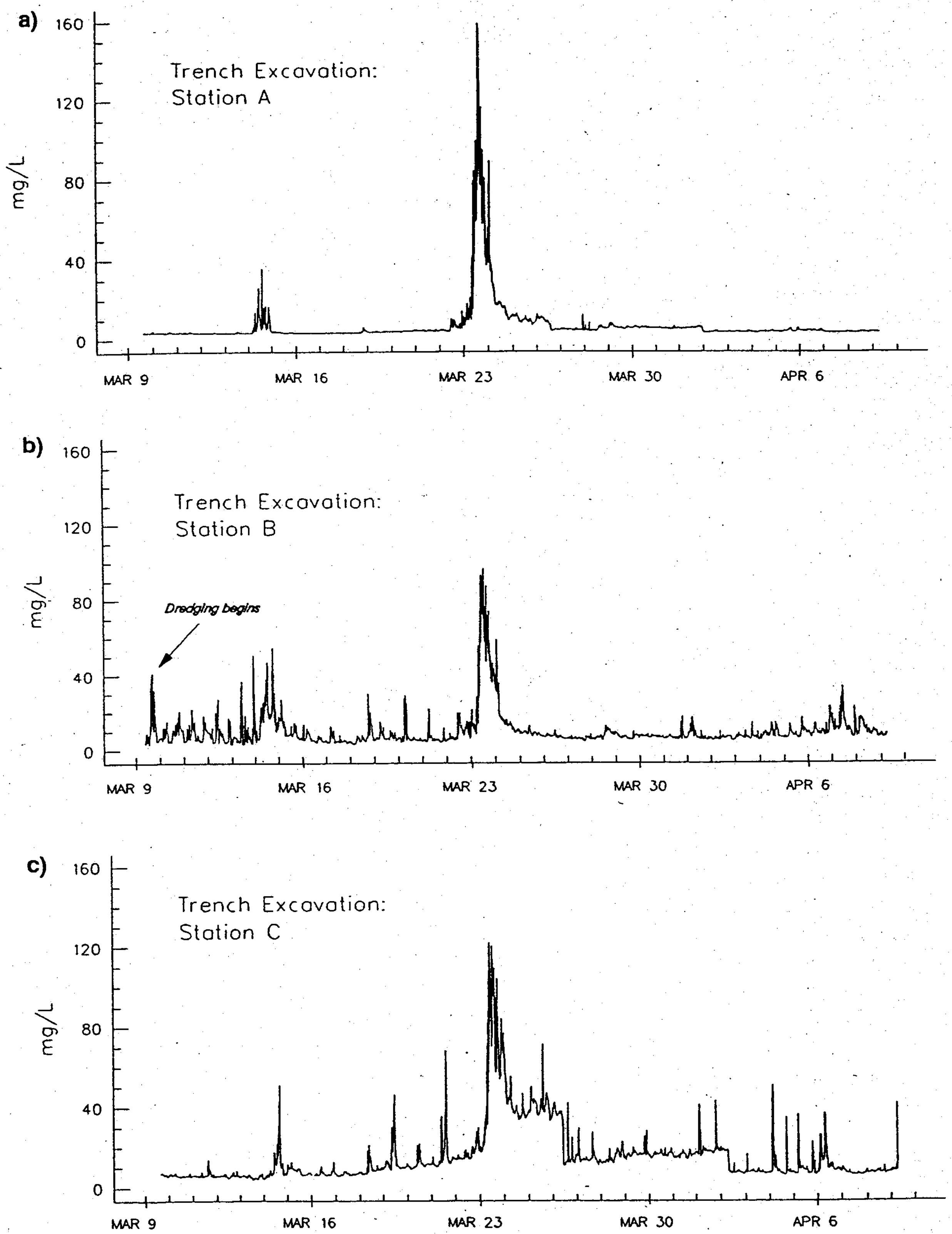


Figure 23 Time series Suspended Material Concentrations
Initial Trench Excavation Period - 1991

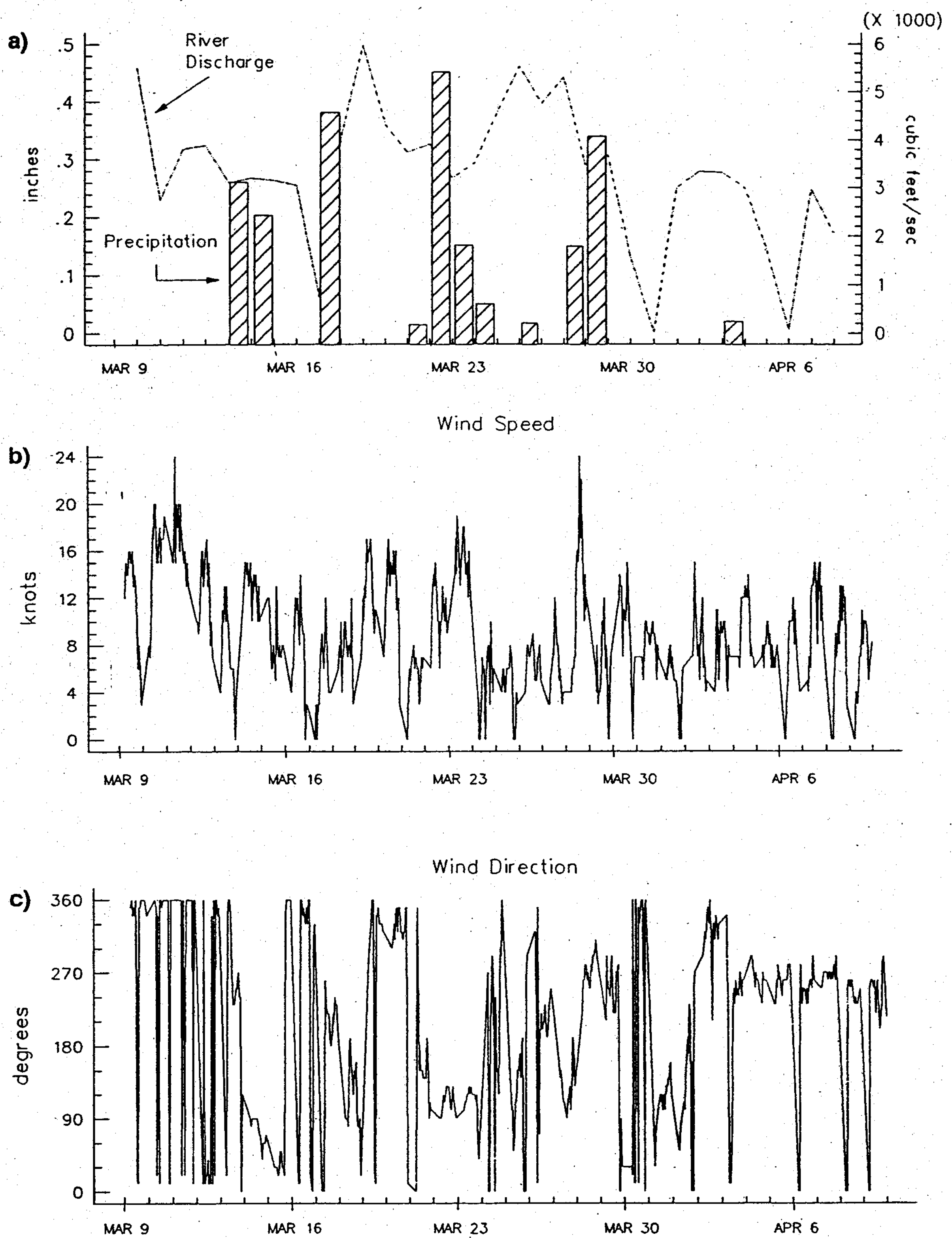


Figure 24 Meteorological and Streamflow Conditions
Initial Trench Excavation Period - 1991

east (Fig.24). These latter wind conditions were sufficient to produce a high energy surface wave field. Analysis of the data provided by the bottom mounted pressure gage indicates that average wave height at Station C during the March 14th event equalled approximately 0.35m with periods ranging from 3 to 5 seconds (Table 7). During the March 23rd event wave heights were signficantly larger with average values of approximately 1m. This increase in height was accompanied by a corresponding increase in wave period with maxima of 6.5 sec. observed. The data provide clear indication of the sensitivity of the local surface wave field to both wind speed and direction and the duration of the wind event.

The event of March 23,1991 served to increase suspended material concentrations in the vicinity of each of the sampling stations by nearly a factor of ten. The increase was least pronounced at Station B, where observed maxima equalled approximately 95 mg/l, and largest at Station A with maxima equal to approximately 160 mg/l. Corresponding maxima at Station C approached 120 mg/l (Fig.23). At each station the evident increase above background persisted for several days, until mid-day on the 27th, despite an evident decrease in wind speeds on March 24,1991. The factors governing this persistence appear to be primarily associated with the combination of rainfall-runoff and instrument artifacts associated with the acccumulation of settling sediments on the windows of the optical sensors. The effect of this latter factor is most evident at Station C where the abrupt decrease in

TABLE 7

Surface Wave Characteristics

STATION	DATE	PEAK WIND SPEED & DIRECTION	APPROXIMATE DURATION(hrs)
C	March 14	24 E	18
C	March 22	17 E	12
	23	27 SE	21
C	March 28	31 W	12
C	April 1	11 E	9
C'	April 10	20 NW	9
	11	30 NW	24
	12	21 N	15
C'	April 17	13 SE	12
	18	15 SE	24
C'	April 20	17 SE	12
	21	29 E	24
	22	21 W	15
C'	April 26	17 SE	12

Hmo(m) Tz(s)

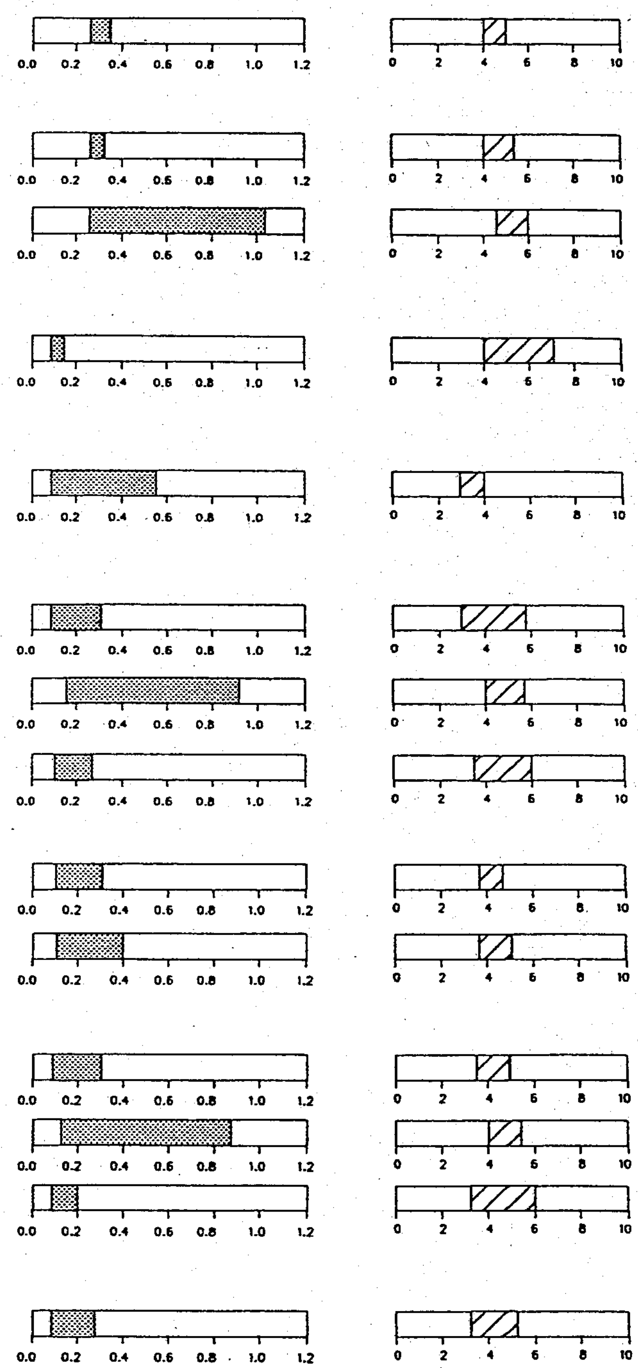
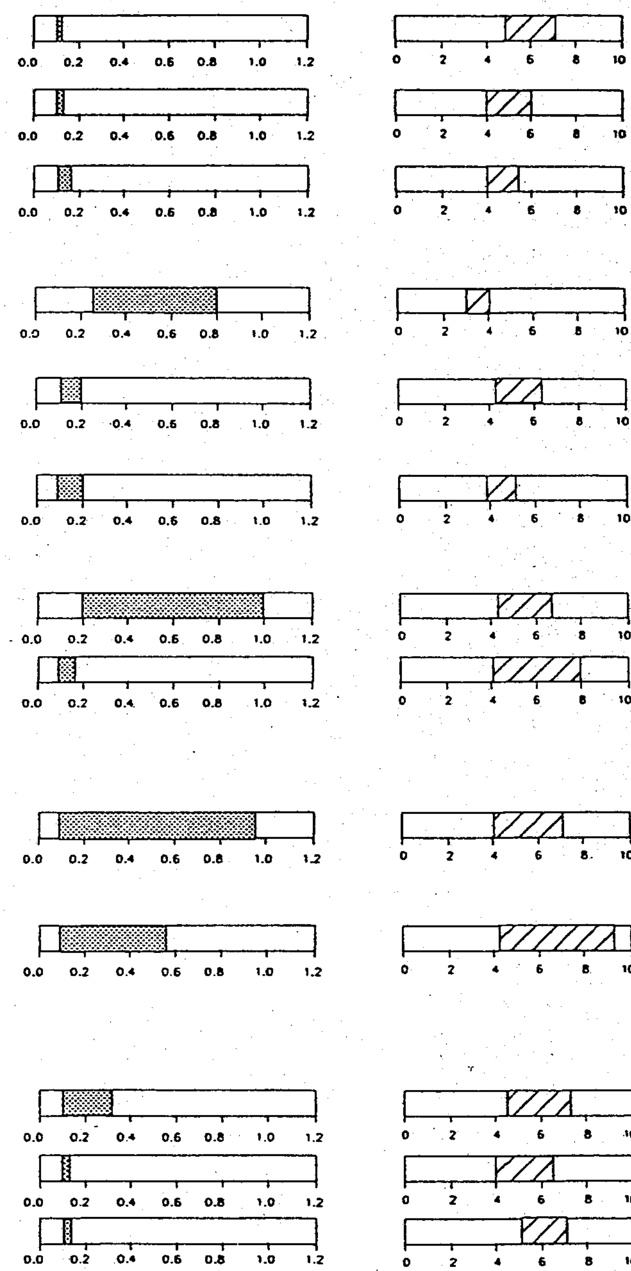


TABLE 7 cont.

Surface Wave Characteristics

STATION	DATE	PEAK WIND SPEED & DIRECTION	APPROXIMATE DURATION(hrs)	Hmo(m)	Tz(s)
C'	May 1	23 NW	12		
	2	28 NW	18		
	3	20 N	6		
C'	May 6	16 SW	9		
C	May 18	16 NE	18		
C	May 23	16 SE	12		
C	June 4	22 E	12		
	5	16 SE	6		
C	June 18	15 SE	21		
C	June 30	17 SE	9		
C	July 3	11 SE	9		
	4	15 E	18		
	5	11 S	6		



material concentration is coincident with the servicing of the array and least apparent at B where the use of an optical backscattering probe favors minimal effects due to fouling of the windows. The progressive decrease in concentration at Station B, approaching background by the 27th, in contrast to the more nearly constant apparent increase in background observed at Stations A and C indicates that only a portion of the elevated concentrations at the latter stations is the result of bias produced by settlement on the windows. The remainder of the signal appears to be associated with an actual increase in local suspended material concentrations as a result of rainfall-runoff. Meteorological observations show that significant rainfall continued in the area through the 26th (Fig.24). Concurrent array data indicate a progressive decrease in near-bottom salinities particularly at Stations A and C indicating the presence of river water and effective mixing over the vertical as a result of the storm associated wind field. The increase cannot be the result of direct dredge induced resuspension since operations were suspended during the period of storm passage and subsequently resumed in the far offshore area, beyond the transport field affecting the inshore study area. It is possible that some portion of the materials displaced by storm waves were sediments previously dredged during the inshore transit of the dredge (Fig.3) and placed along the western limit of the pipeline corridor. Inshore propagation of waves produced by southeasterly winds would tend to favor displacement of these sediments and migration along a northwesterly tending track. Such displacement, in combination with the ambient tidal current field, could result in the westerly migration of some fraction of these materials across the Bar towards Station A where alternating resuspension and deposition during subsequent tidal cycles could produce a persistent increase in background suspended material concentrations for some period of time. The character of the suspended material signal at Station A, however, including the near absence of tidal periodicity during the storm period, the presence of persistence at Station C beyond the area affected by cross-Bar transport, and the coarse grained nature of the sediments dredged from the pipeline trench, indicative of limited far-field transport potential, favors dominance of streamflows relative to dredge associated factors at both A and C.

The passage of the storm of March 23,1991 produced an evident short term increase in amount of sediment suspended in the water column over and adjoining the pipeline corridor resulting in a much more prominent signal than that produced by dredge induced resuspension. Integration of the time series array data (Fig.23) indicates that the mass suspended during the four days including and just after storm passage at Station B was approximately 65% more than that suspended by the dredging operations during the period March 9 to March 14,1991. Similar calculations using the data obtained at Stations A and C indicate a clear dominance of storm effects relative to those produced by the dredge with storm passage serving to displace more than six times the mass of sediment introduced by the transport of dredge suspended materials. In addition to the difference in the mass of sediment suspended by storm passage relative to that introduced by the dredge, the spatial scale of influence of the storm is significantly larger than that of the dredge. Storm associated resuspension is expected to affect the entire nearshore area out to water depths beyond the influence of surface waves (approximately 30 to 60ft). As discussed above, transport of dredge resuspended materials affects, at most, near-bottom downstream areas within approximately 1000yds of the operation. The combination of these larger spatial scales and associated larger mass of suspended sediment indicates that, relative to the dredge, naturally occurring storm events have a greater potential to adversely affect organisms sensitive to above average suspended material concentrations.

On completion of the trench excavation the instrumentation arrays initially located at Stations B and C were relocated to sites west of Charles Island to avoid possible damage during the pipelaying operations (Fig.1). The combination of data provided by these arrays and the unit remaining at Station A indicates that pipeline placement produced no measurable variation in suspended material concentrations with values remaining equal to or less than those observed during the pre-project period (compare Fig.25 to Fig.21). The high frequency variation observed on April 10,1991 is associated with the passage of a small but intense storm event which served to produce an energetic surface wave field with peak amplitudes approaching 1m and periods of approximately 6 sec. (Table 7). After completion of the pipelaying phase, and prior to the initiation of infilling, concentrations in the area were again

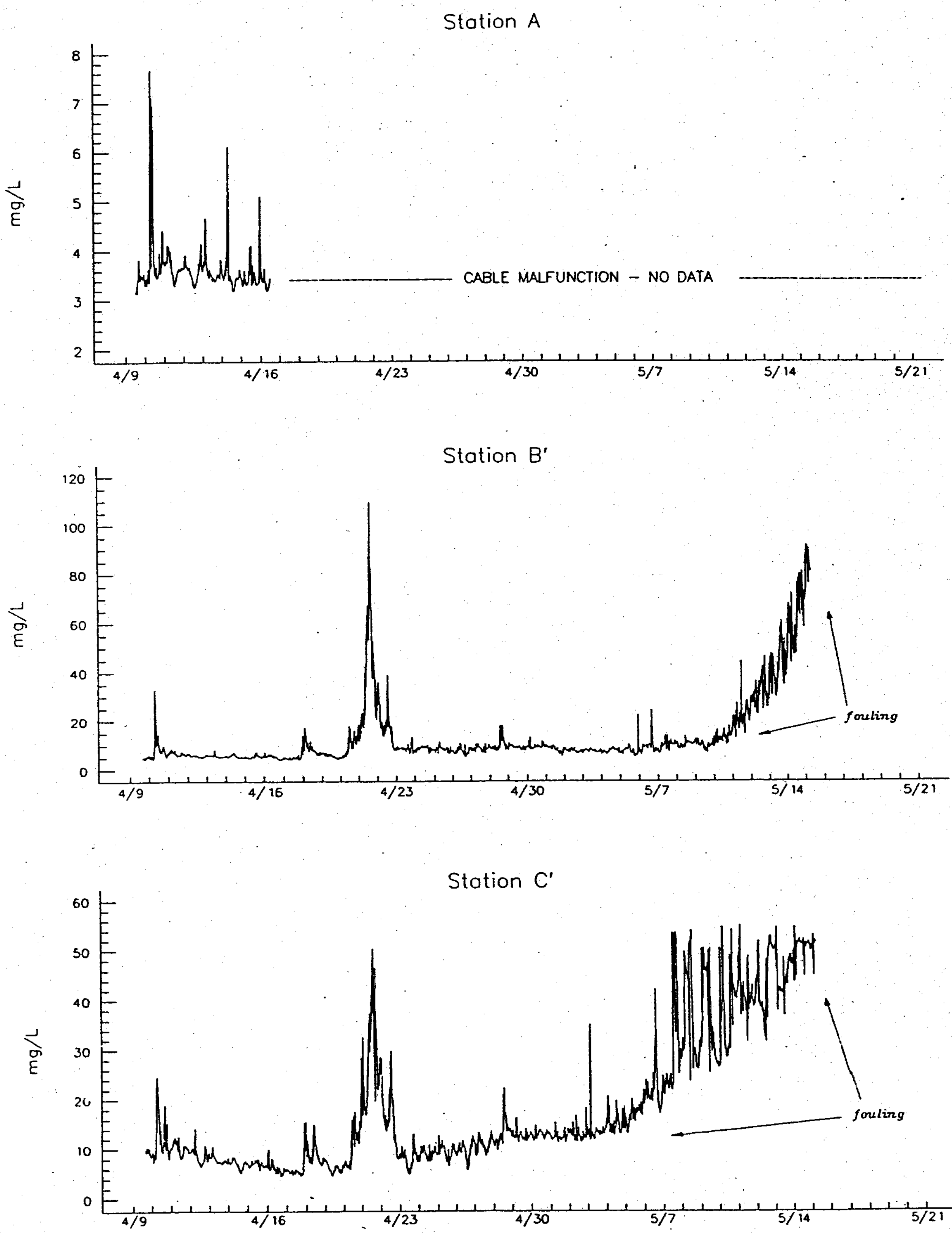


Figure 25 Time Series Suspended Material Concentrations, Pipe Laying/Trench Infilling Period 1991

perturbed by the passage of another high energy storm event which persisted over a two day period, April 20-22,1991 (Fig.25). This event was significantly more energetic than the April 10th storm and was dominated by winds from the east to southeast and accompanied by significant rainfall (Fig.26). The combination served to increase maximum material concentrations at B' and C' by nearly a factor of 10 above ambient average background levels. Surface waves during the event were similar in character to those observed during the April 10th storm (Table 7) but persisted for a significantly longer period of time. This persistence favored enhanced bottom shear stress and sediment resuspension due to interactions between wave induced and tidal velocities resulting in an evident periodicity within the observed perturbations in suspended material concentrations with periods essentially identical to the dominant semi-diurnal tide (Fig.25). Such conditions favor enhanced erosion of the bottom sufficient to resuspend the high water content surficial layer and portions of the underlying sediment column. The observations indicate that it is only under these enhanced stress conditions that the deeper sediment column is subject to erosion and transport. For the remainder of the time transport in the region of the Gulf is confined to the displacement and subsequent settling of the surficial layer of high water content, organic rich, sediments.

As the energies associated with storm passage decreased on April 22,1991 dredging intended to close the pipeline trench began with the dredge located in the vicinity of the northeast corner of

Charles Island (Fig.1). From this site the dredge worked progressively shorewards towards Silver Beach. On April 28,1991 a second dredge was placed in service to accelerate the rate of closure of the trench. For the remainder of the project, two dredges were in service, one working the immediate nearshore and the other the more distant offshore portions of the trench.

The array data indicate that trench infilling resulted in a slight increase in suspended material concentrations in the area immediately west of Charles Island. A comparison of the concentration levels at Station B′ for the period April 12-17,1991 to those observed during the period April 23-28,1991 indicates that an increase in average suspended material concentrations from 5.4 mg/l during the pre-dredge period to approximately 8.25 mg/l during dredging (Fig.27). More significantly, tidal cycle variability during the dredging is increased relative to that observed during the pipelaying period (Fig.27) with the standard deviation of the suspended material field increased by approximately 50%.

The variations at Station C′ are qualitatively similar to those observed at B′ with the majority of the larger amplitude change associated with instrumental bias induced by the settling of sediments on the windows of the optical sensors. The observations indicate that resuspension of fine grained sediments associated with closure of the inshore segments of the pipeline trench resulted in the formation of a plume of suspended materials that migrated westerly across the bar and then to the south and west affecting material concentrations in the area immediately west of Charles Island. These data appear consistent with earlier aerial overflight observations showing a floodtide driven southwesterly migration of turbid water during the initial trench excavation (Fig.28) (D'Amico,1991).

On May 15,1991 the instrument arrays, relocated during the pipelaying and trench infilling portion of the project, were returned to their initial sites at Stations B and C (Fig.1). This move occurred just before the completion of the filling of the offshore segments of the trench and just after initiation of beam smoothing operations. These latter operations, intended to restore the bottom configuration along the pipeline corridor transiting the leased shellfish beds to pre-project contours, began on May 13,1991. Initial operations placed primary emphasis on the area extending inshore from the vicinity of the northeast corner of Charles Island (Fig.1). The array data indicate that the smoothing operations produced a relatively minor increase in average suspended material concentrations in the Gulf. Observations at Station B indicate mean values that are nearly equal to those observed during the pre-project period (compare Fig.29 to Fig.21). The tidal cycle variability during the smoothing operations is enhanced relative to the pre-project data resulting in an evidently larger standard deviation. The combination suggests that smoothing resulted in the resuspension and displacement of the fine grained fractions of the placed sediments producing alterations in local water clarity but only minor increases in the mass of sediment in transport. As a result of these characteristics, subsequent

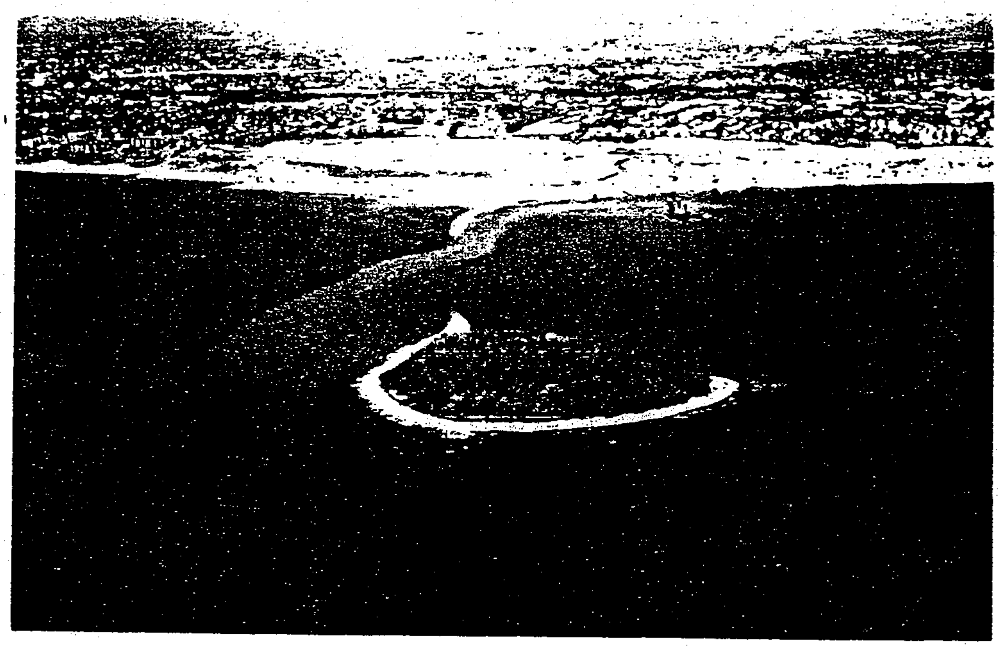


Figure 28 Aerial View of Suspended Sediment Dispersal During Flood Tide
March 20,1991 - 1145est

settling of these suspended sediments following termination of the smoothing operation or far-field transport can be expected to produce thin depositional layers with vertical dimensions on the order of millimeters.

Beyond the Gulf, suspended material concentrations at the observing stations appear to be unaffected by the smoothing operations. At Station A concentrations were nearly identical to those observed during the pre-project period with only slight indication of an increase in tidal cycle variability (Fig.29). At Station C concentrations were significantly higher than those observed during the pre-project period. However, this increase appears to be associated with instrument artifacts produced by changing composition of the suspended material field rather than an actual increase in the mass of material in suspension. Drawn water sampling following repositioning of the instrument arrays indicates that near-bottom suspended material concentrations in the vicinity of Station C averaged approximately 7-8 mg/l (Fig.31-Table 8). During the same period the optical sensor indicates concentrations in excess of 18 mg/l (Fig.29). Review of diver logs for the period, instrument service records showing stable supply voltage, and the limited standard deviation of the record prior to May 28,1991, indicate that this is primarily the result of a seasonal increase in the concentration of relatively low-weight organic particulates. These particulates affect beam transmission characteristics, resulting in an apparent increase in water column concentrations, but represent a relatively minor fraction of the mass of material filtered from the drawn water sample. As a result, the array data from Station C provide an inaccurate measure of the mass of sediment in suspension and are best used as indicators of the occurrence of resuspension events such as wind stress dominated storms and/or short-term increase in streamflows. The data from Station B are not subject to this effect since the array employs an optical backscattering sensor to monitor concentrations rather than a beam transmissometer as used at Station C.

Suspended material concentrations at all stations display an evident increase above average ambient levels beginning on May 28,1991 with values remaining high for an eight (8) day period ending on June 5,1991 (Fig.29). Average concentrations in the vicinity of Station B increased by approximately 100% to slightly more than 20 mg/l. Concentrations at A and C were less pronounced but displayed a significantly greater standard deviation than Station B. This increase appears to be primarily the result of a short-term increase in rainfall-runoff and associated streamflow from the Housatonic River (Fig.30). At Station B the continuing beam smoothing operations produced perturbations that were impressed on the streamflow signal and served to supplement the high frequency variability of the suspended material field. Concentrations at this station decreased rapidly after June 5,1991 with values approaching the mean observed during the period prior to May 28th. A similar response was observed at Stations A and C with some residual increase in material concentration remaining due to accumulations of sediment on the windows of the optical sensors.

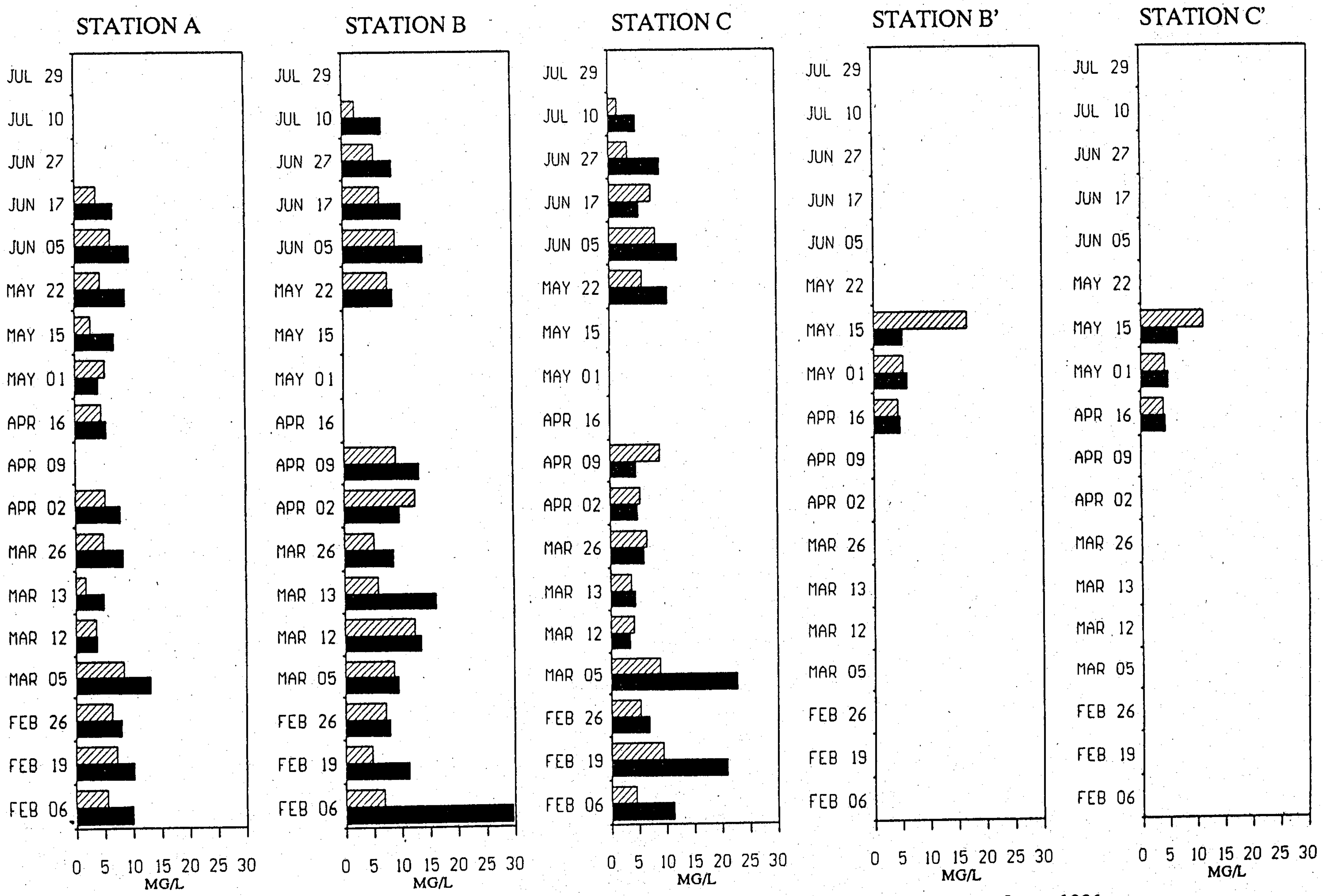


Figure 31 Suspended Material Concentrations - Drawn Water Samples 1991

TABLE 8

Suspended Material Concentrations

Drawn Water Samples 1991

	A		B		C		B'		C'	
DATE	SFC	BTM	SFC	BTM	SFC	BTM	SFC	BTM	SFC	BTM
FEB 06	5.55	10.05	6.91	29.65	4.54	11.36	NA	NA	NA	NA
FEB 19	7.2	10.23	4.83	11.28	9.45	20.95	NA	NA	NA	NA
FEB 26	6.36	8.03	7.19	7.96	5.33	6.92	NA	NA	NA	NA
MAR 05	8.45	13.07	8.75	9.56	8.89	22.76	NA	NA	NA	NA
MAR 12	3.58	3.81	12.41	13.52	4.25	3.55	NA	NA	NA	NA
MAR 13	1.78	4.91	5.97	16.27	3.76	4.43	NA	NA	NA	NA
MAR 26	4.85	8.31	5.31	8.69	6.56	6.11	NA	NA	NA	NA
APR 02	5.31	7.9	12.59	9.8	5.44	4.9	NA	NA	NA	NA
APR 09	NA	NA	9.23	13.3	8.96	4.71	NA	NA	NA	NA
APR 16	4.58	5.51	NA	NA	NA	NA	4.29	4.71	4.11	4.43
MAY 01	5.29	4.2	NA	NA	NA	NA	5.29	6.01	4.3	4.96
MAY 15	2.8	6.9	NA	NA	NA	NA	16.7	5.2	11.18	6.68
MAY 22	4.5	8.84	7.89	8.8	5.89	10.49	NA	NA	NA	NA
JUN 05	6.28	9.59	9.3	14.2	8.33	12.3	NA	NA	NA	NA
JUN 17	3.75	6.73	6.54	10.42	7.59	5.39	NA	NA	NA	NA
JUN 27	NA	NA	5.59	8.8	3.41	9.21	NA	NA	NA	NA
JUL 10	NA	NA	2.28	6.99	1.6	4.99	NA	NA	NA	NA
JUL 29	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
mean	5.02	7.72	7.49	12.09	6.00	9.15	8.76	5.31	6.53	5.36
std dev	1.75	2.60	2.84	5.72	2.39	6.06	6.89	0.66	4.03	1.18
var	3.07	6.75	8.04	32.70	5.72	36.78	47.53	0.43	16.23	1.38
min	1.78	3.81	2.28	6.99	1.60	3.55	4.29	4.71	4.11	4.43
max	8.45	13.07	12.59	29.65	9.45	22.76	16.70	6.01	11.18	6.68

Servicing (see Table 1 for schedule) effectively corrected this bias removing both the accumulated sediments and fouling organisms that settle and grow rapidly during the early summer months. The results of service activities are evident in the array records and generally result in a relatively abrupt return of the output signal to average background values.

The termination of the beam smoothing operations on June 23,1991 resulted in only minor variations in the qualitative and quantitative character of the suspended material field adjoining the pipeline route. Average concentrations at Station B equalled approximately 10 mg/l and were essentially identical to those observed during the pre-project period and throughout much of the construction period (Fig.32). The standard deviation decreased significantly relative to conditions observed during the beam smoothing operations with values approaching those observed during the pipe laying period (Fig.25). Conditions at Station C remained unchanged with concentrations and high frequency variability equal to those observed during the beam smoothing period. Again drawn water sampling indicates significantly lower concentrations than those indicated by the optical sensors consistent with the continuing presence of optical bias Fig.31-Table 8). It is interesting to note that although this is a relatively low energy time of the year, with wind speeds seldom exceeding 10 knots, several events sufficient to significantly perturb suspended material concentrations at Station B did occur. Each appears to have been primarily the result of short-term increases in

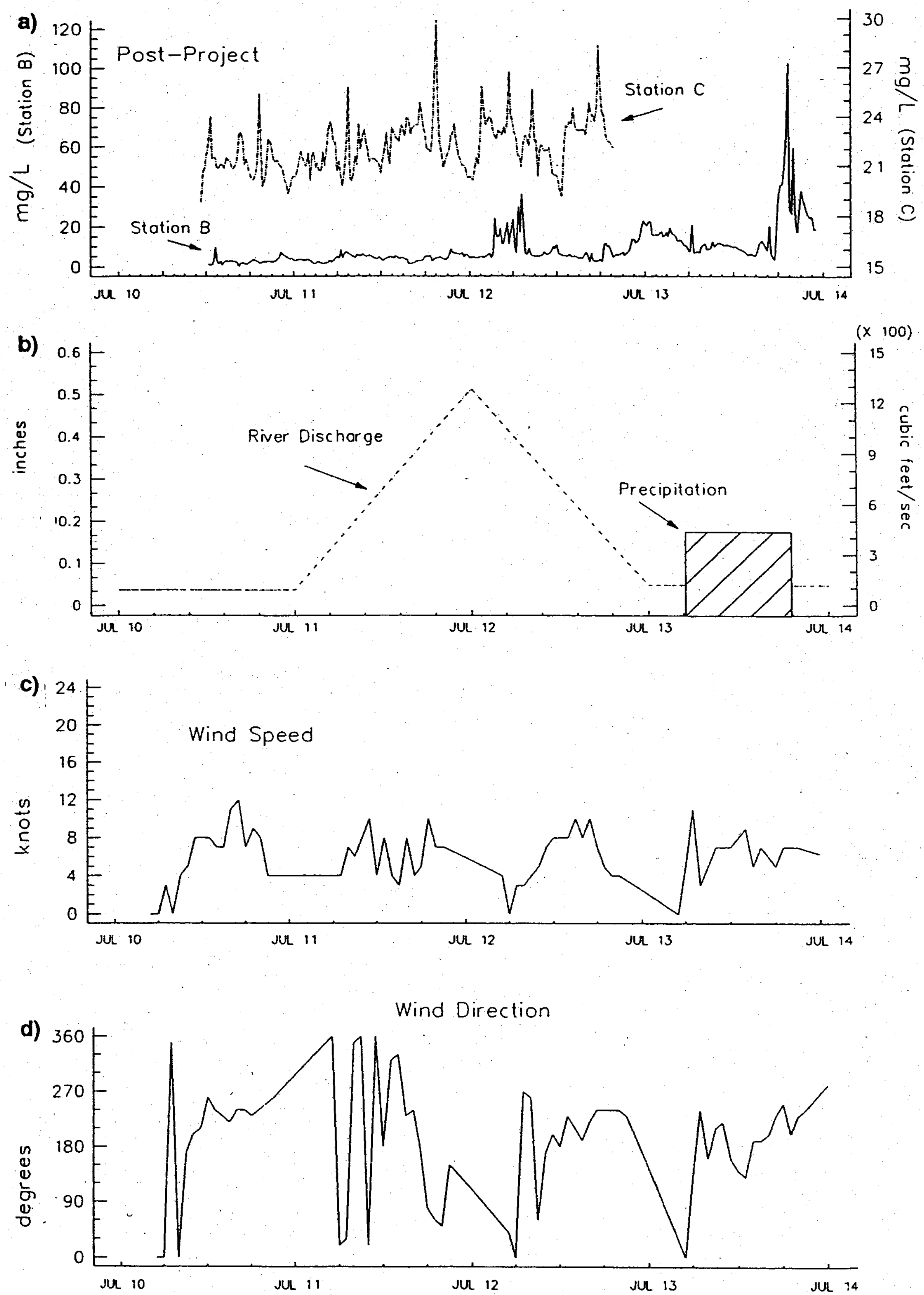


Figure 32 Suspended Material Concentrations and Associated Meteorological and Streamflow Conditions Post-Project Period - 1991

streamflow (Fig.32) producing effects that are essentially confined to a portion of a single tidal cycle. In addition to this limited time scale, the absence of a coincident increase in concentration at Station C indicates that the spatial scale of these effects is limited and most probably confined to the immediate nearshore. The observations during this post-project period provide no indication of residual effects within the suspended material field associated with the pipeline construction activities.

Discussion

The time series observations obtained as part of this investigation indicate that gas pipeline construction activities in the area ofshore of Milford served to produce short-term, small amplitude, changes in the concentration of suspended materials in the area adjoining the pipeline corridor. The spatial scales associated with this change were relatively small and confined to the immediate vicinity of the dredge and/or bottom smoothing beam. The array data indicate that the typical longitudinal or downstream distances were on the order of 500 to 1000yds. Estimates of the lateral scales associated with the operation induced plume of sediment can be developed by observing the horizontal spreading rates of the dye patches used to trace surface currents and through examination of aerial photographs showing sediment plumes extending downstream from an operating dredge. These data indicate that the lateral dimensions of the suspended material plume are substantially smaller than the downstream distances, particularly in the higher velocity, offshore, areas (vicinity of Station C e.g.) with typical scales on the order of 100-200yds. Suspended material concentrations associated with these plumes decay rapidly with distance downstream with the majority of sediment resuspended by the dredge settling within the 100-200ft of the operating bucket. Drawn water sampling in the immediate vicinity of the dredging point indicated significant spatial variability within the turbulent wake of the bucket with concentrations ranging from 50 to 250 mg/l. Although visually apparent, these concentrations are low relative to those observed in the vicinity of a dredge working in fine grained sediment (Bohlen,et.al.,1978) and appear representative of a system in which the majority of the dredged sediment is coarse grained with high settling velocities. In such materials only a small percentage of the dredged sediment mass will remain in suspension for a time sufficient to permit downstream transport, with even this fraction initially experiencing rapid settling due to concentration effects. The response appears consistent with the generally coarse grained nature of the sediments known to dominate much of the study area. These factors, in combination with the generally low velocity currents prevailing in much of the area inshore of the 30ft isobath, favor confinement of the primary project related effects to the immediate vicinity of the operating dredge.

In addition to limiting spatial scales, rapid settling of dredge resuspended sediments constrains the time scales associated

125 yds/day, 24hr day?

with project impacts. In all phases of the operation the su
material perturbations resulting from project related mecl
disturbance were essentially confined to the operational
with values returning to pre-project levels almost immed
following the cessation of dredging and/or smoothing. This factor serves to reduce the time during which benthic or sessile organisms are exposed to elevated suspended material concentrations. The relatively rapid rate of advance of the dredge, proceeding at approximately 125 yds/day, during both the initial excavation and subsequent infilling phases of the project, appears to have taken full advantage of the opportunity to keep exposure time to a minimum.

The relatively discrete nature of the pipeline construction activities in both space and time suggests that it is appropriate to view the operation as a moving point source of suspended materials. The source moves progressively along the axis of the pipeline corridor with resulting suspended materials distributed to the right and left under the alternating influence of local tidal currents. With the effects simply confined to an area extending out to 1000ft each side of the centerline, calculations assuming the continuing presence of the maximum observed suspended material load indicate that associated deposition would result in the accumulation of approximately 0.125in of sediment on the bottom. Distributions over a larger area or selection of lower average suspended material concentrations would necessarily result in thinner depositional layers. These materials would serve to supplement the 3-4in layer of high water content, organic rich, sediment routinely resident along the sediment-water interface throughout the study area and should be rapidly assimilated into this layer. The absence of significant chemical contamination associated with the dredge materials (ERCO,1987) and the similarity in grain size characterisitics relative to regional sediments indicate that the presence of the deposited residue should not significantly alter the character of the interfacial sediment layer nor its potential to induce adverse biological effects.

In contrast to the relatively discrete effects of dredge induced sediment plumes, the array data indicate that naturally occurring storm events tend to perturb the suspended material field throughout the study area. These events produced significantly larger variations in suspended material concentration than pipeline associated operations with effects observed over a significantly larger area. The majority of these events persisted over periods in excess of one day or time scales equal to or longer than those associated with dredge impact on a given area. The records indicate that during the study period, February to July,1991, eleven (11) storm events occurred sufficient to produce increases in concentration in excess of those related to pipeline operations. The common occurrence of these events as well as their spatial and temporal scales and the relatively large mass of sediment resuspended during their passage indicate that organisms living successfully in the area must, over the years, have developed an ability to tolerate short-term increases in suspended material concentrations. These characteristics, in combination with the minimal depth of burial associated with deposition of dredge resuspended sediments and the absence of chemical contaminants in the dredged sediment, effectively confine operation associated biological impacts to areas subject to direct mechanical disturbance including the region of the trench, beam drags areas, and portions of the bottom impacted by anchors restraining the pipelaying barge. Beyond this region the operations affect only the suspended material field on spatial and temporal scales that cannot produce measurable biological change.