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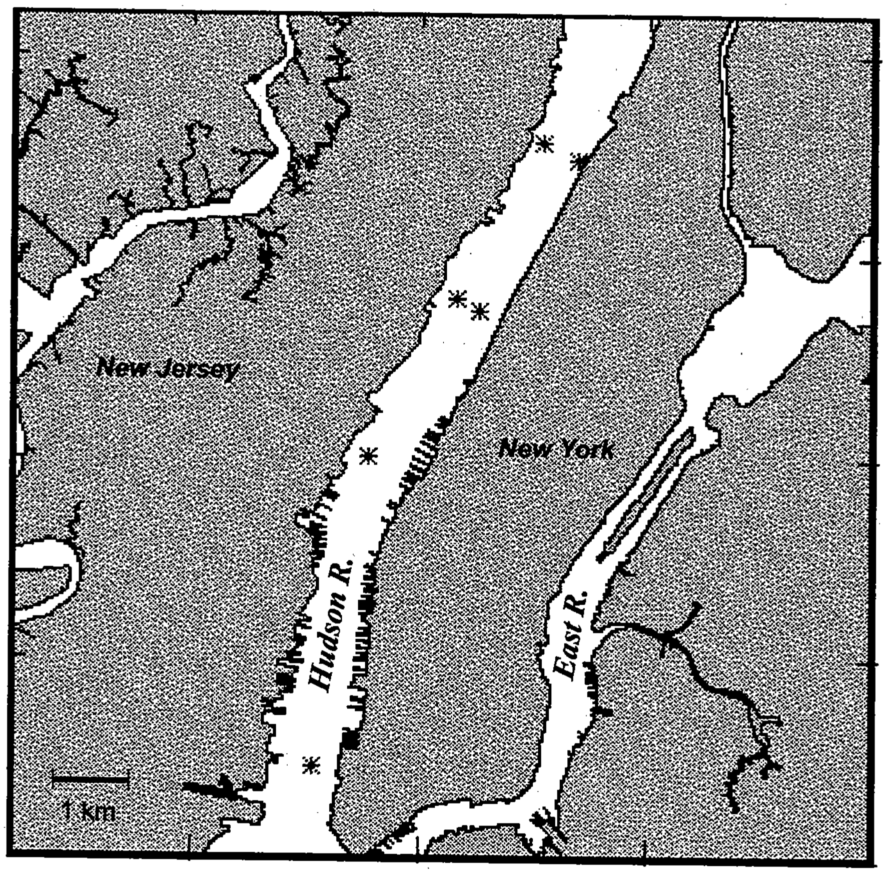
C.1

Woods Hole Oceanographic Institution



Stress, Salt Flux, and Dynamics of a Partially Mixed Estuary

by

J.J. Fredericks, John H. Trowbridge, W. Rockwell Geyer,
A.J. Williams 3rd, Melissa Bowen, Jonathan Woodruff

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Technical Report

Funding was provided by the National Science Foundation
under Grant OCE-94-15617 and The Hudson River Foundation.

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Approved for Distribution:

Dr. Timothy Stanton

Department of Applied Ocean Physics and Engineering

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SECTION I

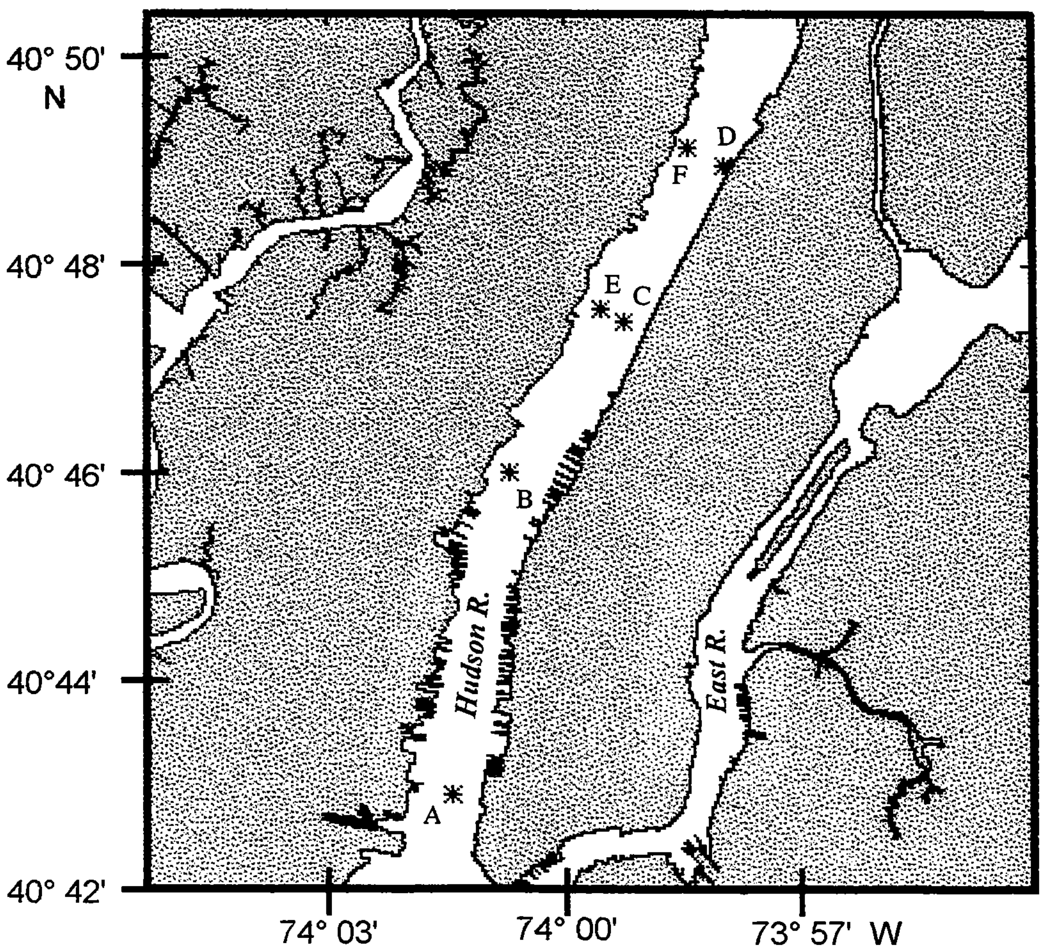
INTRODUCTION

A field study was performed in the lower Hudson River, a partially mixed estuary with a relatively simple geometry (Figure 1), between August and October of 1995. The objectives of the study were (1) to quantify and characterize the turbulent transport of momentum and salt, and (2) to relate the turbulent transport processes to the local and estuary-wide dynamics.

The measurement program consisted of fixed and shipboard components. At a central site, a moored array of temperature-conductivity sensors and optical backscatter sensors (OBS), a bottom-mounted acoustic Doppler current profiler (ADCP), and a bottom-mounted array of acoustic travel-time current sensors (BASS), temperature-conductivity sensors, and OBS sensors resolved the vertical structure of velocity, salinity and turbidity and the near-bottom turbulence structure. Moored and bottom-mounted velocity, temperature, conductivity and pressure sensors at five secondary sites quantified the spatial and temporal variability of velocity, salinity and bottom pressure. Shipboard measurements with an ADCP and a conductivity-temperature-depth (CTD) profiler, accompanied by an OBS sensor, resolved the spatial structure and tidal variability of velocity, salinity and turbidity along several cross-channel and along-channel transects.

This report describes the measurements in detail. Section II describes the instrumentation, Section III describes the deployment and sampling schemes, Section IV describes the data processing, and Section V is a summary of plots of selected data. Section VI documents the data files and Sections VII and VIII give acknowledgments and references.

Figure 1.



SECTION II

INSTRUMENTATION

A. OVERVIEW

This section describes instrumentation developed for the experiment: a quadrapod, six 1-meter tripods, three moorings and the meteorological station, as well as the shipboard data collection system. The tripods and moorings are named A through F, which relate to the deployment sites, as described in Section III and shown in Figure 1.

Table 1. QUADRAPOD, TRIPOD & MOORING INSTRUMENTATION

Temperature (T), Conductivity (C), Pressure (P), Velocity (V), OBS (O)

Inst ID: Site-Type	Height Above Bottom (mab)	Observed Property T	C	P	V	O	Instrument (Model Number)
A-tripod	0.9	T	C	P			Seagauge/26-03 (SG46)
B-tripod	0.9	T	C	P			Seagauge/26-03 (SG41)
C-mooring	depth-2.7	T	C	P	V		S4 "p" (04670927)
	depth-4.3	T	C			O	Seacat (SBE 16-04)/C-1 (SC70) (OBS608)
	depth-6.3	T	C			O	Seacat (SBE 16-04)/C-2 (SC71) (OBS611)
	depth-8.3	T	C			O	Seacat (SBE 16-04)/C-3 (SC73) (OBS420)
	depth-10.3	T	C			O	Seacat (SBE 16-04)/C-4 (SC72) (OBS424)
	depth-12.3	T	C	P			Seacat (SBE 16-04)/C-5 (SC884)
ADCP-tripod	0.9				V		ADCP (SN 0387)
		T	C	P			Seagauge/26-03 (SG45)(PS8202)
BASS-quadrapod	0.3		C		V	O	Seabird-1 (041425) / BASS-1 / OBS-1
		T					Seabird-2 (031718)
	0.6		C		V	O	Seabird-3 (041482*) / BASS-2 / OBS-2
	1.2		C		V	O	Seabird-4 (041481) / BASS-3 / OBS-3
		T					Seabird-5 (031719)
	1.6			P			ParoScientific (59119)
	2.1		C		V	O	Seabird-6 (041462*) / BASS-4 / OBS-4
	2.9	T					Seabird-7 (031720)
			C		V	O	Seabird-8 (648) / BASS-5 / OBS-5
D-tripod	0.9	T	C	P			Seagauge/26-03 (SG49)
	1.1				V		S4 (04911003)
E-mooring	depth-1.0	T	C			O	Seacat (SBE 16-04) (SC68) (OBS409)
E-tripod	0.9	T	C			O	Seacat (SBE 16-04) (SC883) (OBS410)
	1.1				V		S4 (05191143)
F-mooring	depth-1.0	T	C			O	Seacat (SBE 16-04) (SC882) (OBS423)
F-tripod	0.9	T	C	P			Seacat (SBE 16-04) (SC885)
	1.1				V		S4 (18291515)

* Conductivity cells 041462 and 041482 labels had been switched before the first deployment. The labeling was corrected by SeaBird Electronics during the September(1995) calibrations and are shown correctly above.

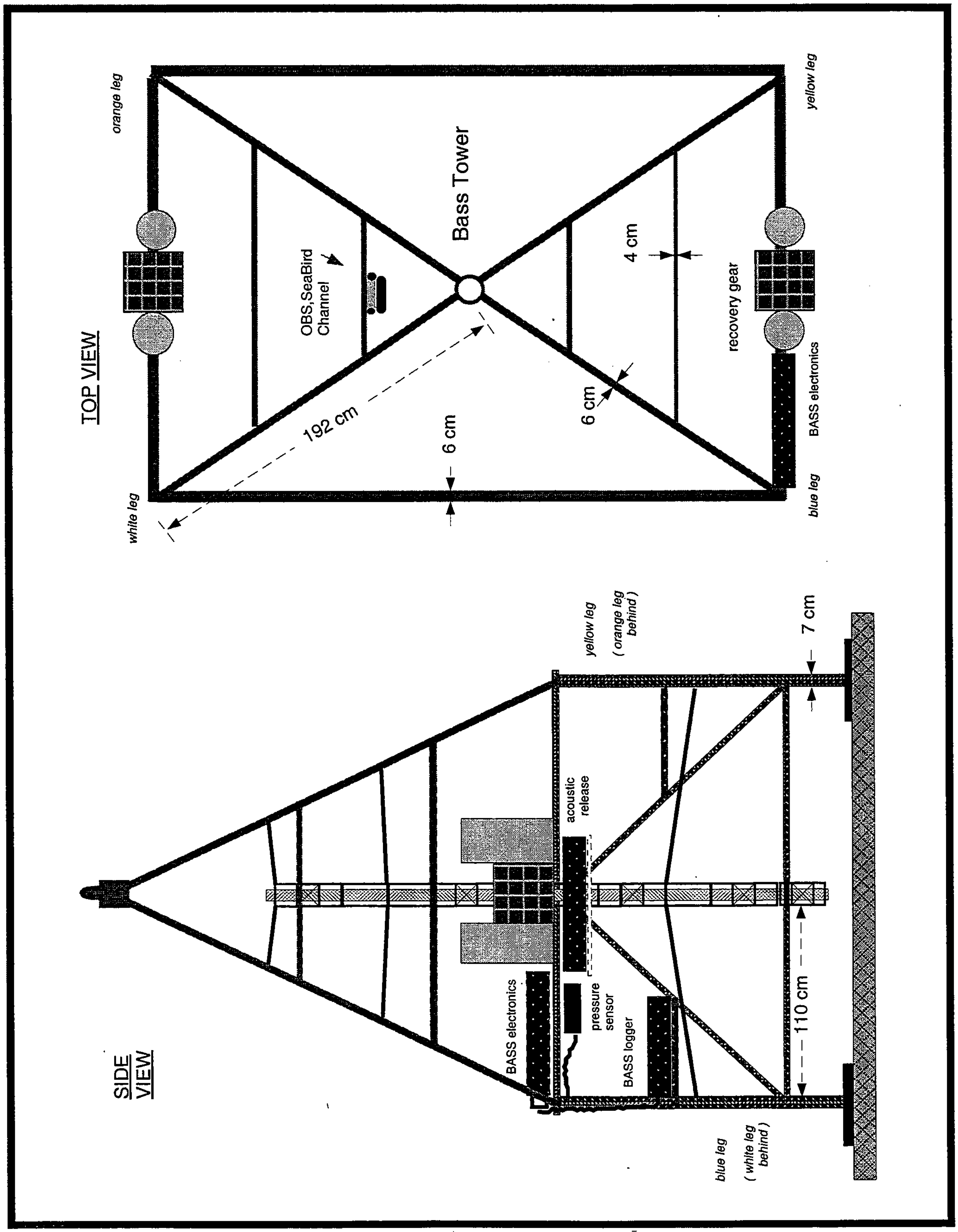


Figure 2a. Side and Top View of Quadrapod

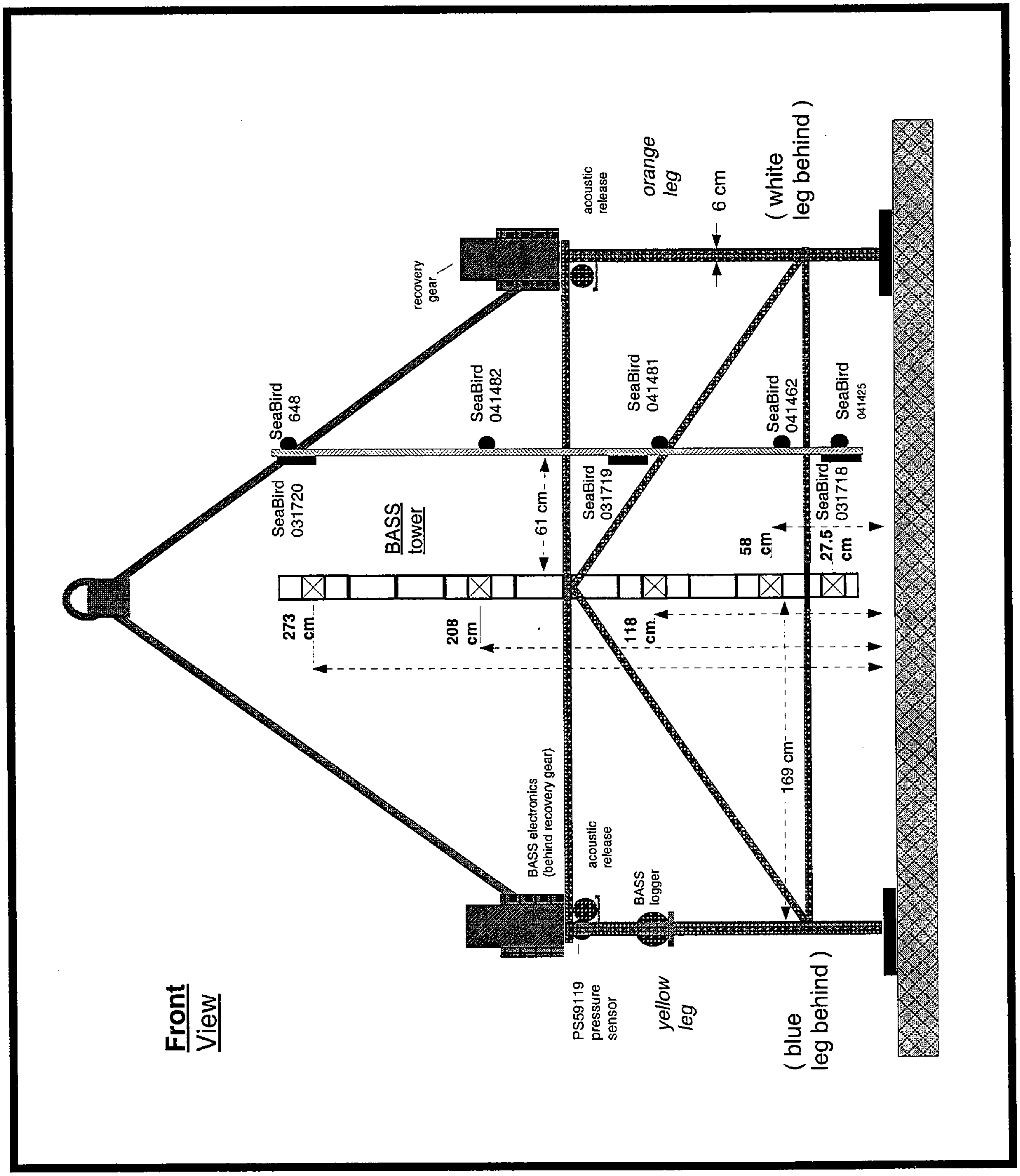


Figure 2b. Front View of Quadrapod

B. QUADRAPOD

A quadrapod was constructed to support five BASS acoustic travel-time velocity sensors (Williams et al., 1987) in a vertical column. The structure also supported five Seabird[1] conductivity sensors, three Seabird temperature sensors, five D & A[2] optical backscatter sensors (OBS), a Digiquartz ParoScientific[3] pressure sensor, a compass and a tiltmeter. (See Table 1 and Figure 2.)

BASS sensors measure differential travel-time of acoustic pulses, along four axes, to compute three dimensional velocity in a 15-cm sample volume. Absolute travel-time was also stored for Path C of each sensor to determine sound speed (Trivett 1991), which is related to salinity, temperature and depth (MacKenzie 1981). High noise levels in the absolute travel-time board prohibit use of the travel time data during the HUDMIX experiment, but the measurements provided an opportunity to resolve critical issues for future development of travel time instrumentation.

The conductivity cells and OBSs were arranged on a channel 0.6 meters away from the BASS tower at the same heights as the BASS sensors and temperature sensors were placed on the same channel at the bottom, middle and top heights. The pressure sensor was approximately 1.7 meters away from the BASS tower, at 1.56 meters above bottom. Counters were used to sample these properties simultaneously (Williams 1995). Pressure cases containing batteries, sensor electronics and data acquisition systems were mounted well away from the sensing volumes.

C. TRIPODS & MOORINGS

Each tripod was equipped with either a Seabird Electronics Seagauge (SBE 26-03) or Seacat (SBE 16-04) sensor to record salinity, temperature and conductivity. Each Seacat had one additional data acquisition port, which was used to accommodate either a strain-gauge pressure sensor or an OBS. See Figure 3 and Table 1 for specific details. A Self-Contained Acoustic Doppler Current Profiler (ADCP), manufactured by RD Instruments,[4] was placed on a tripod to observe horizontal velocity at 1 meter intervals from 1.5 to 15.5 meters above the sensor. InterOcean Systems Model[5] S4 current meters were placed on top of three tripods (D, E and F) to provide horizontal velocity at 1 meter above bottom.

Two tripods (E and F) were equipped with adjacent moorings (Figure 3) to measure conductivity, temperature and optical backscatter 1 meter below the surface.

As seen in Figure 4, the central mooring, or C-mooring, was equipped to observe salinity, temperature and conductivity profiles at 4.3, 6.3, 8.3 10.3 and 12.3 meters below the surface. At 2.7 meters depth, an S4 current meter was equipped to measure conductivity, temperature and pressure, as well as horizontal velocity. OBS cells were mounted to provide estimates of turbidity from depths of 4.3 to 10.3 meters. The Seacat at the bottom of the C-mooring (12.3 meters deep) was equipped with a strain-gauge pressure sensor.

[1] Seabird Electronics, Inc., Bellevue, WA 98005

[2] D&A Instrument Company, Port Townsend, WA

[3] ParoScientific, Redmond, WA 98052

[4] RD Instruments, San Diego, CA 92131

[5] InterOcean Systems, Inc., San Diego, CA 92123-1799

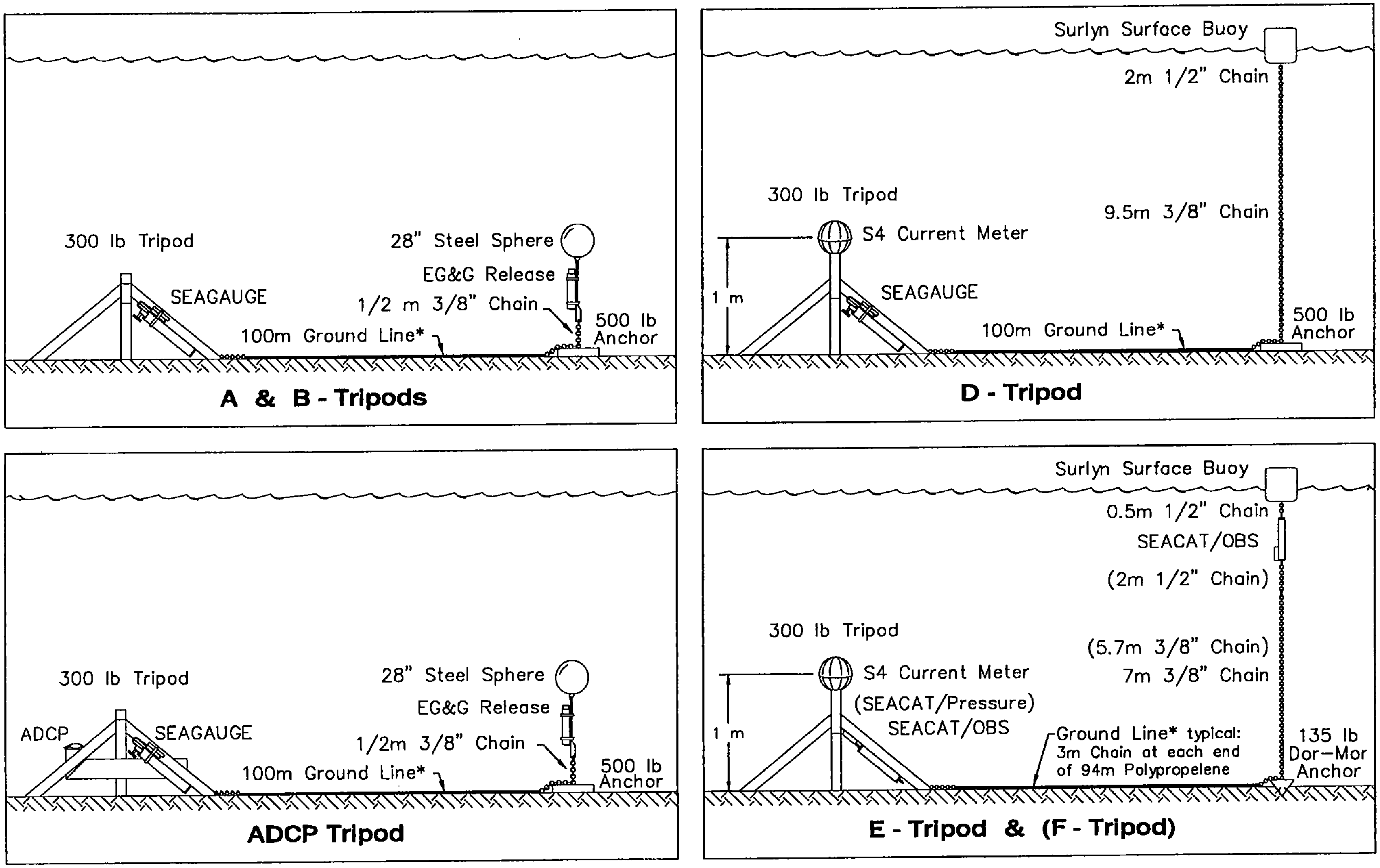


Figure 3. Schematic of Tripods & Moorings (not to scale)

NOTE: The F-Tripod is similar to the E-Tripod. The differences in the F-Tripod are noted in parenthesis.

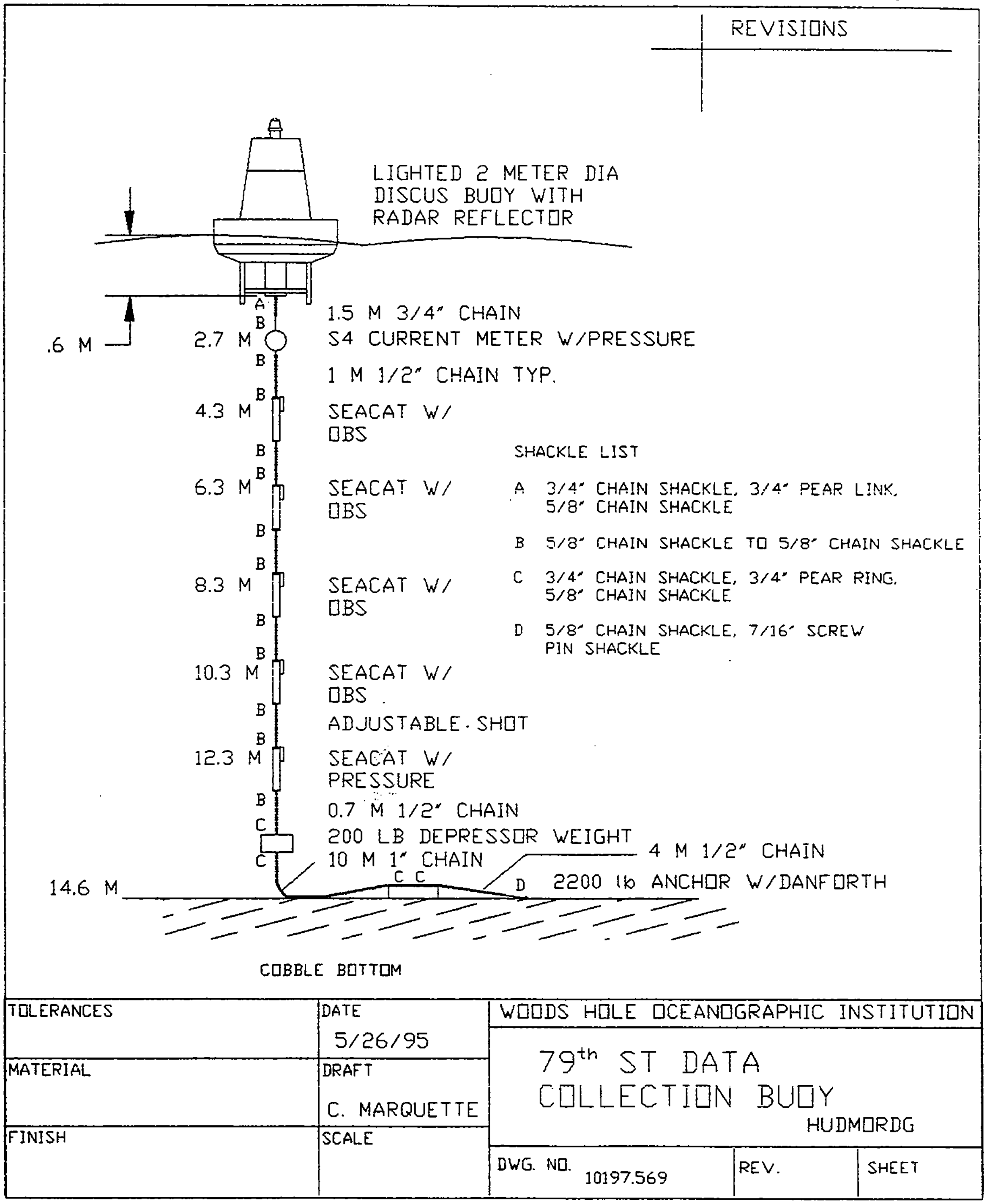


Figure 4. Central Mooring Schematic

NOTE: The S4 current meter was equipped with temperature and conductivity sensors.

D. SHIPBOARD INSTRUMENTATION

The shipboard measurements were performed from the 24' R/V Mytilus (Woods Hole Oceanographic Institution). Instrumentation included:

- an Ocean Sensors[6] CTD profiler (OS200) equipped with an optical backscatterance sensor (D&A Instruments) to measure temperature, salinity, pressure and suspended sediment concentration;
- a 1.2 mHz narrow-band Acoustic Doppler Current Profiler (ADCP, RD Instruments), providing vertical profiles of velocity beneath the vessel;
- a holey-sock drogue, 1-m diameter and 2-m in length, centered at 3.5 meters depth for tracking subsurface currents;
- a Klien (Model 595) sidescan sonar operating at 100 and 500 kHz for recording images of bottom slope variation.

E. METEOROLOGICAL INSTRUMENTATION

Wind speed and direction, air temperature, relative humidity, and atmospheric pressure were collected and processed using a Coastal Environmental Systems [7] Weatherpak-2000 meteorological package.

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[6] Ocean Sensors, San Diego, CA 92121

[7] Coastal Environmental Systems, Seattle, WA 98104

SECTION III

DEPLOYMENTS &

SAMPLING SCHEMES

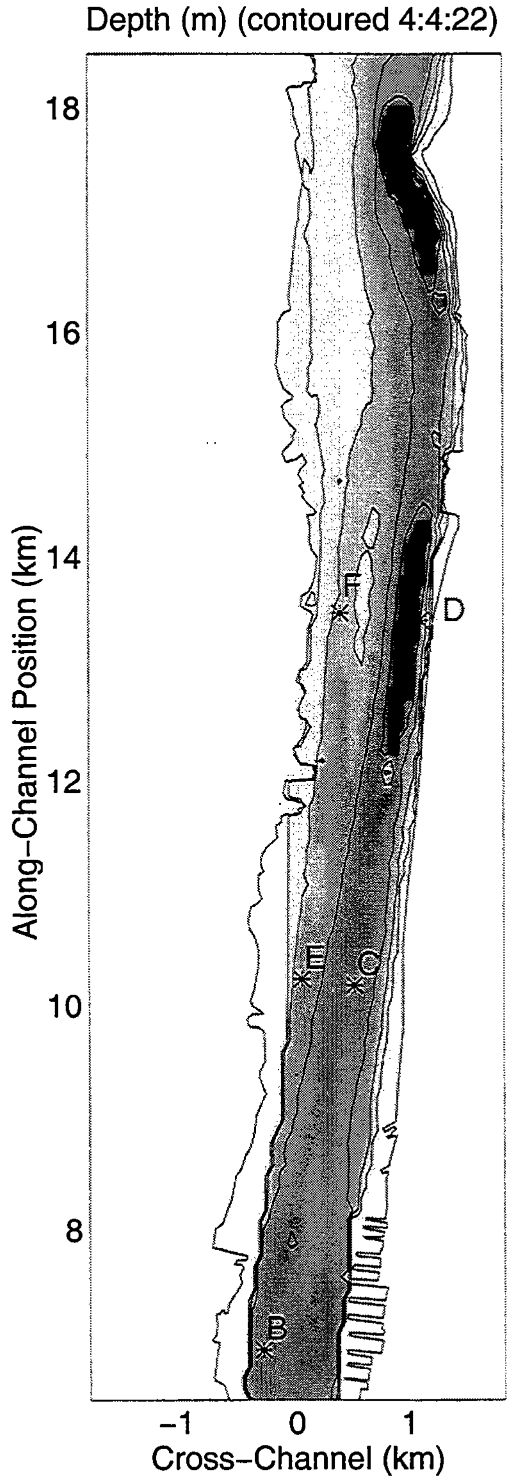

Figure 5. USGS NOS Bathymetry Survey (1934)

A. OVERVIEW

The deployment sites are shown in Figure 5 with the 1934 NOS bathymetry contours. Site A is not shown on this figure and is 3 km seaward of B, as shown in Figure 1. The six tripods and three moorings were onsite from mid-August through the end of October. (See Table 2.) The BASS quadrapod was deployed for two two-week periods, one at the beginning and the other at the end of the study, each spanning one spring-neap tidal cycle.

The C-mooring and tripods A, B and D were deployed in the deepest part of the channel, while Tripods E and F, along with their respective moorings, were deployed on a shelf along the west side of the channel. The BASS quadrapod and the ADCP-Tripod were deployed cross-channel from the central mooring site (Figure 6).

Shipboard CTD surveys were conducted at mooring locations, as well as on along-channel and cross-channel transects, throughout each of the BASS deployment periods. (See Table 3.) Velocity data supplemented the CTD data during transverse and turbidity maximum surveys.

Table 2. SUMMARY OF DEPLOYMENTS (ordered by time of deployment)

Instrument ID	Time In/Out (EDT)	Location Degrees Minutes
C-mooring	8/15/95 17:30 10/26/95 13:10	40° 47.47' N 73° 59.24' W
E-tripod & E-mooring	8/15/95 18:32 10/26/95 9:50	40° 47.92' 73° 59.52'
F-tripod & F-mooring	8/15/95 19:18 10/26/95 10:45	40° 49.20' 73° 58.36'
ADCP-tripod	8/16/95 11:39 10/26/95 09:00	40° 47.49' 73° 59.33'
D-tripod	8/16/95 12:22 10/26/95 12:25	40° 48.96' 73° 57.98'
B-tripod	8/16/95 12:40 10/26/95 08:30	40° 45.97' 74° 00.57'
A-tripod	8/16/95 14:05 10/26/95 07:50	40° 42.92' 74° 01.32'
BASS-quadrapod	8/16/95 16:58 8/30/95 8:53	40° 47.46' 73° 59.19'
Met	8/16/95 17:25 10/26/95 17:10	40° 47.35' 73° 59.02'
BASS-quadrapod	10/17/95 12:05 10/26/95 13:30	40° 47.48' 73° 59.20'

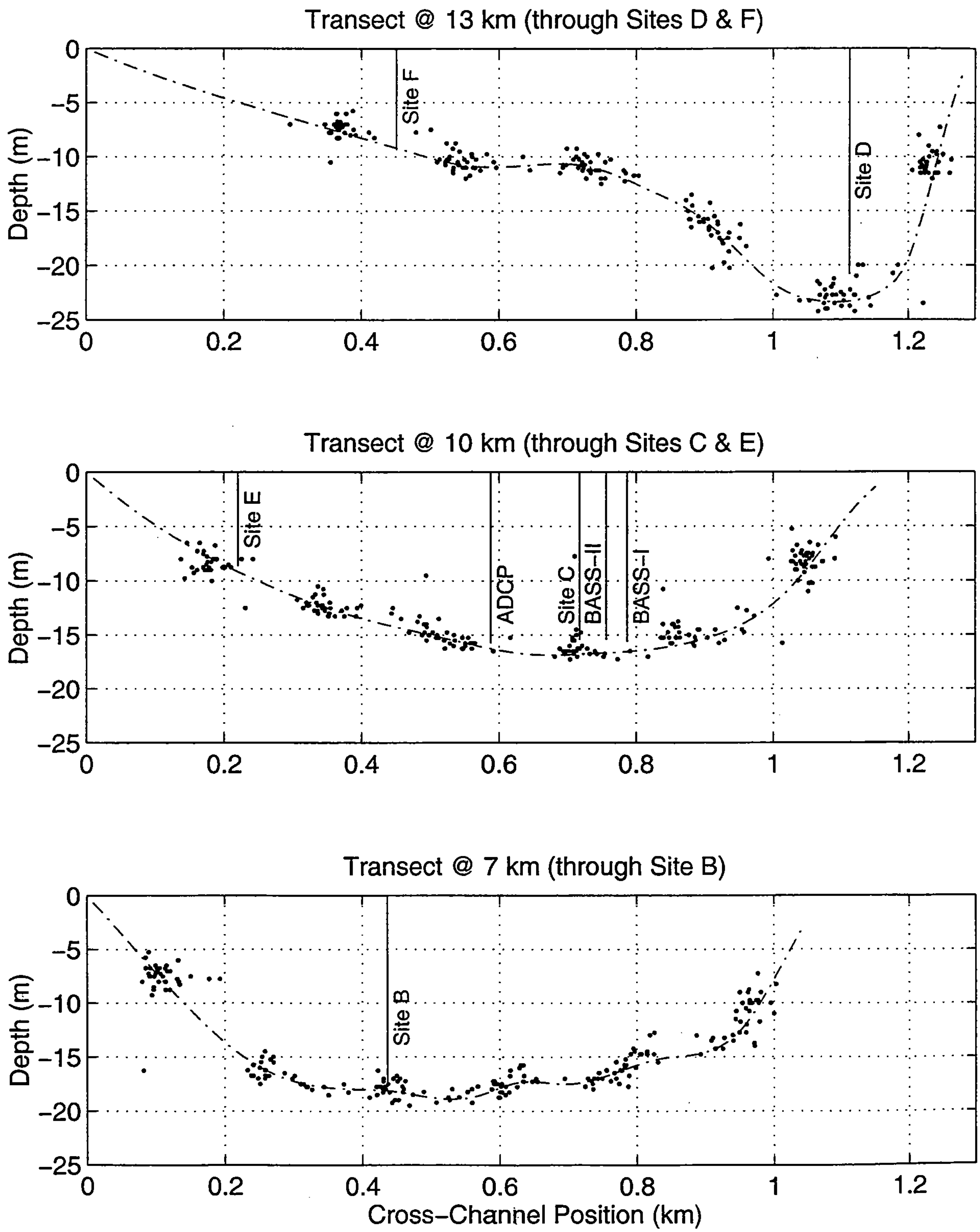

Figure 6. Cross-channel site locations are shown with CTD depths (dots) and estimate of bottom-profile (dash-dot).

B. QUADRAPOD

During August, 1995, the quadrapod was tested in 10 meters of water off the coast near the Woods Hole Oceanographic Institution. These data are not presented in this report.

For the Hudson River deployments, care was taken to align the front of the quadrapod with the primary component of the tidal flow. This minimized flow disturbance from the structure and the instrument pressure cases. Pre- and post-cruise zeroes were conducted by wrapping the sensing volume in plastic and dipping the instrument from the dock.

First deployment:
Pre-deployment zeroes were taken 04:00 - 05:00 GMT on 8/16/95. The quadrapod was deployed on August 16, 1995, approximately 100 meters east of the Central mooring site (C). The orientation was: compass (231° ± 1°), pitch (-0.44° ± 0.09°), roll (-2.38° ± 0.06°). The depth from the pressure sensor was 15.55 ± 0.44 meters. Every 10 minutes, three minutes of data were recorded (1230 samples at 160 millisecond intervals). Post-deployment estimates of zeros were taken from 13:50 - 16:40 GMT on 8/30/95.

Second deployment:
Pre-deployment estimates of zeros were taken from 17:30 - 18:00 GMT on 10/16/95. The instrument was deployed October 17, 1995, at the same location. The quadrapod was not oriented as closely to the tidal flow (13° from Deployment I): compass (218° ± 4°), pitch (-2.29° ± 0.06°), and roll (2.58° ± 0.02°). The depth from the pressure sensor was 15.38 ± 0.50 meters. Every 10 minutes, six minutes of data were recorded (2220 samples at 170 millisecond intervals). Post-deployment estimates of zeros were taken on 10/26/95 (19:51 GMT).

C. TRIPODS & MOORINGS

The C-mooring was deployed at the deepest part of the channel along the central transect of the experiment region. The Seacats with OBS sensors sampled every 5 minutes; the Seacat with the pressure sensor sampled every 20 minutes; and the S4 with pressure recorded a three minute average every 20 minutes.

Tripods A, B and D were also placed in the deepest cross-channel location at positions along the river (Figure 1). The Seagauge sensors were programmed to record a 20 minute average every 20 minutes. The S4 recorded 3 minute averages of 2Hz data every 10 minutes.

Tripods E and F, with the attached moorings, were placed on a shelf on the western side of the channel. The Seagauges on the tripods sampled every 20 minutes, while the S4s recorded 3 minute averages of 2Hz data every 10 minutes. The Seacat on the E-mooring sampled every 5 minutes and the Seacat on the F-mooring sampled every 20 minutes.

The ADCP tripod was deployed approximately 140 meters west of the central mooring site and was configured to provide 15 one-meter depth bins centered at 1.5 to 15.5 meters above bottom. The ADCP was set up to record 9 minute averages every 10 minutes (with 200 pings/ensemble). The Seagauge (with pressure) recorded 20 minute averages every 20 minutes.

D. SHIPBOARD OBSERVATIONS

The CTD was hand-lowered at approximately 1 m/s to within 0.25 meters of the bottom during each cast. A wooden dowel was used to prevent the sensors from touching the bottom. The sampling rate was 10 Hz, yielding a vertical resolution of 10 cm. The ADCP transducer was fixed to the side of the ship at 0.3-m depth, providing velocity data at 1-m intervals from 1.3m below the surface to within 15% of the total water depth. The last 15% was contaminated by the bottom return. Velocity relative to the bottom was determined by bottom