DESCRIPTION OF SALINITY, TEMPERATURE, CHLOROPHYLL, SUSPENDED-SEDIMENT, AND VELOCITY DATA, SOUTH SAN FRANCISCO BAY, CALIFORNIA, FEBRUARY-APRIL 1987

By *Marcus J. Taylor* and *Brian T. Yost*

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CONVERSION FACTORS

For readers who prefer to use inch-pound units rather than the International System of Units (SI), the conversion factors for the terms used in this report are listed below:

Multiply	By	To obtain
centimeter per second (cm/s)	0.3937	inch per second
cubic meter per second (m^3/s)	35.31	cubic foot per second
cubic kilometer (km^3)	0.2399	cubic mile
kilometer (km)	0.6214	mile
kilometer per hour (k/h)	0.05396	knot
liter (L)	0.2642	gallon
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F=1.8(°C)+32.$$

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ABSTRACT

This report describes data collected as part of the hydrodynamics element of an interagency study of the effects of freshwater inflow on the San Francisco Bay-Delta estuary. Vertical profiles of salinity, temperature, and velocity were measured in south San Francisco Bay. In addition, chlorophyll and turbidity samples were collected near the surface and near the bottom of the water column. Four sampling cruises were completed, each done over a 12-hour tidal cycle. Five transects, each consisting of five to seven sampling stations, were completed on each of the first two cruises; two more transects were added for the last two cruises. Continuous velocity, salinity, and temperature data were recorded by four current meters deployed at three stations in a cross section during the sampling period.

INTRODUCTION

This data-collection study was undertaken by the U.S. Geological Survey, in cooperation with the California Department of Water Resources and the California State Water Resources Control Board, as part of the hydrodynamics element of the Interagency Ecological Studies Program for the San Francisco Bay-Delta estuary. The hydrodynamics element was designed to determine the magnitude, duration, and location of biologically significant variations in hydrodynamics, salinity, suspended solids, and pollutant transport within the estuary that result from changes in freshwater outflow from the delta (fig. 1).

The agencies involved in the interagency program include the U.S. Geological Survey, U.S. Bureau of Reclamation, California Department of Water Resources, California State Water Resources Control Board, California Department of Fish and Game, and the U.S. Fish and Wildlife Service. These agencies are working together to support a variety of physical, chemical, and biological studies of the San Francisco Bay-Delta estuary.

PURPOSE AND SCOPE

The data described in this report were collected for use in analyzing the connection between the onset of density stratification caused by pulses of delta-derived freshwater inflow from the northern reach of San Francisco Bay and increased phytoplankton biomass production observed in south San Francisco Bay.

The objectives for collecting and analyzing the data are to:

1. Define tidal-cycle variations in vertical density structure.
2. Measure vertical gradients of density, velocity, and chlorophyll in the shoals.
3. Define and measure tidal-cycle variations in the small-scale horizontal distribution of salinity and chlorophyll.
4. Use measured distributions to estimate horizontal and vertical mixing rates, and, in particular, variations over the neap-spring tide cycle and vertical spatial variations across the San Bruno Shoal (fig. 2), which is considered an important topographic control on mixing.
5. Use synoptic surveys to better define the coupling between the spring blooms that occur in the shoals and channel.
6. Use the measured density field to infer lateral circulations, a first step toward estimating exchange rates between the channel and shoals.

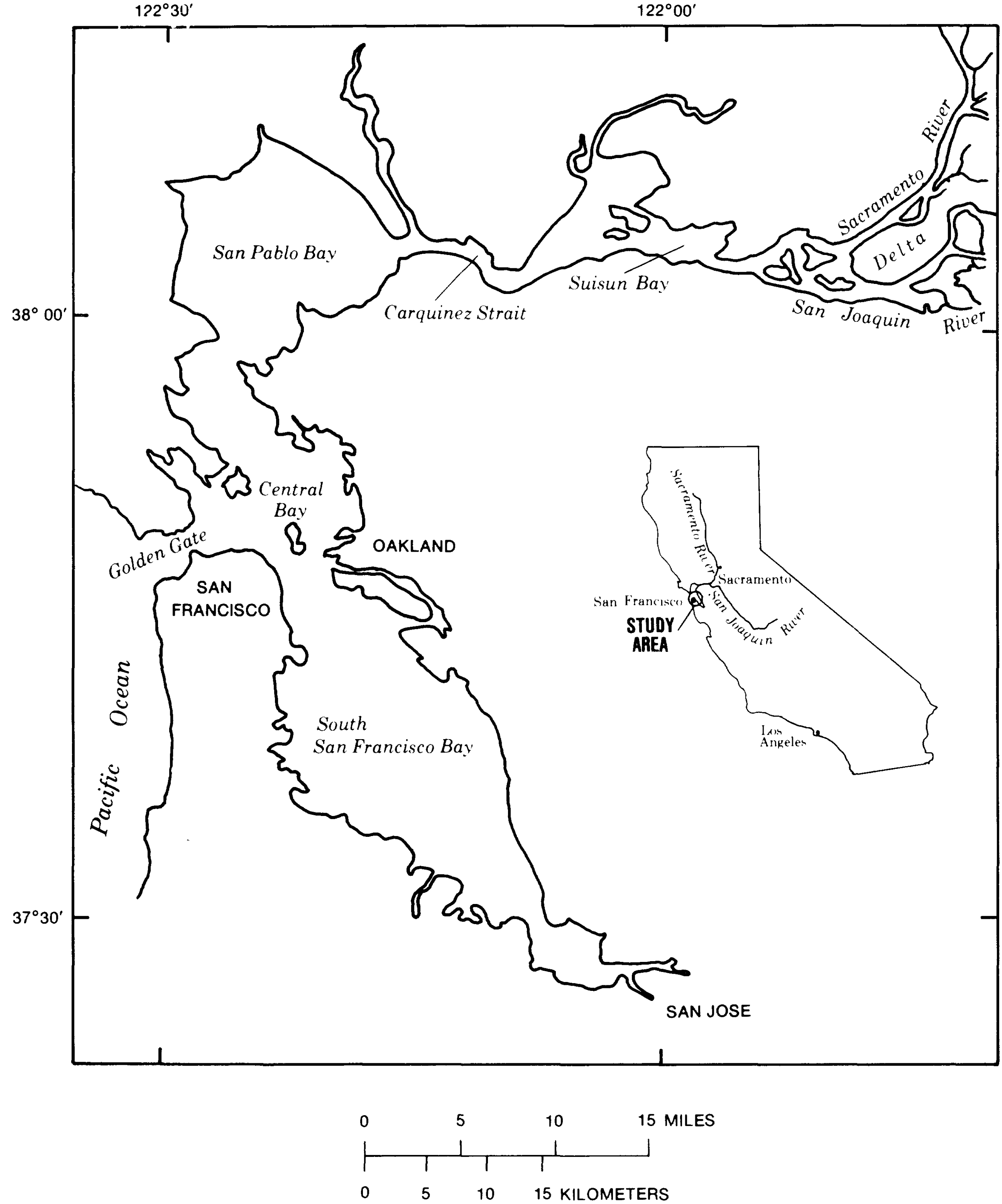

Figure 1. San Francisco Bay estuarine system.

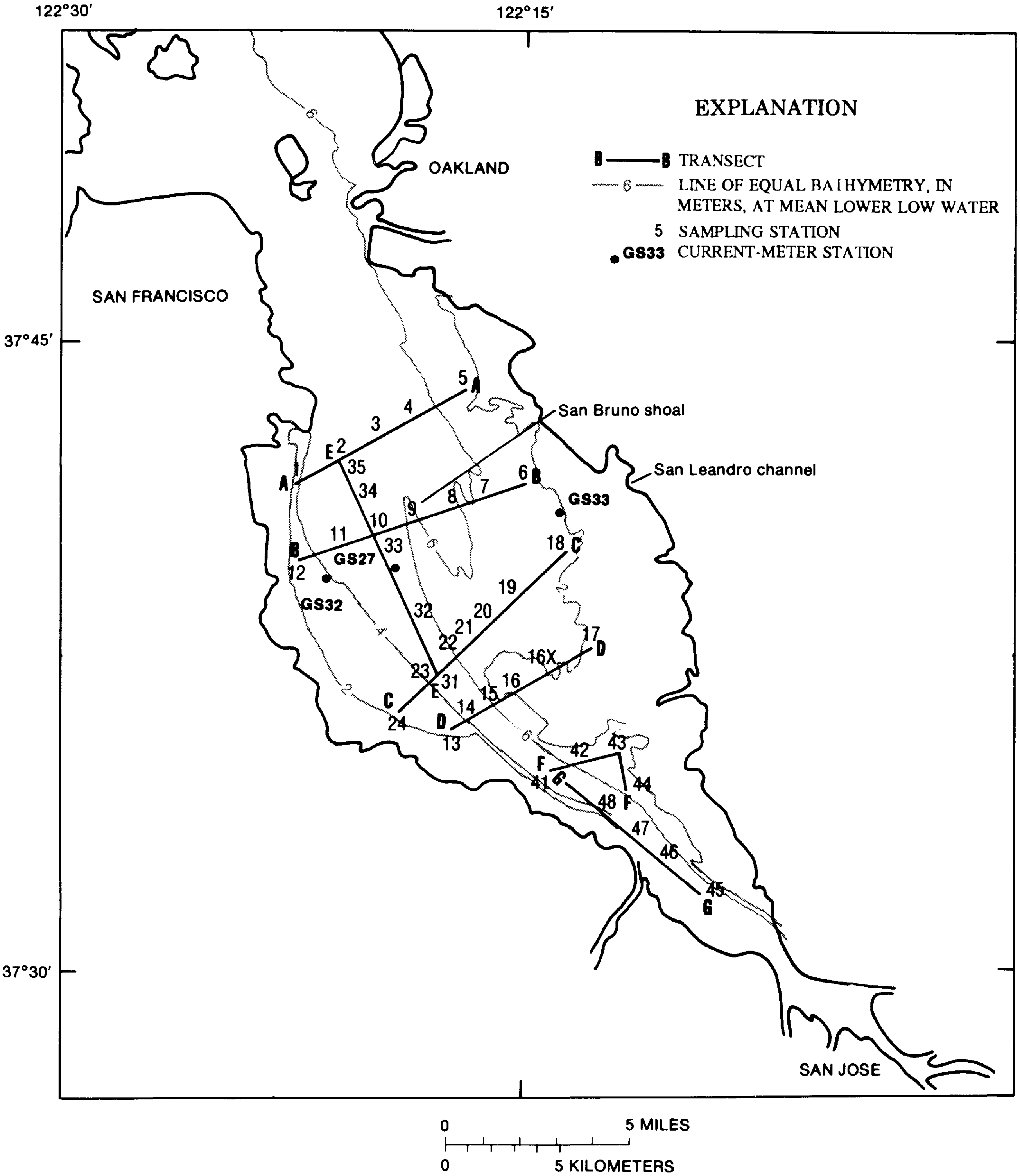

Figure 2. Location of sampling stations, current-meter stations, and transects in south San Francisco Bay.

The scope of the study included the collection of vertical profiles of salinity, temperature, and velocity, in addition to chlorophyll and turbidity samples taken near the surface and near the bottom of the water column in the middle section of south San Francisco Bay. Four sampling cruises were completed during spring to neap tidal variations. Each cruise was done over a 12-hour tidal cycle near the vernal equinox of 1987. Five transects, one longitudinal and four cross sectional, each consisting of five to seven sampling stations (fig. 2; table 1), were done on each of the first two cruises. Two more transects were added on the last two cruises. Recording current meters were deployed at three locations (fig. 2) to provide a continuous record of current velocity, salinity, and temperature data, which could be used to examine changes in the density and velocity structure that occur between the individual sampling dates.

ACKNOWLEDGMENTS

This study was the result of a collaboration between the U.S. Geological Survey, the California Department of Water Resources, the California State Water Resources Control Board, and the U.S. Bureau of Reclamation. Such an extensive field study would not have been possible without the willing and competent assistance of many individuals. In particular we would like to thank Thomas Powell of the University of California at Davis for helping organize and coordinate the field data collection.

DESCRIPTION OF STUDY AREA

San Francisco Bay receives freshwater primarily from the drainage basins of the Sacramento and San Joaquin Rivers. After diversion, storage, and consumption within the delta, the remaining water enters the bay system at the eastern end of Suisun Bay (fig. 1). The bay system can be represented by two estuarine types. The part north of San Francisco, consisting of Suisun, San Pablo, and Central Bays, can be characterized as a partially mixed estuary. The part south of San Francisco, the South Bay, is typically well mixed. This difference occurs because nearly all the freshwater (90 percent) enters the bay system from the delta through the Sacramento and San Joaquin Rivers at the eastern end of the northern reach (Conomos, 1979).

Table 1.--Positions and depths of sampling stations

[MLLW, mean lower low water. There were no stations numbered 25-30 or 36-40]

Sampling station No. (fig. 2)	Latitude (north)	Longitude (west)	Depth (MLLW) (meters)
1	37°41′47″	122°21′47″	7.0
2	37°42′19″	122°20′29″	10.1
3	37°42′50″	122°19′12″	11.3
4	37°43′23″	122°17′53″	7.9
5	37°43′56″	122°16′34″	2.1
6	37°41′48″	122°14′51″	2.7
7	37°41′14″	122°16′25″	4.3
8	37°40′46″	122°17′49″	7.9
9	37°40′32″	122°18′27″	3.0
10	37°40′09″	122°19′31″	7.9
11	37°39′44″	122°20′43″	6.1
12	37°39′20″	122°21′50″	4.3
13	37°35′47″	122°16′59″	2.1
14	37°36′08″	122°16′19″	14.3
15	37°36′23″	122°15′47″	2.1
16	37°37′06″	122°14′22″	3.7
16X	37°37′25″	122°13′45″	2.1
17	37°38′06″	122°12′22″	1.2
18	37°40′23″	122°13′28″	1.8
19	37°39′03″	122°15′27″	3.7
20	37°38′26″	122°16′22″	4.6
21	37°38′05″	122°16′53″	3.7
22	37°37′24″	122°17′55″	11.3
23	37°37′03″	122°18′26″	3.7
24	37°36′36″	122°19′06″	3.0
31	37°37′14″	122°18′08″	11.0
32	37°38′44″	122°18′52″	9.1
33	37°40′07″	122°19′36″	9.1
34	37°40′57″	122°19′58″	8.2
35	37°42′14″	122°20′39″	10.4
41	37°35′00″	122°15′02″	14.3
42	37°35′16″	122°13′08″	2.1
43	37°35′33″	122°11′21″	1.8
44	37°33′55″	122°11′14″	2.7
45	37°31′22″	122°08′40″	11.6
46	37°32′14″	122°10′14″	12.2
47	37°33′25″	122°11′39″	12.2
48	37°34′13″	122°13′16″	14.9

The South Bay (fig. 2) has a wetted surface area of approximately 554 km^2 and a mean depth of 3.4 m at mean lower low water (MLLW) (Cheng and Gartner, 1985). The South Bay is characterized by a deep region in the northern third of the embayment, a deep main channel (greater than 10 m), and an expansive shoal to the east of the main channel (fig. 2). National Oceanographic and Atmospheric Administration (NOAA) bathymetric data indicate that 23 percent of the area has depths greater than 5.5 m, and 52 percent has depths less than 1.8 m (referenced to MLLW). The water properties of the South Bay vary seasonally and are controlled in part by mixing with water of the northern reach and by the seasonal meteorological forcing in the region.

About 0.1 km^3 of freshwater annually enters the South Bay from local tributaries. The salinity of South Bay water is nearly equal throughout the water column and is near oceanic values for much of the year. However, significant stratification may exist in winter and early spring when the maximum flux of freshwater from the delta enters the South Bay via the northern reach (Cheng and Gartner, 1985). During wet years salinity in the South Bay may be depressed to values below 20 ‰ (parts per thousand).

The South Bay has periodic variations in salinity stratification that coincide with neap-spring tidal variations during the winter wet season, but remains well-mixed during summer and autumn (Cloern, 1979, 1984). During periods of prolonged salinity stratification, phytoplankton biomass and primary productivity are high, phytoplankton patchiness increases, turbidity and nutrient concentrations decline in the surface layer, and residual currents accelerate. The South Bay receives more than 75 percent (1.3 km^3) of the total wastewater discharged into the system each year, and during summer months wastewater inflows exceed natural stream inflows (Conomos, 1979).

Typical meteorological conditions for the South Bay region are characterized by prevailing westerly or northwesterly winds in late spring, summer, and early autumn, and more variable conditions in winter. The prevailing westerly summer wind is reinforced by diurnal sea breezes caused by solar heating inland, and the winter wind pattern is influenced by winter storm tracks to the south resulting in winds from the east or southeast.

DATA COLLECTION

Vertical profiles of salinity, temperature, and density, in addition to chlorophyll and turbidity samples taken near the surface and near the bottom of the water column, were collected at 38 locations. Velocity profiles were measured at 12 locations, and continuous records of velocity, salinity, and temperature data were collected at 3 locations. Four sampling cruises were completed on February 26, March 9, March 27, and April 7. The first two cruises utilized three research vessels, the RV *Polaris*, the RV *Scrutiny*, and the RV *Rantz*. A fourth boat, operated by California Department of Water Resources personnel, was added to the fleet for the final two cruises. Each cruise consisted of six 2-hour circuits done over a 12-hour tidal cycle during daylight hours using three or four vessels. Each sampling day began at slack tide shortly before dawn and continued through one tidal cycle, including one ebb and one flood tide, ending at slack tide in the early evening.

Five transects, one longitudinal and four cross-sectional (see fig. 2; table 1), each consisting of five to seven sampling sites, were completed on each cruise. Sixth and seventh transects (F and G) were added for the last two cruises. The longitudinal transect (E) was completed such that conductivity, temperature, and depth (CTD) profiling was done in one direction and continuous surface profiling in the opposite direction. The sampling of each direction required 1 hour. CTD profiling and chlorophyll sampling were done on all four cross-sectional transects. Each cross-sectional transect was completed every other hour. The northernmost and southernmost cross-sectional transects (A and D) were done from west to east on the even hour and the other cross-sectional transects (B and C) were completed on the odd hour in the opposite direction. Velocity profiling was done on the two northernmost cross-sectional transects (A and B).

Four current meters were deployed from February 25 to April 29 at three sites selected to form a cross section perpendicular to the main shipping channel near San Bruno shoal (fig. 2). Two meters were deployed on a taut line mooring at current-meter station GS27 near the main channel west of San Bruno shoal; one meter was within 2 m of the surface and one meter was approximately 1.5 m above the bottom of the site, which was at a depth of 12 m. The third meter was deployed at station GS32 on the west side of the main channel in approximately 3 m of water, on a bottom platform where the meter was approximately 1.5 m above the bottom. The fourth meter was deployed at station GS33 near the San Leandro channel, east of the main channel in 3 m of water, on a bottom platform similar to the one at GS32.

The weather for the February 26 and March 9 cruises was clear with light breezes and calm water conditions. The weather for the March 27 cruise was partly cloudy with winds from the northwest starting during mid-morning and increasing to 15 to 24 knots in the afternoon. Sampling was curtailed in the early evening due to heavy wind conditions. The weather was clear on April 7; the wind was calm in the early morning, increasing to 20 to 25 knots in the afternoon. Sampling was curtailed during the late afternoon because of heavy wind conditions.

Spring 1987 was drier than usual, characterized by low flows and small peaks in delta outflow (fig. 3) from February 1 to April 30. Average daily flows for February, March, and April were 479, 555, and 186 m^3/s, respectively. Peaks in delta outflow were on February 17 (1,010 m^3/s) and on March 17 (1,014 m^3/s). Minimum delta outflow was 137 m^3/s on April 14.

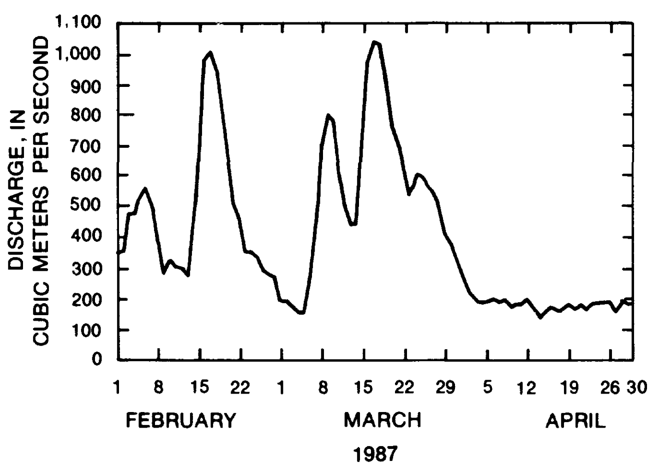

Figure 3. Delta outflow, February 1 to April 30, 1987.

INSTRUMENTATION AND METHODS

CONDUCTIVITY, TEMPERATURE, AND DEPTH (CTD) DATA

A Sea-Bird conductivity, temperature, and depth profiler (CTD model SBE9) was utilized to collect vertical profiles of electrical conductivity and temperature. The system consists of an underwater unit, a deck unit, and a computer. The underwater unit encodes data from conductivity, temperature, and pressure sensors (pressure is an indicator of depth) and converts this information to a computer-compatible format. The computer then records conductivity, temperature, and pressure. Salinity and density are calculated from the recorded data and all data are then entered on floppy disks and magnetic tape. The user may plot this information on a computer screen.

SUSPENDED-PARTICULATE-MATTER AND CHLOROPHYLL-*A* DETERMINATION

On each circuit, surface-water samples were collected with a bucket at each fixed station. Aliquots were placed in 150-milliliter opaque bottles and stored on ice until analyzed during the day of collection. Larger volume (2 L) samples were also collected at selected stations (6, 17, 31 or 35, and 45) on each circuit: these were chilled and later processed for determination of suspended-particulate-matter (SPM) and chlorophyll-*a* concentrations. Turbidity (as arbitrary nephelometric units) and in-vivo fluorescence (also as arbitrary units) were measured on all samples with a Turner Designs Model 40 Nephelometer and a Turner Designs Model 10 Fluorometer, respectively. Nephelometric and fluorescence values were converted to estimated concentrations of SPM and chlorophyll-*a*, using calibrations described below.

From the 2-L samples, aliquots (0.1 to 1.0 L) were filtered with preweighed 47-mm silver filters that were subsequently air dried for about a month and then reweighed to determine seston weight. SPM concentration was calculated using a correction for salt content retained in the filters (Hager and Harmon, 1984). Separate aliquots were filtered onto 47-mm glass fiber filters that were frozen until analyzed in the laboratory for chlorophyll-*a*. Filters were ground with 90 percent acetone, and chlorophyll-*a* concentration determined spectrophotometrically, using methods of Strickland and Parsons (1972) and Lorenzen's (1967) equations that correct for pheopigments.

SPM values from the four cruises were combined (n=80), and the measured SPM concentration was regressed against turbidity (fig. 4). This highly significant linear regression (r^2=0.92) provided a simple method for estimating SPM concentration from turbidity at all stations and circuits (standard error of estimate for SPM was 6.7 milligrams per liter). Calculated values for SPM are given in table 2.

Similarly, chlorophyll-*a* values from the four cruises were combined (n=87), and chlorophyll-*a* concentration was regressed against in-vivo fluorescence (fig. 5). This regression was also highly significant (r^2=0.92) and allowed for estimation of chlorophyll-*a* concentration at all stations and circuits from measured in-vivo fluorescence. Because of problems with the bottom samplers, the estimates for the bottom station were contaminated, so only the surface estimates are provided in table 3. Standard error of the estimated chlorophyll-*a* concentration was 1.0 microgram per liter.

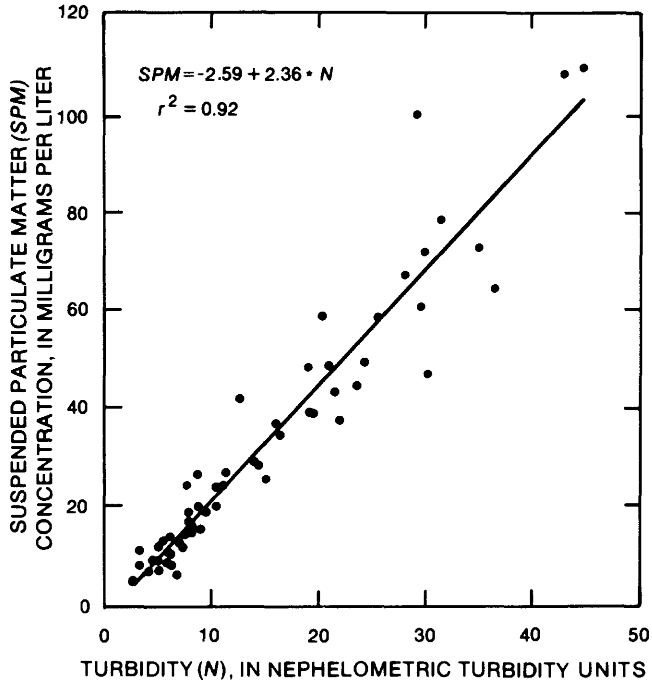

Figure 4. Relation between suspended particulate matter and turbidity.

VELOCITY DATA

A vessel-mounted acoustic Doppler current profiler (ADCP) was utilized to collect velocity profiles. The ADCP was specifically designed to provide earth-referenced water-velocity profiles from a moving vessel in shallow waters typical of estuaries and inland rivers. The ADCP operates on a 1.2-megahertz frequency and utilizes a four-transducer system with a 1-m depth cell resolution and a depth range of 4 to 29 m. Velocity data are recorded and processed using a microcomputer based data-acquisition system. The ADCP has been shown to have a random error of 2.3 cm/s when a 20-second averaging period is used (Simpson, 1986).

Digital recording current meters (Cheng, 1978) were modified (Cheng, 1985) and used to record current speed and direction, water temperature, and electrical conductivity on solid-state CMOS data cartridges. The data recorder built into the current meter is activated at selected times by an internal crystal timer.

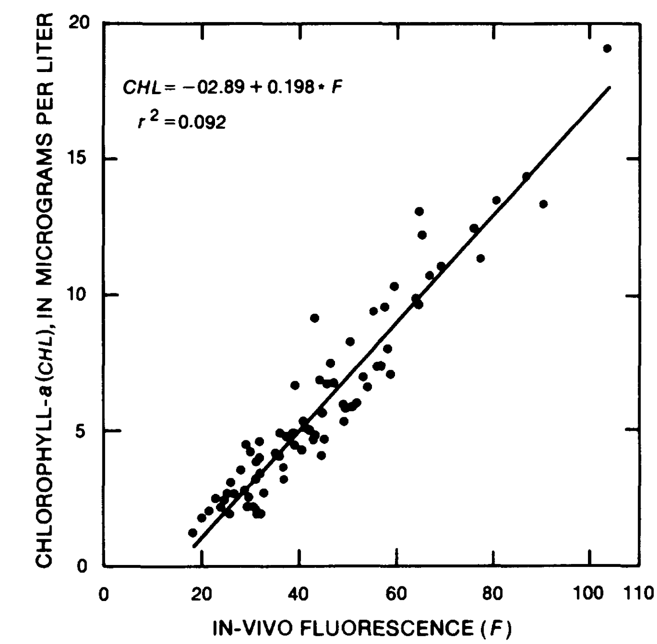

Figure 5. Relation between chlorophyll-*a* and in-vivo fluorescence.

Table 2.--Surface suspended-particulate-matter concentrations, in milligrams per liter, February 26, March 9 and 27, and April 7, 1987

[There were no stations numbered 25-30 or 36-40. --, no data]

Sampling station No. (fig. 2)	Circuit number					
	1	2	3	4	5	6
	February 26, 1987					
1	20.6	35.9	9.4	8.8	29.7	31.6
2	17.8	13.9	6.5	7.4	35.2	50.5
3	14.0	20.6	11.5	7.8	60.7	44.6
4	32.3	21.5	9.8	26.0	40.1	30.5
5	4.2	17.4	9.0	21.0	12.4	7.7
6	11.7	9.6	7.4	8.2	11.2	8.2
7	48.2	27.6	10.3	42.7	65.4	62.6
8	21.0	29.0	10.0	38.5	37.8	38.7
9	26.9	23.8	6.8	26.9	37.3	56.4
10	18.7	23.8	--	10.7	29.0	35.2
11	26.7	14.8	7.1	25.0	39.2	36.8
12	16.0	9.7	--	22.2	30.9	22.0
13	39.7	45.3	21.0	8.3	39.4	42.5
14	19.8	12.3	8.9	6.5	18.4	41.1
15	29.7	32.8	16.5	8.9	45.6	34.2
16	58.8	36.6	11.9	9.2	59.5	59.5
17	83.3	67.5	30.9	57.6	76.0	98.2
18	21.5	11.5	11.2	24.8	35.4	
19	43.4	26.4	13.5	43.7	59.2	81.7
20	32.1	22.4	11.6	31.9	36.3	51.7
21	34.7	31.9	7.0	9.3	26.0	29.7
22	22.9	10.9	8.5	5.5	48.4	49.3
23	38.5	14.8	1.8	24.1	37.5	43.0
24	29.5	12.6	4.2	21.5	15.8	14.9
31	15.8	25.7	12.2	9.7	49.3	65.9
32	19.1	18.9	13.2	12.7	42.3	77.7
33	19.7	32.6	12.0	13.2	35.2	56.4
34	43.2	38.2	--	12.0	--	--
35	39.9	33.5	--	64.7	80.0	39.9

Sampling station No. (fig. 2)	Circuit number					
	1	2	3	4	5	6
	March 9, 1987					
1	6.2	2.7	2.4	6.7	8.4	7.9
2	5.1	2.4	1.8	10.0	5.6	7.3
3	8.2	4.0	1.6	14.9	5.6	10.7
4	4.5	5.7	11.2	17.1	6.7	10.0
5	2.8	8.2	13.1	12.0	5.6	5.8
6	11.4	12.2	13.3	5.1	5.5	10.5
7	7.2	7.9	14.9	13.0	12.8	15.1
8	3.2	4.8	7.7	8.4	4.9	10.8
9	2.2	5.3	8.3	7.8	8.8	12.8
10	4.1	4.0	--	3.6	4.5	10.6
11	--	2.5	7.1	4.2	4.1	9.2
12	--	1.2	8.4	7.9	5.0	11.5
13	9.5	10.6	9.0	16.2	18.1	15.8
14	9.3	4.3	5.1	8.5	10.3	12.0
15	8.2	8.0	12.4	11.7	4.6	11.1
16	12.0	11.0	12.8	10.6	11.3	27.4
17	13.3	14.7	14.0	15.3	16.8	18.6
18	9.1	10.7	11.8	9.9	13.6	15.2
19	8.8	7.6	19.9	16.9	13.3	25.5
20	9.2	6.2	16.2	9.0	11.4	18.8
21	7.8	6.4	6.1	2.0	7.1	15.5
22	7.6	6.9	4.6	3.3	6.9	10.3
23	11.1	5.9	9.7	8.5	9.3	14.1
24	8.0	11.1	11.5	25.3	13.8	10.5
31	--	6.4	--	8.7	8.0	10.6
32	--	5.2	--	11.1	9.7	13.5
33	--	4.8	--	11.1	9.5	11.1
34	--	3.5	--	11.1	9.0	8.3
35	--	4.4	--	10.9	6.6	6.4

Table 2.--Surface suspended-particulate-matter concentrations, in milligrams per liter, February 26, March 9 and 27, and April 7, 1987--Continued

Sampling station No. (fig. 2)	Circuit number						Sampling station No. (fig. 2)	Circuit number					
	1	2	3	4	5	6		1	2	3	4	5	6
	March 27, 1987							April 7, 1987					
1	--	36.1	29.3	--	--	32.6	1	3.9	3.8	3.1	6.3	6.9	--
2	22.9	42.0	16.0	15.5	--	52.4	2	5.8	3.7	1.7	12.3	9.6	--
3	2.6	37.8	27.9	14.9	--	3.3	3	5.9	4.2	3.2	24.8	17.2	--
4	37.1	24.3	19.6	15.1	--	39.4	4	10.6	8.6	25.0	25.3	24.8	--
5	8.6	9.5	8.4	16.0	--	13.2	5	10.1	16.5	20.0	20.7	17.1	--
6	15.9	15.1	9.6	15.4	17.8	--	6	21.7	17.6	9.6	11.2	23.8	--
7	41.5	21.3	10.3	39.4	47.4	--	7	13.9	17.2	26.7	28.8	27.6	--
8	37.5	26.2	26.0	22.4	30.5	--	8	6.5	6.5	17.6	--	21.5	--
9	36.8	31.4	19.9	41.5	37.8	--	9	4.8	14.7	18.3	22.4	28.1	--
10	34.5	20.2	--	29.7	39.9	--	10	3.5	7.9	--	--	--	--
11	40.6	23.4	15.8	--	48.4	--	11	3.4	4.8	15.2	19.4	16.5	--
12	--	14.7	--	26.4	41.1	--	12	2.4	7.4	8.1	--	9.4	--
13	45.1	49.1	21.0	14.5	67.7	49.8	13	19.8	13.1	15.6	22.9	33.5	--
14	22.7	23.6	13.6	12.2	15.4	32.8	14	13.8	9.1	8.6	16.0	22.2	--
15	30.9	33.1	18.7	11.8	27.9	44.1	15	11.9	8.7	19.2	20.3	41.3	--
16	35.2	35.9	16.0	10.7	41.1	43.4	16	17.2	15.5	36.1	32.3	34.2	--
17	35.9	33.1	22.2	30.7	42.0	--	17	44.1	44.4	63.7	78.4	96.1	--
18	14.5	18.6	17.0	20.7	20.6	24.1	18	24.1	26.9	22.9	16.9	34.0	--
19	4.8	31.6	12.1	33.1	50.5	42.0	19	13.9	13.0	20.0	26.4	30.9	--
20	34.7	35.4	11.3	33.1	39.0	31.6	20	13.8	12.6	20.2	24.3	17.2	--
21	38.0	37.8	16.2	19.6	26.2	23.1	21	14.4	8.8	13.0	16.5	31.2	--
22	37.1	21.3	5.1	8.4	55.2	35.6	22	14.7	6.1	11.1	17.9	--	--
23	48.9	31.2	10.5	18.9	55.7	39.9	23	15.5	13.9	20.0	22.2	--	--
24	38.0	14.6	6.6	17.4	21.7	25.3	24	13.5	7.2	14.0	16.8	--	--
31	54.3	60.4	--	59.0	46.5	33.5	31	13.5	11.6	17.9	20.5	24.3	--
32	43.2	65.6	--	57.6	74.8	43.4	32	9.7	13.0	20.1	23.4	20.1	--
33	52.9	73.9	--	67.5	64.7	47.2	33	3.3	9.5	20.5	27.2	26.2	--
34	63.5	48.6	--	147.5	60.2	45.8	34	3.6	3.8	--	22.0	18.4	--
35	66.8	68.5	--	108.3	71.3	31.9	35	4.0	2.1	--	12.3	11.3	--
41	18.8	28.8	12.8	15.0	31.9	40.6	41	14.5	14.2	9.7	14.5	24.1	22.4
42	25.7	34.9	21.0	10.7	40.6	41.5	42	32.8	18.6	39.4	33.5	58.1	77.7
43	22.4	20.5	17.2	15.4	25.5	36.1	43	30.2	29.5	32.1	71.8	126.7	115.7
44	31.4	33.3	20.4	22.2	30.0	46.7	44	22.7	14.5	31.2	59.5	82.1	68.0
45	15.9	30.0	30.7	25.3	30.5	25.5	45	18.5	16.3	21.3	17.4	24.8	31.4
46	20.7	43.2	22.4	17.1	41.1	29.5	46	16.3	16.5	14.0	22.4	25.0	28.1
47	18.6	20.4	18.8	14.6	37.1	29.5	47	15.2	14.3	14.6	41.1	29.7	25.0
48	21.7	36.3	10.8	19.5	21.3	32.6	48	14.0	10.1	19.2	23.4	30.2	23.1

Table 3.--Surface chlorophyll-*a* concentrations, in micrograms per liter, February 26, March 9 and 27, and April 7, 1987

[There were no stations numbered 25-30 or 36-40. --, no data]

Sampling station No. (fig. 2)	Circuit number 1	2	3	4	5	6	Sampling station No. (fig. 2)	Circuit number 1	2	3	4	5	6
February 26, 1987							March 9, 1987						
1	4.6	1.5	1.5	0.7	2.7	2.1	1	0.2	1.1	0.6	1.3	3.3	3.8
2	4.4	1.3	.9	.3	2.1	3.8	2	.9	1.0	.2	.9	1.3	2.3
3	1.3	1.7	1.1	.7	3.3	3.3	3	1.0	1.8	.3	1.3	.5	2.5
4	2.3	2.1	1.3	1.9	4.2	5.6	4	1.2	1.3	1.1	1.7	1.4	2.5
5	3.6	2.5	2.3	3.3	6.6	6.6	5	2.1	1.7	2.1	2.7	3.6	8.6
6	4.4	4.8	3.6	6.0	8.4	7.2	6	1.7	1.9	5.2	6.4	8.8	7.6
7	3.1	2.7	1.7	3.8	4.8	5.2	7	1.3	1.3	2.1	3.1	4.0	3.1
8	2.7	1.9	1.1	2.9	3.6	3.6	8	1.6	1.0	1.7	1.7	2.3	1.9
9	2.3	1.7	.5	2.5	3.6	3.5	9	1.4	.9	1.7	1.5	2.5	1.9
10	2.3	1.9	--	2.1	2.5	3.5	10	1.4	.7	--	.8	2.3	2.1
11	2.7	1.3	1.0	2.7	3.3	3.3	11	--	.4	2.5	3.8	5.6	4.4
12	2.3	2.1	--	8.0	.7	0.4	12	--	.4	7.2	11.8	16.5	11.2
13	7.4	3.5	2.1	2.1	9.6	7.4	13	3.1	3.1	2.3	3.8	4.0	3.8
14	2.3	1.3	1.1	1.7	3.3	3.8	14	2.1	2.1	2.1	3.3	3.6	4.0
15	3.6	2.1	1.7	1.9	3.3	3.6	15	1.3	2.3	2.7	2.5	4.0	3.5
16	3.8	3.8	2.5	4.4	4.8	4.2	16	1.7	2.1	2.9	4.2	5.2	7.4
17	5.2	4.6	3.5	4.8	6.8	7.8	17	3.1	3.5	4.8	8.2	6.8	7.4
18	4.2	4.4	4.6	5.4	7.8	--	18	2.7	2.5	4.2	5.2	7.6	8.0
19	3.5	2.7	3.1	3.6	5.4	5.8	19	1.7	1.5	2.5	4.0	4.8	4.0
20	4.0	2.7	2.3	4.6	5.4	3.8	20	1.3	1.3	2.5	3.1	4.6	3.3
21	3.5	2.5	1.3	4.0	3.3	3.8	21	1.1	1.1	1.5	2.1	2.3	2.3
22	1.7	1.3	.7	.7	4.6	3.3	22	1.3	.6	2.3	4.0	3.3	2.3
23	3.1	1.9	.2	2.7	8.6	4.2	23	1.5	2.5	2.1	3.8	2.7	2.1
24	1.9	1.9	.4	3.5	4.8	.5	24	7.6	5.2	7.2	6.0	6.6	6.4
31	3.5	2.0	2.0	2.4	4.2	4.2	31	--	2.1	--	2.9	3.6	2.7
32	1.9	2.3	1.9	1.7	2.7	3.8	32	--	1.9	--	2.5	3.5	2.9
33	2.2	2.3	1.3	1.7	2.7	3.5	33	--	1.4	--	2.3	2.9	2.3
34	2.6	1.6	--	1.6	--	--	34	--	1.1	--	2.5	2.7	2.1
35	2.5	1.5	--	2.4	3.3	2.3	35	--	.8	--	1.3	2.3	2.1

Table 3.--Surface chlorophyll-*a* concentrations, in micrograms per liter, February 26, March 9 and 27, and April 7, 1987--Continued

Sampling station No. (fig. 2)	Circuit number						Sampling station No. (fig. 2)	Circuit number					
	1	2	3	4	5	6		1	2	3	4	5	6
March 27, 1987							April 7, 1987						
1	--	2.5	2.6	--	--	5.9	1	2.1	2.1	1.4	3.4	5.0	--
2	2.4	2.2	2.2	2.7	--	2.5	2	2.5	2.6	1.3	3.0	3.3	--
3	2.6	2.8	3.2	2.3	--	3.2	3	2.6	2.4	1.1	4.7	5.0	--
4	3.0	2.6	3.2	2.7	--	4.9	4	2.7	2.5	4.4	4.8	5.2	--
5	6.1	2.2	2.7	3.6	--	3.6	5	2.8	3.8	3.9	4.0	4.5	--
6	6.3	4.1	2.7	6.1	8.6	--	6	3.3	3.0	4.9	5.8	7.0	--
7	4.2	2.5	1.2	4.3	7.8	--	7	2.9	3.9	5.6	7.0	6.9	--
8	3.1	2.2	2.7	3.0	3.5	--	8	3.1	2.2	5.3	--	6.2	--
9	3.1	2.3	2.7	3.2	3.7	--	9	3.1	4.1	4.9	5.6	5.7	--
10	2.9	1.7	--	2.4	2.9	--	10	2.1	2.8	--	--	--	--
11	3.1	2.6	2.4	--	4.0	--	11	2.1	2.9	4.3	5.1	4.1	--
12	--	2.0	--	4.1	5.2	--	12	1.7	5.0	6.0	--	4.5	--
13	5.3	4.1	2.3	1.6	6.2	6.7	13	4.2	5.1	6.5	6.4	7.5	--
14	4.0	3.3	1.8	1.4	5.0	5.9	14	4.9	6.0	5.0	7.2	7.3	--
15	4.3	3.5	3.4	2.6	5.2	7.2	15	4.6	5.4	6.0	7.4	8.6	--
16	5.8	4.5	3.6	3.3	8.8	7.6	16	5.4	6.5	8.0	9.5	10.7	--
17	10.0	8.1	5.7	9.9	3.6	--	17	5.9	6.8	9.7	13.0	2.8	--
18	4.2	3.8	4.3	5.5	5.9	5.3	18	4.0	3.7	3.8	4.8	5.0	--
19	4.8	3.8	2.5	5.6	9.0	12.1	19	4.7	4.7	6.1	8.1	7.8	--
20	3.3	3.3	1.7	3.6	7.5	7.3	20	3.9	4.6	6.4	7.6	6.3	--
21	3.1	3.1	3.0	2.8	4.8	4.4	21	4.5	4.1	6.0	6.9	8.4	--
22	3.2	2.5	1.7	1.6	4.7	4.9	22	4.5	2.6	5.6	6.3	--	--
23	3.5	2.9	7.6	3.0	4.7	4.8	23	4.4	5.5	6.2	6.6	--	--
24	3.3	2.0	7.6	4.4	8.2	7.7	24	4.3	3.2	4.9	5.6	--	--
31	3.2	3.4	--	4.5	5.6	5.1	31	5.4	6.0	5.6	5.3	5.3	--
32	2.9	3.1	--	2.9	4.6	4.3	32	3.3	4.6	5.6	5.6	5.8	--
33	2.9	2.6	--	2.9	3.8	3.8	33	2.5	3.5	4.0	5.7	5.2	--
34	3.4	3.3	--	3.4	3.4	3.3	34	2.5	2.1	--	4.6	3.9	--
35	3.3	3.0	--	3.0	3.5	3.2	35	2.3	2.3	--	3.7	2.8	--
41	4.9	4.1	2.3	5.3	6.6	6.7	41	5.9	5.3	5.8	7.4	8.4	6.6
42	3.4	6.3	5.7	5.0	5.6	8.1	42	7.1	6.7	9.0	9.4	13.4	12.8
43	5.8	5.9	8.0	4.9	9.6	12.7	43	7.9	8.5	8.8	12.6	14.0	14.2
44	5.6	5.8	5.3	5.2	10.3	25.9	44	7.1	6.1	10.2	12.8	15.4	13.2
45	9.2	7.4	6.6	9.6	12.9	14.2	45	9.0	8.6	10.4	12.1	12.5	10.8
46	8.8	5.4	5.2	7.5	9.8	11.7	46	6.6	9.4	9.2	12.1	10.7	9.8
47	6.4	4.4	4.8	6.5	9.1	9.7	47	6.0	8.1	9.0	10.8	9.3	8.6
48	4.1	4.1	4.2	6.6	9.1	8.4	48	6.5	4.7	8.2	9.8	8.4	7.2

DATA FILE STRUCTURE AND STORAGE

Data collected during this study are available on request from the U.S. Geological Survey, California District, Sacramento, California. Copies of the data may be obtained by the use of interactive terminals, via modem communicating with the Prime computer, on magnetic tapes, or IBM compatible diskettes.

CONDUCTIVITY, TEMPERATURE, AND DEPTH (CTD) DATA

Each individual CTD processed data file has header information associated with arrays of water-property information in relation to depth (table 4). The header information includes the station identifier, date, time, latitude, longitude, and the agency collecting the data. Water-property information includes electrical conductivity, water temperature, pressure (which indicates depth), density, and salinity.

ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) DATA

Each individual ADCP data file has header information associated with the arrays of velocity information in relation to depth (table 5). Header information includes the date, time, station identifier, latitude, longitude, number of Doppler pings in the ensemble, earth-referenced vessel velocity, profiler and sounder depths, and vessel heading. Below the header information are arrays of depth, east-west ("u") velocity, north-south ("v") velocity, and a percentage good, which is an indication of confidence in the measurement.

CURRENT-METER DATA

Each individual current-meter data file has header information associated with time series of velocity, electrical conductivity, and temperature measurements. The data are structured in accordance with the National Oceanographic Data Center data format. Header information includes station location, current-meter type and serial number, and dates of collection. Arrays of observed time, current direction and speed, temperature, pressure, and electrical conductivity are given below the header.

Table 4.--Data file structure--Conductivity, temperature, and depth (CTD)

Parameter	Fortran format	Example
Station:	A10	1-1 (Circuit 1, station 1)
Date:	A10	26-Feb-1987
Time:	A10	09:18:16
Lat:	A9	37°49′10″
Long:	A9	122°25′59″
Agency:	A15	USGS RV *Rantz*

Parameter:

Cond Siemens/ meter	Temp Degrees Celsius	Pressure Decibar	Density Sigma-T	Salinity ppt

Fortran format:

2X, F7.5, 3X, F7.4, 6X, F4.2, 3X, F7.4, 3X, F7.4

Table 5.--Data file structure--Acoustic Doppler current profiler (ADCP)

Parameter	Fortran format	Example
Date:	A11	22-Oct-1987
Time:	A8	10:16:00
Station:	A10	SAAC101
Lat:	A9	37°49′10″
Long:	A9	122°29′59″
# of pings:	A8	19 pings
Earth referenced u velocity:	A12	GND u 4.882
Earth referenced v velocity:	A12	GND v 17.486
Profiler depth:	A20	Profiler depth 10.62
Sounder depth:	A20	Sounder depth 10.9
Vessel heading:	A22	Vessel heading 252.13

Parameter:

Depth meter	u vel centimeter/ second	v vel centimeter/ second	% good

Fortran format:

F3.1, 7X, F8.3, 7X, F8.3, 6X, F6.2

EXAMPLES OF DATA

SALINITY AND DOPPLER VELOCITY PROFILES

The salinity and velocity profiles characterized below were obtained at a middepth site, sampling station 5 on transect B eastward of the San Bruno shoal in approximately 10 m of water. Profiles from this site for each of the four cruises are used to show examples of data collected during the study (figs. 6-9). The following discussion is of a qualitative nature and is meant to provide the reader with an understanding of the range of salinities and velocities obtained during the study. The salinities presented below are accurate to 0.1 ‰ and the velocities are accurate to 2 cm/s.

The February 26 cruise was during a spring tide and was characterized by calm, clear conditions. The salinity structure remained relatively constant over the sampling period (fig. 6*A*). Salinity was 27.4 ‰ and was equal throughout the water column and had a slight depression of approximately 0.2 ‰ near the surface (1-m layer). There was minimal temporal variability between successive salinity profiles and minimal salinity stratification (less than 0.2 ‰ between the surface and the bottom).

The early morning (0745 hours) of February 26 was characterized by a strong southeasterly floodtide; velocities were in the range of 70 cm/s near the surface to 50 cm/s near the bottom of the water column (fig. 6*B*). The tide in midmorning (0918 hours) was still flooding, but the velocity had decreased to 50 cm/s near the surface and 30 cm/s near the bottom. By late morning (1117 hours) the tide had reversed, and flow was northwesterly; velocities were 18 cm/s near the surface and 16 cm/s near the bottom. The ebbtide velocity peaked in early afternoon (1316 hours); flow was northwesterly and velocities were in the range of 70 cm/s near the surface and 50 cm/s near the bottom. The ebbtide continued to decrease in strength during the afternoon. At midafternoon (1508 hours) the velocity was about 60 cm/s, and by late afternoon (1659 hours) it had decreased to 35 cm/s near the surface and 25 cm/s near the bottom. Two general observations are that the degree of vertical shear in the water column created by interaction with the bottom seems generally much more pronounced at higher velocities, and the current vectors in the vertical do not seem to rotate in a consistent direction, as would be expected from classical Ekman theory (Bowden, 1983).

The March 9 cruise was during a neap tide and was characterized by calm, partly cloudy conditions. The water column was weakly stratified in the early morning (0737, 0909 hours) and had salinities of 27.3 ‰ near the surface and 27.6 ‰ near the bottom (fig. 7*A*). This slight stratification had dissipated by late morning, and salinity in the water column remained equal over the remainder of the sampling period, ranging from 27.2 ‰ (1322 hours) to 27.5 ‰ (1719 hours).

The velocity structure in the early morning (0739 hours) of March 9 was near high slack tide, just beginning to ebb (fig. 7*B*). At midmorning (0910 hours), the ebb currents were moderate and had velocities of 35 cm/s near the surface and 25 cm/s near the bottom in a northwesterly direction. The ebb continued into the early afternoon (1120, 1323 hours). By mid-afternoon (1519 hours) the current reversed, weakly flooding in a southeasterly direction at 10 to 15 cm/s. At the end of sampling (1721 hours), the flood velocity had increased in strength to 40 cm/s near the surface.

The March 27 cruise was during a spring tide and was characterized by clear, relatively calm conditions in the morning, which gave way to.high winds in the afternoon. The salinity remained equal over the sampling period, ranging from 25.9 to 26.7 ‰ (fig. 8*A*). In the early morning (0728 hours) the salinity was 26.4 ‰, decreasing to 25.9 ‰ near high slack water in the late morning (1119 hours), and then increasing to 26.7 ‰ in the midafternoon. There was minimal salinity stratification (less than 0.1 ‰ between the surface and the bottom) in the water column.

The early morning (0730 hours) of March 27 was characterized by a strong southeasterly flood that had velocities of 80 cm/s near the surface and 60 cm/s near the bottom (fig. 8*B*). By midmorning the flood velocities had decreased to 50 cm/s at the surface and 30 cm/s at the bottom. In the late morning (1119 hours) the current had turned and a weak northwesterly ebb was beginning to develop that had velocities of 5 cm/s at the surface and 15 cm/s near the bottom. By early afternoon the ebb had increased in strength to 60 cm/s at the surface and 50 cm/s at the bottom. It is interesting to note that during this sampling day the salinity minimum occurred at high slack, which illustrates the fact that the tides are not synchronous with the currents, as South Bay flows are a combination of standing and progressive waves (Walters and others, 1985).

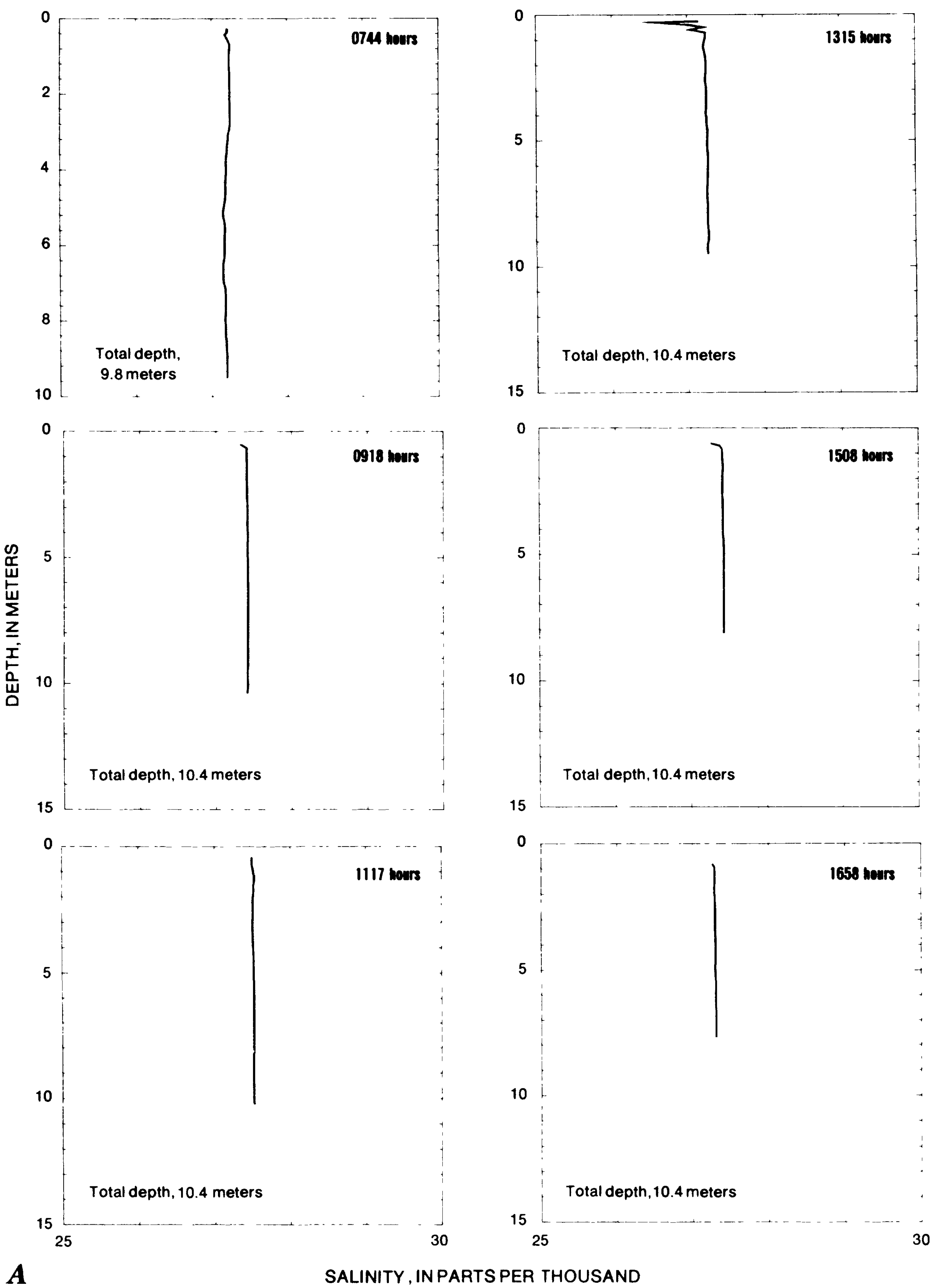

Figure 6. Profiles of (*A*) salinity and (*B*) velocity at sampling station 5 (see fig. 2 for location), February 26, 1987.

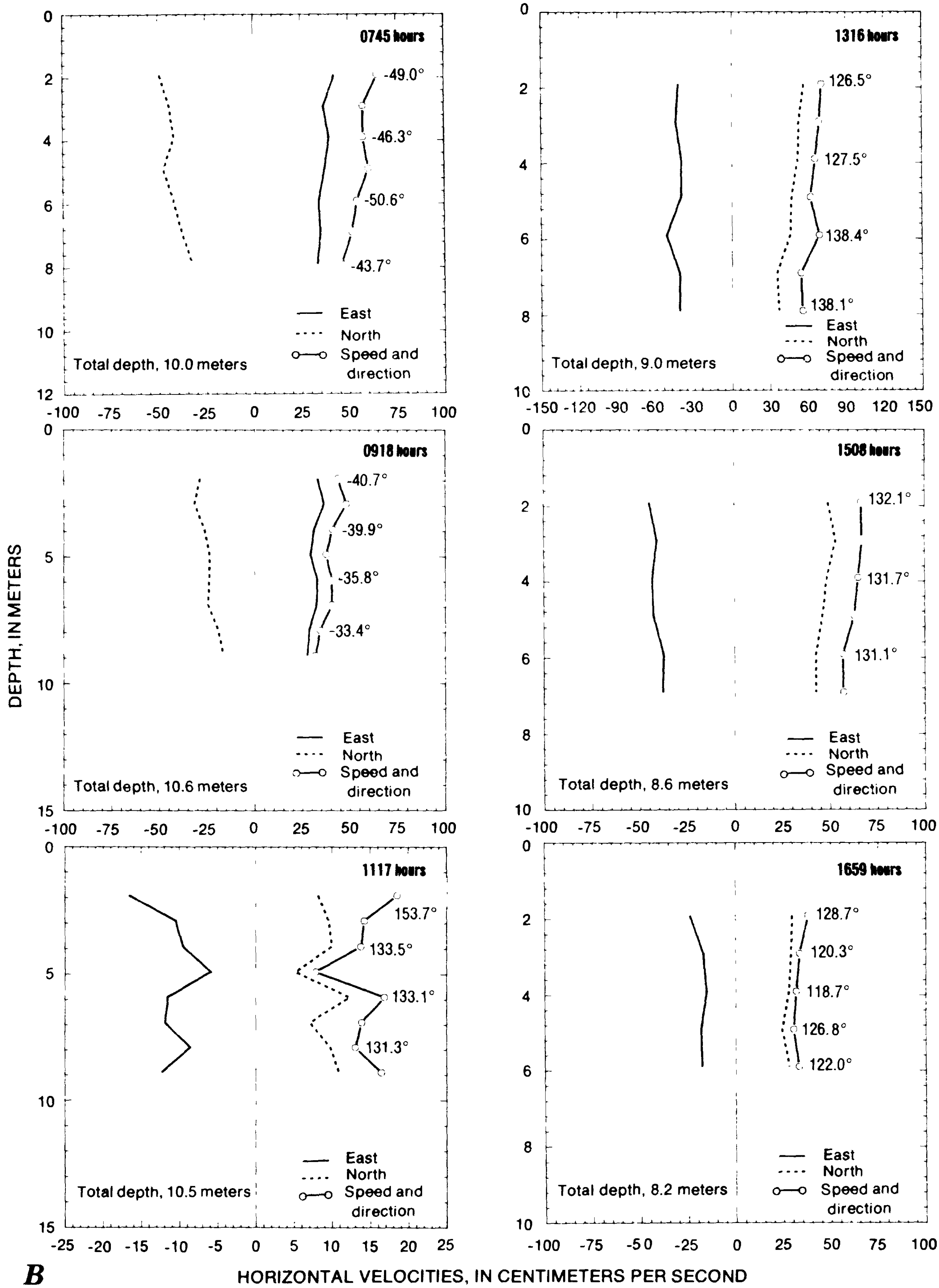

Figure 6. Continued.

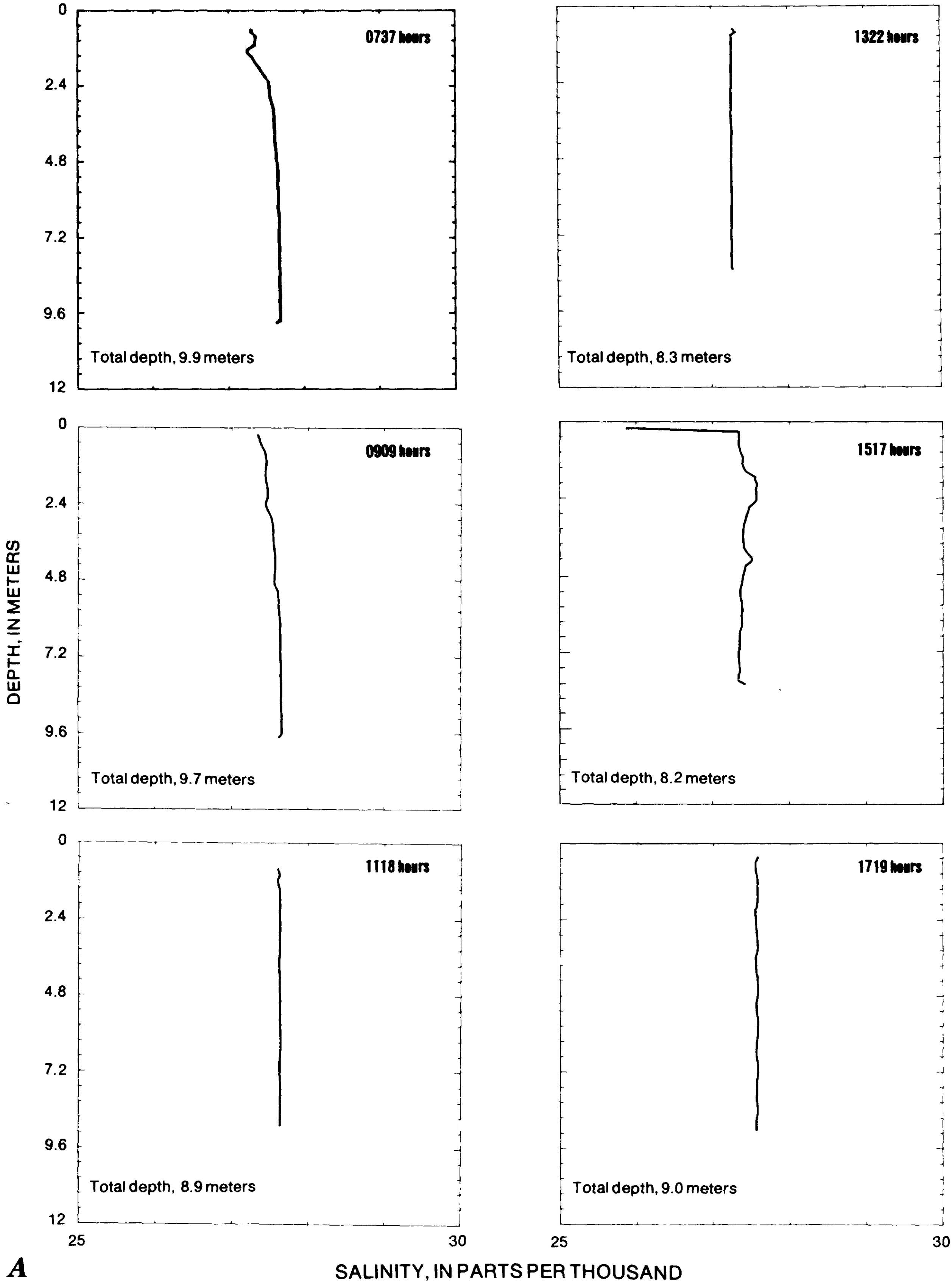

Figure 7. Profiles of (*A*) salinity and (*B*) velocity at sampling station 5 (see fig. 2 for location), March 9, 1987.

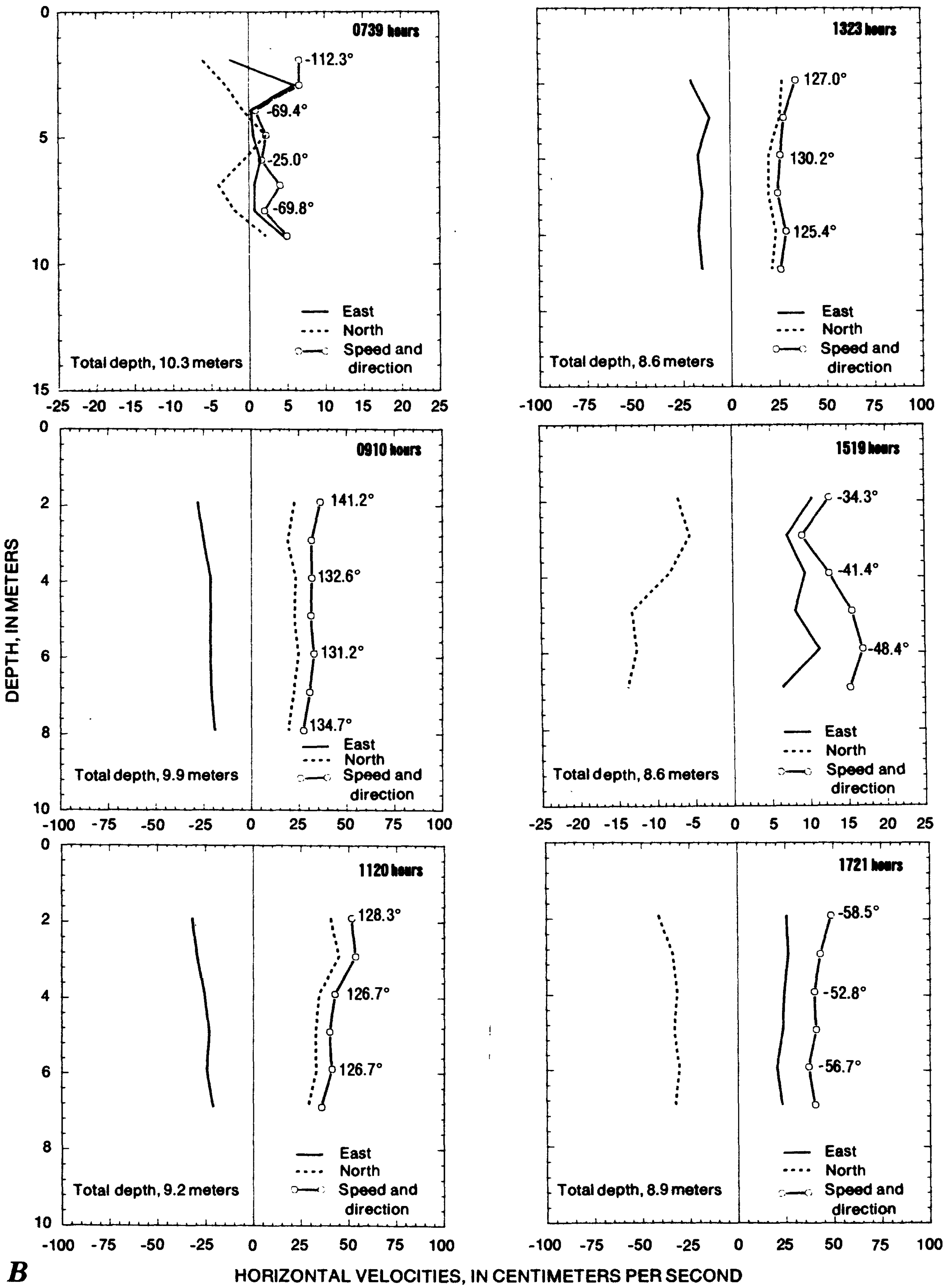

Figure 7. Continued.

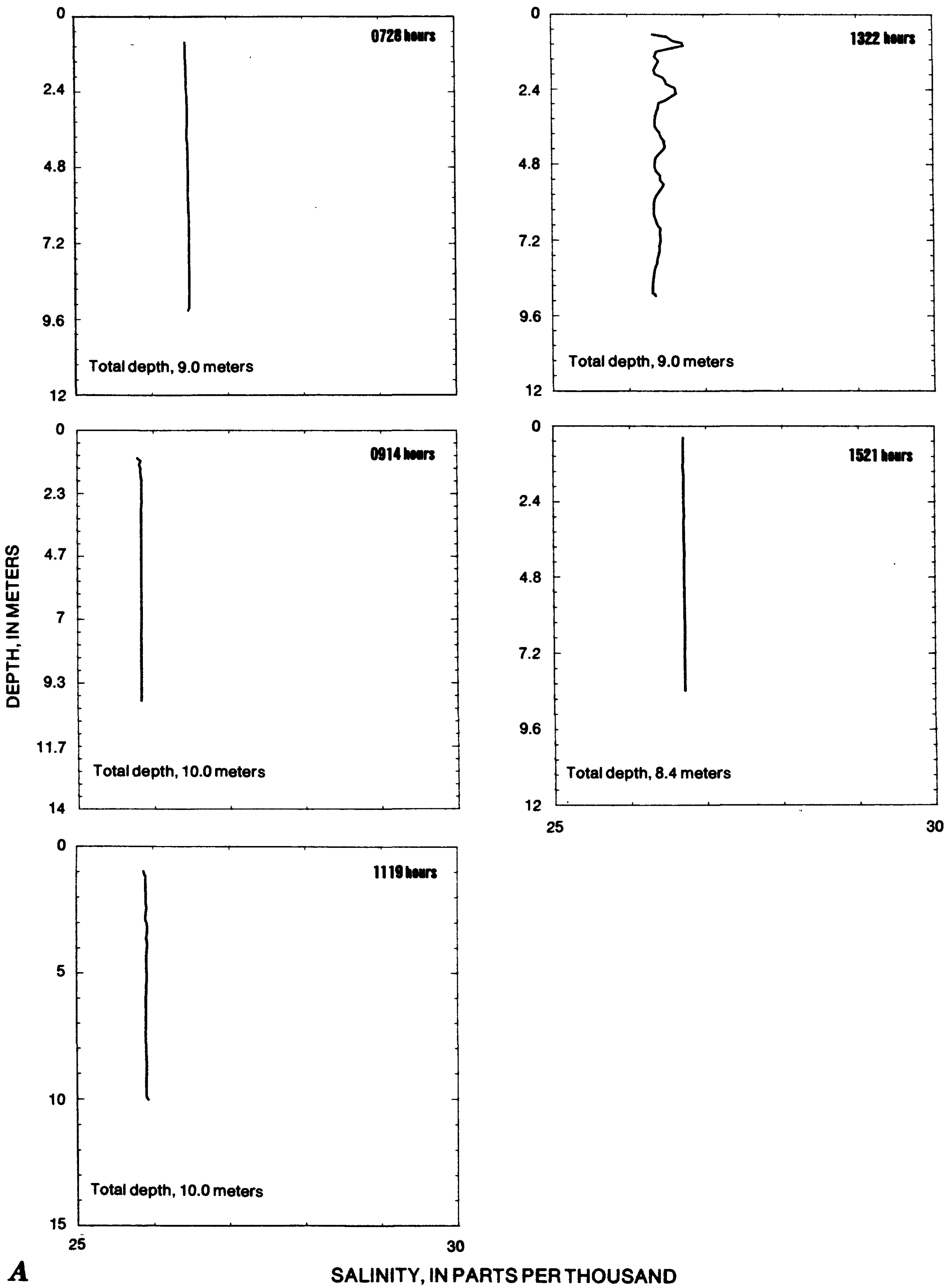

Figure 8. Profiles of (*A*) salinity and (*B*) velocity at sampling station 5 (see fig. 2 for location), March 27, 1987.

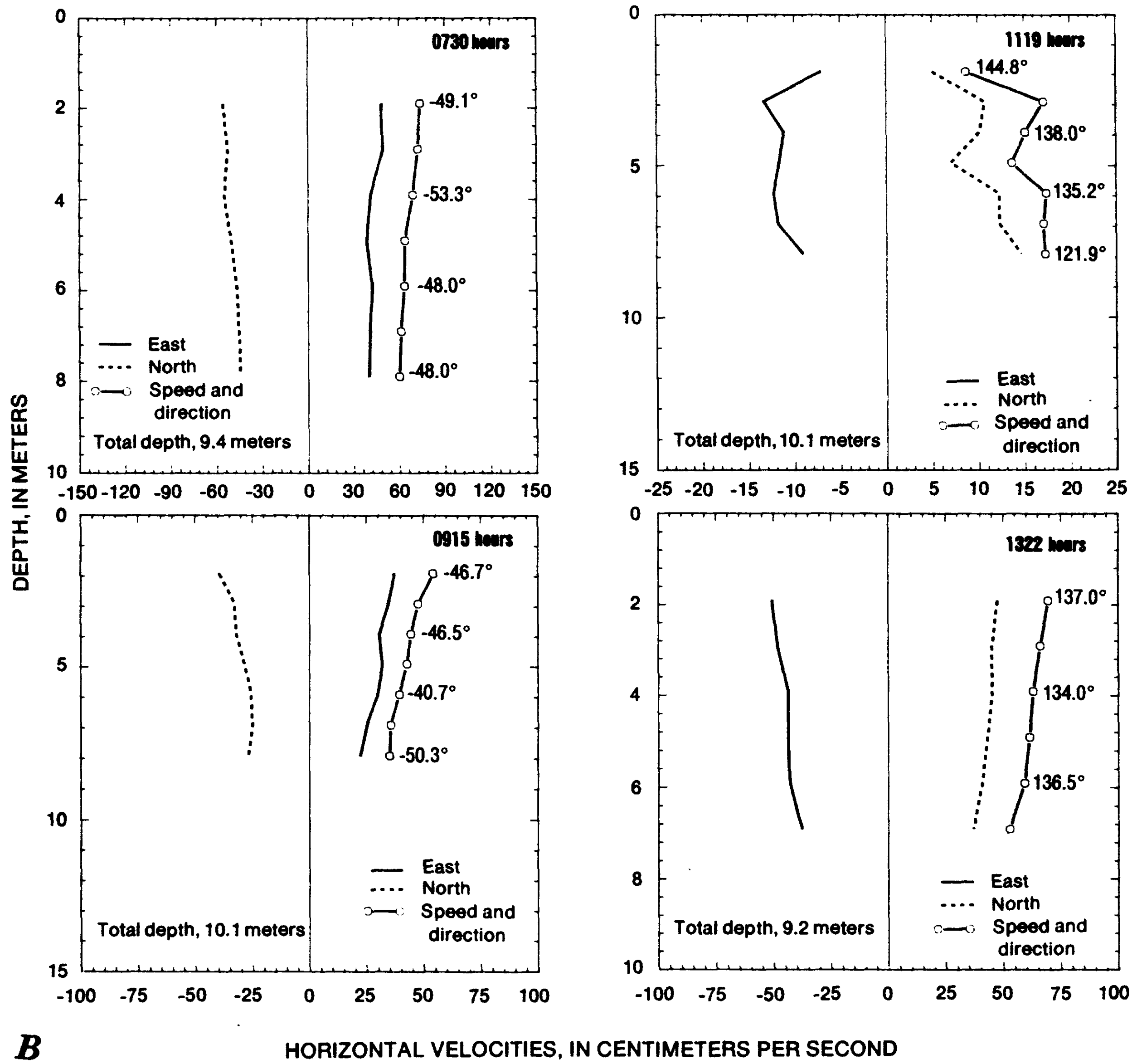

Figure 8. Continued.

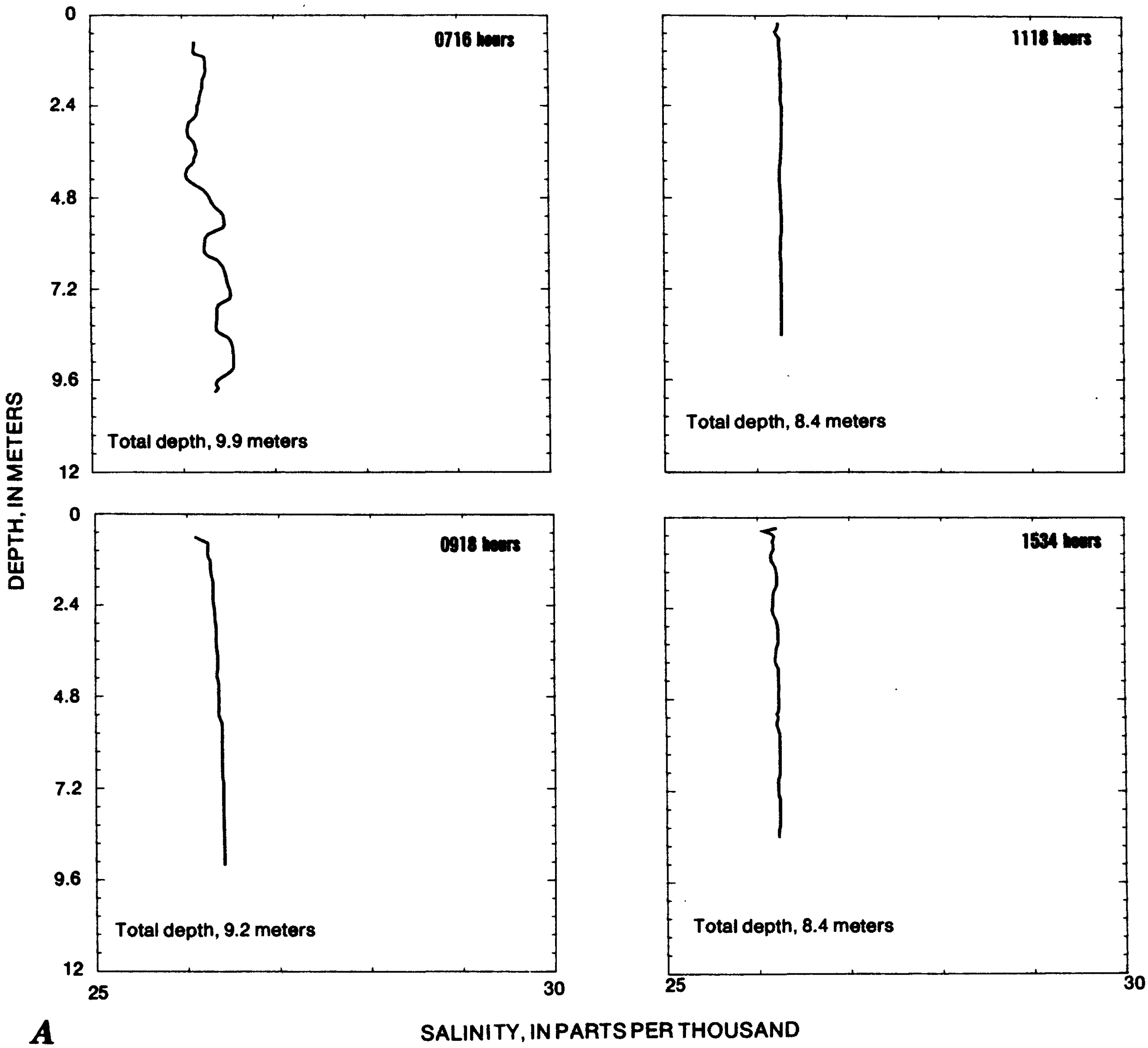

Figure 9. Profiles of (*A*) salinity and (*B*) velocity at sampling station 5 (see fig. 2 for location), April 7, 1987.

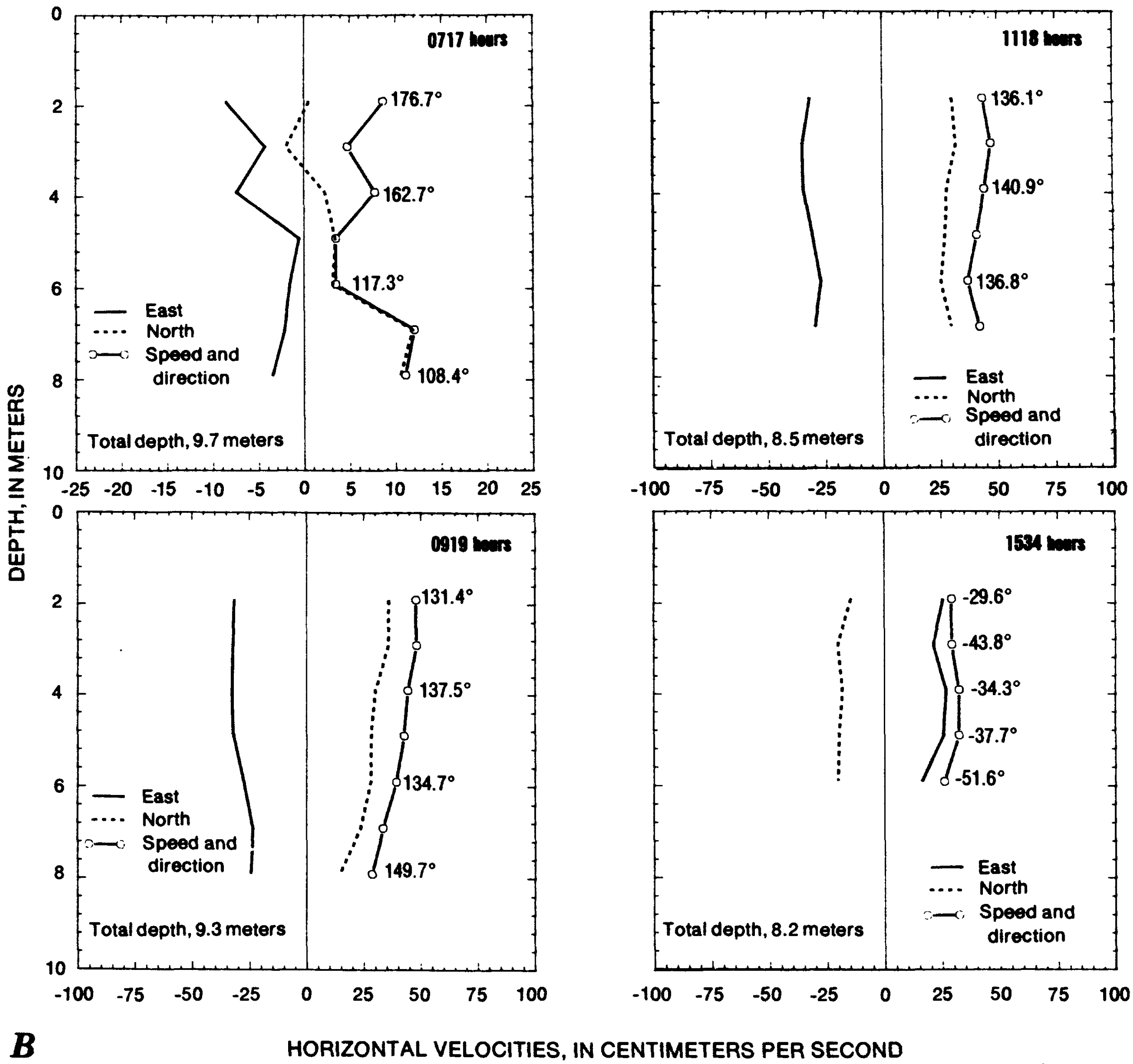

Figure 9. Continued.

The April 7 cruise was during a neap tide and was characterized by clear, relatively calm conditions in the morning. The salinity structure was characterized by a slight stratification (0.2 ‰ difference between the surface and the bottom) in the early morning (0719, 0918 hours), which quickly dissipated in the afternoon, leaving salinity throughout the water column equal to 26.2 ‰ (1534 hours) (fig. 9*A*). The mixing of the water column was probably influenced by the wind.

In the early morning (0716 hours) of April 7, the velocity was near slack (10 cm/s) at the beginning of a weak ebb (fig. 9*B*). By midmorning (0918 hours) the southeasterly ebb had increased in strength to velocities of 50 cm/s near the surface and 30 cm/s near the bottom. In the late morning (1118 hours) the ebb had decreased in strength to 35 cm/s. By midafternoon (1534 hours) the current had reversed and had flood velocities of 25 cm/s in a southwesterly direction.

CURRENT-METER VELOCITY, TEMPERATURE, AND SALINITY

The time-series plots of current speed and direction, temperature, and salinity (figs. 10-12) were obtained from four current meters deployed at three current meter stations (fig. 2) in a cross section perpendicular to the main shipping channel near San Bruno shoal, from February 25 to March 26 and from March 26 to April 29.

Due to a combination of mechanical problems and data loss from faulty CMOS cartridges, no data were recovered from station GS32 during the first deployment, and no data were recovered from the bottom meter at station GS27 during either deployment. The instrument accuracy is as follows: speed ±3.0 percent of full scale (233 cm/s); direction ±7.2°; temperature ±0.2 °C; and conductivity ±0.55 millisiemen per centimeter.

February 25-March 26

STATION GS27 (fig. 10*A*)--The meter was positioned at 1.2 m below mean lower low water (MLLW) in 8.5 m of water. It recorded speeds as high as 90 cm/s; the current direction varied between 160° (relative to true north) on floodtides to 340° on ebbtides. The temperature and salinity records remained relatively constant throughout the deployment. The average temperature was 12 °C varying by 1 °C, and the average salinity was 28.5 ‰ varying by 1 ‰.

STATION GS33 (fig. 11*A*)--The meter was positioned at 1.8 m below MLLW in 3.1 m of water. It recorded speeds as high as 50 cm/s; the current direction varied between 120° (relative to true north) on floodtides to 300° on ebbtides. The temperature record began at 11 °C and rose to as high as 15 °C. The salinity record remained relatively constant throughout the deployment, averaging 26.0 ‰ and varying by 1 ‰.

March 26-April 29

STATION GS27 (fig. 10*B*)--The meter was positioned at 1.2 m below MLLW in 8.5 m of water, and produced a partial record, from March 26 to April 6. On April 6 the current lodged a dead waterfowl in the meter's impeller, rendering the rest of the record useless. The meter recorded speeds as high as 85 cm/s, and the current direction varied between 160° (relative to true north) on floodtides to 340° on ebbtides. The temperature record began at 13 °C and increased to 17 °C by the end of the record. The salinity record remained relatively constant throughout the deployment, averaging 27.5 ‰ and varying by 2 ‰.

STATION GS32 (fig. 12)--The meter was positioned at 1.8 m below MLLW in 3.1 m of water. It recorded speeds as high as 45 cm/s, and the current direction varied between 150° (relative to true north) on floodtides to 330° on ebbtides. The spikes in the salinity record beginning on April 13 and continuing through the remainder of the record are due to heavy wave action, coupled with low tidal heights, which pumped air through the sensors, contaminating both the salinity and temperature records. The temperature record began at 13.5 °C and rose to as high as 18 °C. The salinity record remained nearly constant throughout the deployment, beginning at 26.0 ‰ and rising to 28.0 ‰.

STATION GS33 (fig. 11*B*)--The meter was positioned at 1.8 m below MLLW in 3.1 m of water. It recorded speeds as high as 50 cm/s, and the current direction varied between 120° (relative to true north) on floodtides to 300° on ebbtides. The spikes in the salinity record beginning on April 3 and continuing through the remainder of the record are due to heavy wave action, coupled with low tidal heights, which pumped air through the sensors, contaminating both the salinity and temperature records. The temperature record began at 13 °C and rose to as high as 19 °C. The salinity record remained nearly constant throughout the deployment, averaging 27.0 ‰ and varying by 1 ‰.

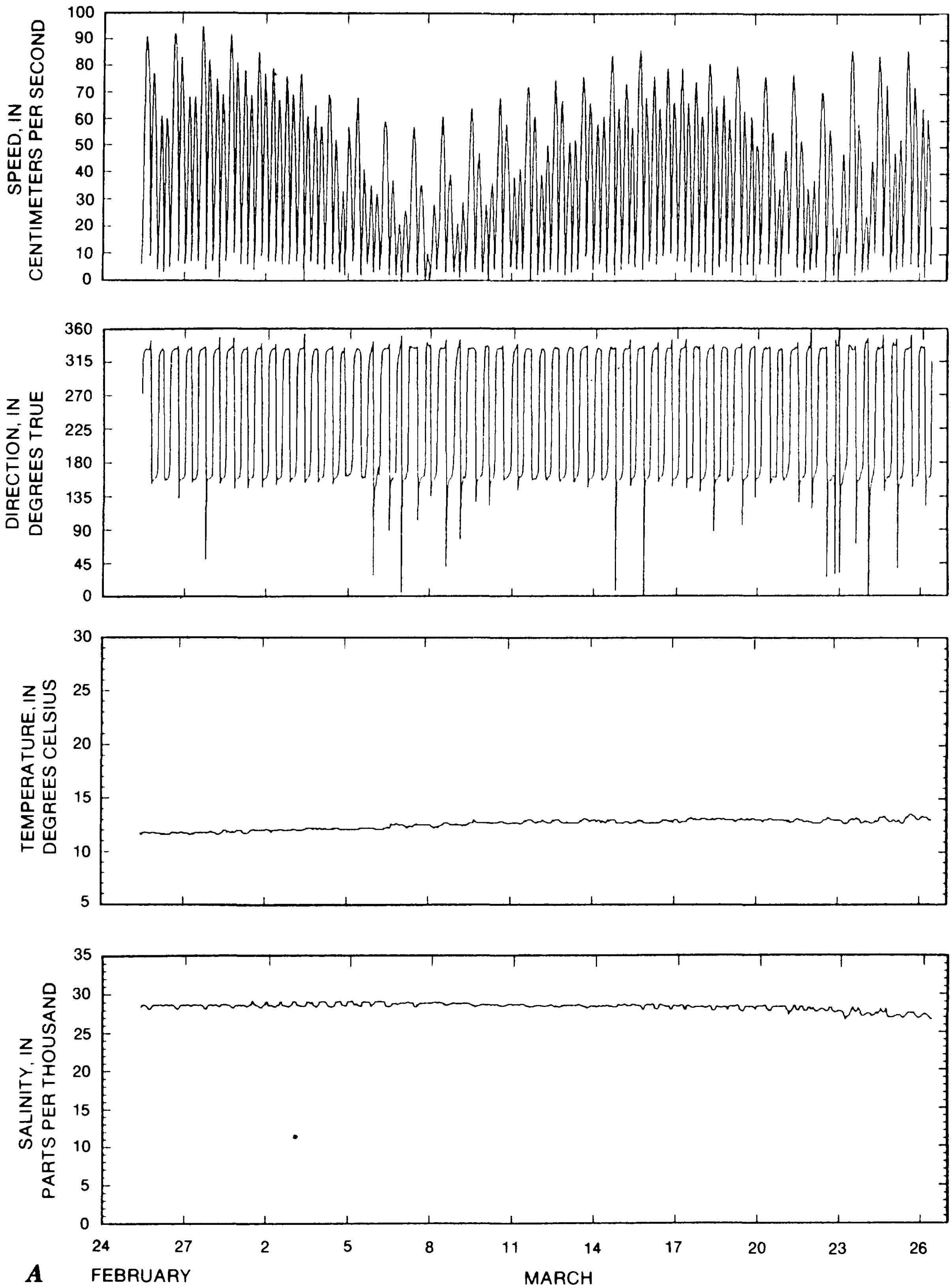

Figure 10. Time-series plots of current speed and direction, temperature, and salinity collected from current meter moored at station GS27 (see fig. 2 for location). *A*, February 25-March 26, 1987. *B*, March 26-April 29, 1987. Current meter positioned 1.2 meters below mean lower low water in 8.5 meters of water. Current-meter observations are 30-minute averages.

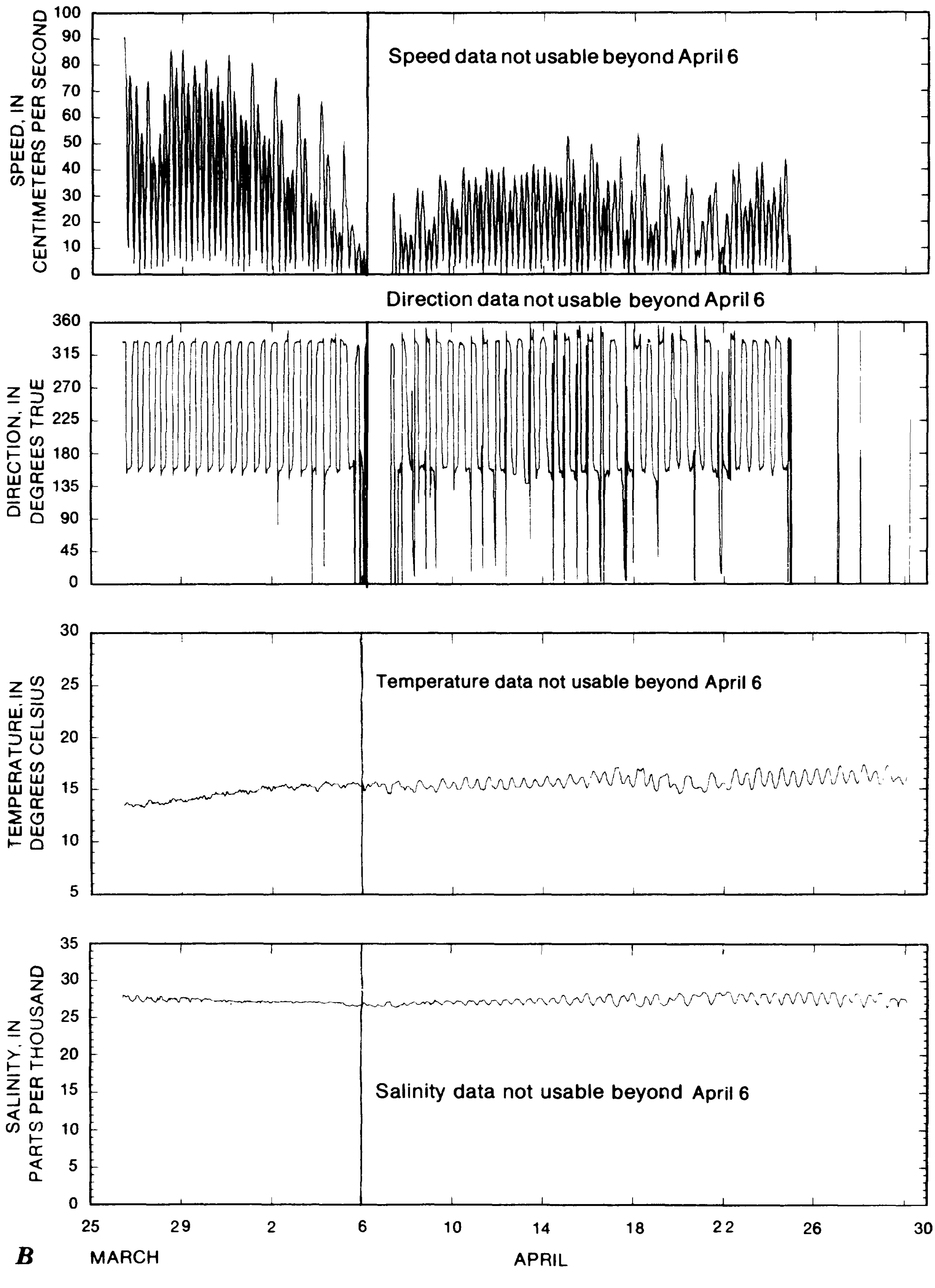

Figure 10. Continued.

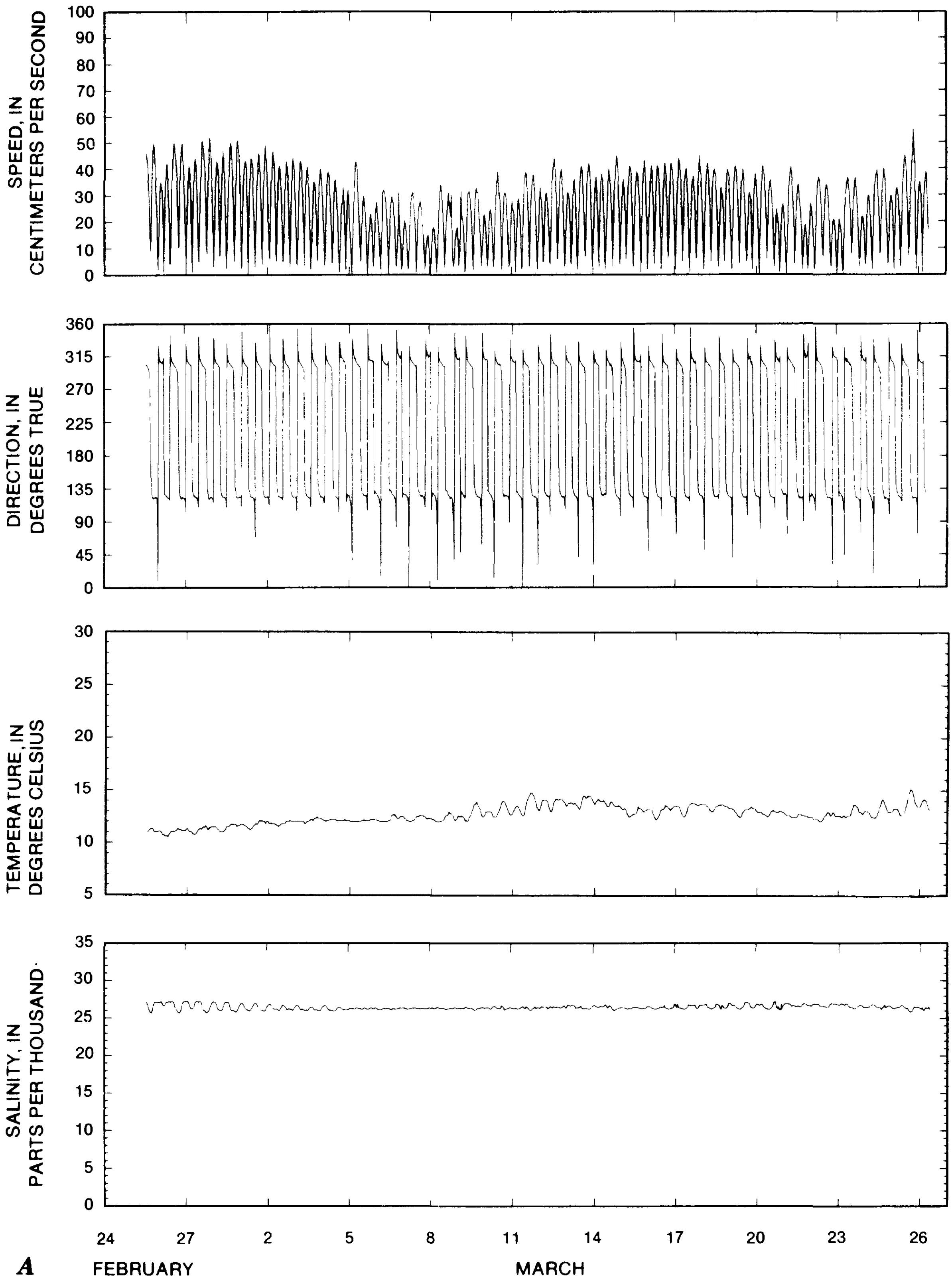

Figure 11. Time-series plots of current speed and direction, temperature, and salinity collected from current meter moored at station GS33 (see fig. 2 for location). *A*, February 25-March 26, 1987. *B*, March 26-April 29, 1987. Current meter positioned 1.8 meters below mean lower low water in 3.1 meters of water. Current-meter observations are 30-minute averages.

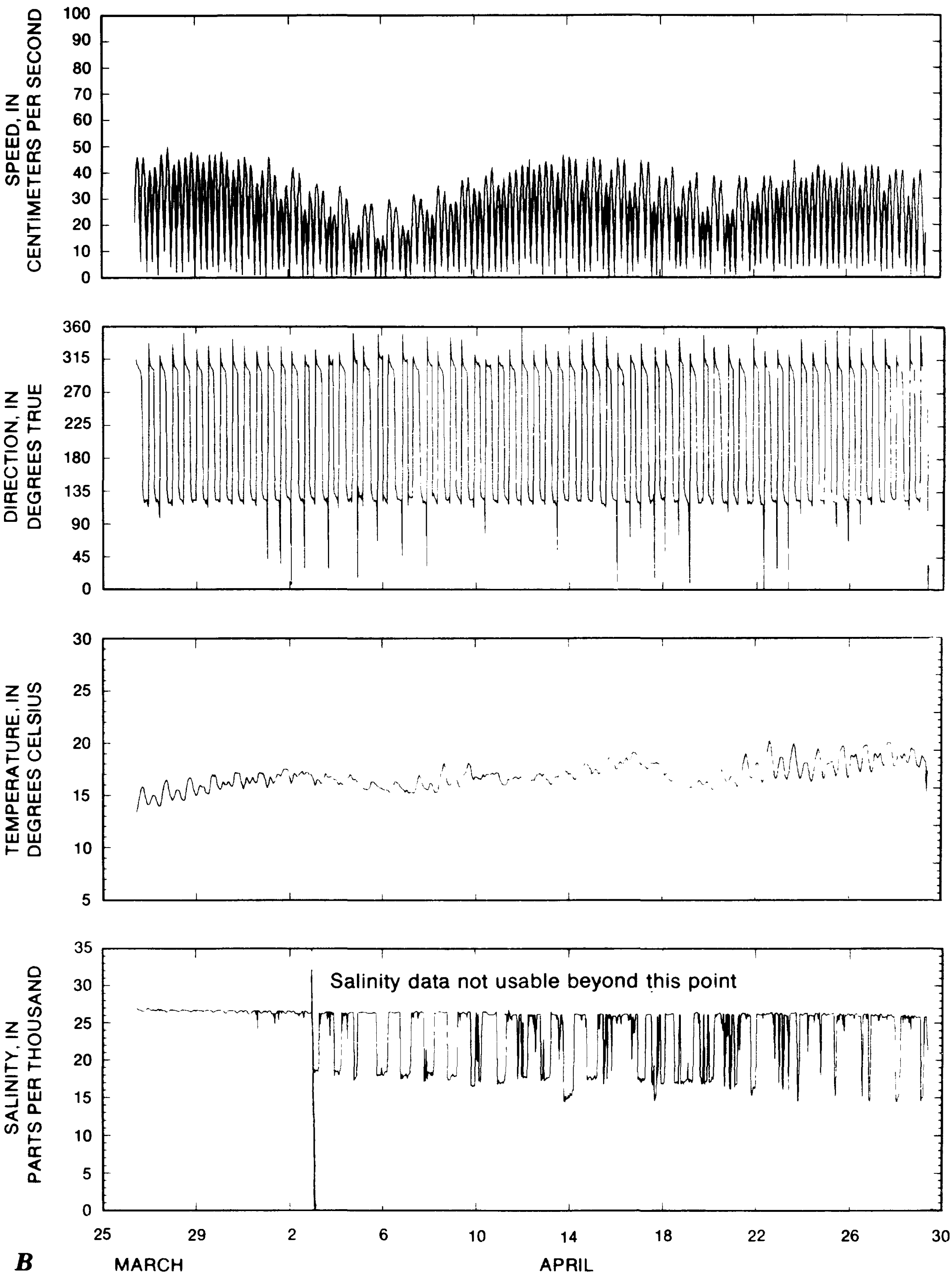

Figure 11. Continued.

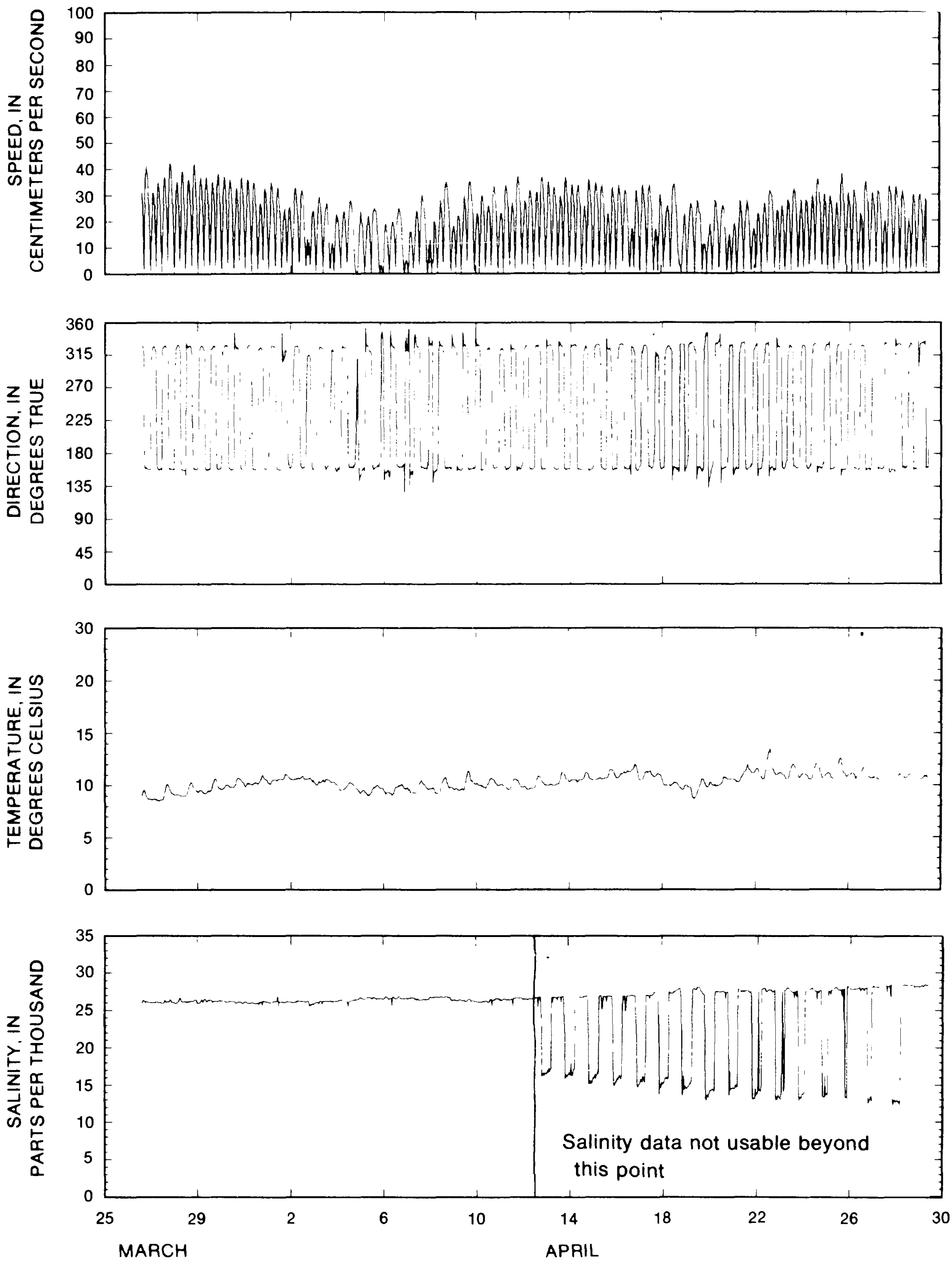

Figure 12. Time-series plots of current speed and direction, temperature, and salinity collected from current meter moored at station GS32 (see fig. 2 for location), March 26-April 29, 1987. Current meter positioned 1.8 meters below mean lower low water in 3.1 meters of water. Current-meter observations are 30-minute averages.

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