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HYDRODYNAMIC MEASUREMENTS IN SUISUN BAY, CALIFORNIA, 1992-93

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Water-Resources Investigations Report 99-4039

Prepared in cooperation with the
CALIFORNIA DEPARTMENT OF WATER RESOURCES
AND U.S. BUREAU OF RECLAMATION

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Hydrodynamic Measurements in Suisun Bay, California, 1992–93

By Jeffrey W. Gartner *and* Jon R. Burau

U.S. GEOLOGICAL SURVEY

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Sacramento, California
1999

U.S. DEPARTMENT OF THE INTERIOR
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CONVERSION FACTORS, ABBREVIATIONS, ACRONYMS, DATA-COLLECTION STATIONS, TIDAL SYMBOLS, AND JULIAN DATE CALENDAR

Multiply	By	To obtain
centimeter (cm)	0.3937	inch
centimeter per millibar (cm/mbar)	0.3937	inch per millibar
centimeter per second (cm/s)	0.3937	inch per second
cubic meter (m^3)	0.0008107	acre-foot
cubic meter per second (m^3/s)	35.31	cubic foot per second
decibar (dbar)	1.0197	meters of water (at 4°C)
meter (m)	3.281	foot
meter per second (m/s)	3.281	foot per second
millibar (mbar)	0.0145	pounds per square inch
square kilometer (km^2)	0.3861	square mile
square meter (m^2)	10.76	square foot

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Abbreviations:

deg, degrees
deg. T, degrees true
kHz, kiloHertz
mS/cm, millisiemens per centimeter
mmohs/cm, millimhos per centimeter
ppt, parts per thousand
psu, practical salinity units

Acronyms:

ADCP,	acoustic Doppler current profiler
CT,	conductivity-temperature
CTD,	conductivity-temperature-depth
DWR,	California Department of Water Resources
EC,	electrical conductivity
IEP,	Interagency Program for the San Francisco Bay Delta Estuary
MLLW,	mean lower low water
SC,	specific conductance
USGS,	U.S. Geological Survey
2D,	Two dimensional

Data-collection stations:

BULL	CONC	CUT	GRIZ	HB	HDOL
HS	MAL	MART	MID	RYER	WICK

Tidal symbols:

J_1	K_1	K_2	L_2	M_1	M_2	M_4	Mk_3
μ_2	N_2	ν_2	O_1	P_1	Q_1	S_2	T_2

Vertical Datum

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

All depths in this report are referenced to mean lower low water (MLLW). For the purpose of this report, the difference between MLLW and sea level is assumed to be 1.0 m within Suisun Bay.

Salinities in this report are presented without (practical salinity) units because salinity is a conductivity ratio; therefore, it has no physical units.

Julian Date Calendar

For nonleap years

Day	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Day
1	-30	1	31	60	91	121	152	182	213	244	274	305	335	1
2	-29	2	32	61	92	122	153	183	214	245	275	306	336	2
3	-28	3	33	62	93	123	154	184	215	246	276	307	337	3
4	-27	4	34	63	94	124	155	185	216	247	277	308	338	4
5	-26	5	35	64	95	125	156	186	217	248	278	309	339	5
6	-25	6	36	65	96	126	157	187	218	249	279	310	340	6
7	-24	7	37	66	97	127	158	188	219	250	280	311	341	7
8	-23	8	38	67	98	128	159	189	220	251	281	312	342	8
9	-22	9	39	68	99	129	160	190	221	252	282	313	343	9
10	-21	10	40	69	100	130	161	191	222	253	283	314	344	10
11	-20	11	41	70	101	131	162	192	223	254	284	315	345	11
12	-19	12	42	71	102	132	163	193	224	255	285	316	346	12
13	-18	13	43	72	103	133	164	194	225	256	286	317	347	13
14	-17	14	44	73	104	134	165	195	226	257	287	318	348	14
15	-16	15	45	74	105	135	166	196	227	258	288	319	349	15
16	-15	16	46	75	106	136	167	197	228	259	289	320	350	16
17	-14	17	47	76	107	137	168	198	229	260	290	321	351	17
18	-13	18	48	77	108	138	169	199	230	261	291	322	352	18
19	-12	19	49	78	109	139	170	200	231	262	292	323	353	19
20	-11	20	50	79	110	140	171	201	232	263	293	324	354	20
21	-10	21	51	80	111	141	172	202	233	264	294	325	355	21
22	-9	22	52	81	112	142	173	203	234	265	295	326	356	22
23	-8	23	53	82	113	143	174	204	235	266	296	327	357	23
24	-7	24	54	83	114	144	175	205	236	267	297	328	358	24
25	-6	25	55	84	115	145	176	206	237	268	298	329	359	25
26	-5	26	56	85	116	146	177	207	238	269	299	330	360	26
27	-4	27	57	86	117	147	178	208	239	270	300	331	361	27
28	-3	28	58	87	118	148	179	209	240	271	301	332	362	28
29	-2	29	59	88	119	149	180	210	241	272	302	333	363	29
30	-1	30		89	120	150	181	211	242	273	303	334	364	30
31		31		90		151		212	243		304		365	31

Julian Date Calendar—Continued

						For leap years								
Day	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Day**
1	-30	1	31	61	92	122	153	183	214	245	275	306	336	1
2	-29	2	32	62	93	123	154	184	215	246	276	307	337	2
3	-28	3	33	63	94	124	155	185	216	247	277	308	338	3
4	-27	4	34	64	95	125	156	186	217	248	278	309	339	4
5	-26	5	35	65	96	126	157	187	218	249	279	310	340	5
6	-25	6	36	66	97	127	158	188	219	250	280	311	341	6
7	-24	7	37	67	98	128	159	189	220	251	281	312	342	7
8	-23	8	38	68	99	129	160	190	221	252	282	313	343	8
9	-22	9	39	69	100	130	161	191	222	253	283	314	344	9
10	-21	10	40	70	101	131	162	192	223	254	284	315	345	10
11	-20	11	41	71	102	132	163	193	224	255	285	316	346	11
12	-19	12	42	72	103	133	164	194	225	256	286	317	347	12
13	-18	13	43	73	104	134	165	195	226	257	287	318	348	13
14	-17	14	44	74	105	135	166	196	227	258	288	319	349	14
15	-16	15	45	75	106	136	167	197	228	259	289	320	350	15
16	-15	16	46	76	107	137	168	198	229	260	290	321	351	16
17	-14	17	47	77	108	138	169	199	230	261	291	322	352	17
18	-13	18	48	78	109	139	170	200	231	262	292	323	353	18
19	-12	19	49	79	110	140	171	201	232	263	293	324	354	19
20	-11	20	50	80	111	141	172	202	233	264	294	325	355	20
21	-10	21	51	81	112	142	173	203	234	265	295	326	356	21
22	-9	22	52	82	113	143	174	204	235	266	296	327	357	22
23	-8	23	53	83	114	144	175	205	236	267	297	328	358	23
24	-7	24	54	84	115	145	176	206	237	268	298	329	359	24
25	-6	25	55	85	116	146	177	207	238	269	299	330	360	25
26	-5	26	56	86	117	147	178	208	239	270	300	331	361	26
27	-4	27	57	87	118	148	179	209	240	271	301	332	362	27
28	-3	28	58	88	119	149	180	210	241	272	302	333	363	28
29	-2	29	59	89	120	150	181	211	242	273	303	334	364	29
30	-1	30	60	90	121	151	182	212	243	274	304	335	365	30
31		31		91		152		213	244		305		366	31

Hydrodynamic Measurements in Suisun Bay, California, 1992–93

By Jeffrey W. Gartner *and* Jon R. Burau

ABSTRACT

Sea level, velocity, temperature, and salinity (conductivity and temperature) data collected in Suisun Bay, California, from December 11, 1992, through May 31, 1993, by the U.S. Geological Survey are documented in this report. Sea-level data were collected at four locations and temperature and salinity data were collected at seven locations. Velocity data were collected at three locations using acoustic Doppler current profilers and at four other locations using point velocity meters. Sea-level and velocity data are presented in three forms (1) harmonic analysis results, (2) time-series plots (sea level, current speed, and current direction versus time), and (3) time-series plots of the low-pass filtered data. Temperature and salinity data are presented as plots of raw and low-pass filtered time series.

The velocity and salinity data collected during this study document a period when the residual current patterns and salt field were significantly altered by large Delta outflow (three peaks in excess of 2,000 cubic meters per second). Residual current profiles were consistently seaward with magnitudes that fluctuated primarily in concert with Delta outflow and secondarily with the spring-neap tide cycle. The freshwater inputs advected salinity seaward of Suisun Bay for most of this study. Except for a 10-day period at the beginning of the study, dynamically significant salinities (>2) were seaward of Suisun Bay, which resulted in little or no gravitational circulation transport.

INTRODUCTION

The data described in this report were collected in cooperation with the California Department of Water Resources (DWR) and the U.S. Bureau of Reclamation (USBR) as part of ongoing research by the U.S. Geological Survey (USGS) into the hydrodynamics of the San Francisco Bay Estuary. This research is done as part of the Interagency Ecological Program (IEP) for the San Francisco Bay-Delta Estuary. Other agencies involved in the IEP include the California Department of Fish and Game, and the U.S. Fish and Wildlife Service. The USGS conducts a variety of research and monitoring activities in the San Francisco Bay estuary (Cloern and others, 1995). Research includes a wide range of disciplines, including climate change (Peterson and others, 1995), hydrodynamics (Smith and others, 1995), phytoplankton dynamics (Cloern and Jassby, 1995), toxic contaminants (Luoma and others, 1993; Kuivila and Foe, 1995), and exotic species (Nichols and others, 1990). For an updated list of USGS publications, see the Access USGS web site at http://sfbay.wr.usgs.gov/access_sfb.html.

This report documents physical data collected between December 11, 1992, and May 31, 1993, in the Suisun Bay region, California (fig. 1). These data were collected to document the initial response of the salt field to large Delta inflows, which primarily is an advective process. The data also document the subsequent return of salinity into Suisun Bay, which primarily results from the relaxation of horizontal salinity gradients and a variety of dispersive processes (Monismith and others, 1996).

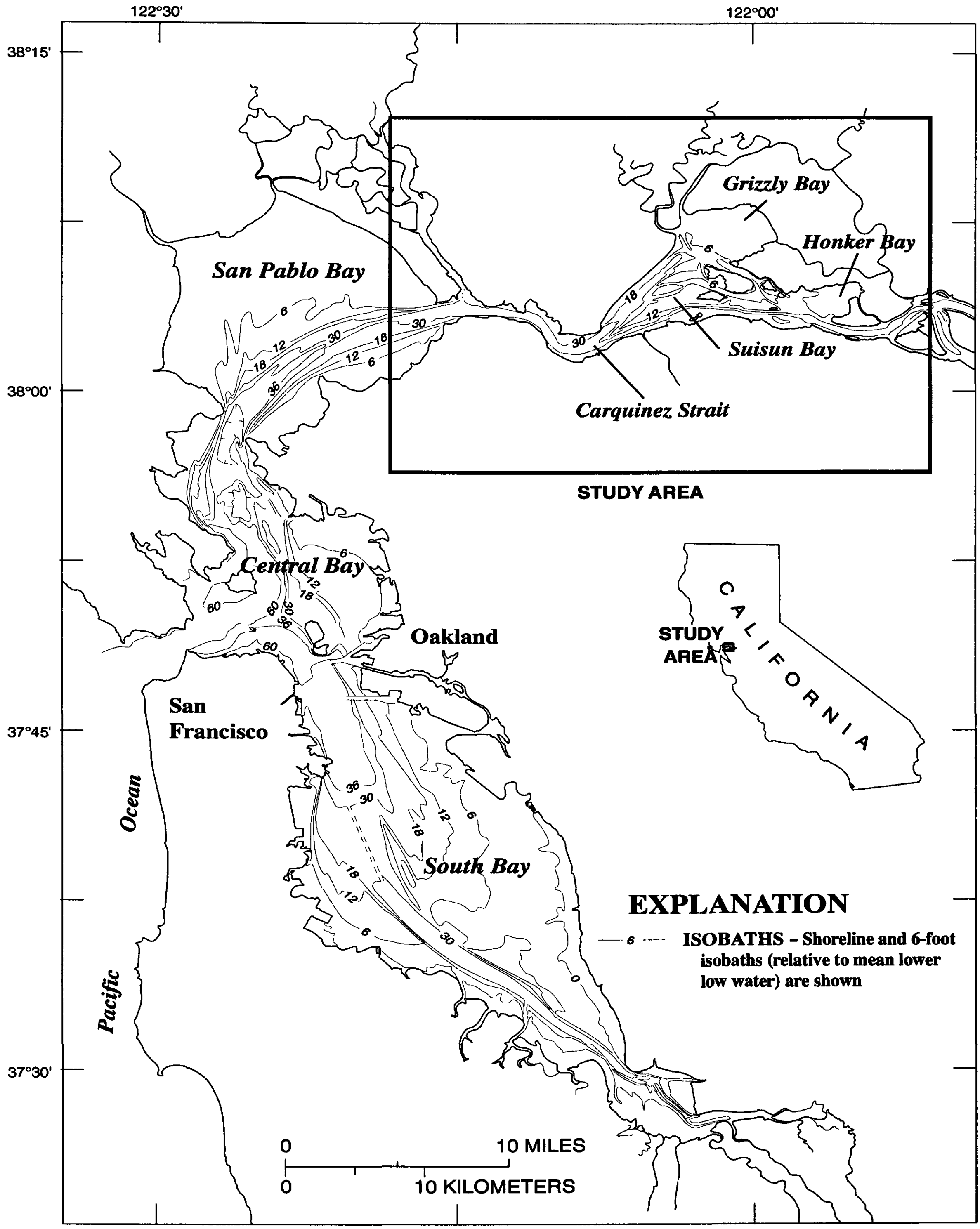

Figure 1. San Francisco Bay Estuary, California.

Purpose and Scope

The purpose of this report is to document a suite of hydrodynamic, hydrologic, and meteorological data collected in Suisun Bay from December 11, 1992, to May 25, 1993, through plots and harmonic analysis results. Four distinct types of data were collected and analyzed; (1) sea level (either measured with a pressure sensor at depth or a surface float), (2) vertical velocity profiles [acoustic Doppler current profilers (ADCPs)], (3) point velocity measurements (ducted impeller current meters), and (4) salinity measurements (computed from conductivity and temperature). The data given in this report are organized by location (fig. 2) and are presented primarily as time-series plots, although harmonic analysis results (which characterize the tidal motions) and low-pass filtered data [which characterize the residual (tidally averaged) motions] also are given. Additional characteristics of the tidal velocities, such as root-mean-square speed, tidal form number, principal current direction, and spring-tide maximum and neap-tide minimum velocities also are presented.

Study Area

Suisun Bay is hydrodynamically complex (Walters and Gartner, 1985; Smith and Cheng, 1987) and ecologically important (Jassby and others, 1995). Suisun Bay provides the hydraulic connection between the Sacramento-San Joaquin Rivers Delta with the rest of San Francisco Bay (fig. 1). Suisun Bay (fig. 2) has a surface area of approximately 94 square kilometers (km^2), a mean depth of 4.3 meters (m) and bottom

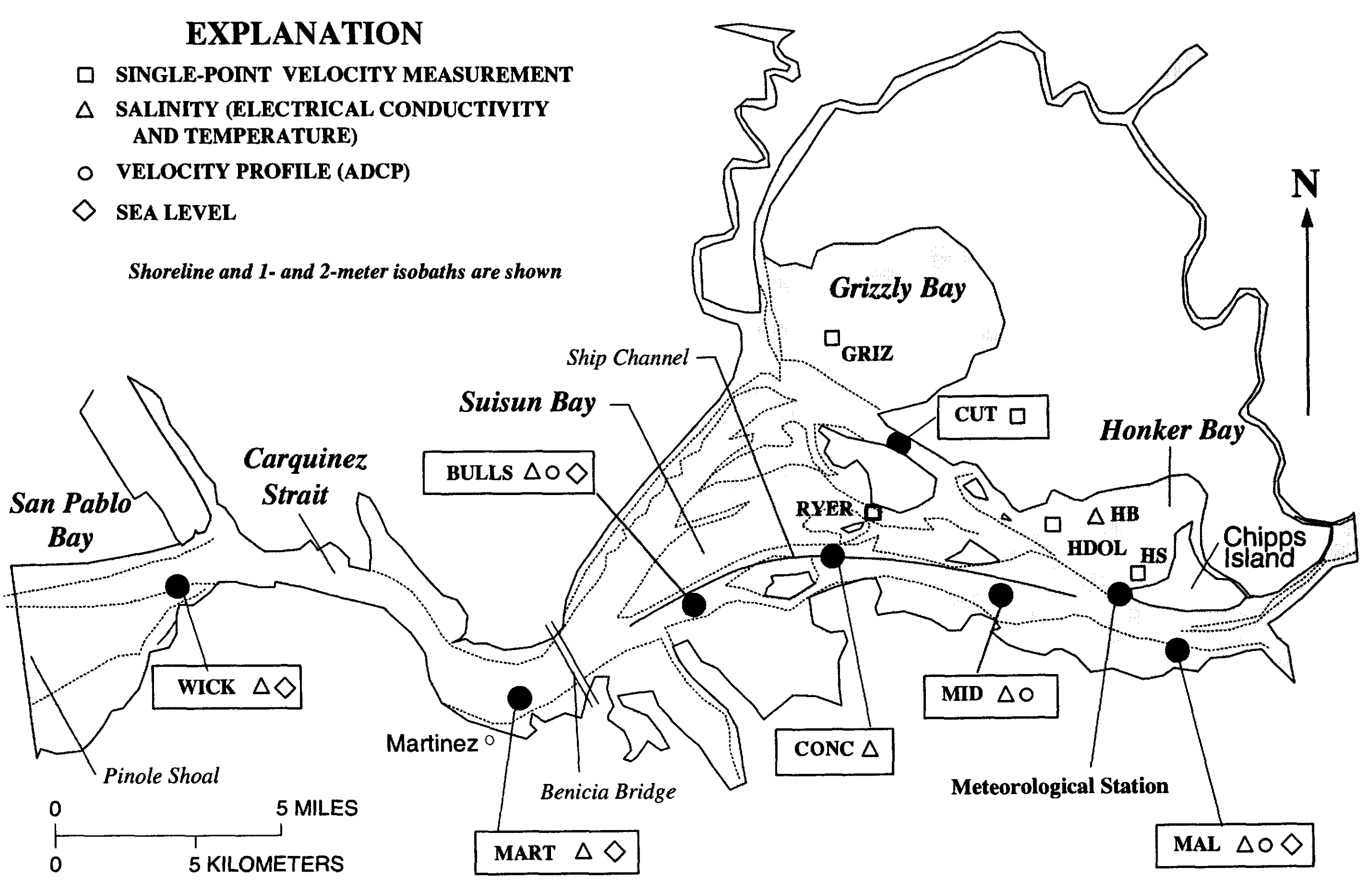

Figure 2. Data-collection locations and station names, Suisun Bay, California.

topography characterized by a network of deep channels separated by a series of islands. The channels are bounded to the north by two large, shallow regions (Honker and Grizzly Bays) that are thought to play an important role in maintaining salinities throughout the northern reach during late summer through early winter (Fischer, 1976).

The combination of complex bathymetry and brackish water makes the hydrodynamics of Suisun Bay among the most complicated in the San Francisco Bay system. The tides and tidal currents, to a large degree, are controlled by the bathymetry. Tidal current speeds [about 100 centimeters per second (cm/s) in the channels] generally vary in direct proportion to depth and are directed parallel to the prevailing bathymetry contours (Cheng and Gartner, 1984b). Friction and shoreline reflection produce the tidal-propagation characteristic of standing waves in the vicinity of Grizzly and Honker Bays, whereas tidal propagation more closely resembles a progressive wave in the deep channels of Suisun Bay (Burau and Cheng, 1988). Because tides are mixed and mainly semidiurnal in San Francisco Bay (Cheng and Gartner, 1984b), shallow water systems such as Suisun Bay act as low-pass filters (Aubrey and Speer, 1985) selectively damping the high frequencies; therefore, the semidiurnal frequencies are reduced in amplitude, and the tides become progressively more diurnal as one moves landward (Cheng and others, 1993). Although the tides dominate the hydrodynamics in Suisun Bay, Delta outflow and atmospheric forcing can, at times, have a significant effect on the residual circulation patterns (Walters and Gartner, 1985).

The juxtaposition of the saltwater-freshwater mixing zone with the large shallow regions is thought to increase the biological productivity of the Bay-Delta ecosystem during the spring (Arthur and Ball, 1979; Jassby and others, 1995). The rate at which salinity intrudes into the Delta is, to a large degree, controlled by Delta outflow and the hydrodynamics of the saltwater-freshwater mixing zone (Fischer, 1976). This zone is located in Suisun Bay for most of the summer during water years with average rainfall (Jassby and others, 1995). This ecologically important mixing zone moves with the salt field, which, in turn, responds at seasonal timescales to the amount of water entering the bay from the Sacramento/San Joaquin Delta. The location, movement, and character (spatial gradients) of the salt field in the northern reach are controlled by a balance between a number of dispersive mechanisms (primarily shear-induced mixing and gravitational circulation) that tend to move salt landward, and Delta outflow that tend to move the salt field seaward (Monismith and others, 1996). When all of these mechanisms are in balance, the salt field remains stationary. If they are out of balance, the salt field moves.

This balance changes seasonally (1) during the winter, Delta outflow dominates and the salt field moves seaward; (2) during the spring, dispersive mechanisms take precedence and the salt field moves landward, and; (3) during the summer the combined effects of Delta outflow and dispersive mechanisms on the salt field are roughly balanced and the salt field is relatively stationary or slow moving. Although there can be considerable variability in the position of the salt field, depending on the exact timing and quantity of the freshwater inputs to the bay, in general, the salt field begins its annual migration toward the delta from farther downstream (for example: San Pablo and Central Bays) in wet years. In wet years, therefore, Suisun Bay can be completely fresh for a significant part of the year. Conversely, in dry years, the salt field is closer to the delta and dispersive mechanisms move salinity into and through Suisun Bay earlier in the year, making Suisun Bay relatively salty for a significant part of the year.

Although there are a number of secondary sources of freshwater (Napa River, Petaluma River, and so forth) that flow into the San Francisco Bay system, the major source of freshwater is the Sacramento-San Joaquin Delta (Jassby and others, 1995), which is a combination of the Sacramento and San Joaquin watersheds, located east of Suisun Bay (fig. 1). In winter and spring, inflows from the Sacramento Valley watershed typically are large enough to significantly alter the hydrodynamics of Suisun Bay. For example, residual currents during the summer are on the order of 10 cm/s. During the winter, freshwater inflow into the system can produce residual currents on the order of the tidal currents (~60 cm/s) (station C22 deployed February 7, 1980, in Cheng and Gartner, 1984b). Moreover, these winter freshwater flows can advect salt seaward of Suisun Bay, effectively removing density-driven circulation from Suisun Bay during the winter and early spring.

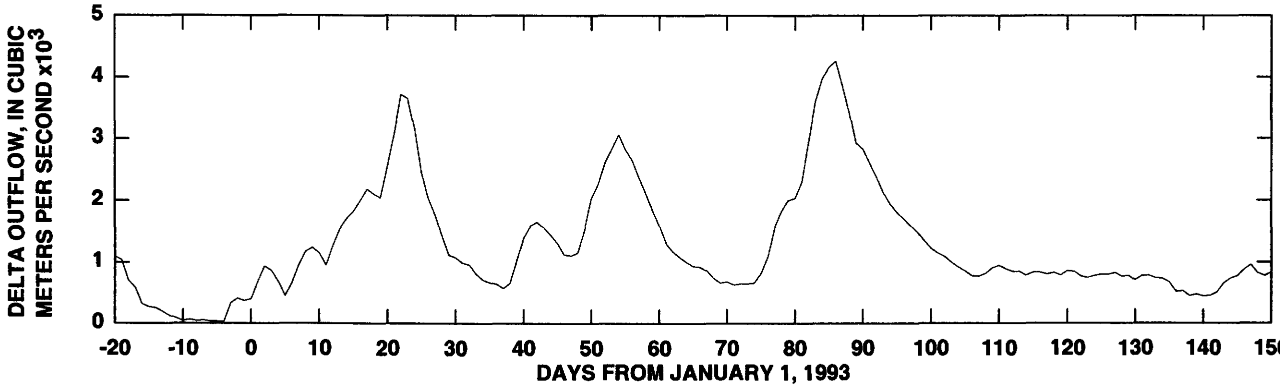

Figure 3. California Department of Water Resources Delta outflow estimates, December 11, 1992, through May 31, 1993, Sacramento-San Joaquin Delta, California (California Department of Water Resources, 1986).

Figure 3 and other time series figures in this report show calendar days, as shown on a Julian date calendar (page IX), which are numbered consecutively from January 1 through December 31. Day 1 is January 1 and day 365 is December 31, except in leap years where day 366 is December 31. In this report, the period of study ranged from the month of December into the following year. Therefore, in keeping with the Julian date format of day 1 being January 1, days in December are numbered in reverse date order and considered to be negative; December 31 is day 0 and December 1 is day -30.

Meteorological conditions indirectly affect San Francisco Bay through runoff derived from precipitation in the watersheds of the Sacramento and San Joaquin Rivers, and they also can have a direct effect on hydrodynamics through atmospheric pressure and wind. Figure 4 shows the wind speed, wind direction, and visible light measured during the study period and figure 5 shows barometric pressure.

Day -25 (December 6, 1992; not shown in figs. 4 and 5), the beginning of the study period, through day 60 (March 1, 1993), was stormy, as characterized by the large fluctuations in barometric pressure (fig. 5) and wind speed and direction (fig. 4). The variability in visible light (fig. 4) is the result of intermittent cloud cover. In contrast, day 60 was the beginning of a period of relatively stable barometric pressure. Wind stress on the water surface can produce a current that flows in the direction of the wind at the surface and opposite the wind direction at depth in channels (Fischer and others, 1979; Hunter and Hearn, 1987). Wind direction is reported as the direction from which the wind is coming (westerly winds have a principal direction of 270°). Winds in Suisun Bay have been characterized by prevailing westerly or southwesterly winds in late spring, summer, and early autumn and by more intermittent southerly winds in winter (Gartner and Cheng, 1983). During this study, however, the direction of the prevailing winds fluctuated between easterly and westerly directions during the storm periods prior to day 60 (March 1, 1993), but were primarily westerly after day 60, as shown in figure 6, which has the daily fluctuations removed by a low-pass filter (described later in this report).

Atmospheric pressure can induce residual currents in Suisun Bay by significantly raising and lowering sea level (Walters and Gartner, 1985). Atmospheric pressure and sea level are inversely related such that an atmospheric pressure rise causes a lowering of sea level. Sea-level variations caused by atmospheric pressure changes typically are greater than hydrostatic in San Francisco Bay, corresponding to about 1 to 1.5 centimeters per millibar (cm/mbar) (Walters and Heston, 1982). The barometric pressure in San Pablo Bay and low-pass filtered sea level at Martinez for the study period are plotted in figure 5. Unfortunately, changes in atmospheric pressure often are accompanied by periods of intense winds that make it difficult to differentiate the effects of wind on sea level from fluctuations in sea level caused by atmospheric pressure. For example, the large drop in barometric pressure around day 50 (February 19, 1993) in figure 5 was accompanied by high winds, as shown

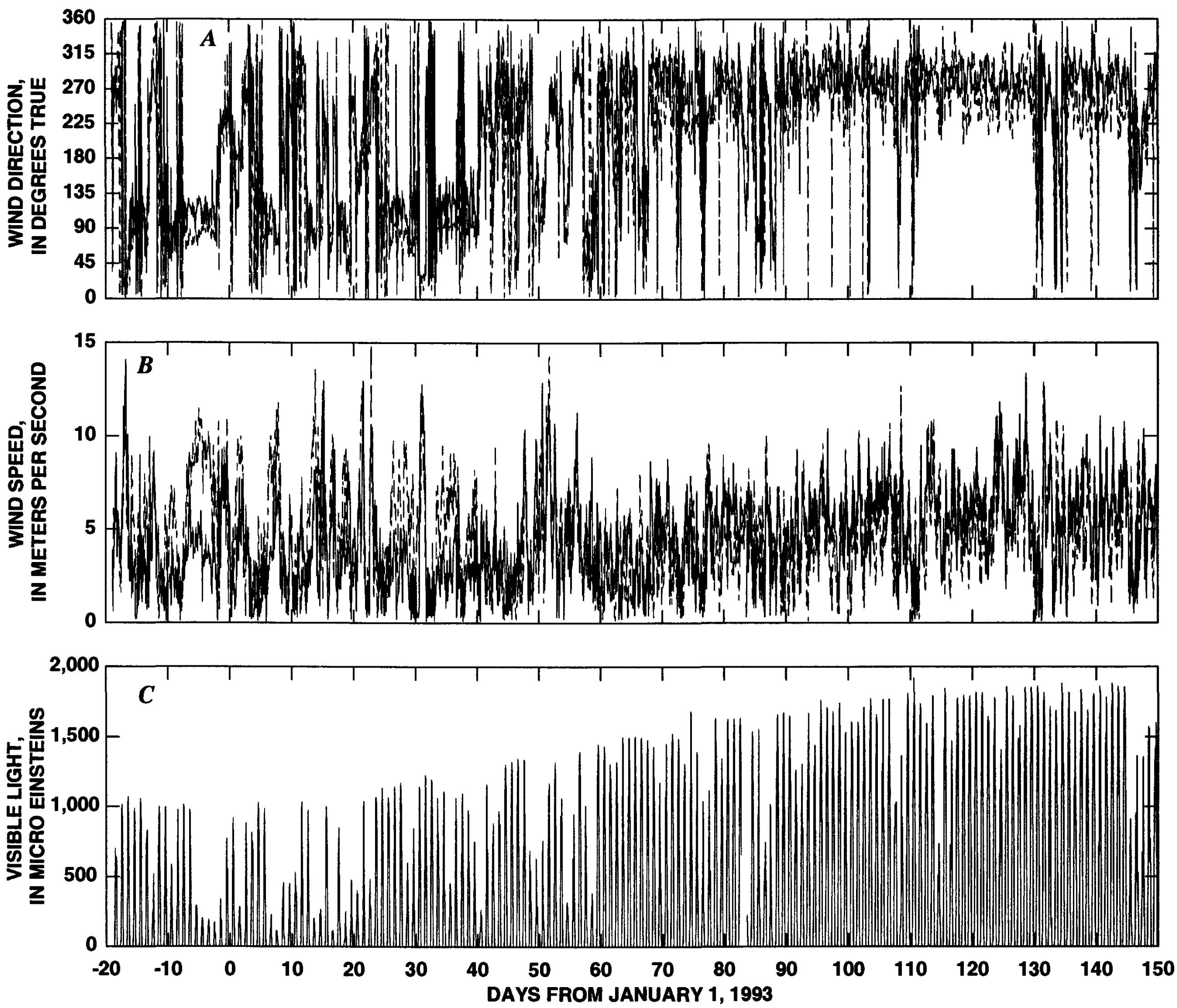

Figure 4. ***A,*** Wind direction; and ***B,*** speed at channel marker 27 in Suisun Bay (solid) and channel marker 11 in San Pablo Bay (dashed), and ***C,*** visible light at channel marker 11 in San Pablo Bay, California, December 11, 1992, through May 31, 1993. Wind direction is reported as the direction the wind is coming from (westerly winds have a principal direction of 270°).

in figure 4. Examples of the coupling between atmospheric pressure and sea level are indicated in figure 5 by dashed lines on calendar days −1, 8, 40, and 52. To appreciate the effect of atmospheric pressure changes on the residual currents, consider that the sea-level increase of 51 centimeters (cm) that occurred from day 45 to day 51 theoretically resulted in the storage of an additional 4.8×10^7 cubic meters (m^3) of water in Suisun Bay alone. This storage would cause a net flow of about 93 cubic meters per second (m^3/s) through Carquinez Strait into Suisun Bay during this period, which would generate an area average current of 0.53 cm/s in Carquinez Strait [assuming the cross-sectional area of Carquinez Strait is ~17,600 square meters (m^2)].

Sampling Strategy

The principal objective for collecting data presented in this report was to measure the spatial and temporal variability in the residual currents and salinity in the ship channel (stations BULL, CONC, MID,

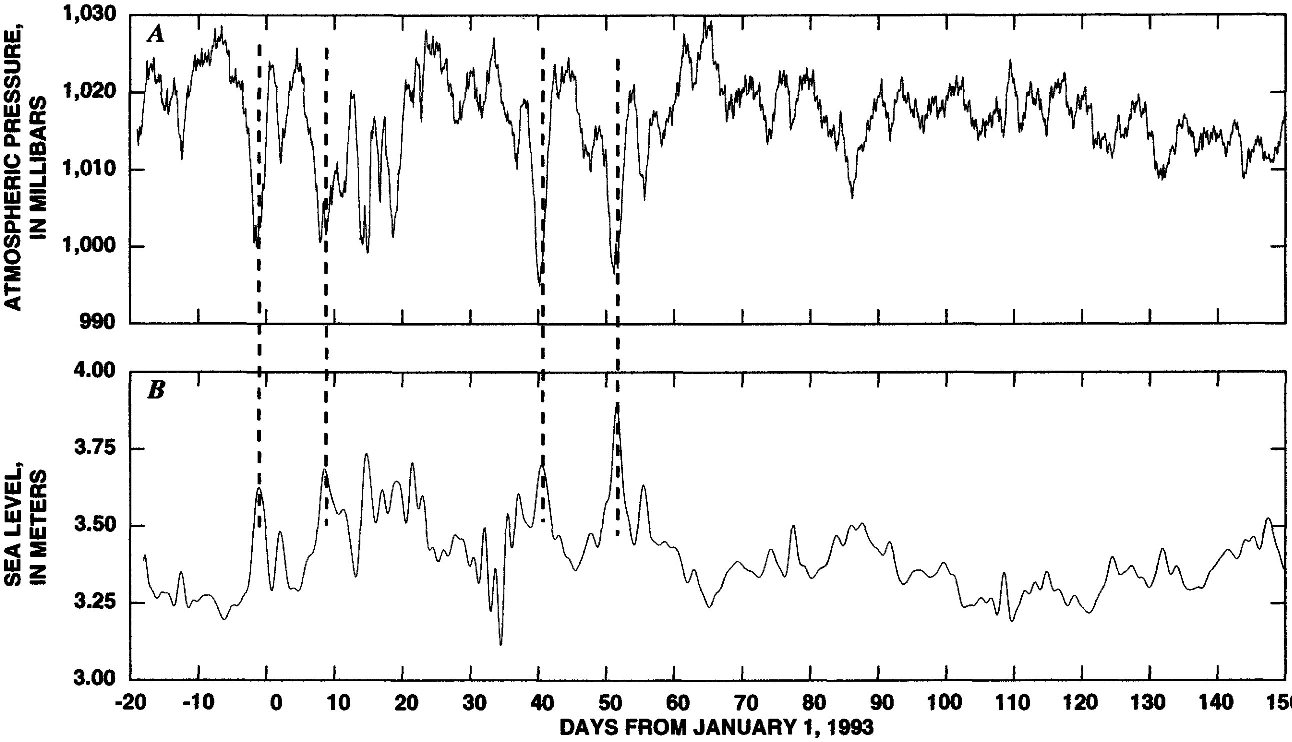

Figure 5. ***A***, Barometric pressure collected at channel marker 11 in San Pablo Bay; and ***B***, low-pass-filtered sea level at Martinez, California, December 11, 1992, through May 31, 1993. Vertical dashed lines show the inverse relation between atmospheric pressure and sea level.

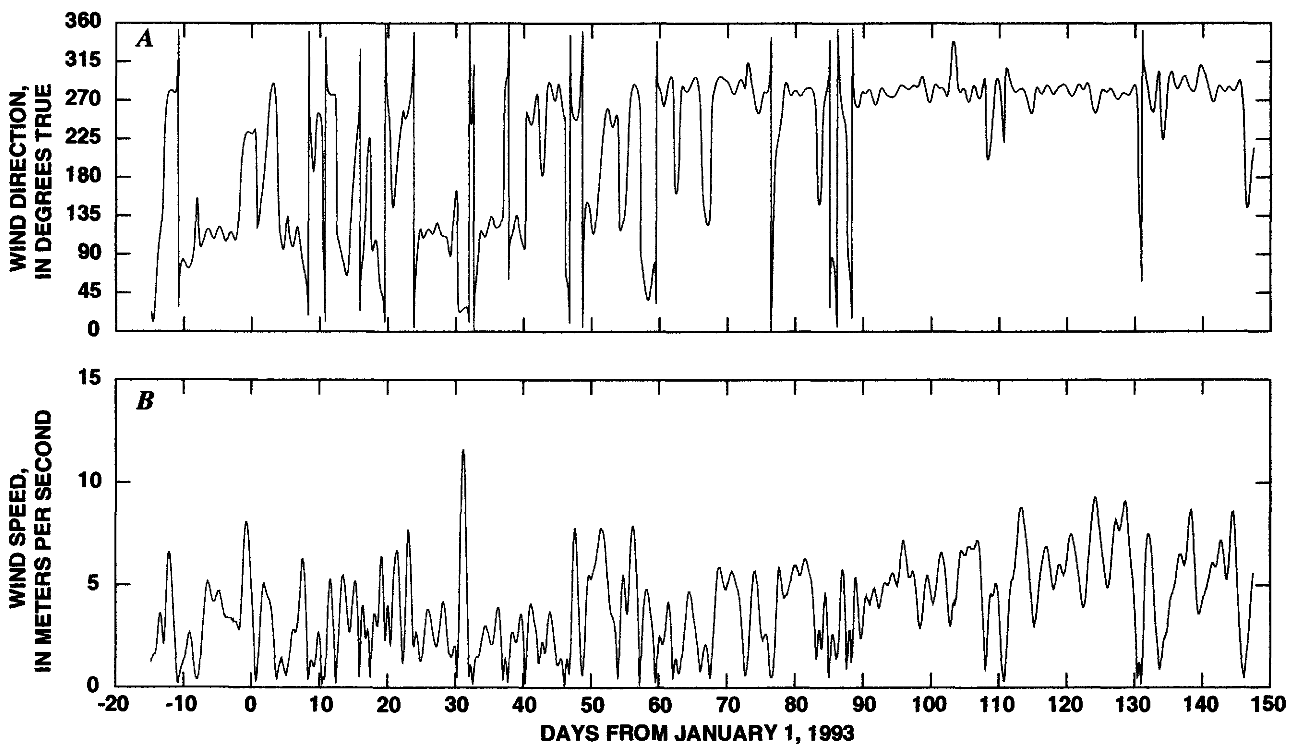

Figure 6. Low-pass-filtered ***A***, wind direction; and ***B***, speed, channel marker 27, December 11, 1992, through May 31, 1993, Suisun Bay, California.

Table 1. Data-collection station instruments locations and periods of deployment, Suisun Bay, California

[Meteorological station locations: San Pablo Bay, channel marker 11, 38°03'11"N, 122°19'46"W; Suisun Bay, channel marker 27, 38°03'08"N, 121°55'54"W. nb, narrow-band acoustic Doppler current profiler; s, salinity sensor; p, pressure or sea-level sensor; v, velocity sensor; bb, broad-band acoustic Doppler current profiler]

Station	Instrument type	Latitude/longitude	Depth (meters below mean lower low water)	Sensor depth (meters below mean lower low water)	Period of deployment
BULLS	nb, s, p	38°03'44"N/122°04'15"W	11.5	10.8	1/21/93-5/25/93
BULLS	s	38°03'47"N/122°04'11"W	11.5	1.10 and 10.3	12/11/92-5/25/93
CONC	s	38°03'51"N/122°01'38"W	8.2	1.2 and 7.0	12/11/92-5/26/93
CUT	v	38°05'18"N/122°00'21"W	11.0	2.8 and 8.9	1/13/93-5/26/93
GRIZ	v	38°06'13"N/122°02'26"W	4.3	3.8	1/19/93-3/16/93
GRIZ	s	38°06'12"N/122°02'26"W	4.9	3.8	3/16/93-5/26/93
HB	s	38°04'29"N/121°56'46"W	3.1	2.0	12/11/92-5/25/93
HDOL	v	38°04'07"N/121°57'46"W	3.7	2.7	1/13/93-5/26/93
HS	v	38°03'23"N/121°55'58"W	6.1	3.8	1/13/93-5/25/93
MAL	nb	38°02'33"N/121°54'59"W	15.2 and 15.5	14.5 and 14.8	1/22/93-5/25/93
MART	s, p	38°01'40"N/122°08'22"W	8.0	1.0 and 7.5	1/1/93-5/31/93
MID	bb	38°03'30"N/121°58'48"W	9.8 and 10.7	9.1 and 10.0	1/22/93-5/25/93
MID	s	38°03'31"N/121°58'48"W	10.7	2.5 and 9.5	12/11/92-5/25/93
RYER	v	38°04'24"N/122°01'25"W	7.0	4.2	1/13/93-5/26/93
WICK	s, p	38°03'30"N/122°14'24"W	15.2	.7 and 9.0	1/1/93-5/31/93

MAL) and the secondary channels (stations RYER and CUT) in Suisun Bay. A secondary objective was to relate the variability in the channels with the variability in the shoals (stations GRIZ, HDOL, HB, HS). Station locations are shown in figure 2 and their respective latitudes and longitudes are given in table 1.

Instruments were deployed to measure conductivity and temperature during the week of December 11, 1992. The remaining instruments were deployed the week of January 13, 1993. Although salinities in Suisun Bay had not reached their typical summer values, all equipment was recovered during the week of May 5, 1993. Deployment dates are given in table 1. Three ADCPs were deployed along the channel axis to define the vertical velocity structure. Several ducted impeller-type current meters were deployed in shallow water and in the secondary channels near Ryer Island. Conductivity-temperature-depth (CTD) sensors were deployed adjacent to velocity measuring instruments (where possible) to estimate salt fluxes. Specifications of instruments deployed in Suisun Bay are presented in table 2.

Acknowledgments

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Table 2. Specifications of instruments deployed, Suisun Bay, California

[°C, degrees Celsius; mS/cm, millisiemens per centimeter at 25°C; ppt, parts per thousand; psu, practical salinity units; dbar, decibar; cm/s, centimeters per second; CT, conductivity-temperature-sensor; CTD, conductivity-temperature-depth sensor; 2D, two dimensional; ADCP, acoustic Doppler current profiler]

Instrument	Range	Accuracy	Resolution
DataSonde 2000 CT:			
Temperature	-2 to 50°C	0.2°C	0.025°C
Conductivity	0 to 150 mS/cm	1.0 percent[1]	.1 percent[1]
Salinity[2]	0 to 60 ppt	1.0 percent[1]	.1 ppt
Ocean sensors OS200 CTD:			
Temperature	-2 to 35°C	.01 percent[1]	.001 percent[1]
Conductivity	.5 to 65 mS/cm	.02 percent[1]	.001 percent
Salinity[2]	1 to 45[3]	.03 percent[1]	.001 percent
Pressure	0 to 50 dbar	.50 percent[1]	.005 percent
Endeco current meter:			
Current speed	0 to 223 cm/s	3.00 percent[1]	.89 cm/s
Direction	0 to 360°	7.2°	1.4°
Temperature	-5 to 45°C	.2°C	.098°C
Conductivity	5 to 55 mS/cm	.55 mS/cm	.098 mS/cm
Salinity[2]	5 to 45 ppt	.6 ppt	.098 ppt
EG&G marine instruments ACM3 current meter:			
Current speed	0 to 360 cm/s	1 cm/s or 3 percent[1, 4]	.2 cm/s
Direction	0 to 360°	5.0°	1.0°
Temperature	-2 to 35°C	.05°C	.01°C
Pressure	0 to 999.9 dbar	.50 percent[1]	.4 dbar
ADCP (broad band):			
Velocity[5]	±1,000 cm/s	<1 cm/s[6]	.1 cm/s
Heading	0 to 360°	2°	.2°
ADCP (narrow band):			
Velocity[5]	± 1,000 cm/s	<1 cm/s[6]	.1 cm/s
Heading	0 to 360°	2°	.2°
YSI #33 CT:		±.15°C	.01
Temperature	-2 to 50°C	±2.5 mS/cm	1 mS/cm
Conductivity	0 to 50 mS/cm	.2 psu	.1 psu
Salinity	1 to 40[3]		

[1]All percent values refer to percent of full scale.
[2]All salinities are calculated values.
[3]Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).
[4]Larger of the two values.
[5]Along-beam components.
[6]Based on averaging sufficient acoustic pings/data ensemble.

DATA PRESENTATION

A standard suite of data-processing procedures was applied to each type of data. This section describes the products from these processing procedures. For each station (location), data are presented as follows:

(a) Deployment schematic;
(b) Time-series plots of sea level, temperature, and salinity;
(c) Time-series plots of low-pass filtered sea level, temperature, and salinity;
(d) Time-series plots of velocity measurements;
(e) Time-series plots of low-pass filtered longitudinal and transverse velocity components;
(f) Stick plots of low-pass filtered velocity time series;
(g) Harmonic analysis results from sea-level (depth or pressure) measurements; and
(h) Harmonic analysis results from velocity measurements.

Not all types of data were collected at each station. In these cases, a subset of the previous list is presented in the indicated order. When ADCP data are presented, the bottom and near-surface depth cell (bin) for each velocity profile is presented as an individual time series. An ADCP determines the velocity profile by sampling reflected acoustic signals at discrete time intervals that correspond to depth intervals (bins).

The deployment schematic (a) shows the equipment used, deployment configuration, relevant depths, and any other pertinent site-specific information. Time-series plots (b and c) of sea level, temperature, salinity, and current speed and direction depict the raw data. Low-pass filtering (d, e, and f) removes the high-frequency variability caused by the tides from the time series. Delta outflow, spring-neap tidal variations, and meteorological forcing often produce a low-frequency response in hydrodynamic variables, which can be observed more easily in the filtered time series. Harmonic analysis (g and h) (Cheng and Gartner, 1984a) provides a useful synopsis of the tidal time scale character of sea-level and velocity measurements at a given location.

Plotting of Oceanographic Data

There are generally two philosophies regarding the presentation of oceanographic data that depend on the intent of the data analysis. The first philosophy emphasizes the details of each sampling location by selecting the plot scales to only bracket each data set. Using this approach, however, one cannot easily compare information between locations. The second philosophy, which is used in this report, plots the data on a consistent set of scales. This philosophy allows the comparison of data from different locations and therefore emphasizes basin-scale phenomena.

In this report, data are plotted from day -20 to day 150 (December 11, 1992, to May 30, 1993) referenced to January 1, 1993. Because the currents in the shallows are weaker, by about a factor of two, than the currents in the channels, the measured velocities are plotted using two scales; 0-75 cm/s for the shallows and 0-150 cm/s for the channels. The residual (or low-pass filtered) currents are plotted using a consistent scale of -30 to + 20 cm/s (negative values are in the seaward or ebb direction). Depth (CTDs deployed near the bed) and sea level (water level measured by a surface float) data are plotted using a range of 2.5 m. Finally, temperature and salinity data are plotted using scales of 5-20°C and salinities of 0-20, respectively.

Harmonic Analysis

Sea level (h) and each velocity component (u, v) can be represented by a sum of cosine functions,

$$h = H_o + \sum f_i H_i \cos[\omega_i t - (\kappa_i - E_i)]$$

$$u = U_o + \sum f_i U_i \cos\{\omega_i t - [(\kappa_u)_i - E_i]\}$$

$$v = V_o + \sum f_i V_i \cos\{\omega_i t - [(\kappa_v)_i - E_i]\},$$

each with known frequency (ω_i) of astronomical origin (table 3), defined by a unique amplitude (H_i, U_i, V_i) and phase [κ_i, $(\kappa_u)_i$, $(\kappa_v)_i$] (or local epoch), where t is time reconciled to a known reference and E_i is the equilibrium argument at the reference time, and f_i is the node factor reciprocal. The E_i's and f_i's are straightforwardly calculated following the relations given in Schureman (1976). In this report, the modified epoch (κ_i') also is presented. The modified epoch is used for predictions and basically is the local epoch, κ, plus a longitude and time meridian correction,

$$\kappa'_i = \kappa + pL - \frac{aS}{15},$$

where p is the subscript of the partial tide (1 for diurnal, 2 for semidiurnal), L is the longitude, a is the hourly angular frequency, and S is the longitude of the time meridian (120° for San Francisco Bay). Methods for determining the phase and amplitude (harmonic constants) of these cosine functions are well documented (Schureman, 1976; Foreman, 1977). In this report, results are presented from a least-squares method described in detail by Cheng and Gartner (1984a,b; 1985). This method minimizes the squared differences between the sum of a fixed number of cosine functions (16 in this report) with observed data. In the case of a short time series of sea level and velocity data (<120 days), the harmonic constants for six partial tides (O_1, K_1, N_2, M_2, S_2, M_4) are determined by the least-squares method. For data records of less than 120 days, the remaining nine partial tides (Q_1, M_1,

Table 3. Principal astronomical tidal frequencies, Suisun Bay, California

Tidal symbol	Period (solar hours)	Angular frequency (degrees per hour)	Origin and name
		Diurnal Species	
K_1	23.93	15.0411	Luni-solar
O_1	25.82	13.9430	Principal lunar
P_1	24.07	14.9589	Principal solar
Q_1	26.87	13.3987	Larger lunar elliptic
J_1	23.10	15.5854	Small lunar elliptic
M_1	24.83	14.4967	Smaller lunar elliptic
		Semidiurnal Species	
M_2	12.42	28.9841	Principal lunar
S_2	12.00	30.0000	Principal solar
N_2	12.66	28.4397	Larger lunar elliptic
K_2	11.97	30.0821	Luni-solar
ν_2	12.63	28.5126	Larger lunar evectional
L_2	12.19	29.6285	Smaller lunar elliptic
T_2	12.02	29.9589	Larger solar elliptic
μ_2	12.87	27.9682	Variational
		Terdiurnal Species	
Mk_3	8.18	44.0252	M_2-K_1 interaction
		Quarter Diurnal Species	
M_4	6.21	57.9682	Lunar quarter diurnal

P_1, J_1, μ_2, ν_2, L_2, T_2, K_2) are determined by inference (Cheng and Gartner, 1984a). In the case of velocity data, harmonic constants from the two velocity components are combined in the form of a tidal-current ellipse for each tidal constituent (cosine function). The primary flood and ebb directions are determined from the orientation of the major axis of the ellipse; the maximum tidal-current speed is determined from the magnitude of the semimajor axis; and the phase angle can be compared with the modified epoch (phase) of the corresponding partial tide obtained in a sea-level harmonic analysis (Cheng and Gartner, 1984b).

Harmonic analysis summaries for sea-level and velocity data are reported in the appendices. These summaries include the mean amplitude, epoch, and modified epoch (harmonic constants) for each major astronomical tidal constituent. General properties of tidal currents, including the root-mean-squared current speed, spring-tide current maximum, neap-tide current minimum, principal current direction, and tidal current form number (F) were calculated from the harmonic constants. The principal direction (assumed positive in the landward direction) was computed using the semimajor axis weighted average of the major axis directions from the M_2, S_2, K_1, and O_1 partial tides. The tidal current form number is defined as the ratio of the sums of the amplitudes of the diurnal tidal species over the sum of the amplitudes of the semidiurnal species. Defant's (1958) simplified definition was used where

$F = \frac{O_1 + K_1}{M_2 + S_2}$. If F is less than 0.25, the tide is referred to as semidiurnal, and if F is greater than 3.0, the tide is diurnal. Values of F between 0.25 and 3.0 are considered mixed tides.

Low-Pass Filter

Applying a low-pass filter to the data selectively removes frequencies that are greater than a specified cutoff value. In the analysis of data from tidally affected waters like San Francisco Bay, the objective is to remove signals in the data whose frequencies have periods less than 30 hours (most importantly, the tides). The data in this report were filtered using a discrete Fourier transform filter similar to that described by Walters and Heston (1982). A cosine taper was applied between a stop frequency of 30 hours and a pass frequency of 40 hours to reduce "ringing" in the results (Burau and others, 1993).

Low-pass-filtered velocity data are presented in time-series and stick-plot formats. In both formats, the currents are rotated into the principal current direction. Because the currents are bidirectional, the principal direction is given as the flood direction, by convention. Two velocity components are generated by this rotation—the longitudinal component that is aligned with the principal direction and the transverse component that is perpendicular to the principal direction. In general, most tidal and residual currents are contained in the longitudinal component; the transverse component usually is small. These components are plotted directly in the time-series format. In the stick-plot format, residual velocities are represented by a "stick" diagram. Sticks directed above zero on the horizontal axis represent landward net flow. Conversely, sticks pointing below the zero axis represent seaward residual currents. The transverse component is seen in the angling of the sticks where sticks angled to the left are indicative of a positive transverse velocity (a right-hand coordinate system is used). The magnitude of the transverse currents in the stick plots are proportional to the angling of the sticks.

Hydrologic and Meteorologic Conditions

During this study, freshwater inflow was relatively high for a prolonged period (about 100 days). On three occasions, Delta outflow exceeded 3,000 cubic meters per second (m^3/s) (fig. 3). Delta outflow is calculated (using DAYFLOW model) from the summation of measured Delta inflows (primarily the Sacramento and San Joaquin Rivers and other east-side streams) subtracting measured exports and estimated within delta consumptive use (California Department of Water Resources, 1986).

TIDAL CURRENTS

Hydrodynamic conditions in Suisun Bay during the study period were significantly altered by freshwater inflows. Delta outflow varied from about 100 m^3/s to peak values of 4,000 m^3/s. High inflows to the bay significantly lowered salinities and reduced the magnitude of the horizontal density gradient. These conditions resulted in tidal current characteristics not seen in drought years. During low flow (drought) conditions in 1990-91, ADCP data collected in Suisun Bay indicate that the near-bed currents reverse direction before the surface currents (M.R. Simpson, U.S. Geological Survey, written commun., 1998). Specifically, at low slack water, near-bed water began to flood while near-surface water was still ebbing. At slack before ebb, near-surface and near-bottom water reversed direction at the same time. In contrast, ADCP data collected during this study (with higher Delta outflow) indicate that near-surface currents reversed direction before the near-bottom currents. That is, near-surface water began to ebb while near-bottom water was still flooding. At low slack, near-surface water began to flood prior to, or at the same time as, near-bottom water.

Figure 7 shows the water column phases relative to the surface velocity, $(\phi_i - \phi_s)\frac{T}{6}$, determined from harmonic analysis for each ADCP velocity bin. These phases are plotted versus depth for the M_2 and K_1 partial tides in figure 7 where ϕ_i is the phase of the ith

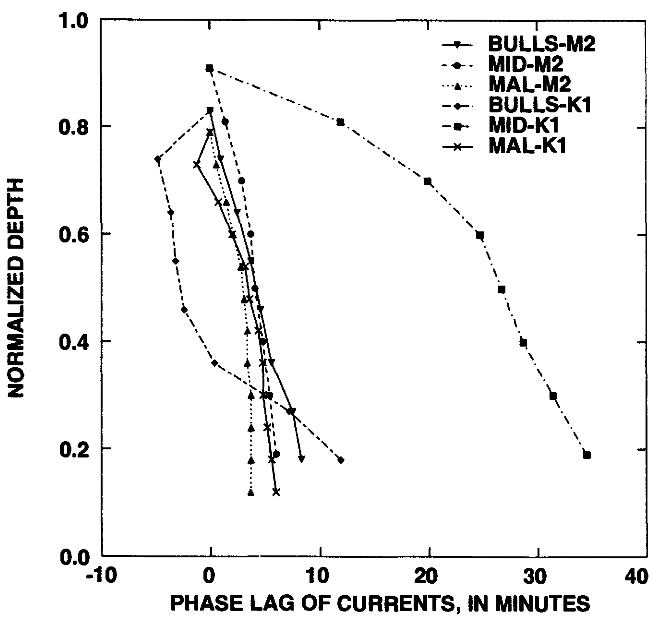

Figure 7. Water-column variation in phase (timing of the currents) with respect to the surface current for the M_2 and K_1 partial tides, Suisun Bay, California. The tidal current, on average, reverses later near the bed.

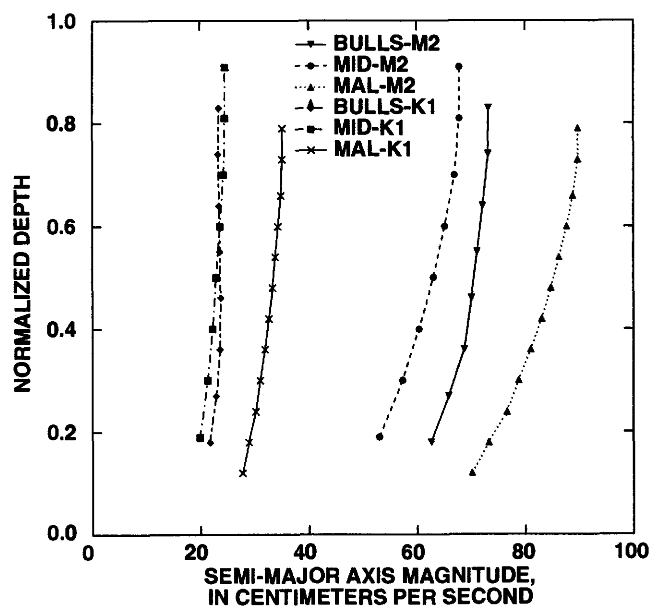

Figure 8. Water-column variation in semimajor axis magnitude for the M_2 and K_1 partial tides, Suisun Bay, California.

Table 4. Summary of harmonic analysis results at in situ single-point measurement current meter sites, January through May 1993, Suisun Bay, California

[CUT_t, top sensor at station CUT; CUT_b, bottom sensor at station CUT; cm/s, centimeters per second; deg. T, degrees true north; deg. degrees]

	Roe/Ryer Island	Ryer Island		Honker Bay	
	RYER	CUTt	CUTb	HDOL (west)	HS (east)
Root-mean-square speed (cm/s)	40.3	52.8	41.3	28.8	31.1
Primary direction (deg. T)	105.7	128.3	129.0	100.2	40.7
Tidal form number	.51	.54	.46	.44	.38
Spring maximum (cm/s)	83.8	106.7	84.0	57.8	38.5
Neap minimum (cm/s)	30.0	42.7	29.4	21.5	12.2
M_2 phase (deg.)	23.7	43.9	41.0	25.2	35.3
M_2 major axis (cm/s)	46.8	61.7	46.1	34.2	23.7
M_2 minor axis (cm/s)	.9	.4	.1	3.6	.6
K_1 phase (deg.)	101.4	110.8	116.2	96.1	112.4
K_1 major axis (cm/s)	18.4	24.3	15.8	12.2	8.9
K_1 minor axis (cm/s)	.3	.1	.1	.8	.0

BIN, ϕ_s is the phase at the surface, and T is the period of a given partial tide (M_2 or K_1), in hours, as given in table 3. Normalized depth is $\bar{d} = \frac{d_i}{d_T}$, where d_i is the depth of BIN "i" and d_T is the total depth. Each of the two deployments from stations MID and MAL were combined into a single record prior to harmonic analysis to reduce the variability in harmonic analysis results (especially phase). The change in the tidal current phase throughout the water column is most apparent at station MID where the K_1 current reverses, on average, about 35 minutes later near the bed than at the surface. M_2 at MID, and both constituents at the other stations reverse near the bed about 5 to 10 minutes later than at the surface. One degree of phase corresponds to about 2 minutes for a semidiurnal tidal constituent and about 4 minutes for a diurnal tidal constituent.

Figure 8 shows the profiles of the semimajor axis magnitude for the M_2 and K_1 partial tides. As shown in figure 8, most of the shear in the water column is carried by the M_2 partial tide.

Tidal phases calculated by harmonic analysis show that the phase delay in the currents from west to east across Suisun Bay amounts to about 30 minutes. Most of that phase delay occurs between stations BULLS and MID based on the M_2 partial tide. The tidal current phase is about the same at stations RYER and HDOL, whereas at station CUT, the tides occur about 45 minutes later than both RYER and HDOL. Tidal currents at station CUT in Suisun Cutoff have about the same phase as those at station MAL near Mallard Island. Surprisingly, tidal currents at stations RYER and HDOL precede those at station MID. A summary of harmonic analyses results is given in table 4.

RESIDUAL CURRENTS

Residual circulation (Eulerian) can be deduced from velocity data through an averaging or filtering technique. Residual circulation is the result of nonlinear interactions between tides and tidal currents with the basin geometry and can be generated by wind stress, atmospheric pressure changes, river inflow, and density gradients. The Eulerian residual currents (filtered velocity data) typically are about an order of magnitude less than the tidal currents.

Gravitational circulation is believed to be an important residual transport mechanism in San Francisco Bay (Peterson and others, 1975). Gravitational circulation, driven by horizontal density (salinity) gradients, is a net landward near-bed current with a net seaward current near the surface.

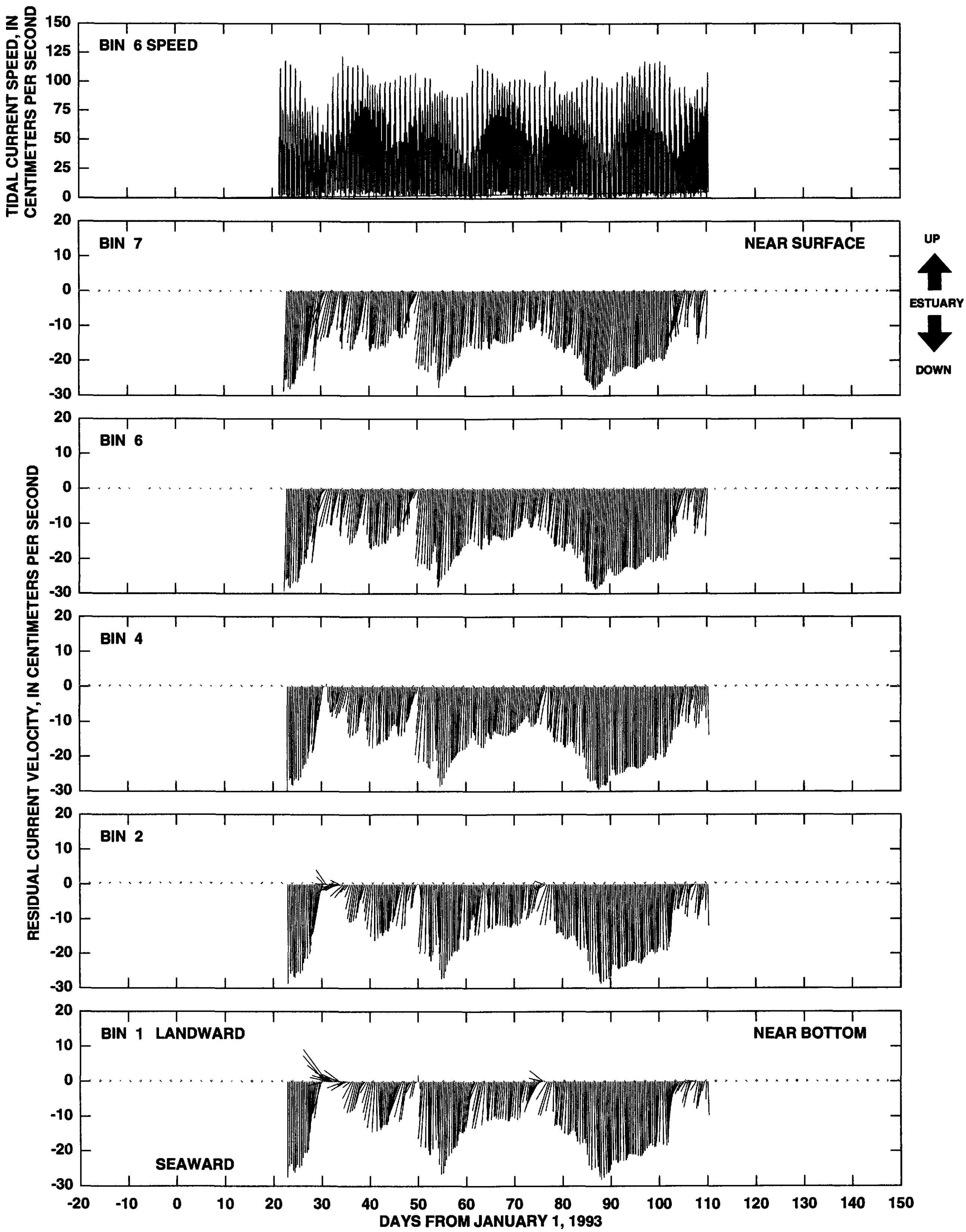

Figure 9. Low-pass-filtered residual current velocity data, station BULLS, January 21 through March 21, 1993, Suisun Bay, California. Principal direction is 73.5°. Tidal current speed at BIN 6 is shown in the top panel for reference. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward. BIN refers to a discrete measurement location in the vertical.

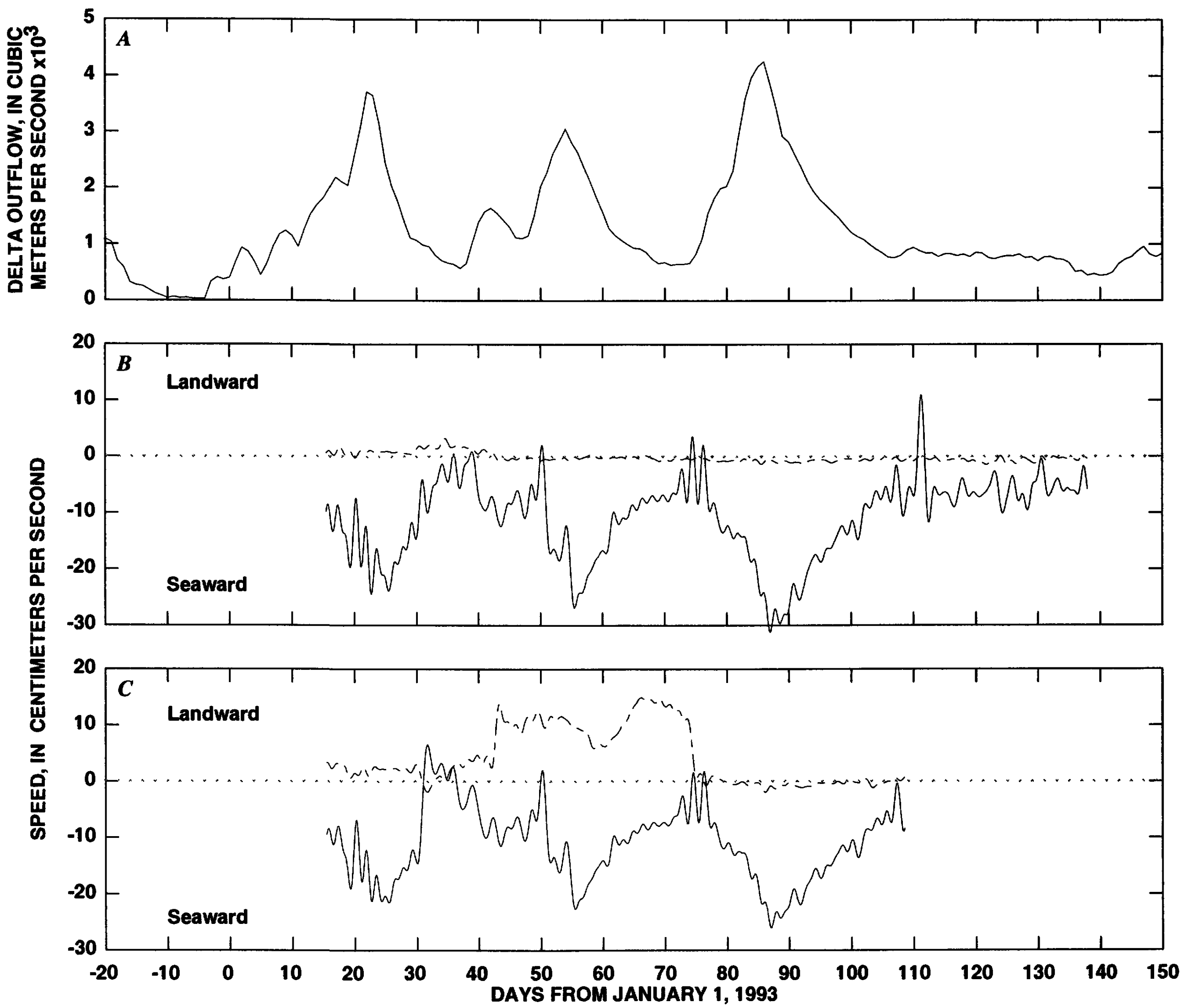

Figure 10. Time-series plots of ***A***, Delta outflow; ***B***, near-surface; and ***C***, near-bed longitudinal (solid) and transverse (dashed) residual current speed, station CUT, Suisun Bay, California. Principal direction is 128.5°.

Gravitational circulation can occur even if the estuary is vertically well mixed because a longitudinal density gradient results in vertical isohalines, and, in the absence of other forces, the natural tendency is for the estuary to become stratified (horizontal isohalines). During most of this study, however, high inflows of freshwater entering Suisun Bay advected salinity out of the bay so that the required horizontal density gradient for gravitational circulation did not exist in Suisun Bay.

Residual flows were nearly always seaward at the ADCP stations (station BULLS, fig. 9), as well as at the single-point velocity current meter stations (station CUT, fig. 10). Figure 11 shows Delta outflow, the longitudinal and transverse near-bed residual current speeds, and the low-pass filtered salinity at station BULLS. The seaward residual currents at station BULLS exceeded 20 cm/s near the peaks in Delta outflows. These residual current peaks occurred on calendar days 23, 56, and 88 (January 23, February 25, and March 29, 1993) as shown in figure 11. During periods of low or decreasing flows and neap tidal conditions near calendar days 40, 50, 69, and 70 and after about day 90 (February 9 and 19, March 10–11, and after March 31, 1993), the seaward components of residual flows decreased substantially. The principal reason that peaks in the near-bed residuals do not coincide exactly with peaks in Delta outflow is because the northern reach generally fills with water during the

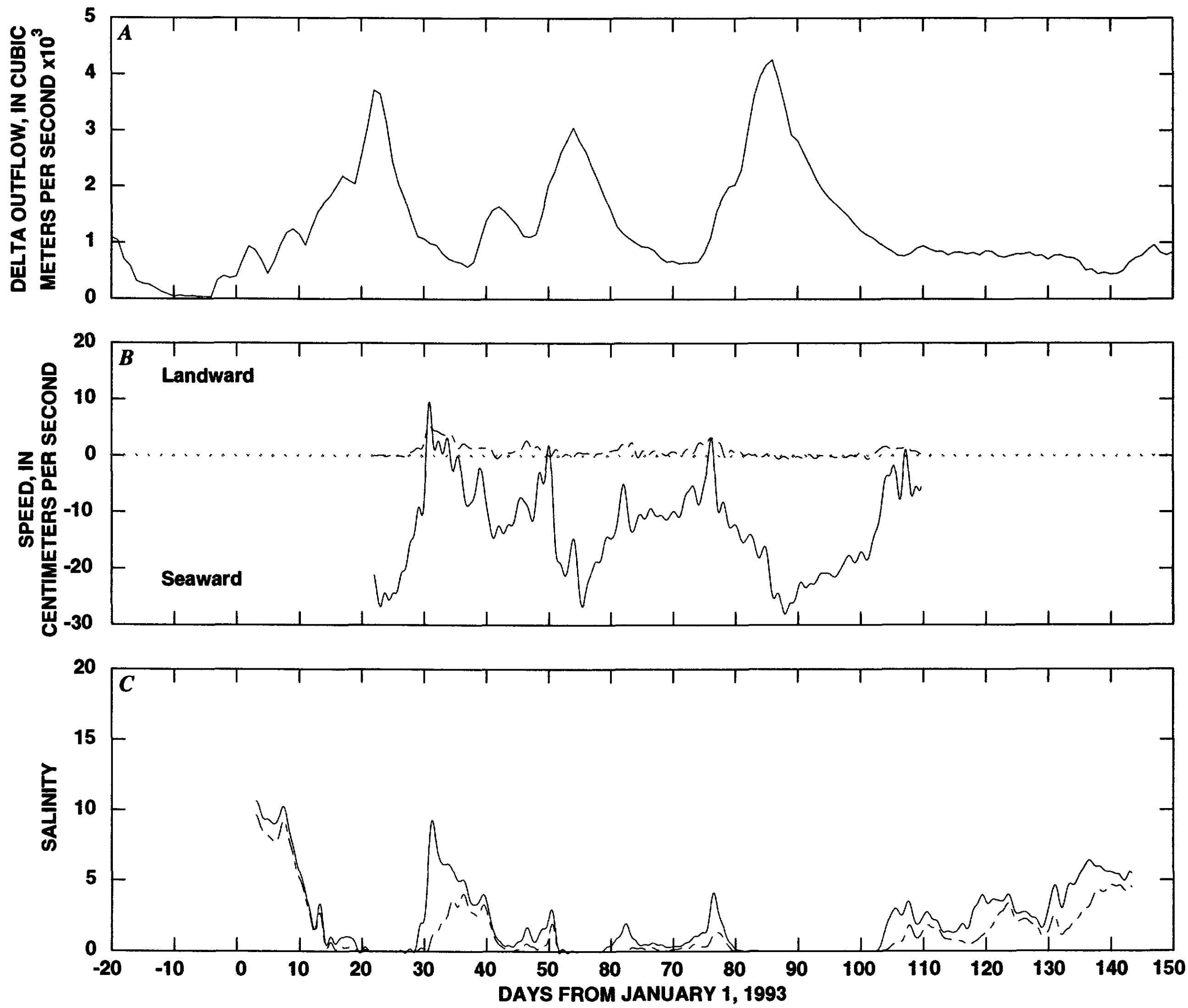

Figure 11. Time-series plots of ***A***, Delta outflow; ***B***, near-bed longitudinal (solid) and transverse (dashed) residual current speed; and ***C***, near-bed (solid) and near-surface (dashed) low-pass-filtered salinity, station BULLS, Suisun Bay, California. Principal direction is 73.5°. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

transition from spring to neap tides. There was a substantial transverse velocity component in the near-bed current meter at station CUT during calendar days 38 to 74 (February 7 to March 15, 1993) (fig. 10), which probably is because the instruments were not deployed in precisely the same horizontal position, resulting in a slight change in the principal direction. However, no corresponding transverse component was recorded by the upper current meter.

Stations HDOL and HS (fig. 12) indicate the presence of clockwise residual circulation within Honker Bay late in the season during the period of decreasing inflows (after calendar day 112; April 22, 1993). Basically figure 12 shows the residual currents entering the bay through station HDOL (fig. 2) at about 10 cm/s and leaving the bay through station HS at 25 cm/s.

Taken together, the residual flows indicate strong seaward flows in the channels, including the secondary channels between Roe and Ryer Islands and Suisun Cutoff. Current-meter data from station GRIZ indicate a southwesterly flow from Grizzly Bay into Suisun Cutoff (station CUT in fig. 2), and the two current meters in Honker Bay (fig. 12) indicate a clockwise residual circulation.

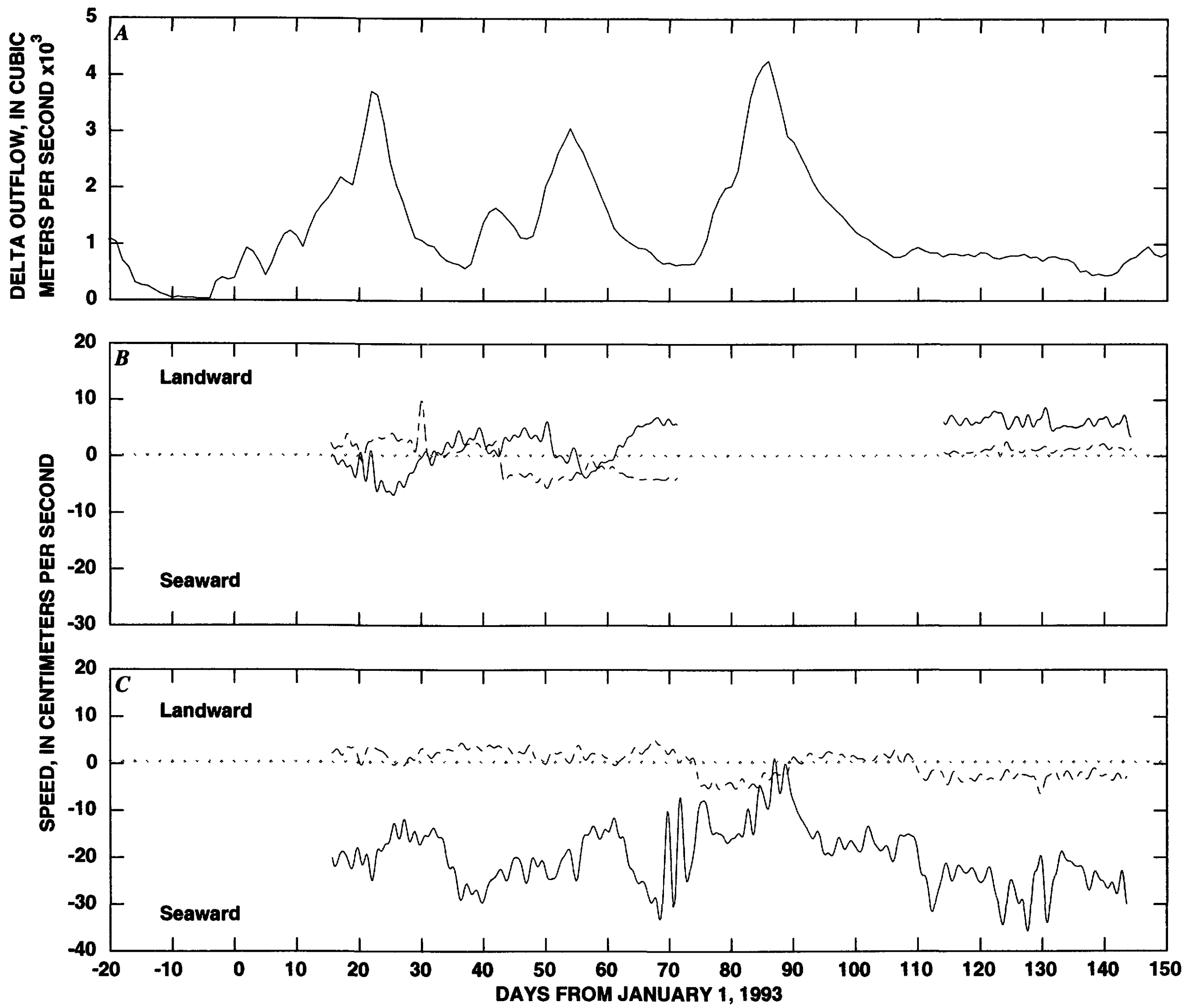

Figure 12. Time-series plots of ***A***, Delta outflow; and ***B***, longitudinal (solid) and transverse (dashed) residual current speed, station HDOL (principal direction is 100.2°); and ***C***, station HS (principal direction is 40.7°) Suisun Bay, California.

SALINITY CHARACTERISTICS

For the period of this study, the salt field and the ecologically important mixing zone (~salinity of 2) cycled out of and into Suisun Bay three different times following three distinct outflow events (>3,000 m^3/s) (fig. 12). The typical inverse relation between Delta outflow and low-pass filtered salinity is shown in figure 11. Following the first pulse of freshwater near calendar day 24 (January 24), salinities recovered rapidly on the west side of Suisun Bay to about half the previous values. The return of salinities at station BULLS was accompanied by large vertical stratification where the low-pass filtered salinity difference between the near-bed and near-surface sensors exceeded about 10 on calendar day 31 (January 31, 1993) (fig. 11). The rapid recovery of salinities, accompanied by a large vertical stratification, was likely the result of a combination of decreasing inflows, a rapid relaxation of the local horizontal density gradients, and reduced vertical mixing during neap tides (fig. 9). After each inflow peak in excess of 2,000 m^3/s, the salinity and the salinity gradient were pushed farther seaward, which caused longer, successive returns of salinity into Suisun Bay.

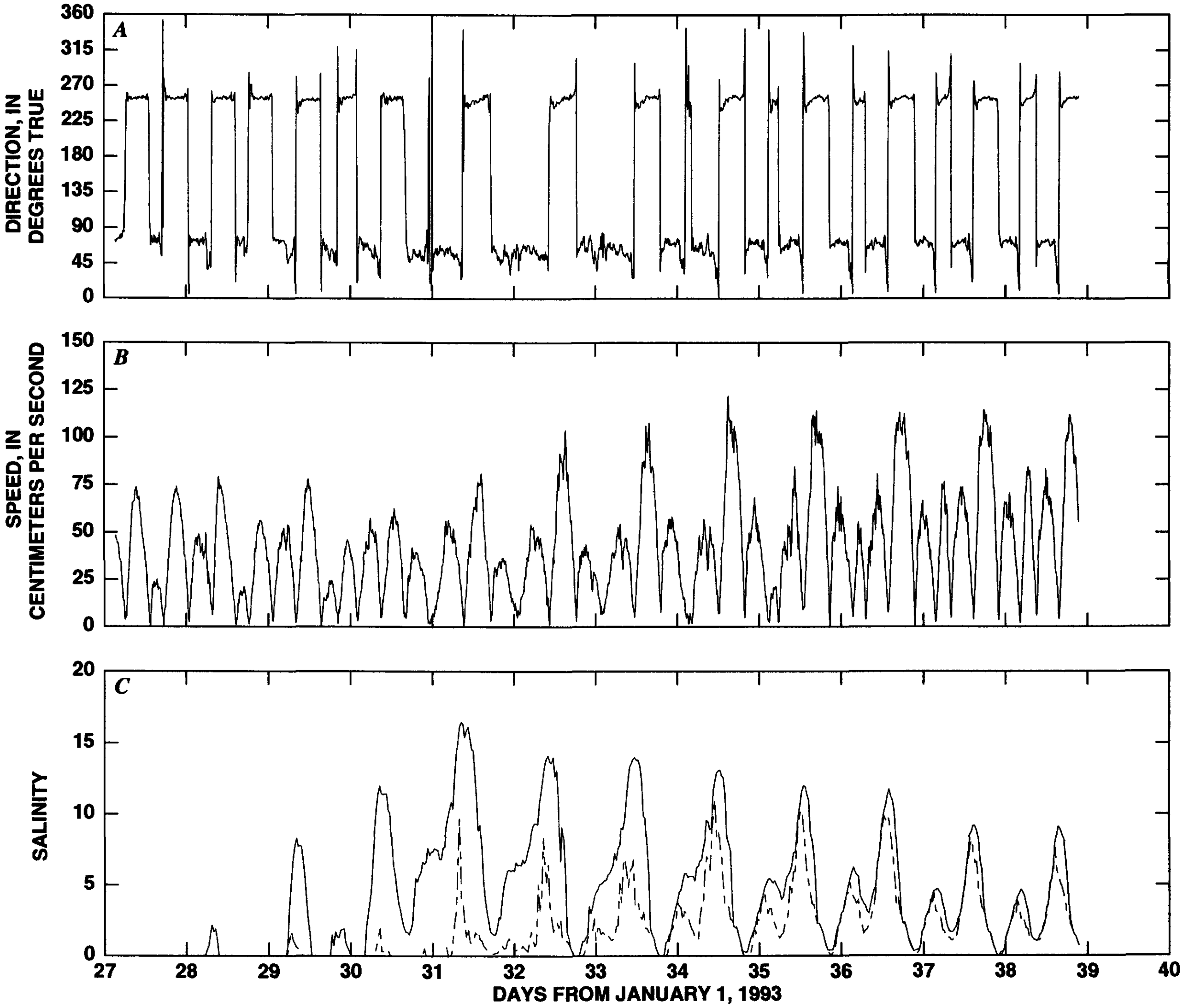

Figure 13. Time-series plots of ***A,*** Delta near-bed current direction; ***B,*** current speed; and ***C,*** near-bed (solid) and near-surface (dashed) salinity, station BULLS, Suisun Bay, California. Salinity shown without units.

The tidal time-scale details of the return of salinity to station BULLS after the first Delta outflow peak are shown in figure 13. The weak ebbs on calendar days 31-34 were virtually nonexistent (fig. 13), producing a landward residual near the bed (fig. 9). This observation, coupled with the fact that the near-bed salinities increased from 0 to 16 in 3 days, suggests that a near-bed tidal time-scale density current pulse that brought high salinity water landward, created a rapid increase in salinity and vertical stratification. As spring tides approached after day 33, tide-induced vertical mixing increased, which reduced vertical stratification.

SUMMARY

Hydrodynamic measurements were made by the USGS in Suisun Bay, California, between December 11, 1992, and May 31, 1993. The data are presented in time-series form where the tidal timescale characteristics are reflected in raw data plots and in harmonic analysis results. The tidally averaged variations in the data are captured in plots of the low-pass filtered data. These data show that transport in Suisun Bay depends on tides, tidal currents, horizontal and vertical salinity gradients, changes in freshwater inflows, and the interactions among them. The direct effects of large variations in freshwater inflows in

Suisun Bay are documented by the data presented in this report.

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APPENDICES

APPENDIX A—DATA-REDUCTION DETAILS

Basic data and equipment descriptions, formats, and data processing procedures are discussed by data type beginning with ADCP data. Specifications for all in situ instruments used are listed in table 2.

Acoustic Doppler Current Profiler Data

An ADCP determines water current velocity profiles by transmitting sound pulses at a fixed frequency into the water column and measuring the frequency (or phase) shift in acoustic echoes reflected from inorganic and organic material (scatterers) in the water. The frequency or phase shift provides Doppler information used to determine current-velocity components along the axes of the acoustic beams, typically, four transducers project sound into the water column at 30° or 20° from the vertical. Trigonometric relations convert three of the four velocity measurements along the acoustic beams into three orthogonal velocity components (the fourth transducer is for redundancy). The velocity profile is determined by sampling the reflected acoustic signals at discrete time intervals that correspond to depth intervals (also called BINs). The ADCPs used in this study were SC-1200 units manufactured by RD Instruments, Inc. The SC-1200 ADCP transmits its acoustic signals at 1,229 kiloHertz (kHz), is self contained, and is capable of storing data in internal Erasable Programable Read Only Memory (EPROM). A complete description of ADCP principles of operation is given by RD Instruments, Inc. (1989). In practice, the upper 15 percent (6 percent for the broad band with 20° transducer beam angles used in this study) of the water column cannot be sampled accurately because of parasitic acoustic side lobes that interfere with the primary acoustic signals. The center of the first measured BIN above the transducers is equal to the transmit pulse plus the blanking distance (1.5 m for the narrow-band ADCP and 1.2 m for the broad-band ADCP). Blanking distance is the distance (time) necessary for transducers and associated electronics to recover before receiving reflected acoustic signals.

For this study, the ADCPs were suspended from metal (nonmagnetic materials such as aluminum, monel, or stainless steel) platforms to protect the transducers and to keep the transducer head level at 0.7 m above the bed. In the case of the narrow-band instruments, the BIN width was set to 1 m; velocity profiles include data starting at 2.2 m (center of BIN 1) above the estuary bed. In the case of the broad band, the BIN width was set at 50 cm; the center of the first BIN was 1.9 m above the bed. The sampling interval was 10 minutes and each data sample (ensemble) was an average of a sufficient number of acoustic pings such that the standard deviation (short-term random error) of the ensemble was less than 1 cm/s. Complete descriptions of velocity errors in ADCPs are given in reports by Chereskin and others (1989) and Burau and others (1993).

Sea-Level Data

Sea-level data at stations MART and MAL (fig. 2) were obtained from DWR. At stations MART and MAL, a JGS model SE-104 incremental encoder with a float and tape is used to measure sea level to an accuracy of 0.3 cm.

Salinity Data

Salinity is a computed quantity derived from conductivity and temperature measurements. Salinities given in this report were computed using the 1985 UNESCO standard (UNESCO, 1985) and a low salinity (<2) correction as reported by Hill and others (1986). Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). The sensors, the calibration methods, and the computational details are presented in this section.

Conductivity-Temperature Sensors

The in situ conductivity-temperature sensor (CT) data-loggers used in this study were the Hydrolab, DataSonde I, series 2000, digital recording, water-quality instruments. This instrument is self-contained and is capable of storing as much as about 35 days of data when recording at the 30-minute sample interval used in this study.

The CT instruments were serviced routinely to reduce biofouling. The deployment configuration figures for each station provide the exact servicing intervals. Prior to deployment, each CT sensor was calibrated to known conductance standards. Upon recovery, but prior to sensor cleaning, the instrument readings were compared to conductance standards. Table A1 gives the post-deployment differences between the known standards and the instrument readings. In general, frequent sensor cleaning, coupled with the relatively fresh low-temperature water in Suisun Bay during this study, kept sensor drift from marine biofouling to a minimum.

For completeness, CT data collected by USGS and DWR at Wickland Pier, Martinez, and Mallard Island also are presented in this report. The CT sensors at station WICK are YSI model 33 with the following specifications: (1) temperature range -2°C–50°C and accuracy ±0.15°C; (2) conductivity range 0–50 millisiemens per centimeter (mS/cm) and accuracy ±2.5; and (3) salinity range 0-40 and accuracy 0.2. The Wickland station is serviced monthly.

The data for stations MART and MAL were obtained from DWR. The near-surface CT sensors at stations MART and MAL were Schneider Instruments model RM25-C, and the near-bed conductivity sensors were Foxboro model 872. These stations were visited approximately every 14 days. During these visits, all probes were cleaned and the data were verified.

Conductivity-Temperature-Depth Sensors

An Ocean Sensors OS200 CTD (pressure) instrument was attached to the mooring platform of the narrow-band ADCP deployed in Bulls Head Channel (station BULLS). This instrument is self-contained and was set up to record date, time, pressure, temperature, conductivity, and salinity at 15-minute intervals.

Salinity Computation

Conductivity and temperature measured by the water-quality sensors were converted to salinity following the 1985 UNESCO standard (UNESCO, 1985) in the range of 2-42. Salinities below 2 were computed using the extension of the practical salinity scale proposed by Hill and others (1986). The relations used to convert measured temperatures, T (°C), and conductivities, $C_{S,T,P}$, into the salinities presented in this report are as follows:

$$S = \sum_{i=0}^{5} (a_i + b_i\, f(T)) R_t^{\frac{i}{2}} - \frac{a_0}{1 + 1.5x + x^2} - \frac{b_0\, f(T)}{1 + y^{\frac{1}{2}} + y + y^{\frac{3}{2}}} \quad (1)$$

where $C_{S,T,P}$ is the reciprocal of the resistivity, in ohms, normalized to a 1-cm cube of a liquid at a specified temperature. $C_{S,T,P}$ has the units ohm^{-1} cm^{-1}. The reciprocal of the ohm was formerly called a "mho." Thus, units of conductivity were mhos cm^{-1}, or, in estuarine waters, millimhos cm^{-1} (mmhos/cm). Present SI usage is the mS/cm.The first term represents the 1985 practical salinity scale and the second and third terms are the low salinity extension where

$$f(T) = \frac{(T - 15)}{1 + k(T - 15)} \quad (2)$$

$$x = 400R_t,\ y = 100R_t,\ k = 0.0162 \quad (3)$$

$$a_0 = 0.0080,\ a_1 = -0.1692,\ a_2 = 25.3851 \quad (4)$$

$$a_3 = 14.0941,\ a_4 = -7.0261,\ a_5 = 2.7081 \quad (5)$$

$$b_0 = 0.0005,\ b_1 = -0.0056,\ b_2 = -0.0066 \quad (6)$$

$$b_3 = -0.0375,\ b_4 = 0.0636,\ b_5 = -0.0144 \quad (7)$$

where R_t is the ratio between the conductivity of some unknown sample and the standard sea water conductivity at some constant temperature T°C and zero pressure.
R_t is computed as

$$R_t = \frac{C_{S,T,P}}{C_{35,T,P}} \quad (8)$$

where $C_{S,T,P}$ is the conductivity of water with S salinity;

T is temperature, in °C; and

p is pressure, in bars.

$C_{35,T,P}$ is computed using methods reported by Kjerfve (1979) as

$$C_{35,T,0} = \sum_{i=0}^{3} c_i T^i \quad (9)$$

Table A1. Differences between conductance standards and instrument readings after each field deployment at stations, Suisun Bay, California

[Values given in millisiemens per centimeter at 25°C; serial numbers shown on figures B1, C1, D1, E1, F1, G1, H1, I1, J1, K1, L1, and M1]

Station	Serial number	Standard	Reading	Difference
		First Deployment		
BULLS	8	2.54	2.55	0.01
BULLS	5	2.54	2.51	-.03
CONC	7	2.54	2.68	.14
CONC	2	2.54	2.47	-.07
MID	3	2.54	2.52	-.02
MID	4	2.54	2.58	.04
HB	1	2.54	2.61	.07
		Second Deployment		
BULLS	8	2.54	2.61	.07
BULLS	8	10.10	10.57	.47
BULLS	5	2.54	2.45	-.09
BULLS	5	10.10	9.97	-.13
CONC	7	2.54	2.52	-.02
CONC	7	10.10	9.80	-.30
CONC	2	2.50	2.49	-.01
CONC	2	10.10	10.22	-.12
MID	4	2.50	2.41	-.09
MID	4	10.10	9.80	-.30
MID	3	2.50	2.42	-.08
MID	3	10.10	9.65	-.45
HB	1	2.54	[1]—	—
HB	1	10.10	—	—
		Third Deployment		
BULLS	8	2.50	2.54	.04
BULLS	8	10.10	10.19	.09
BULLS	5	2.50	2.51	.01
BULLS	5	10.10	9.93	-.17
CONC	7	2.50	2.44	-.06
CONC	7	10.10	10.12	.02
CONC	2	2.50	2.29	-.21
CONC	2	10.10	9.92	-.18
MID	4	2.50	2.54	.04
MID	4	10.10	10.29	.19
MID	3	2.50	[2]—	—
MID	3	10.10	—	—
HB	6	2.54	2.50	-.04
HB	6	10.10	10.02	-.08

Table A1. Differences between conductance standards and instrument readings after each field deployment at stations, Suisun Bay, California—Continued

Station	Serial number	Standard	Reading	Difference
		Fourth Deployment		
BULLS	8	2.54	2.49	-0.05
BULLS	8	10.10	9.69	-.41
BULLS	5	2.50	2.52	.02
BULLS	5	10.10	9.74	-.36
CONC	7	2.54	2.48	-.06
CONC	7	10.10	9.75	-.35
CONC	2	2.54	2.16	-.38
CONC	2	10.10	9.35	-.75
MID	4	2.50	2.37	-.13
MID	4	10.10	10.10	.00
MID	1	2.50	2.43	-.07
MID	1	10.10	9.65	-.45
HB	6	2.50	2.49	-.01
HB	6	10.10	9.84	-.26
GRIZ	3	2.50	2.46	-.04
GRIZ	3	10.10	9.62	-.48
		Fifth Deployment		
BULLS	8	2.53	2.64	.11
BULLS	8	10.00	10.07	.07
BULLS	5	2.50	2.56	.06
BULLS	5	10.00	9.91	-.09
CONC	7	2.53	2.64	.11
CONC	7	10.00	10.08	.08
CONC	2	2.53	2.39	-.14
CONC	2	10.00	9.40	-.60
MID	4	2.50	[3]—	—
MID	4	10.00	—	—
MID	1	2.50	2.51	.01
MID	1	10.00	9.76	-.24
HB	6	2.50	2.47	-.03
HB	6	10.01	9.75	-.26
GRIZ	3	2.53	2.60	.07
GRIZ	3	10.00	9.81	-.19
Mean				-.10
Standard deviation				.21

[1]Instrument (conductance board) failed after recovery of data.
[2]Instrument failed; no data collected so data check omitted.
[3]Instrument lost.

$$c_0 = 29.03916, c_1 = 8.6297124 \times 10^{-1}, c_2 = 4.515879 \times 10^{-3} \quad (10)$$

$$c_3 = 2.291189 \times 10^{-5} \quad (11)$$

To compute salinity, $C_{35,T,0}$ is first computed with the measured temperature, T, using equation 9. R_t is then computed from equation 8 using the measured conductivity $C_{S,T,0}$, and $C_{35,T,0}$. R_t and the measured temperature, T, are substituted into equation 1 to compute the measured salinity.

Finally, the term specific conductance (SC) is used in this report when measurements are made at or corrected to a standard temperature, typically 25°C. To compute SC from the measured electrical conductivity, the following relation may be used (Miller and others, 1988):

$$SC = \frac{C_{S,T,0}}{1 + 0.0191(T - 25)} \quad (12)$$

Current-Meter Data

The in-situ current meters used during this study were Endeco-174 digital recording current meters and an EG&G ACM3 acoustic current meter. The Endeco-174 is an axial-flow, ducted-impeller instrument that is capable of storing as much as 40 days of data when recording at the 2-minute sample interval used during these deployments. The Endeco-174 had a conductivity sensor with a limited range of 5-55 mS/cm; thus, low salinity values fell below the sensor threshold during much of the study. Current speed on the Endeco-174 was determined by measuring the displacement of a speed encoder that is driven by the impeller through a 500:1 reduction gear and thus represents an average speed during the recording period. Current direction on the Endeco-174 was determined from a damped magnetic compass at the time of the sample reading. Time series of 2-minute data were averaged (velocity data were vector averaged) to 30-minute time series before plotting. An EG&G ACM3 acoustic current meter also was used to measure water velocity, water depth, water temperature, and suspended-solids concentration. This instrument has an internal magnetic compass and tilt sensors that provide velocity output in terms of current speed and direction. A pressure transducer was used to measure the mean water depth, an optical sensor was used to measure suspended-solids concentration.

File Formats

Two file formats are described in the following sections to facilitate data transfers: (1) time-series and (2) ADCP data.

Time-Series File Format

The time-series format is used to store all the data described in this report except the ADCP data. Figure A1 shows an example time series. In this format, the header information describes the number of channels, what data are stored in the various channels and in what order. Each line in this example is described in detail in what follows:

LINE 1: Station name.

LINE 2: Header information, stored as a character variable.

LINE 3: Header that gives a description for the next line of data.

LINE 4: *yr*: Start year of time series xxxx, where xxxx is the year; columns 8-9.

- *mn*: Start month of time series; columns 11-12.
- *dy*: Start day of series; columns 14-15.
- *hr*: Start hour of series in decimal hours*100 (for example, 3:45pm is 1575); columns 17-20.
- *days*: Represents the number of days referenced to the year 2000 to the first day of the year or record (for example, days = 0 on January 1, 2000). This allows for absolute time referencing when time series are compared with differing deployment start years; columns 25-30.
- *dt*: Sampling interval, in minutes; columns 31-40.
- *nchan*: Number of data channels (excluding time information); columns 41-46.
- *mxdig*: Maximum number of digits used for end data channel; columns 47-52.

LINE 5: Header information stored as a character variable.

```
Station name: HDOL                                          LINE  1
Position: 38 02.896, 122 06.019                             LINE  2
start:-yr-mn-dy---hr-----days----------dt-nchan-mxdig       LINE  3
   1995  7 17 910  -1826 10.00000    6    6                 LINE  4
                                                            LINE  5
ch---------------name-digit-dtype-isens--ivec--iblg         LINE  6
 1CONDUCT, mS/CM  2    8    1    0    0                     LINE  7
 2TEMP, DEG. C.   2    6    1    0    0                     LINE  8
 3DEPTH, M        2    4    1    0    0                     LINE  9
 4SALINITY        2    5    1    0    0                     LINE 10
 5OBS VOLT        2   18    1    0    0                     LINE 11
 6FLOUR VOLT      3   29    1    0    0                     LINE 12
--------days--------ch1-----ch2--ch4------ch5--ch6          LINE 13
 19838208  -11 2114    76    0     132  366                 LINE 14
 19838875  -12 2111    72    0     132  368                 LINE 15
 19839583  -12 2112    73    0     122  362                 LINE 16
 19840292  -12 2116    65    0     130  370                 LINE 17
   .    .    .    .    .    .    .    .    .    .
   .    .    .    .    .    .    .    .    .    .
   .    .    .    .    .    .    .    .    .    .
```

Figure A1. Example time-series file format.

LINE 6: Header that gives a description for the next line of data.

LINES 7—12:

ch: Channel number represents the column number to the right of time column in lines 13 forward (for example, for the data set pictured, ch1 is conductance, ch2 is temperature, and so forth). The assignment of these data columns is completely flexible and will change depending on the data type; columns 1-2.

name: The name of the channel and the units the data are collected in. The name is used for plotting and output of data; column 3-22.

digit: All data are stored as integers to reduce the size of the files. *Digit* represents the location of the decimal place. The actual data are obtained by dividing the integer values in a given column by 10^{digit}; columns 23-28.

dtype: Data type code. This code (a two-digit integer) allows the same data types to be overlaid on the same plot. Examples of data type codes are conductivity=8, water temperature=6, and so forth; columns 29-34.

isens: Sensor number, where isens=1 is the bottom sensor; columns 36-40.

ivec: Indicates whether data are scalar (0) or vector quantity (1); columns 41-46.

iblg: Associates two parts of a vector quantity, *iblg*=1 is direction and *iblg*=2 is speed; columns 47-52.

LINE 13: Header that gives a description for the next line of data.

LINE 14: Number of days since the beginning of the start year $*10^5$. Absolute referencing to the year 2000 is obtained by adding days in **LINE 4** to the days in this column. Note: January 1, 19xx, equals calendar day 1. The days field takes nine spaces (columns).

The next six columns of data are defined by the header information. There are six columns because, in this case, there are six data channels. The number of data channels is defined by the value of **NCHAN**. Each data channel takes six spaces (or columns).

Acoustic Doppler Current Profiler File Format

The ADCP file format described below applies to the raw data and the low-pass filtered data. The ADCP file format begins with header information that describes the station name, start and end dates, the number of samples in the vertical (BINs), the time step, and the station location. An example of this format is given in figure A2. After the header is a time series of profiles that begins with a time stamp followed by the profile information.

LINE 1: Station name

LINE 2: Columns 1-3: starting calendar day of the time series
Columns 4-7: starting year of the time series
Columns 8-10: ending calendar day of the time series
Columns 11-14: ending calendar year of the time series

LINE 3: Latitude: degrees (columns 1-2), minutes (columns 3-4), seconds (columns 6-7)
Longitude: degrees (columns 7-9), minutes (columns 10-11), seconds (columns 12-13)

LINE 4: Columns 1-5: first BIN in profile
Columns 11-15: last BIN in profile
Columns 21-30: time step in decimal hours (in this case 10 minutes)

LINE 5: Columns 1-5: start year, xxxx
Columns 6-10: start month
Columns 11-15: start day
Columns 16-20: start hour in decimal hour*100 (for example, 3:45pm is 1575)

LINES 6-15: Contain the first velocity profile where **LINE 6** is the time when the profile was taken and **LINES 7-15** contain the velocity data. In this case, nine BINs make up the velocity profile, as specified in **LINE 4** of the header.

LINE 6: Columns 1-10: elapsed time, in decimal hours
Columns 11-20: zero (not used)
Columns 21-25: year (19xx) of sample
Columns 26-30: month of sample
Columns 31-35: day of sample
Columns 36-70: decimal hour*100 of sample (for example, 3:45pm is 1575)

LINES 7-15: Contain the profile data
Columns 1-6: BIN number where BIN 1 is near the ADCP transducer.
Columns 7-16: U or east velocity component
Columns 17-26: V or north velocity component

```
VNB1                                     station name                     LINE   1
2119931101993                            Start and stop dates             LINE   2
38 3441220415                            latitude and longitude           LINE   3
 1      9      0.16667                   first BIN, last BIN Delta T      LINE   4
1993   1  21  771                        start date and time of series    LINE   5
 0.00000  0.00000  93  1   21   771                                       LINE   6
  1   -2.95    -1.20                                                      LINE   7
  2   -2.10    -0.60                                                      LINE   8
  3   -2.50     0.30                                                      LINE   9
  4   -2.80     0.10                                                      LINE  10
  5   -1.65     1.10                                                      LINE  11
  6   -2.40     1.40                                                      LINE  12
  7   -0.85     1.05                                                      LINE  13
  8   -2.20     1.85                                                      LINE  14
  9   -1.75     1.25                                                      LINE  15
 0.17000  0.00000  93  1   21   788                                       LINE  16
  1   -4.43    -1.80                                                        .    .
  2   -3.15    -0.90                                                        .    .
  3   -3.75     0.45                                                        .    .
  4   -4.20     0.15
  5   -2.47     1.65
  6   -3.60     2.10
  7   -1.28     1.57
  8   -3.30     2.78
  9   -2.63     1.88
 0.3400   0.00000  93  1   21   805
  1   -5.16    -2.10
  2   -3.67    -1.05
  .     .      .
  .     .      .
  .     .      .
  .     .      .
```

Figure A2. Example acoustic Doppler current profiler file format.

APPENDIX B—STATION BULLS

Station Name: **BULLS**
(Bulls Head Channel)
Position: Lat 38° 03' 44" N
Long 122° 04' 15" W
Depth: 11.5 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t:	Hydrolab	8	12/11/92 (-20) - 05/25/93 (145)
CT_m:	Hydrolab	5	12/11/92 (-20) - 05/25/93 (145)
CTD_b:	Ocean Sensors	224	01/21/93 (21) - 04/26/93 (116)
ADCP:	RDI	386	01/21/93 (21) - 04/26/93 (116)

CT Sensors serviced: 01/13/93 (13), 02/11/93 (42), 03/16/93 (75), 04/01/93 (91)

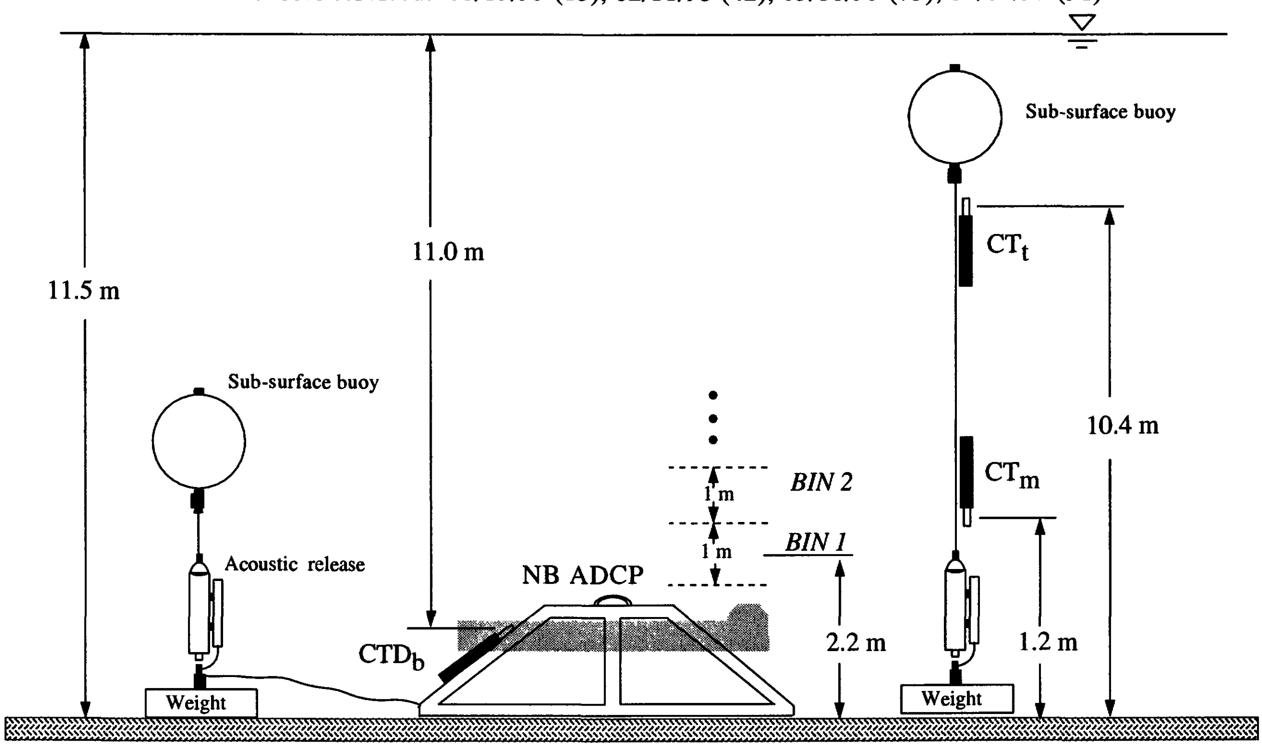

Figure B1. Configuration of instrument deployment, station BULLS, December 11, 1992, through May 25, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

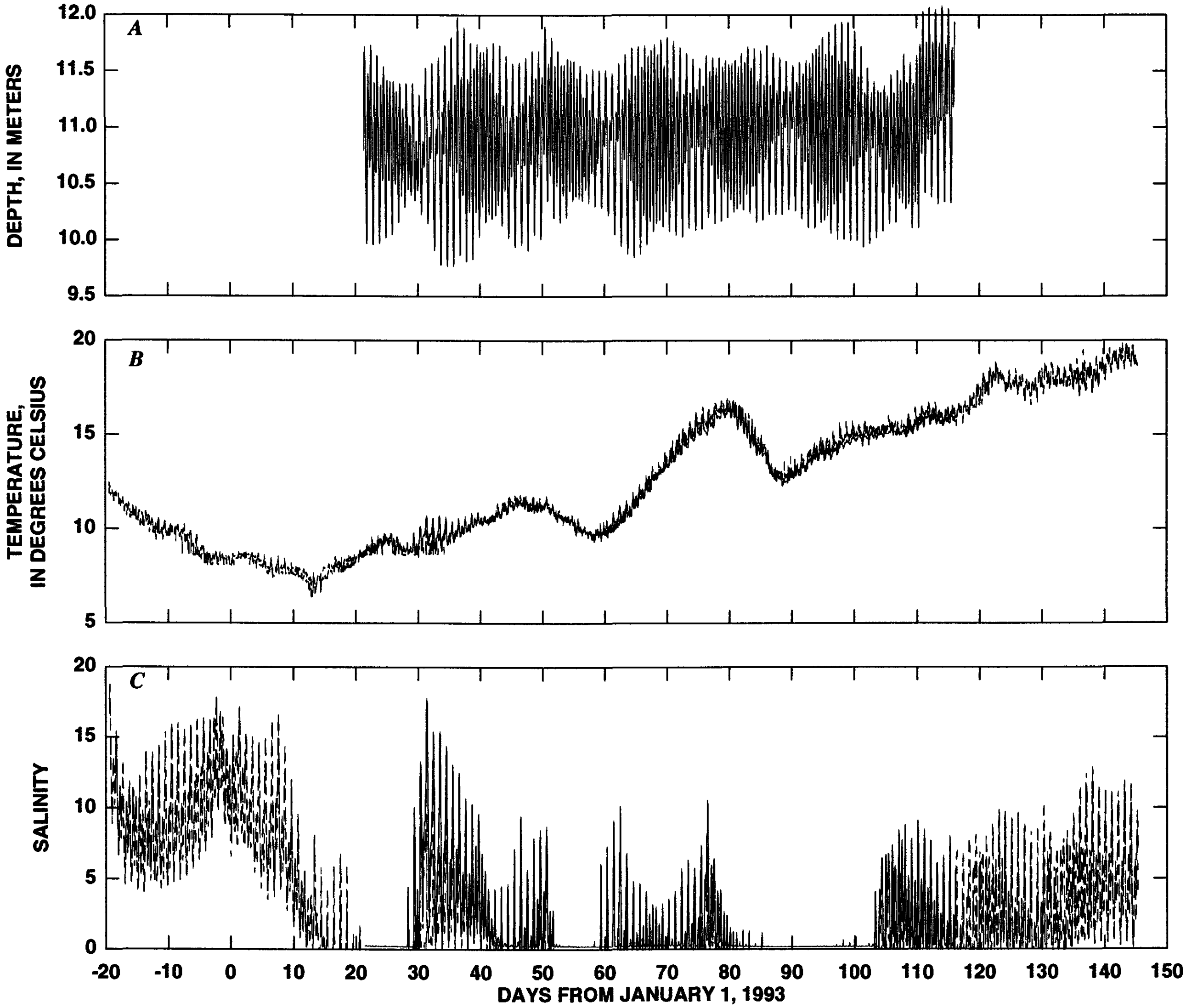

Figure B2. Time-series plots of ***A***, depth; ***B***, temperature; and ***C***, salinity, station BULLS, December 11, 1992, through May 25, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) mid-depth sensor, (chain dashed), near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

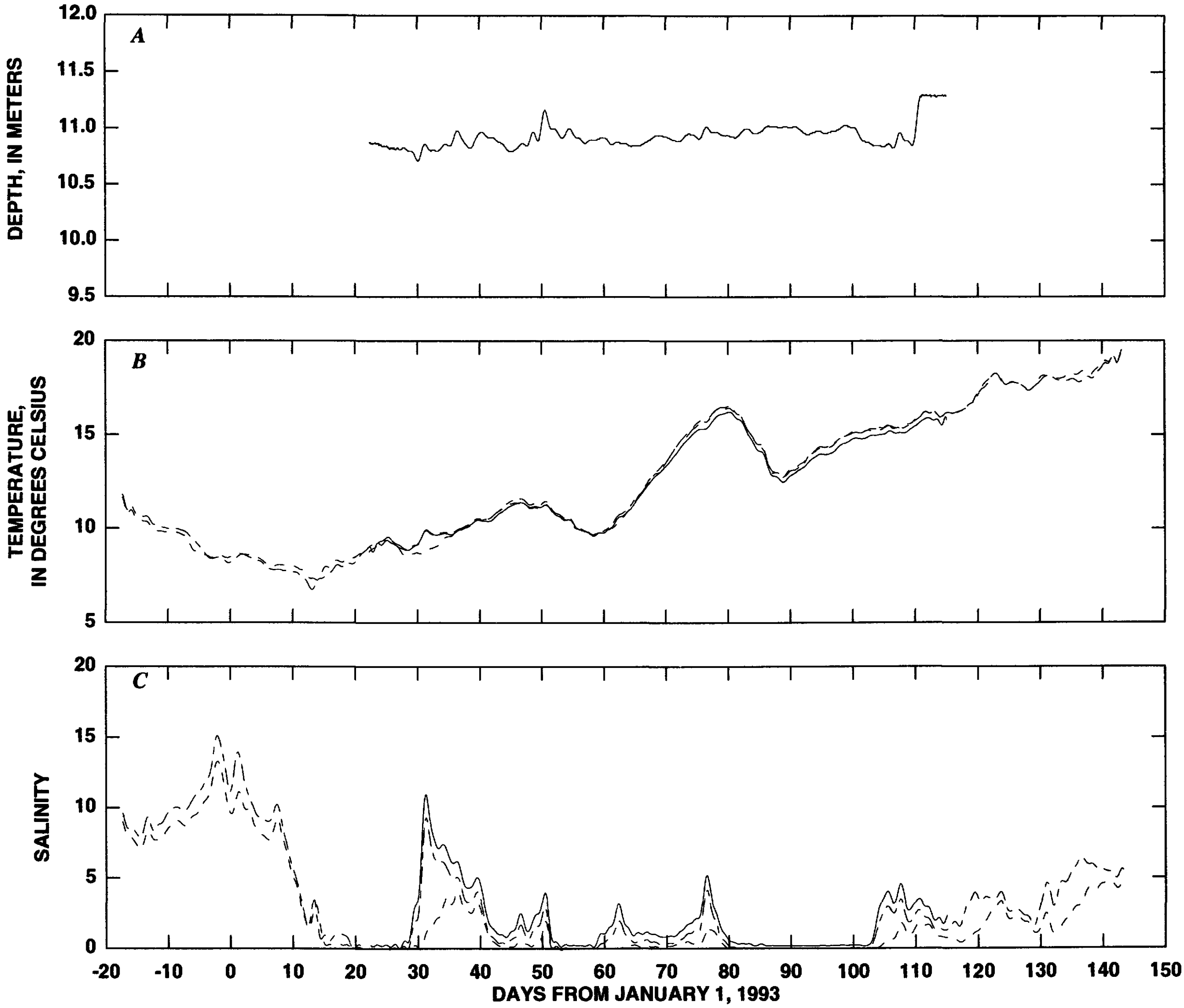

Figure B3. Time-series plots of low-pass filtered ***A***, depth; ***B***, temperature; and ***C***, salinity, station BULLS, December 11, 1992, through May 25, 1993, Suisun Bay, California. (Solid) mid-depth sensor, (dashed) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

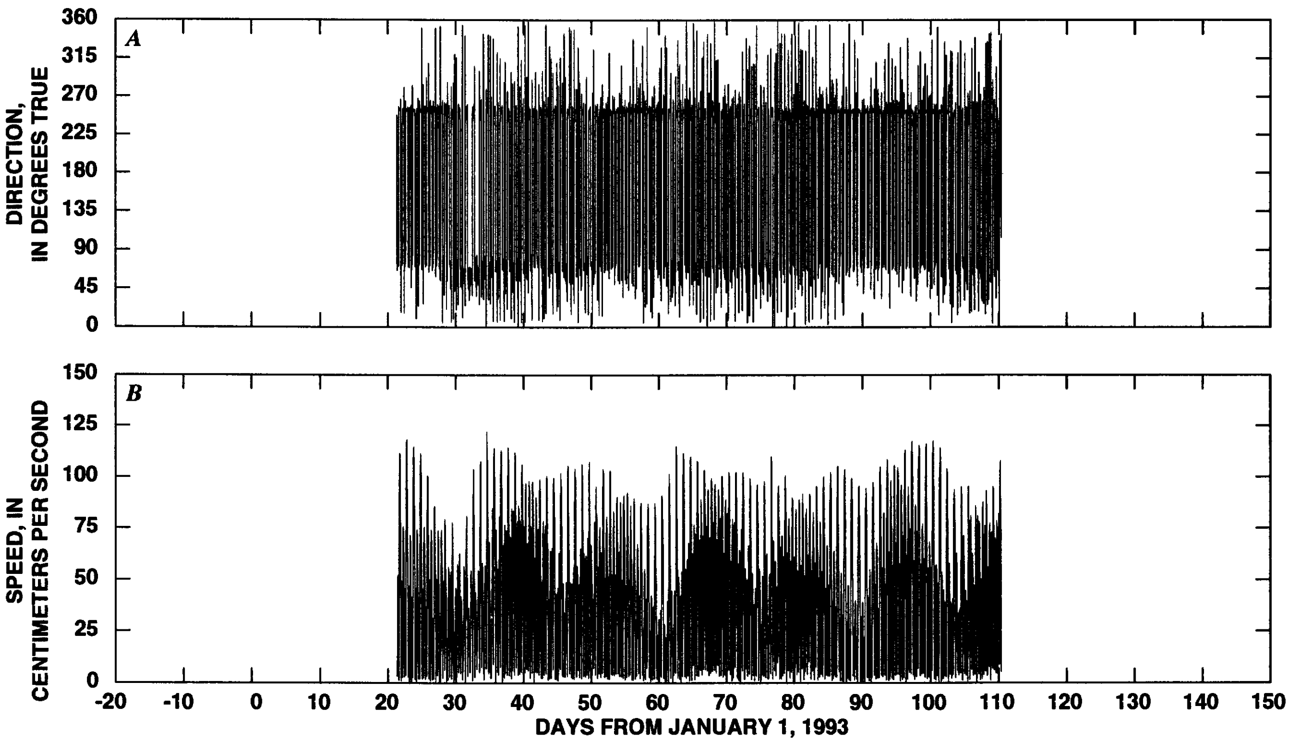

Figure B4. Time-series plots of tidal currents, station BULLS, January 21 through April 20, 1993, BIN 1 near-bottom BIN, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

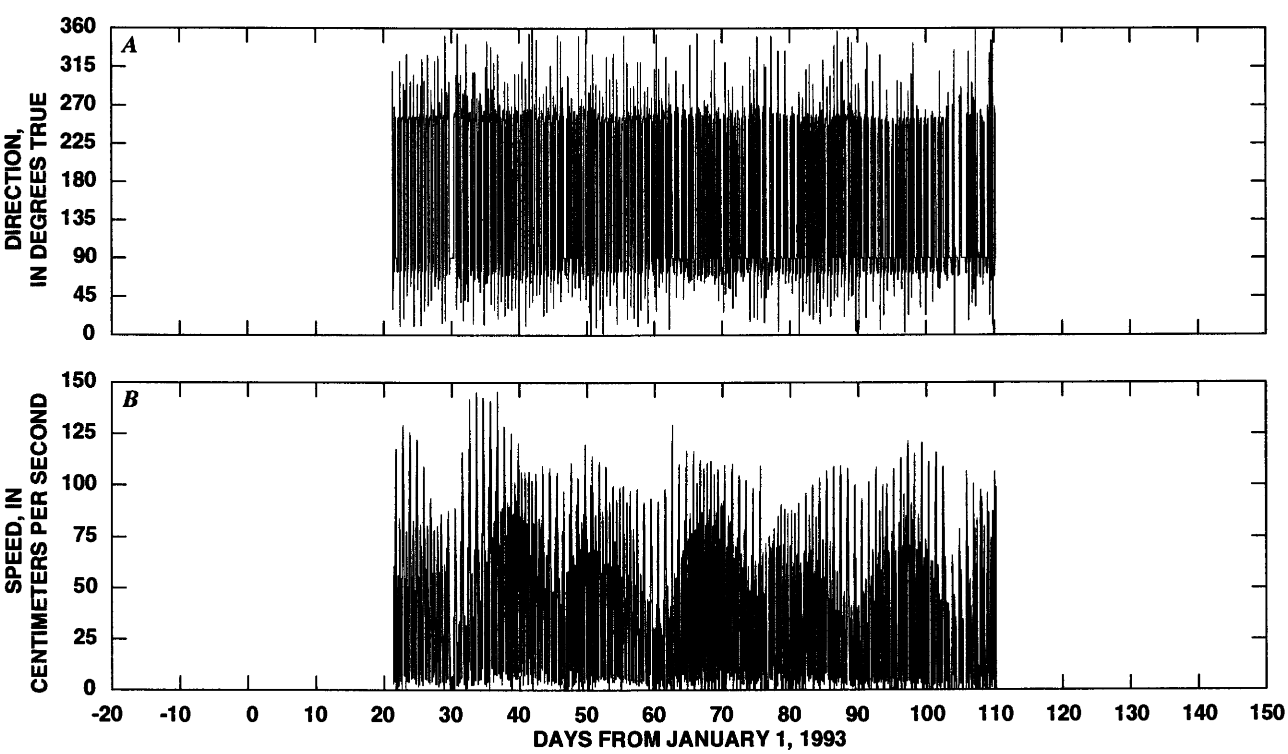

Figure B5. Time-series plots of tidal currents, station BULLS, January 21 through April 20, 1993, BIN 7 near-surface BIN, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

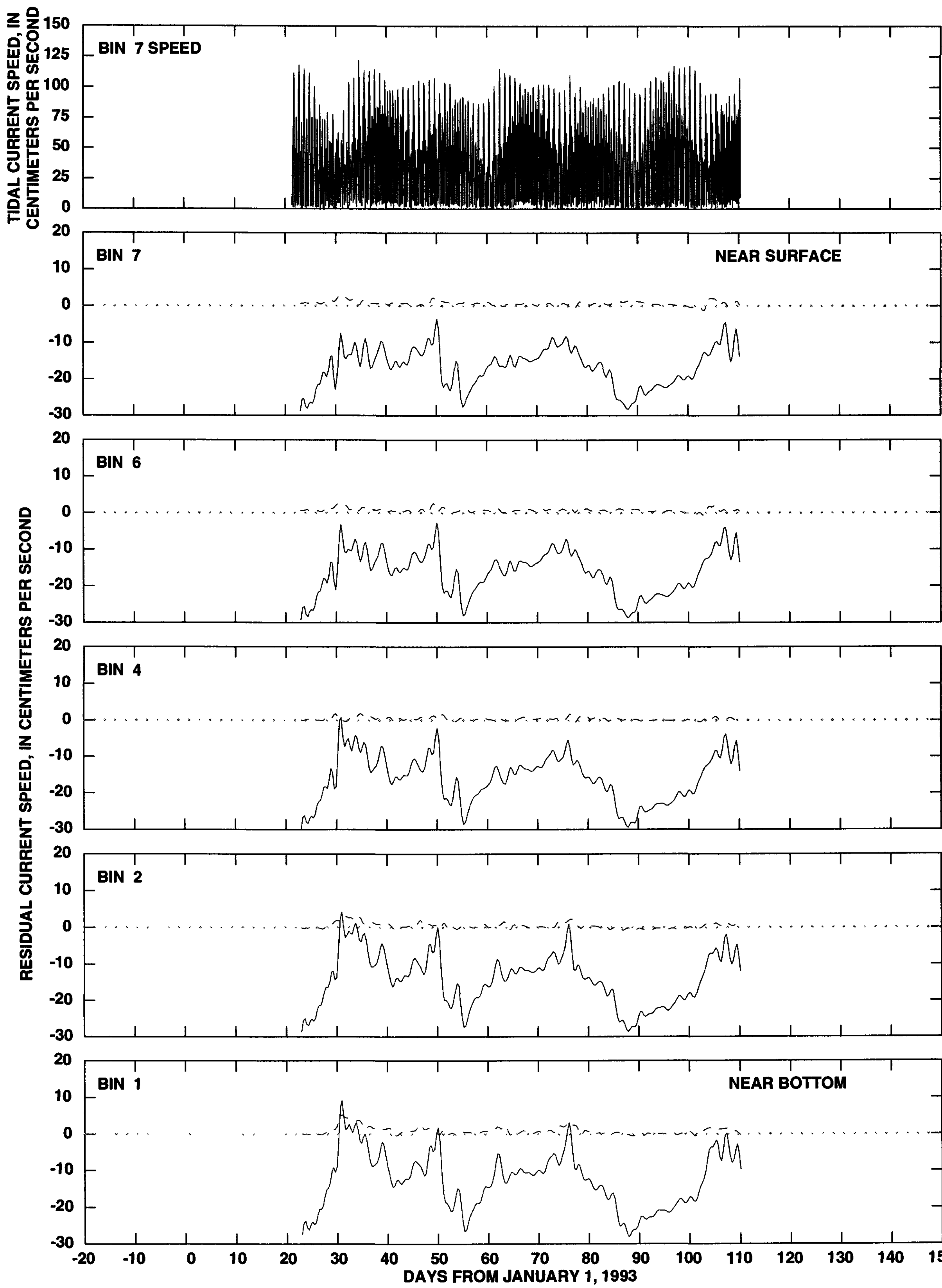

Figure B6. Longitudinal and transverse residual currents, station BULLS, January 22 through April 19, 1993, Suisun Bay, California. Tidal current speed at BIN 7 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 73.5°. (Solid) streamwise speed, positive upstream; (dash) transverse speed.

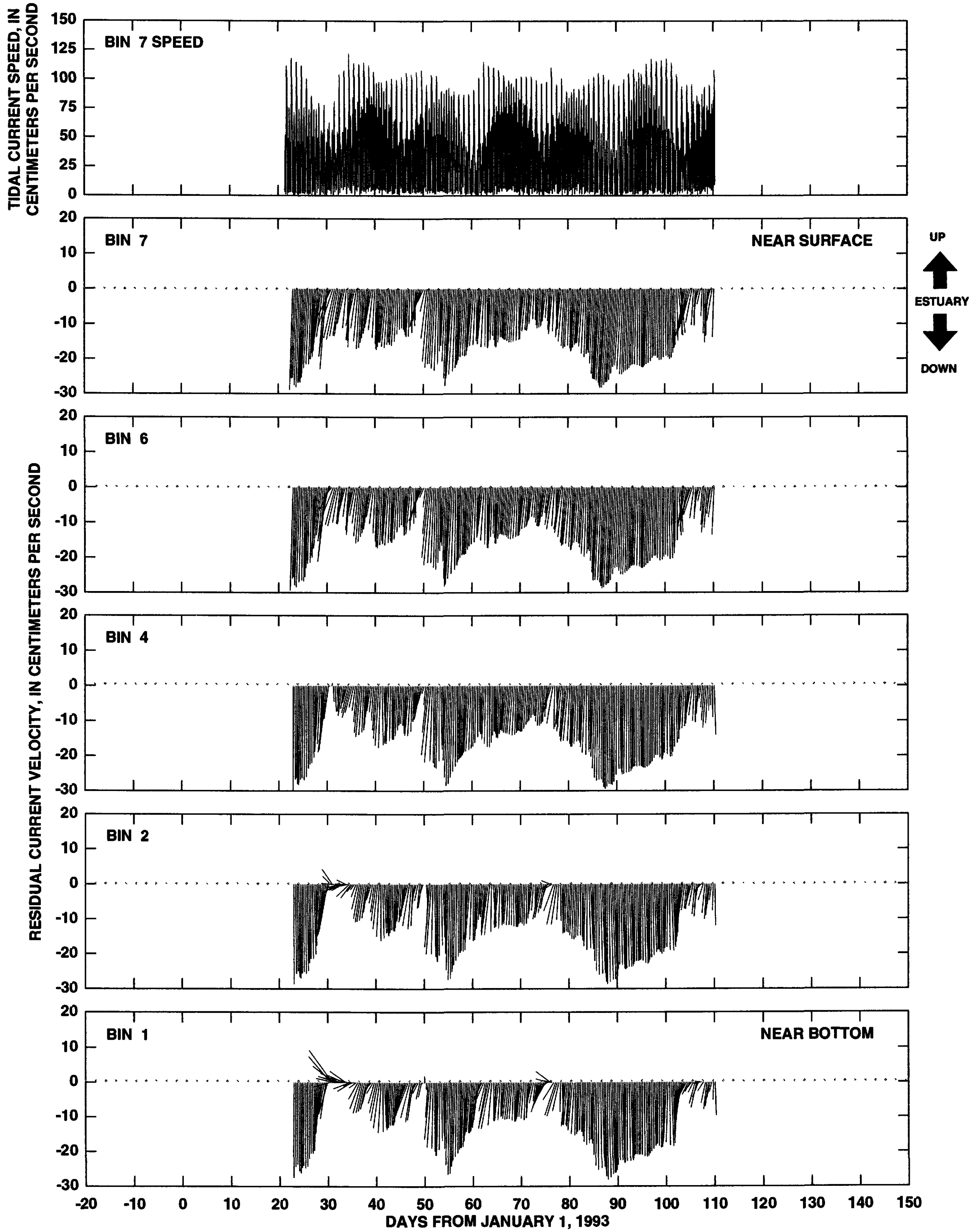

Figure B7. Residual currents, station BULLS, January 22 through April 19, 1993, Suisun Bay, California. Tidal current speed at BIN 7 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 73.5°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table B1. Harmonic analysis results for sea level, station BULLS, January 21 through April 26, 1993, Suisun Bay, California

Time series mean: 10.93890
Standard deviation: 0.13780
Harmonic constants: After tidal inference

Tidal symbol	Cycles (per day)	Mean amplitude (centimeters)	Local epoch (degrees)	Modified epoch (degrees)
Q_1	0.89324	0.03869	115.18045	129.90753
O_1	.92954	.19942	120.88507	131.25717
M_1	.96645	.01416	126.63568	132.57852
P_1	.99726	.09945	131.52371	133.76865
K_1	1.00274	.30046	132.38629	133.97412
J_1	1.03903	.01575	138.09091	135.32376
μ_2	1.86455	.01337	19.47844	39.56555
N_2	1.89598	.15537	3.95203	20.26697
ν_2	1.90084	.03014	7.37522	23.10733
M_2	1.93227	.55704	29.49823	41.45819
L_2	1.96857	.01560	55.04443	62.64938
T_2	1.99726	.00682	39.11723	43.27853
S_2	2.00000	.11556	39.51802	43.35078
K_2	2.00548	.03143	40.32962	43.50531
M_4	3.86455	.00606	316.22708	340.14694
Mk_3	2.93501	.00900	110.85887	124.40666

Table B2. Harmonic analysis results for velocity, station BULLS, January 21 through April 20, 1993, BIN 1 near-bottom BIN, Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 1
Station: BULLS
Start time of the series (local): Year, 1993; Month, 1; Day, 21; Hour, 7:42
Time meridian: 120°W
Station position: 38°03'44"N/122°04'15"W
Record length: 172 M2 Cycle: 12818 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	15.24	0.66	71.8	91.7	114.2	Counter-clockwise
K_1	21.76	.43	72.6	103.6	155.1	Counter-clockwise
N_2	13.70	.09	72.1	348.5	153.6	Clockwise
M_2	62.55	.06	72.5	15.8	273.4	Counter-clockwise
S_2	17.75	.60	74.7	15.9	231.3	Clockwise
M_4	1.78	.40	82.3	257.1	186.9	Clockwise

Root-mean-square speed (cm/s):	53.73
Standard deviation, U series (cm/s):	12.02
Standard deviation, V series (cm/s)	5.46
Tidal form number:	0.46
Spring tidal current maximum (cm/s):	117.32
Neap tidal current maximum (cm/s):	38.28
Principal current direction (deg. T):	72.75

Table B3. Harmonic analysis results for velocity, station BULLS, January 21 through April 20, 1993, BIN 7 near-surface BIN, Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 7
Station: BULLS
Start time of the series (local): Year, 1993; Month, 1; Day, 21; Hour, 7:42
Time meridian: 120°∞W
Station position: 38°03'44"N/122°04'15"W
Record length: 172 M2 Cycle: 12818 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	17.49	0.33	75.8	86.2	114.2	Clockwise
K_1	23.40	.01	76.0	100.7	155.1	Counter-clockwise
N_2	15.59	.38	76.0	342.6	153.6	Clockwise
M_2	73.18	1.69	76.0	11.6	273.4	Clockwise
S_2	19.69	.08	74.0	6.9	231.3	Counter-clockwise
M_4	1.07	.18	104.6	61.6	186.9	Clockwise

Root-mean-square speed (cm/s):	58.96
Standard deviation, U series (cm/s):	12.08
Standard deviation, V series (cm/s)	4.07
Tidal form number:	0.44
Spring tidal current maximum (cm/s):	133.75
Neap tidal current maximum (cm/s):	47.58
Principal current direction (deg. T):	75.68

APPENDIX C—STATION CONC

Station Name: **CONC**
(Near Concord)
Position: Lat 38°03'51"N
Long 122°01'38" W
Depth: 8.2 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t:	Hydrolab	7	12/11/92 (-20) - 05/26/93 (146)
CT_b:	Hydrolab	2	12/11/92 (-20) - 05/26/93 (146)

CT sensors serviced: 01/11/93 (11), 02/10/93 (41), 03/16/93 (75), 04/21/93 (111)

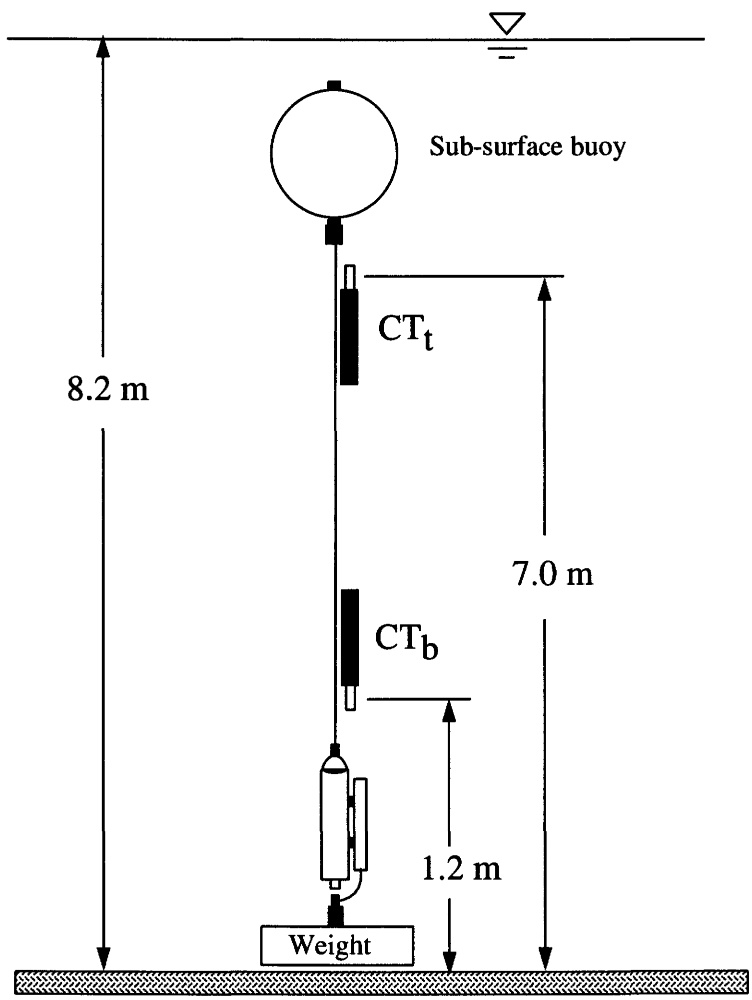

Figure C1. Configuration of instrument deployment, station CONC, December 11, 1992, through May 26, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

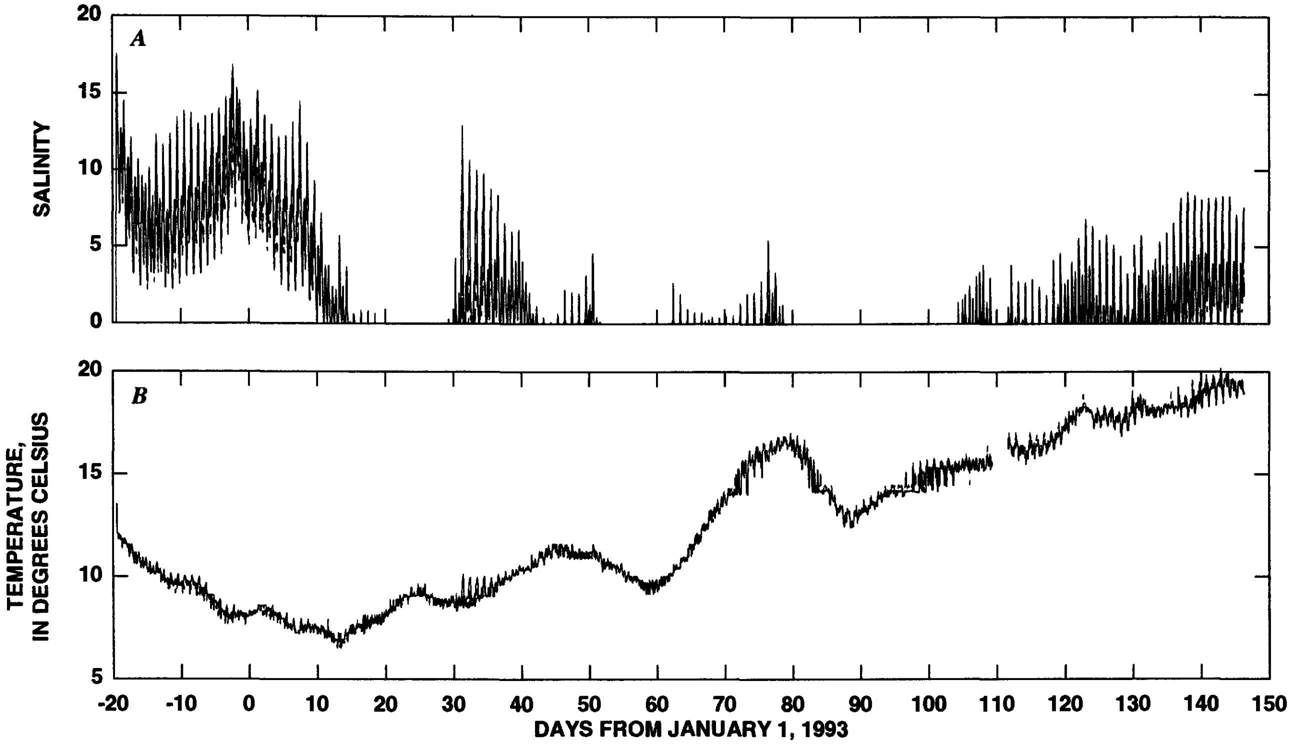

Figure C2. Time-series plots of ***A***, salinity and ***B***, temperature, station CONC, December 12, 1992, through May 26, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

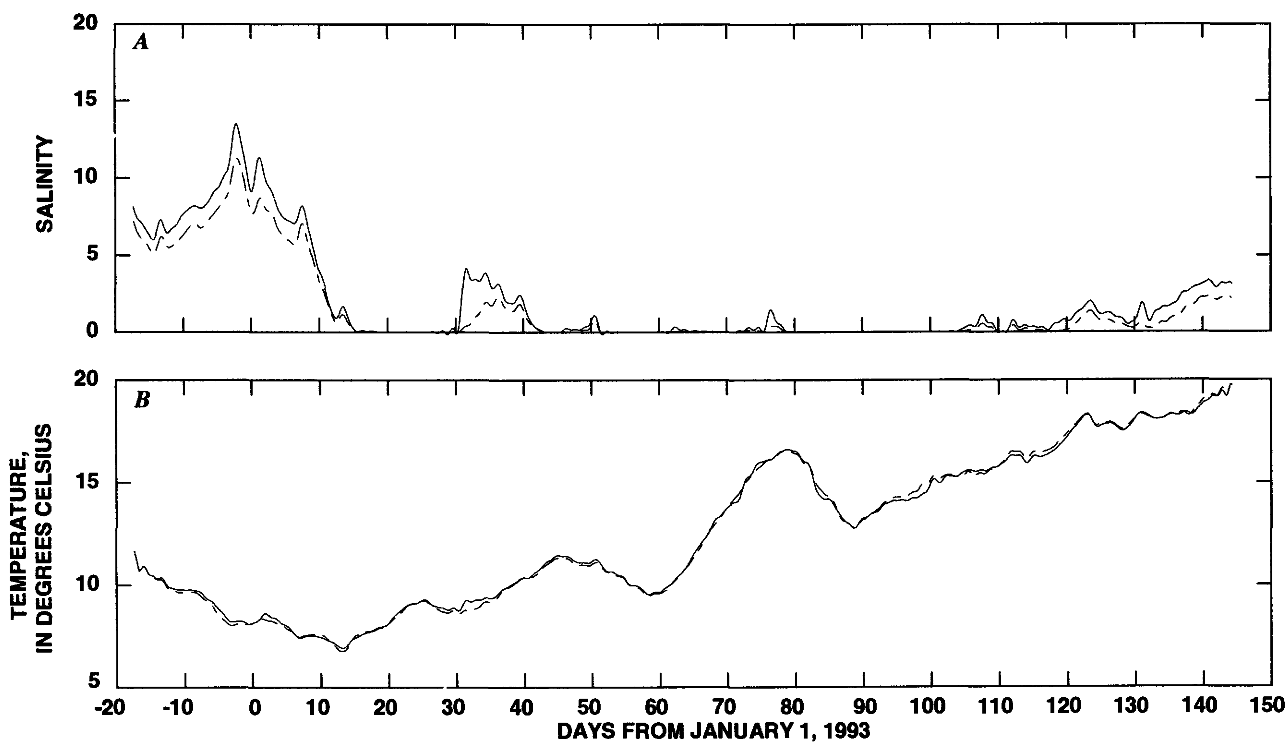

Figure C3. Time-series plots of low-pass filtered ***A***, salinity and ***B***, temperature, station CONC, December 12, 1992, through May 26, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

APPENDIX D—STATION CUT

Station Name: **CUT**
(Suisun Cutoff)

Position: Lat 38° 05' 18" N
Long 122° 00' 21" W

Depth: 11.0 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
V_t:	Endeco	31	01/13/93 (13) - 05/20/93 (140)
V_b:	Endeco	33	01/13/93 (13) - 04/20/93 (110)

Sensors serviced: 02/11/93, 03/15/93, 04/21/93

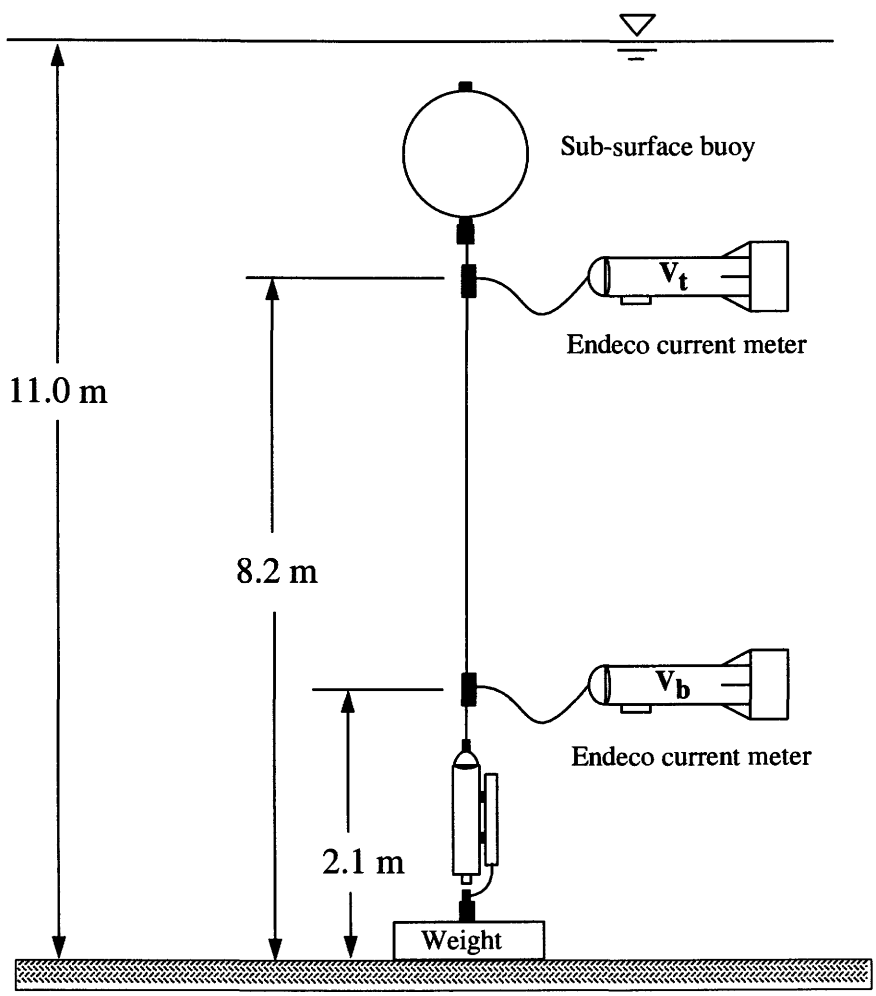

Figure D1. Configuration of instrument deployment, station CUT, December 13, 1992, through May 20, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

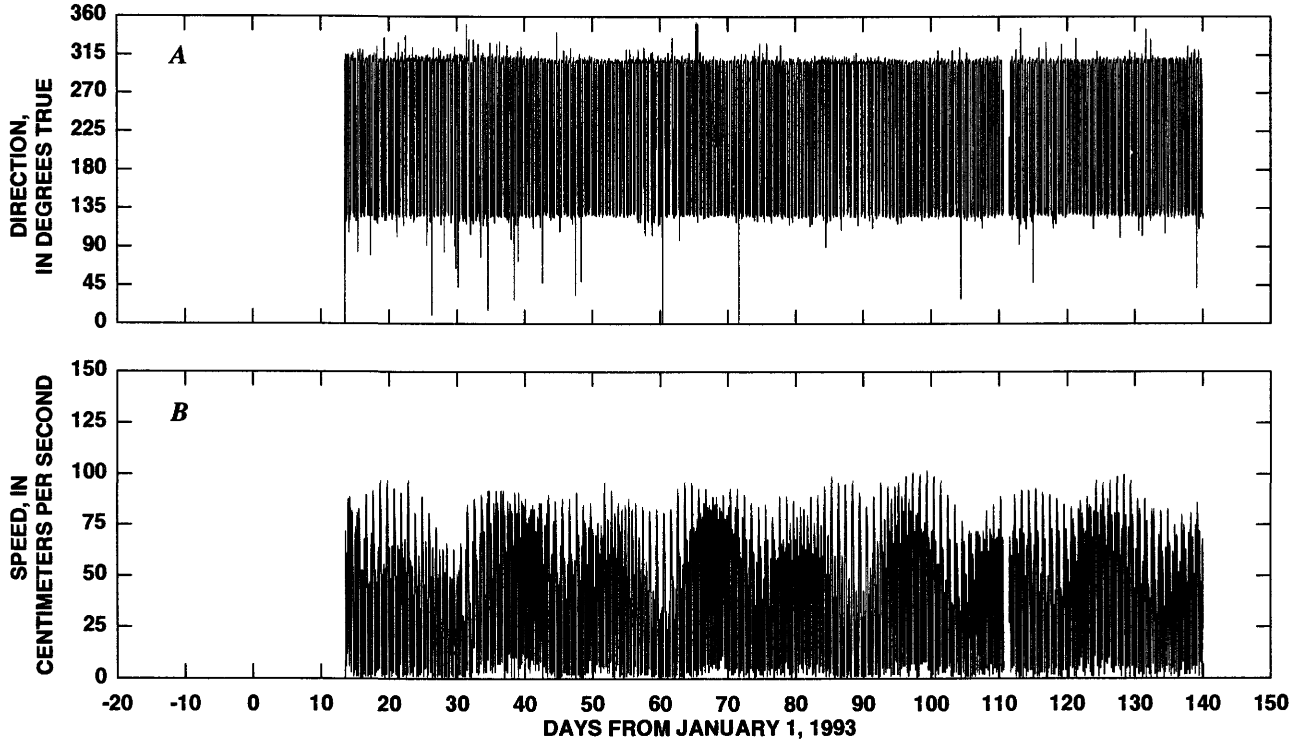

Figure D2. Time-series plots of ***A***, current direction; and ***B***, speed, station CUT near-surface meter, January 13 through May 20, 1993, Suisun Bay, California.

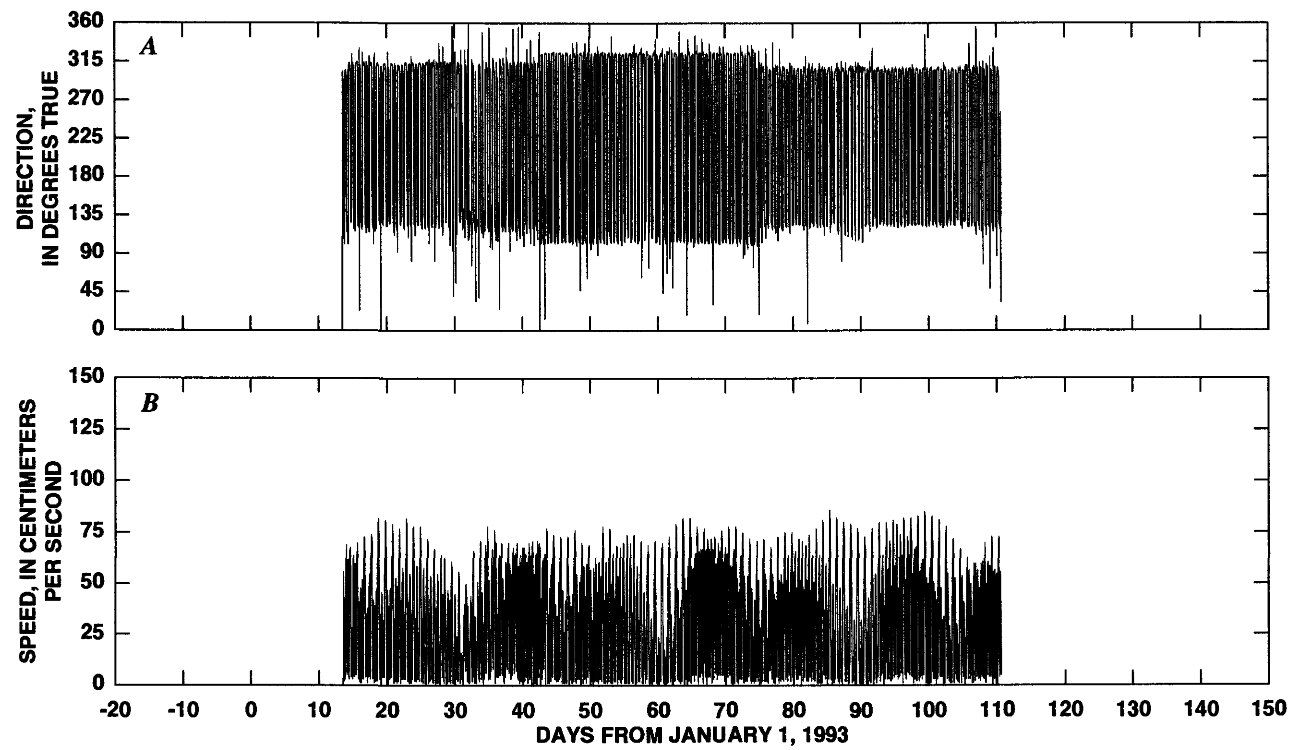

Figure D3. Time-series plots of ***A***, current direction; and ***B***, speed, station CUT near-bed meter, January 13 through April 20, 1993, Suisun Bay, California.

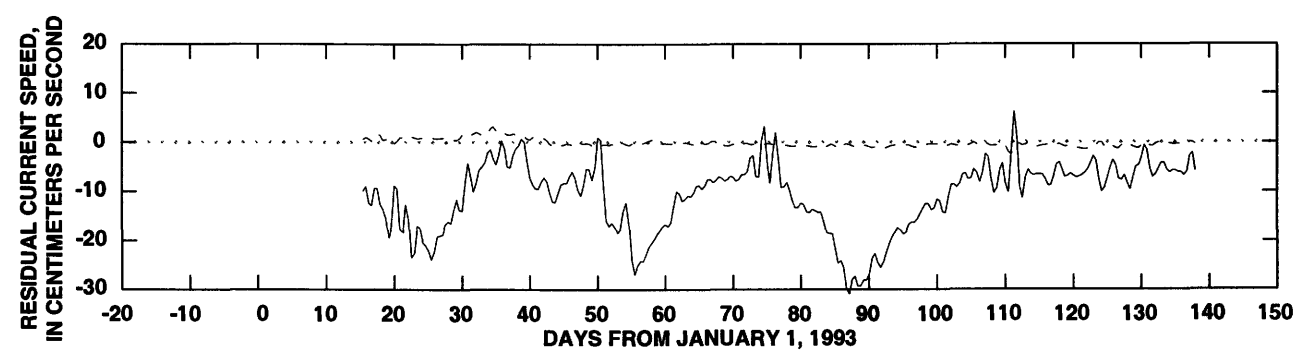

Figure D4. Longitudinal (solid) and transverse (dashed) residual currents, station CUT near-surface meter, January 13 through May 20, 1993, Suisun Bay, California. Principal direction is 128.3°.

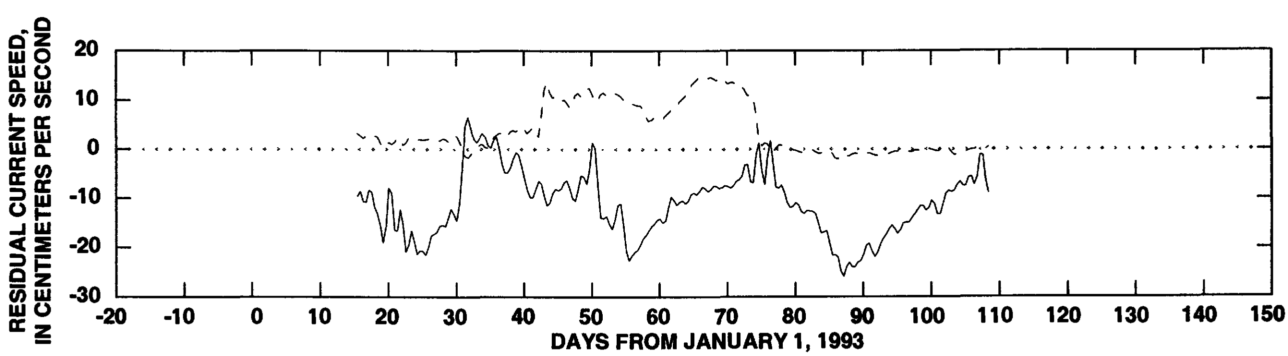

Figure D5. Longitudinal (solid) and transverse (dashed) residual currents, station CUT near-bed meter, January 13 through April 20, 1993, Suisun Bay, California. Principal direction is 129.0°. Shifts in transverse current speed due to repositioning of instruments.

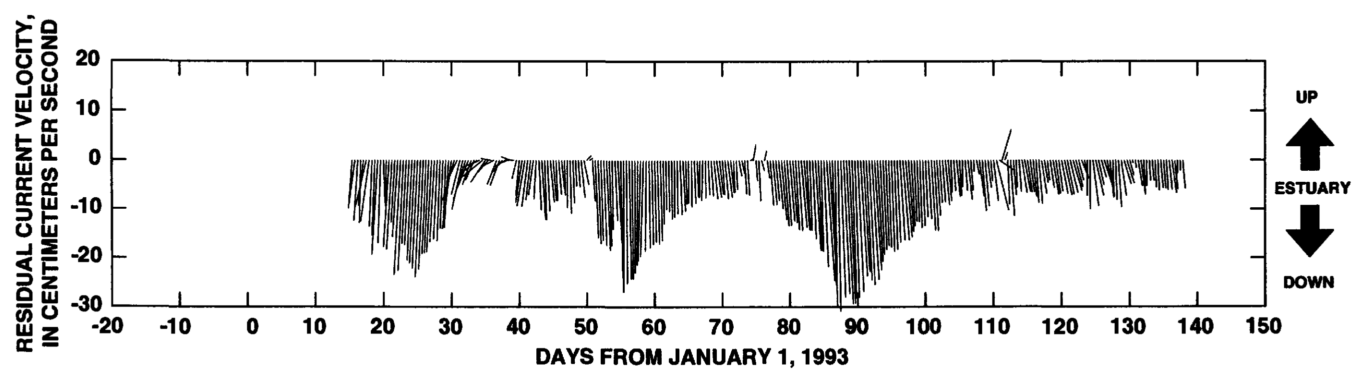

Figure D6. Residual currents, station CUT near-surface meter, January 13 through May 20, 1993, Suisun Bay, California. Principal direction is 128.3°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

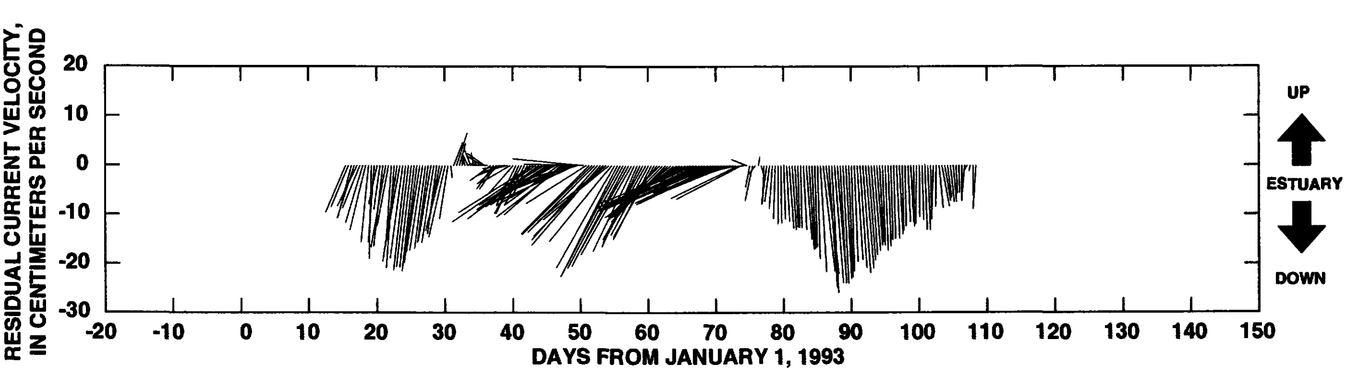

Figure D7. Residual currents, station CUT near-bed meter, January 13 through April 20, 1993, Suisun Bay, California. Principal direction is 129.0°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward. Shifts in transverse current speed due to repositioning of instruments.

Table D1. Harmonic analysis results for velocity, station CUT, near-surface meter, January 13 through May 20, 1993, Suisun Bay, California

[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	13.82	0.05	128.3	100.9	335.1	Counter-clockwise
K_1	25.60	.08	128.2	110.4	166.6	Counter-clockwise
N_2	10.72	.09	128.4	29.7	129.9	Clockwise
M_2	62.62	.40	128.2	43.9	145.9	Clockwise
S_2	11.89	.18	129.3	52.6	270.0	Counter-clockwise
M_4	2.98	.02	128.5	93.3	291.8	Counter-clockwise

Root-mean-square speed (cm/s):	53.21
Standard deviation, U velocity (cm/s):	10.70
Standard deviation, V velocity (cm/s)	8.48
Tidal form number:	0.53
Spring tidal current maximum (cm/s):	113.93
Neap tidal current maximum (cm/s):	38.95
Principal current direction (deg. T):	128.32

Table D2. Harmonic analysis results for velocity, station CUT, near-bed meter, January 13 through April 20, 1993, Suisun Bay, California

[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	10.56	0.06	135.5	105.5	342.1	Clockwise
K_1	15.79	.14	130.2	116.9	174.1	Clockwise
N_2	9.27	.36	123.0	15.0	144.1	Clockwise
M_2	45.94	.06	127.8	41.1	160.4	Clockwise
S_2	11.60	.38	126.3	42.7	285.0	Clockwise
M_4	2.53	.18	51.7	99.8	320.7	Counter-clockwise

Root-mean-square speed (cm/s):	41.20
Standard deviation, U velocity (cm/s):	11.62
Standard deviation, V velocity (cm/s)	8.95
Tidal form number:	0.46
Spring tidal current maximum (cm/s):	83.89
Neap tidal current maximum (cm/s):	29.12
Principal current direction (deg. T):	128.99

APPENDIX E—STATION GRIZ

Station Name: **GRIZ**
(Grizzly Bay)
Position: Lat 38° 06' 13" N
Long 122° 02' 26" W
Depth: 4.3 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
VTD:	EG&G	ACM3-16356	01/19/93 (19) - 03/16/93 (75)
CT:	Hydrolab	3	03/16/93 (75) - 05/26/93 (146)

Sensors serviced: 02/12/93 (43), 02/20/93 (51)

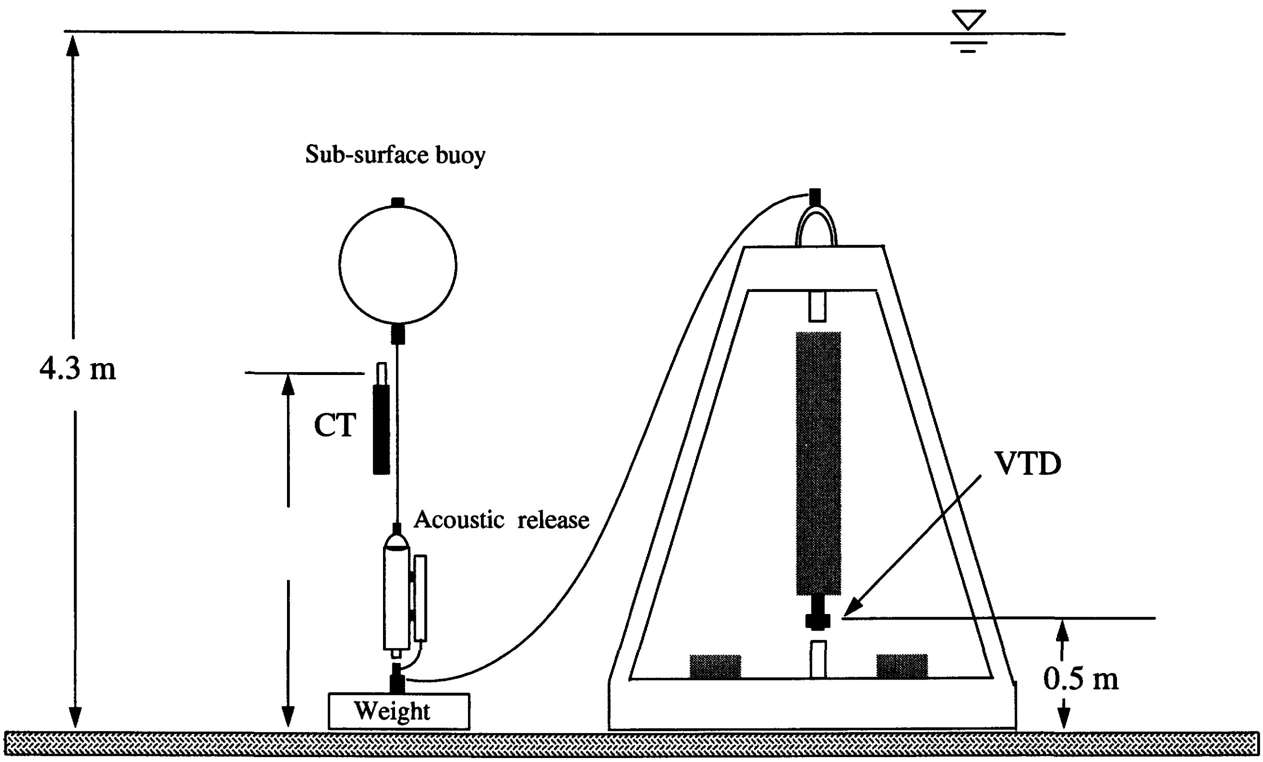

Figure E1. Configuration of instrument deployment, station GRIZ, January 19, 1993, through May 26, 1995, Suisun Bay, California. m, meters; MLLW, mean lower low water.

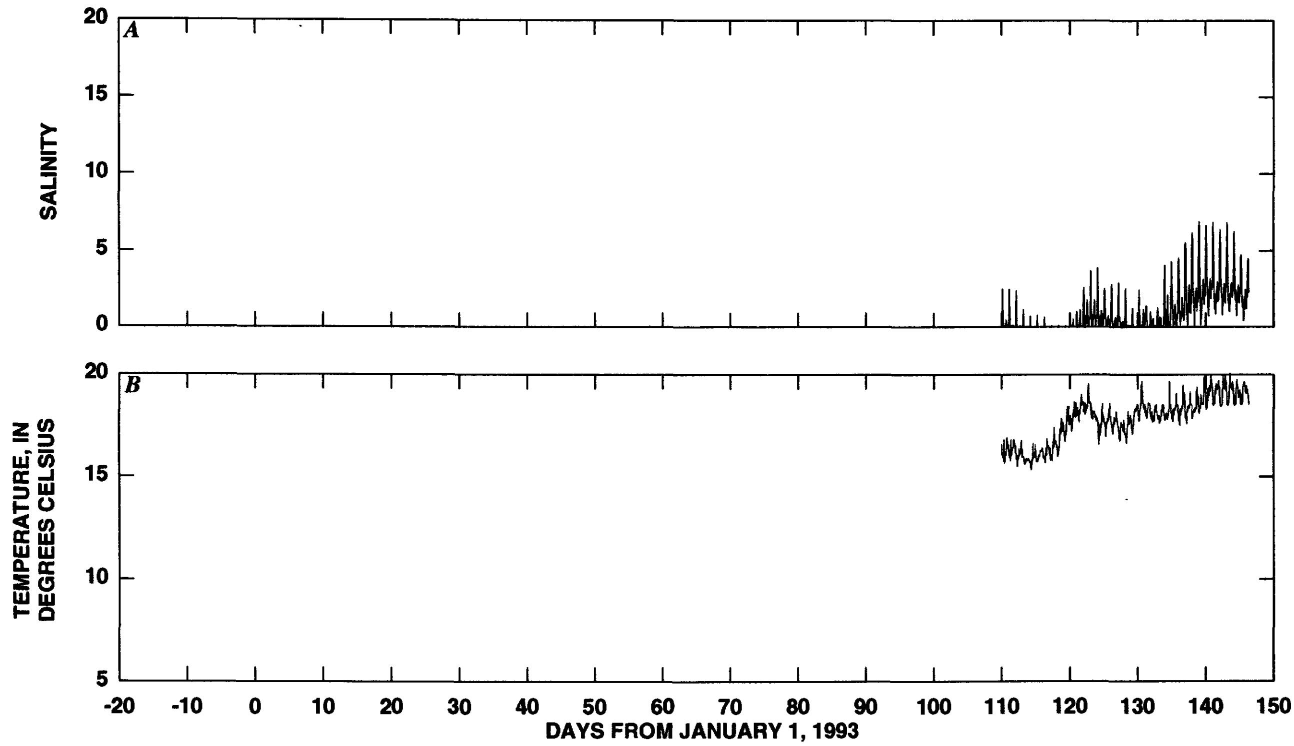

Figure E2. Time-series plots of ***A***, salinity; and ***B***, temperature, station GRIZ, April 20 through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

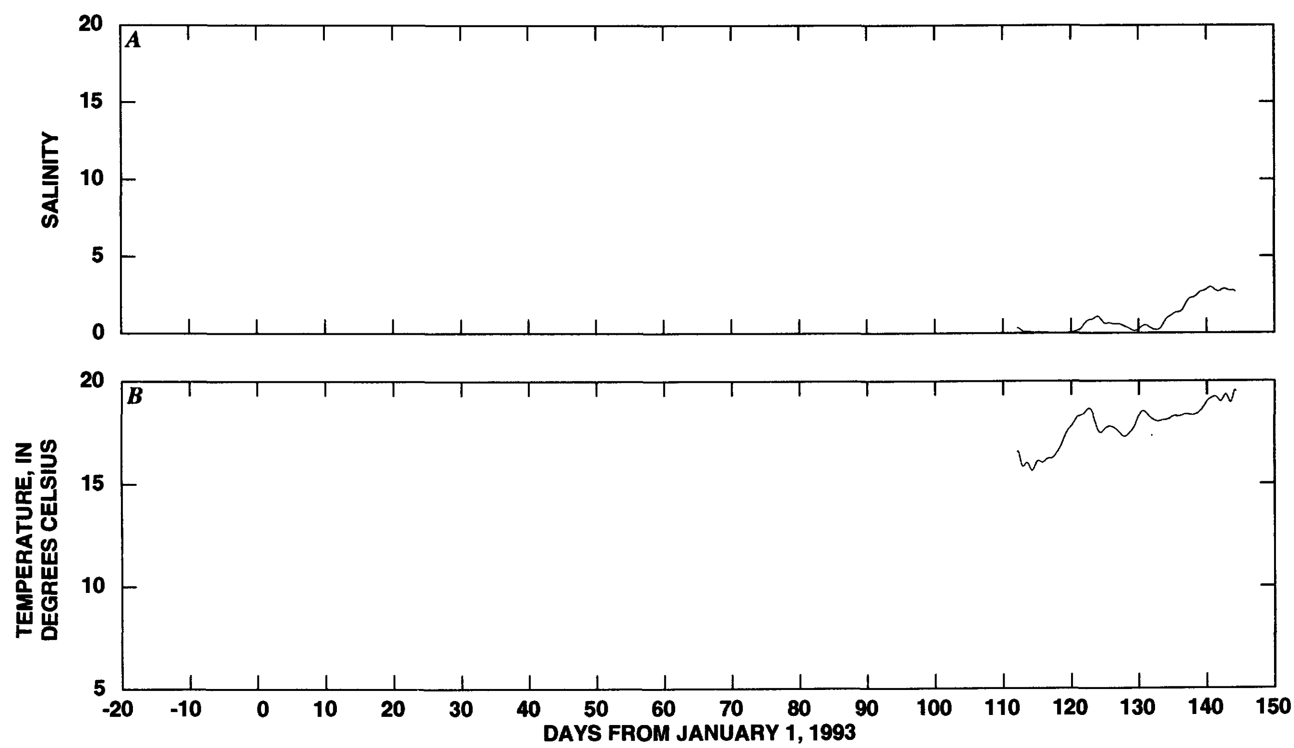

Figure E3. Time-series plots of low-pass filtered ***A***, salinity; and ***B***, temperature, station GRIZ, April 20 through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

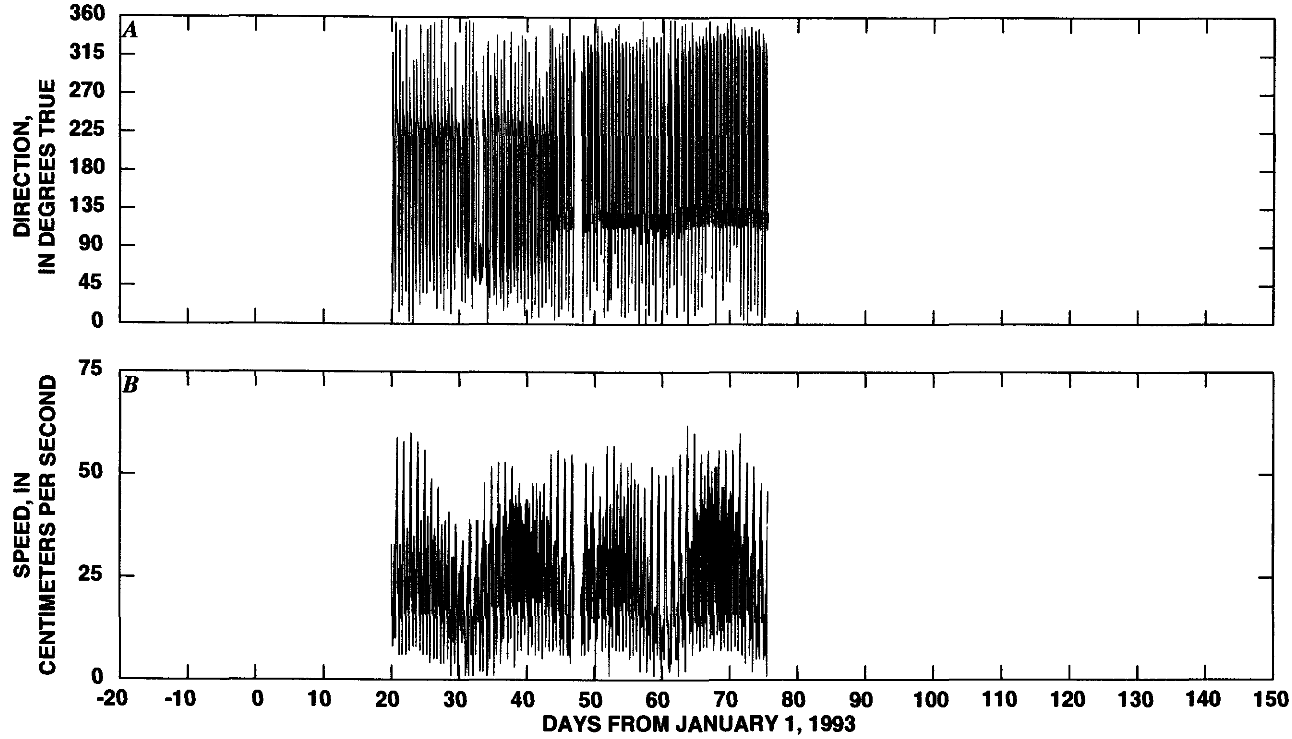

Figure E4. Time-series plots of ***A***, current direction; and ***B***, speed, station GRIZ, January 19 through March 16, 1993, Suisun Bay, California.

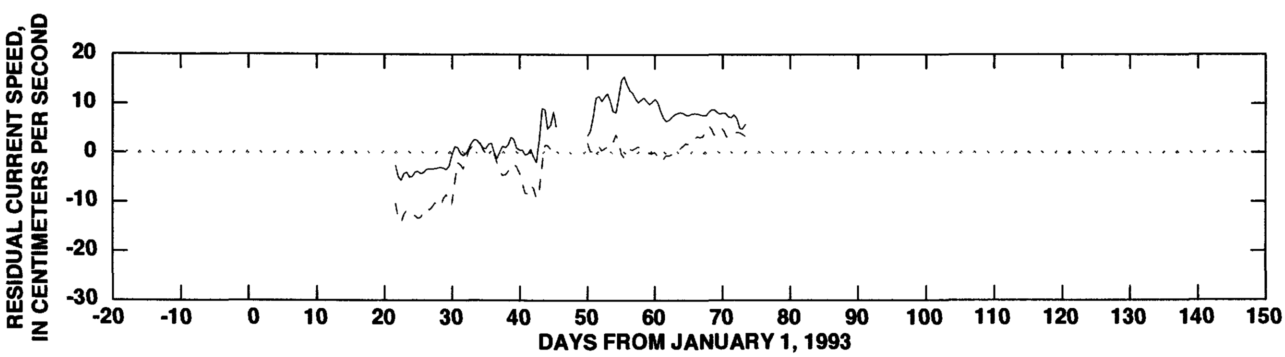

Figure E5. Longitudinal (solid) and transverse (dashed) residual currents, station GRIZ, January 19 through March 16, 1993, Suisun Bay, California. Principal direction is 116.8.

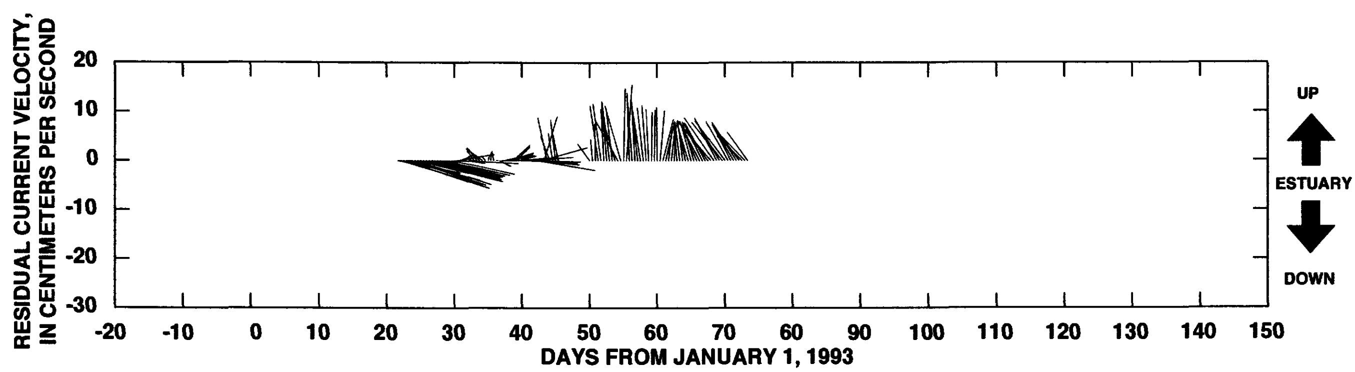

Figure E6. Residual currents, station GRIZ, January 19 through March 16, 1993, Suisun Bay, California. Principal direction is 116.8°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table E1. Harmonic analysis results for velocity, station GRIZ, January 19 through March 16, 1993, Suisun Bay, California

[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	5.50	0.76	162.0	286.8	246.2	Counter-clockwise
K_1	7.12	1.13	3.6	120.5	240.8	Clockwise
N_2	4.96	1.05	150.1	172.4	34.3	Clockwise
M_2	18.50	1.88	172.1	212.7	131.2	Counter-clockwise
S_2	5.64	.59	34.4	51.9	46.2	Clockwise
M_4	2.52	.09	13.4	342.3	262.4	Counter-clockwise

Root-mean-square speed (cm/s):	29.61
Standard deviation, U velocity (cm/s):	22.98
Standard deviation, V velocity (cm/s)	8.75
Tidal form number:	0.52
Spring tidal current maximum (cm/s):	36.76
Neap tidal current maximum (cm/s):	11.23
Principal current direction (deg. T):	116.82

APPENDIX F—STATION HB

Station Name: **HB**
(Honker Bay)
Position: Lat 38° 04' 29" N
Long 122° 56' 46" W
Depth: 3.1 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT:	Hydrolab	1	12/11/92 (-20) - 02/10/93 (41)
CT:	Hydrolab	6	02/10/93 (41) - 05/25/93 (145)

Sensors serviced: 01/13/93 (13), 02/10/93 (41), 03/15/93 (74), 04/19/93 (109)

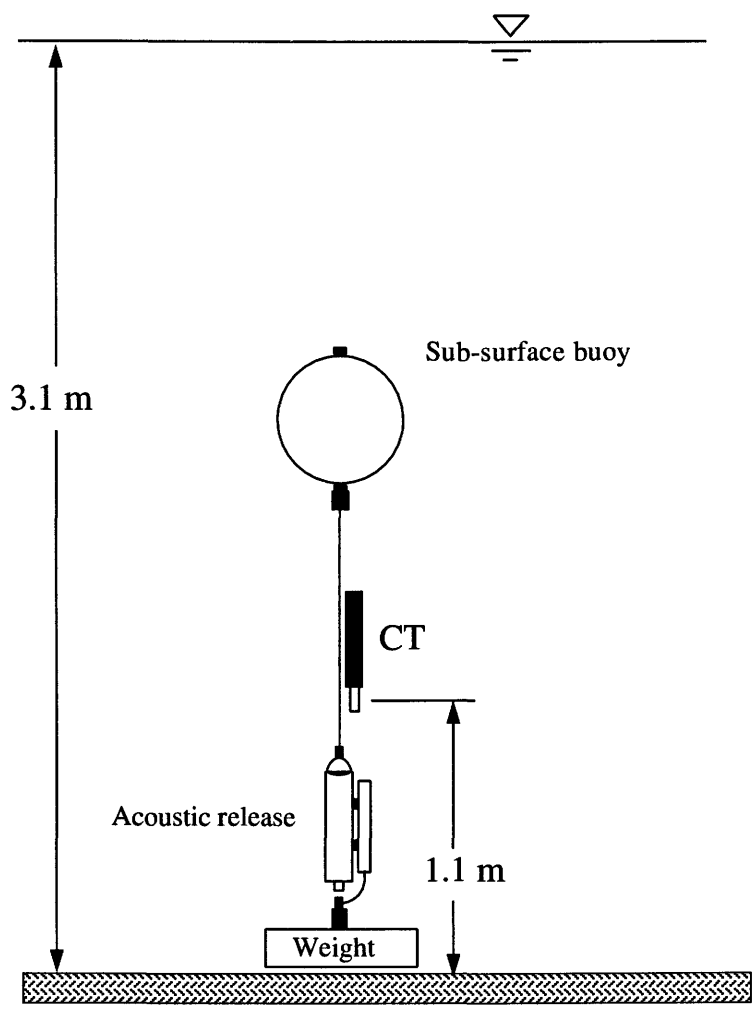

Figure F1. Configuration of instrument deployment, station HB, December 11, 1992, through May 25, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

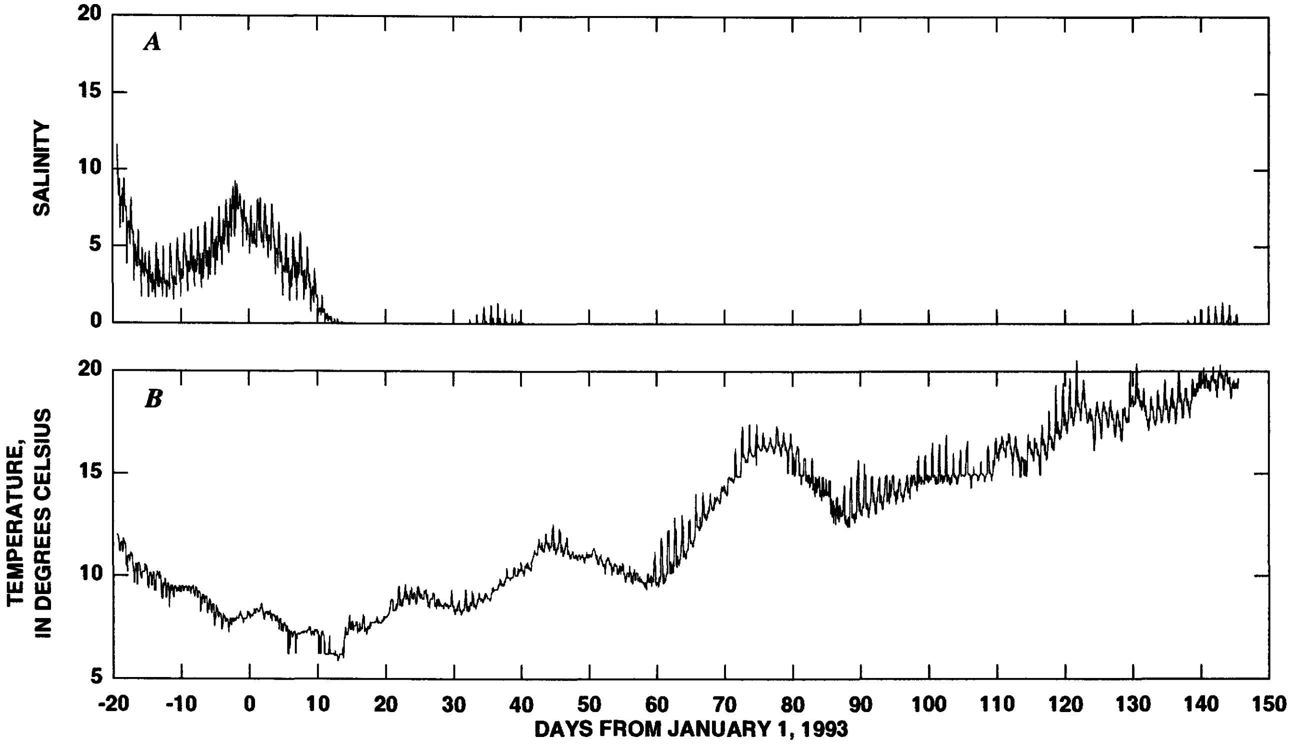

Figure F2. Time-series plots of ***A***, salinity; and ***B***, temperature, station HB, December 12, 1992, through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

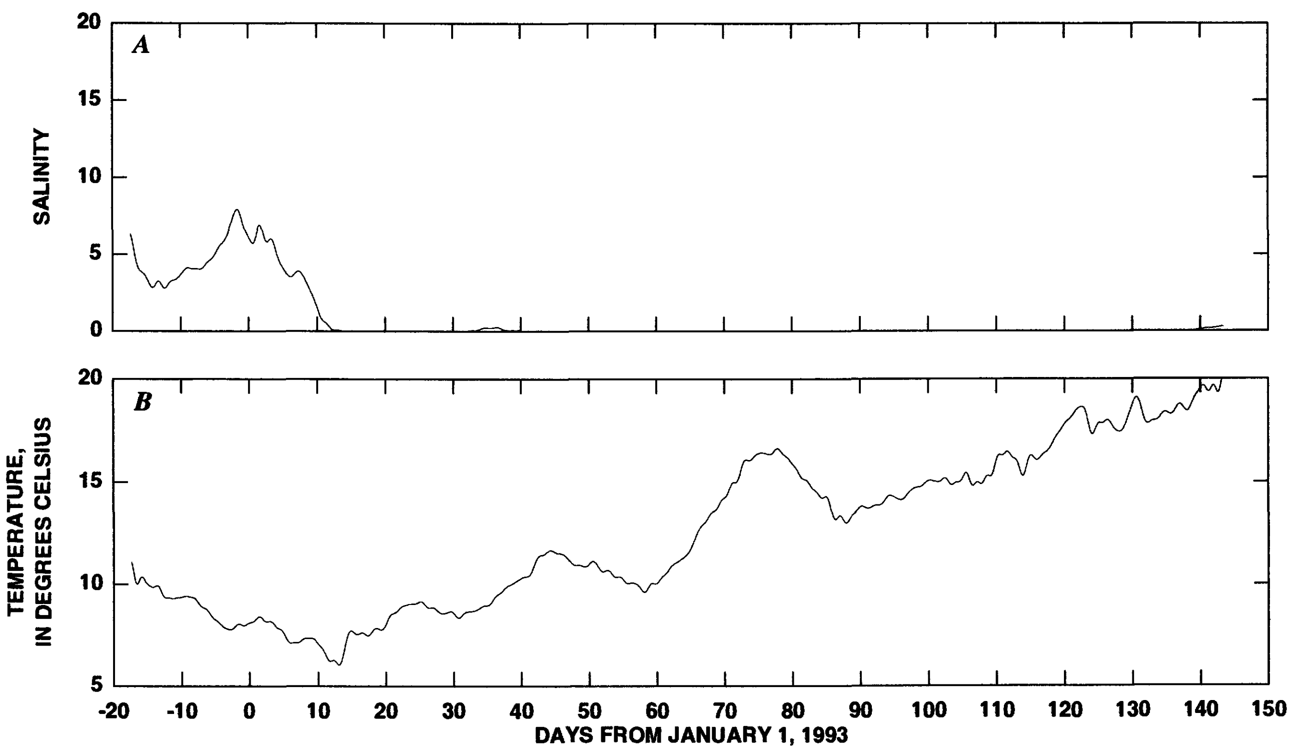

Figure F3. Time-series plots of low-pass-filtered ***A***, salinity; and ***B***, temperature, station HB, December 12, 1992, through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

APPENDIX G—STATION HDOL

Station Name: **HDOL**
(Honker Bay near Dolphin)
Position: Lat 38° 04' 07" N
Long 121° 57' 46" W
Depth: 3.7 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
V:	Endeco	34	01/13/93 (13) - 03/15/93 (74)
V:	Endeco	37	04/19/93 (109) - 05/26/93 (146)

Sensors serviced: 02/11/93 (42), 03/15/93 (74)

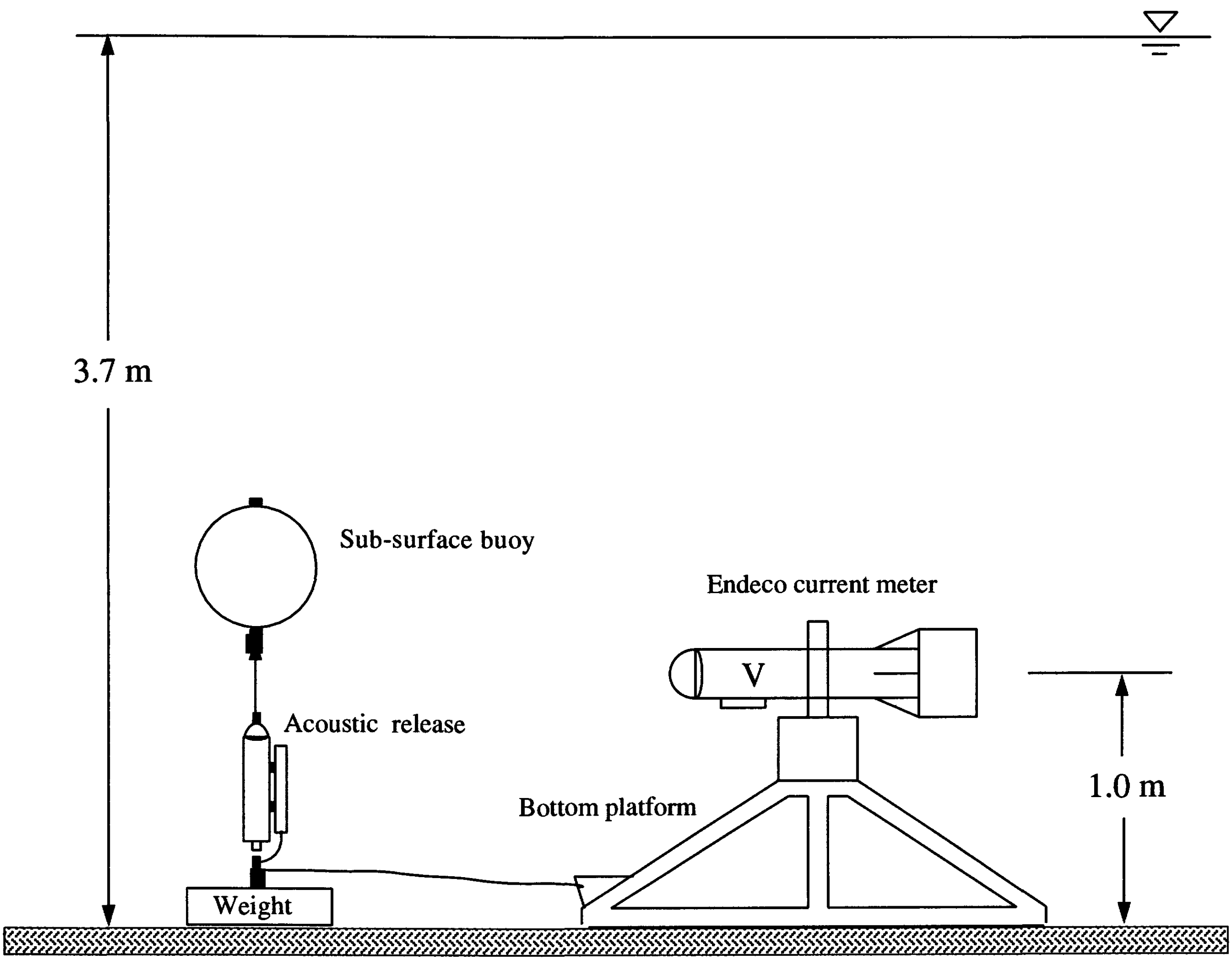

Figure G1. Configuration of instrument deployment, station HDOL, January 13 through May 26, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

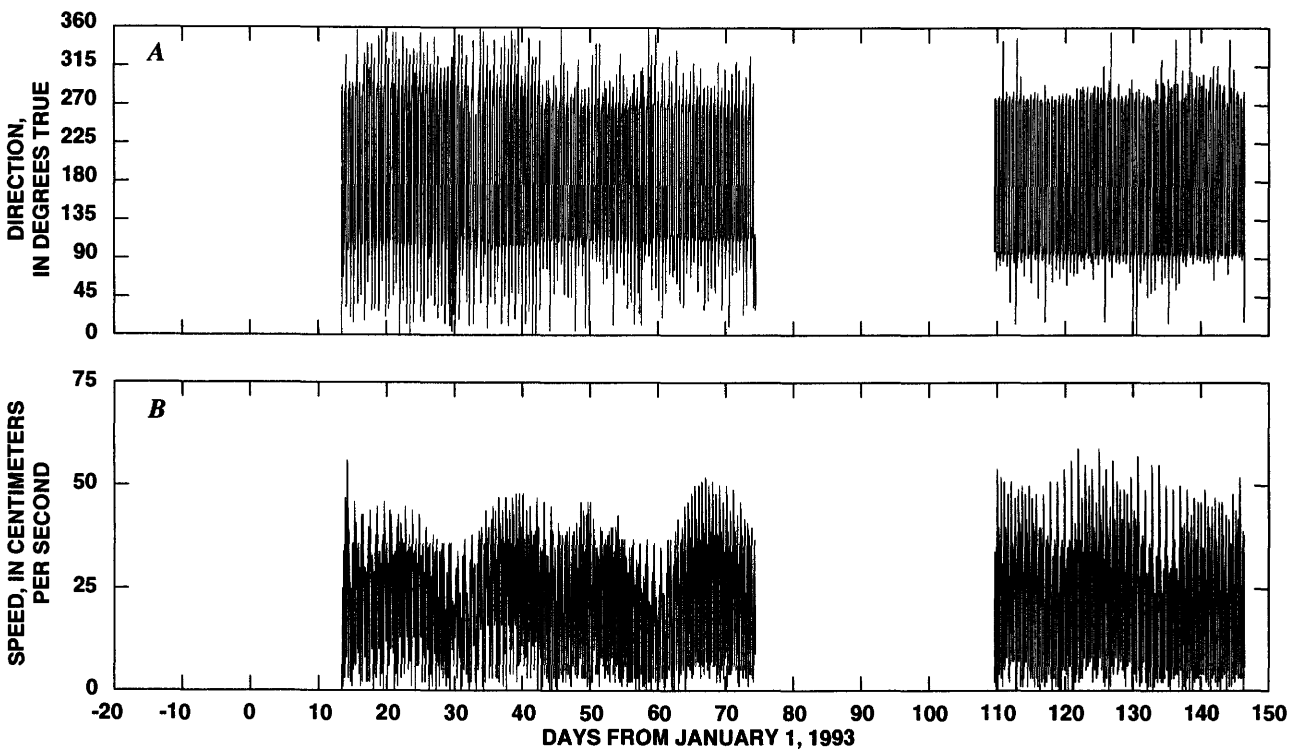

Figure G2. Time-series plots of ***A***, current direction; and ***B***, speed, station HDOL, January 13 through May 26, 1993, Suisun Bay, California.

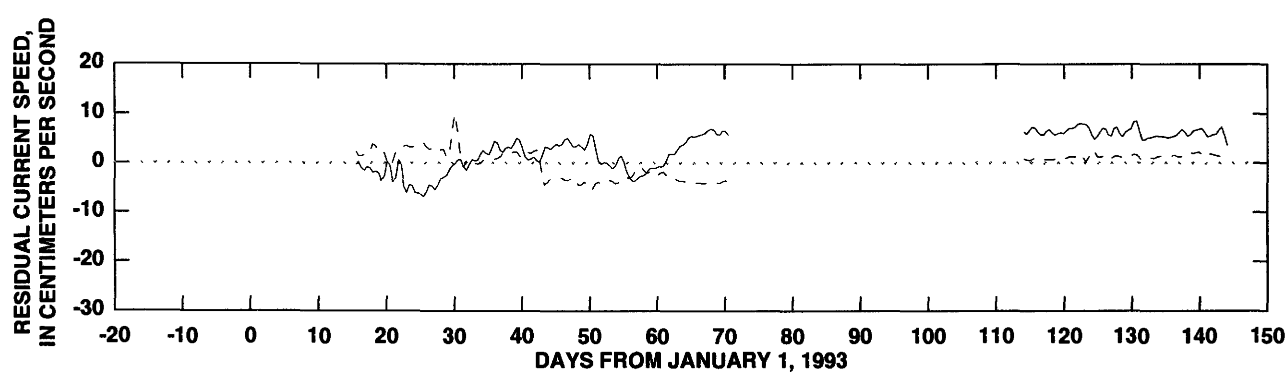

Figure G3. Longitudinal (solid) and transverse (dashed) residual currents, station HDOL, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 100.2°.

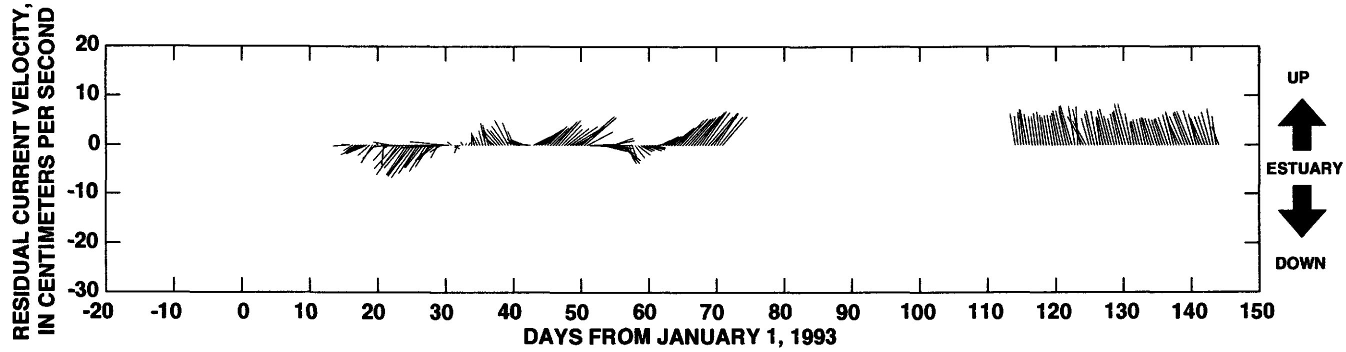

Figure G4. Residual currents, station HDOL, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 100.2°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table G1. Harmonic analysis results for velocity, station HDOL, January 13 through May 26, 1993, Suisun Bay, California

[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
Q_1	1.52	0.01	101.3	100.3	325.8	Counter-clockwise
O_1	5.41	.65	101.4	87.2	342.1	Clockwise
M_1	.63	.04	104.2	158.4	176.9	Clockwise
P_1	3.82	.70	103.5	119.2	119.6	Counter-clockwise
K_1	12.24	.83	99.4	96.6	174.1	Clockwise
J_1	.73	.35	99.7	145.2	194.6	Counter-clockwise
μ_2	1.71	.30	101.3	199.0	33.7	Clockwise
N_2	5.50	.63	102.4	4.9	144.1	Clockwise
ν_2	1.73	.00	105.6	4.5	50.0	Counter-clockwise
M_2	34.19	3.60	99.2	25.2	160.4	Clockwise
L_2	2.72	.24	95.9	17.5	350.5	Counter-clockwise
T_2	1.46	.09	55.8	321.1	275.0	Clockwise
S_2	5.88	.66	106.5	29.0	285.0	Clockwise
K_2	2.98	.15	104.7	13.7	167.9	Counter-clockwise
M_4	2.03	.47	115.0	122.8	320.7	Counter-clockwise
Mk_3	3.68	.21	105.5	159.7	334.5	Clockwise

Root-mean-square speed (cm/s):	28.83
Standard deviation, U velocity (cm/s):	7.44
Standard deviation, V velocity (cm/s)	4.12
Tidal form number:	0.44
Spring tidal current maximum (cm/s):	57.71
Neap tidal current maximum (cm/s):	21.48
Principal current direction (deg. T):	100.22

APPENDIX H—STATION HS

Station Name: **HS**
(Honker Bay south side)

Position: Lat 38° 03' 23" N
Long 121° 55' 58" W

Depth: 6.1 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
V:	Endeco	37	01/13/93 (13) - 03/15/93 (74)
V:	Endeco	34	03/15/93 (74) - 05/25/93 (145)

Sensors serviced: 02/12/93 (43), 03/15/93 (74), 04/19/93 (109)

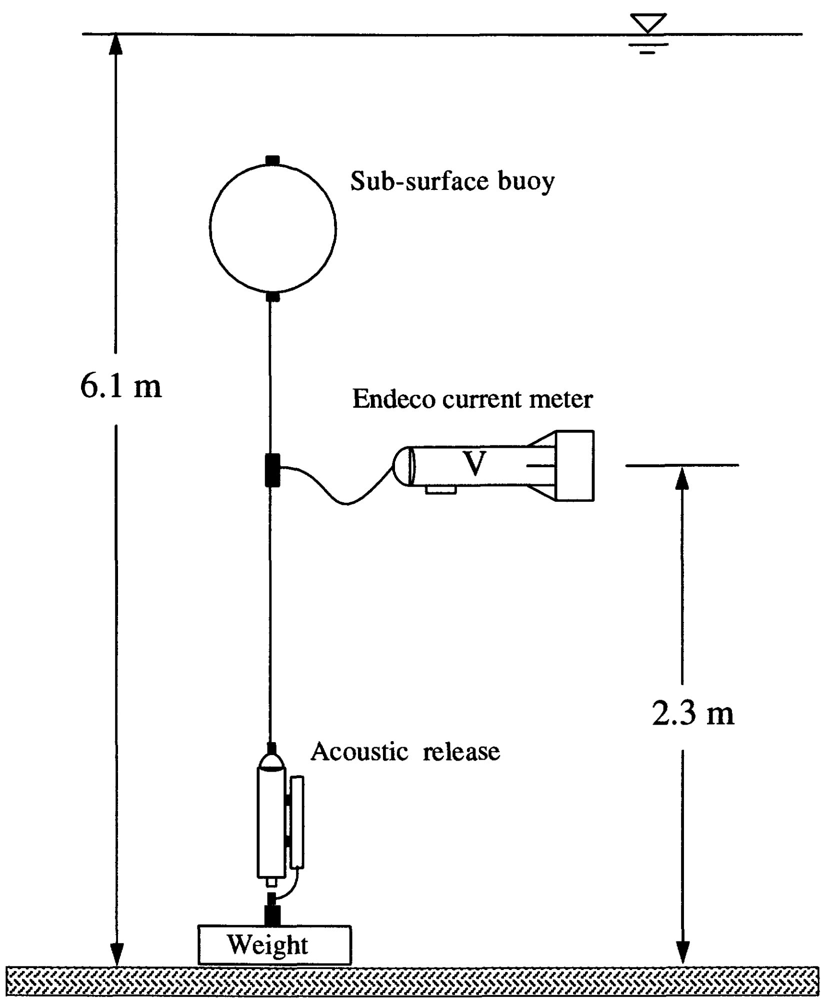

Figure H1. Configuration of instrument deployment, station HS, January 13 through May 25, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

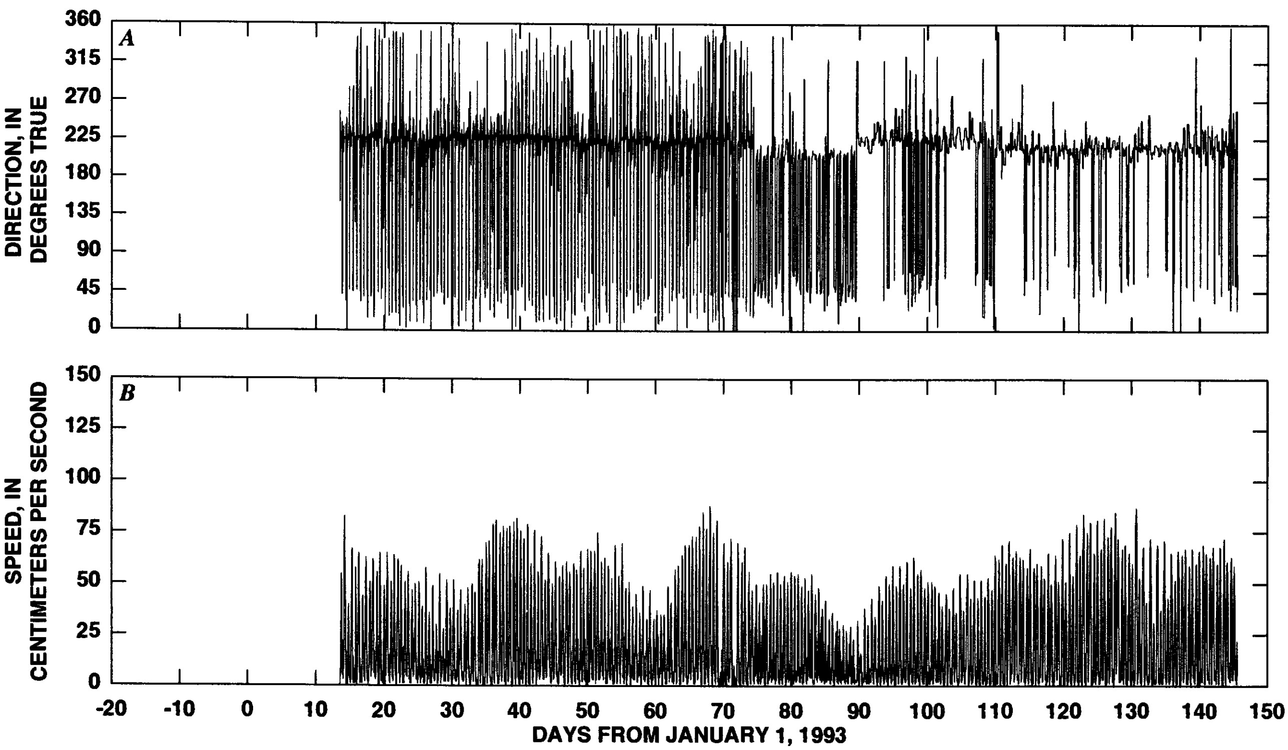

Figure H2. Time-series plots of ***A***, current direction; and ***B***, speed, station HS, January 13 through May 26, 1993, Suisun Bay, California.

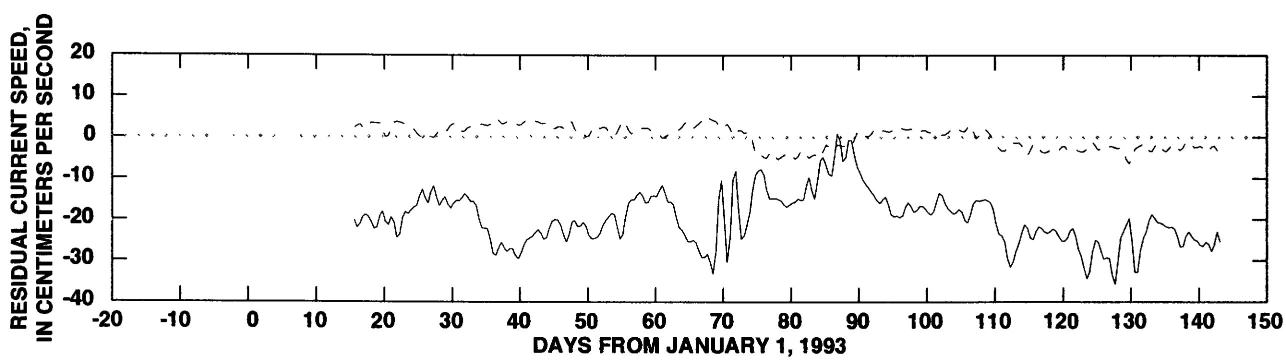

Figure H3. Longitudinal (solid) and transverse (dashed) residual current speed, station HS, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 40.7°.

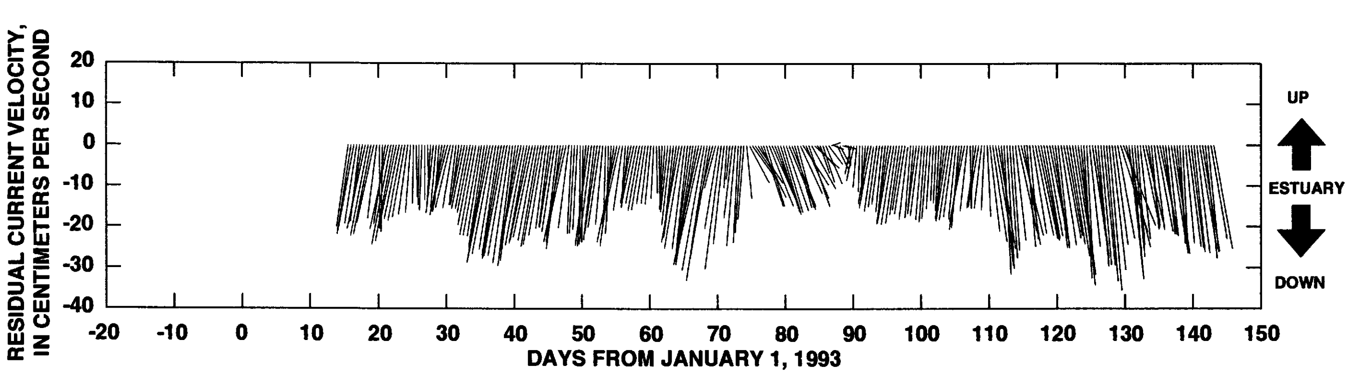

Figure H4. Residual current velocity, station HS, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 40.7°.Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table H1. Harmonic analysis results for velocity, station HS, January 13 through May 26, 1993, Suisun Bay, California
[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
Q_1	1.07	0.08	50.3	324.8	359.3	Counter-clockwise
O_1	1.64	.22	49.6	298.7	16.9	Clockwise
M_1	.34	.02	61.1	315.5	213.1	Counter-clockwise
P_1	2.83	.90	35.9	308.6	157.0	Counter-clockwise
K_1	8.88	.02	38.5	292.5	211.7	Counter-clockwise
J_1	1.26	.01	46.7	354.3	233.5	Counter-clockwise
μ_2	.55	.14	45.3	349.6	103.7	Counter-clockwise
N_2	4.58	.31	46.4	193.0	215.2	Clockwise
ν_2	1.65	.30	54.1	160.7	121.3	Clockwise
M_2	23.75	.60	40.9	215.3	232.8	Clockwise
L_2	1.82	.22	178.3	41.4	64.3	Counter-clockwise
T_2	1.82	.52	24.2	108.4	349.9	Clockwise
S_2	4.26	.19	40.9	222.9	.0	Counter-clockwise
K_2	2.37	.17	44.0	197.4	243.1	Counter-clockwise
M_4	6.67	.06	43.1	255.5	105.7	Clockwise
Mk_3	6.47	.08	40.3	320.1	84.6	Clockwise

Root-mean-square speed (cm/s):	31.08
Standard deviation, U velocity (cm/s):	8.71
Standard deviation, V velocity (cm/s)	9.70
Tidal form number:	0.38
Spring tidal current maximum (cm/s):	38.52
Neap tidal current maximum (cm/s):	12.25
Principal current direction (deg. T):	40.74

APPENDIX I—STATION MAL

Station Name: **MAL**
(Near Mallard Island)
Position: Lat 38° 02' 33" N
Long 121° 54' 59" W
Depth: 15.3 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t :	Schnieder	RM25 C	DWR monitoring
CT_b :	Foxboro	872	DWR monitoring

ADCP: RDI 297 01/22/93 (22) - 05/25/93 (145)

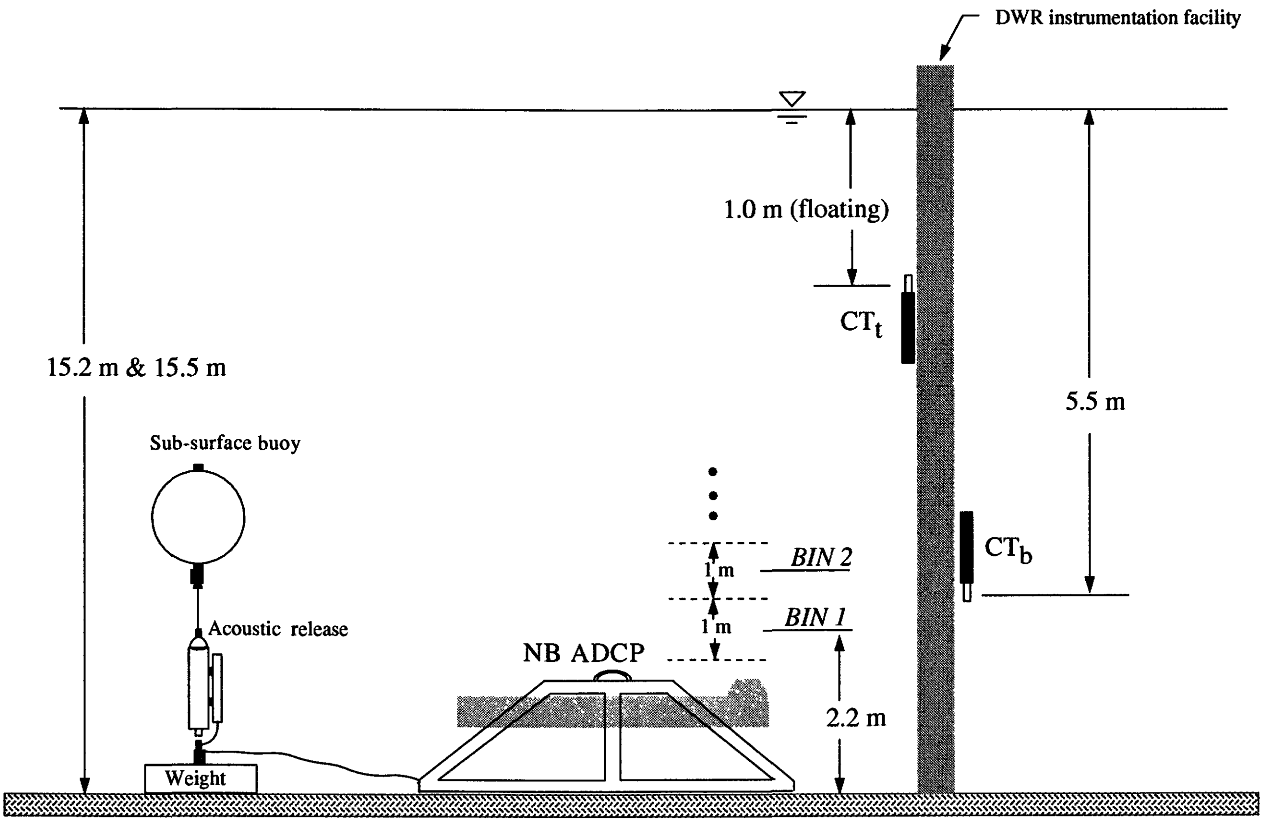

Figure I1. Configuration of instrument deployment, station MAL, January 22 through May 25, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water; DWR, California Department of Water Resources. NB ADCP, narrow-band acoustic Doppler current profiler.

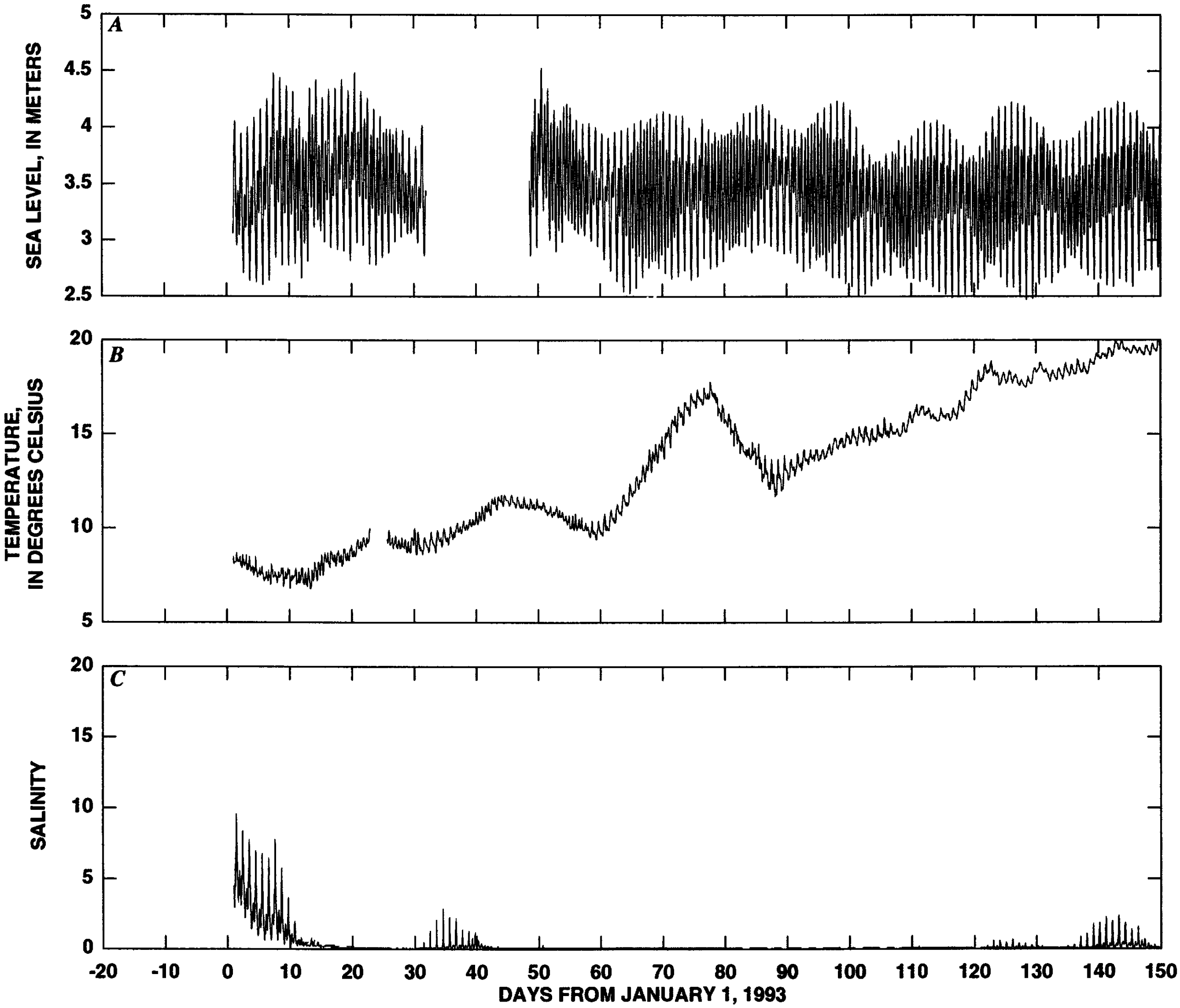

Figure I2. Time-series plots of *A*, sea level; ***B***, temperature; and ***C***, salinity, station MAL, January 1 through May 31, 1993, Suisun Bay, California. (Solid) mid-depth sensor, (dashed) floating sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 0.9 meters.

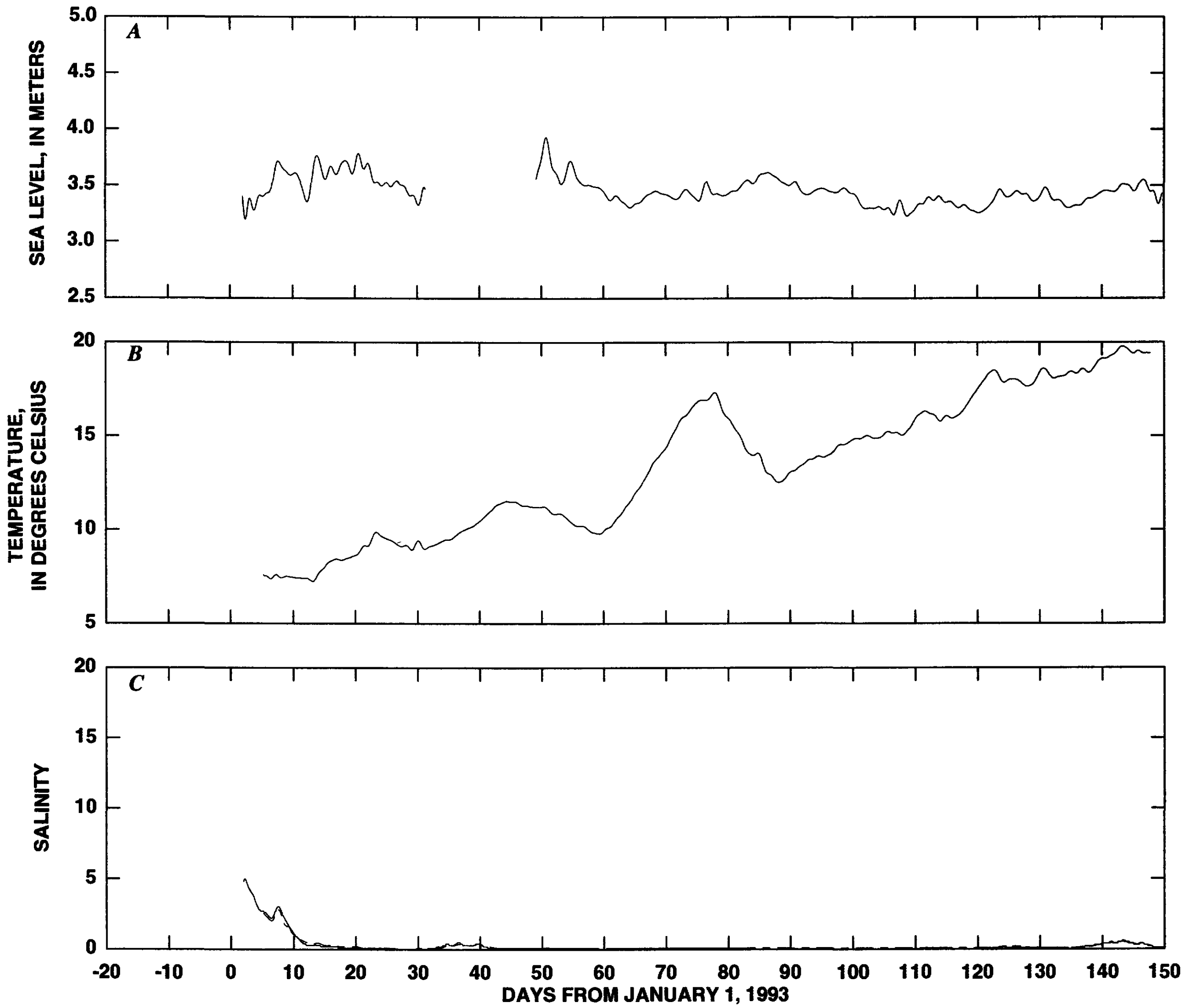

Figure I3. Time-series plots of low-pass-filtered ***A***, sea level; ***B***, temperature; and ***C***, salinity, station MAL, January 1 through May 31, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) floating sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 0.9 meters.

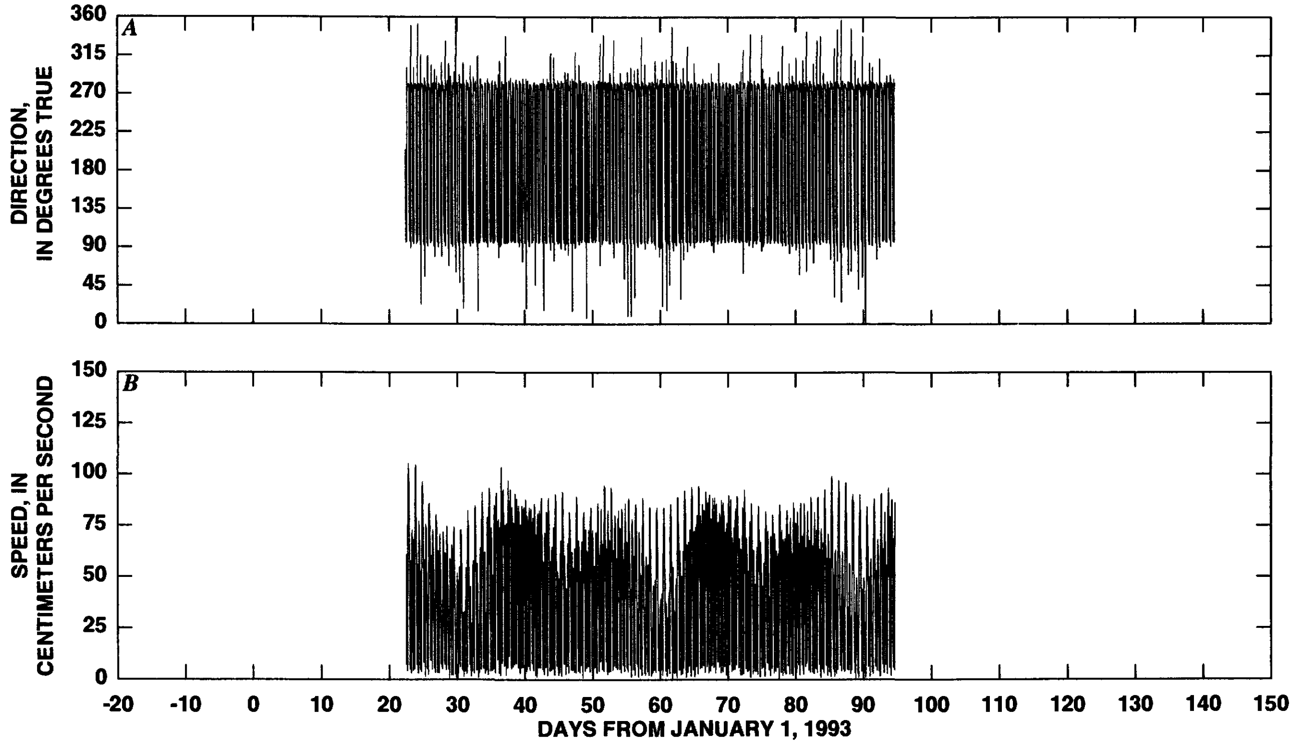

Figure 14. Time-series plots of tidal currents, station MAL, January 21 through April 4, 1993, BIN 1 near-bottom BIN, first deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

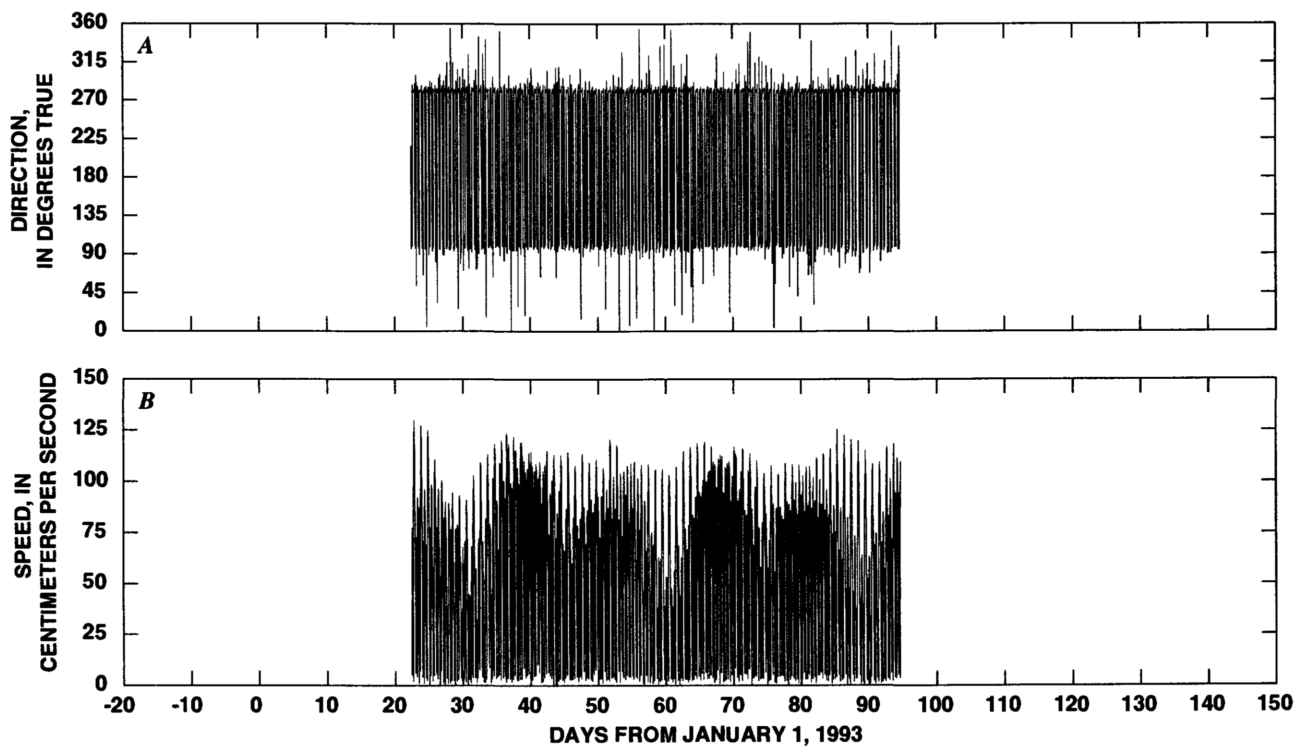

Figure 15. Time-series plots of tidal currents, station MAL, January 21 through April 4, 1993, BIN 9 near-surface BIN, first deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

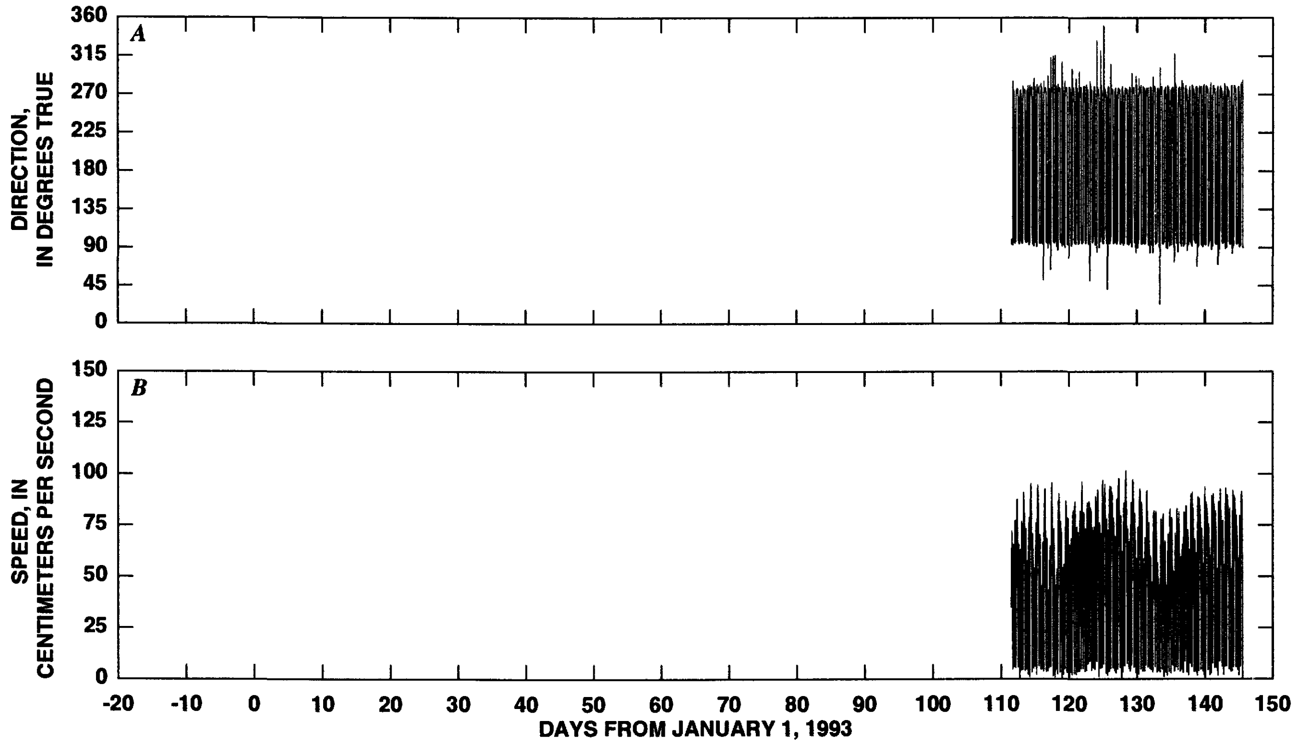

Figure 16. Time-series plots of tidal currents, station MAL, April 21 through May 26, 1993, BIN 1 near-bottom BIN, second deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

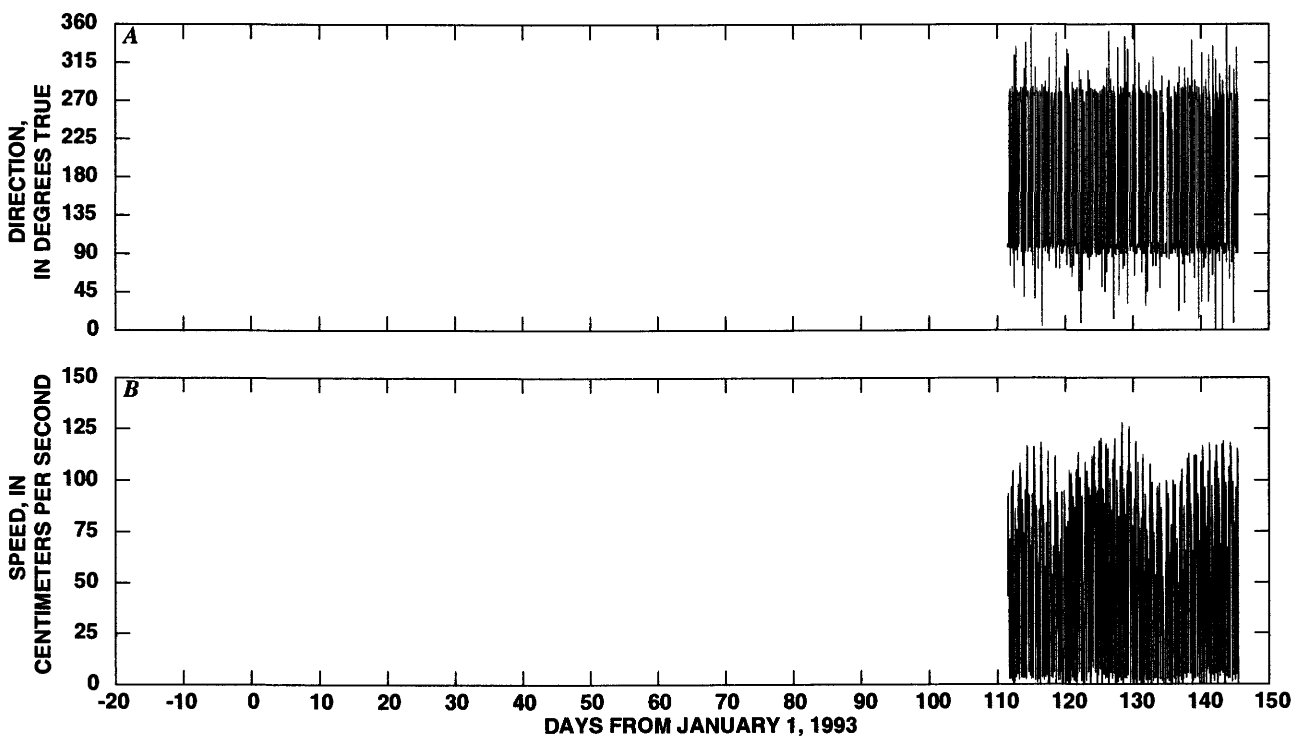

Figure 17. Time-series plots of tidal currents, station MAL, April 21 through May 26, 1993, BIN 13 near-surface BIN, second deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

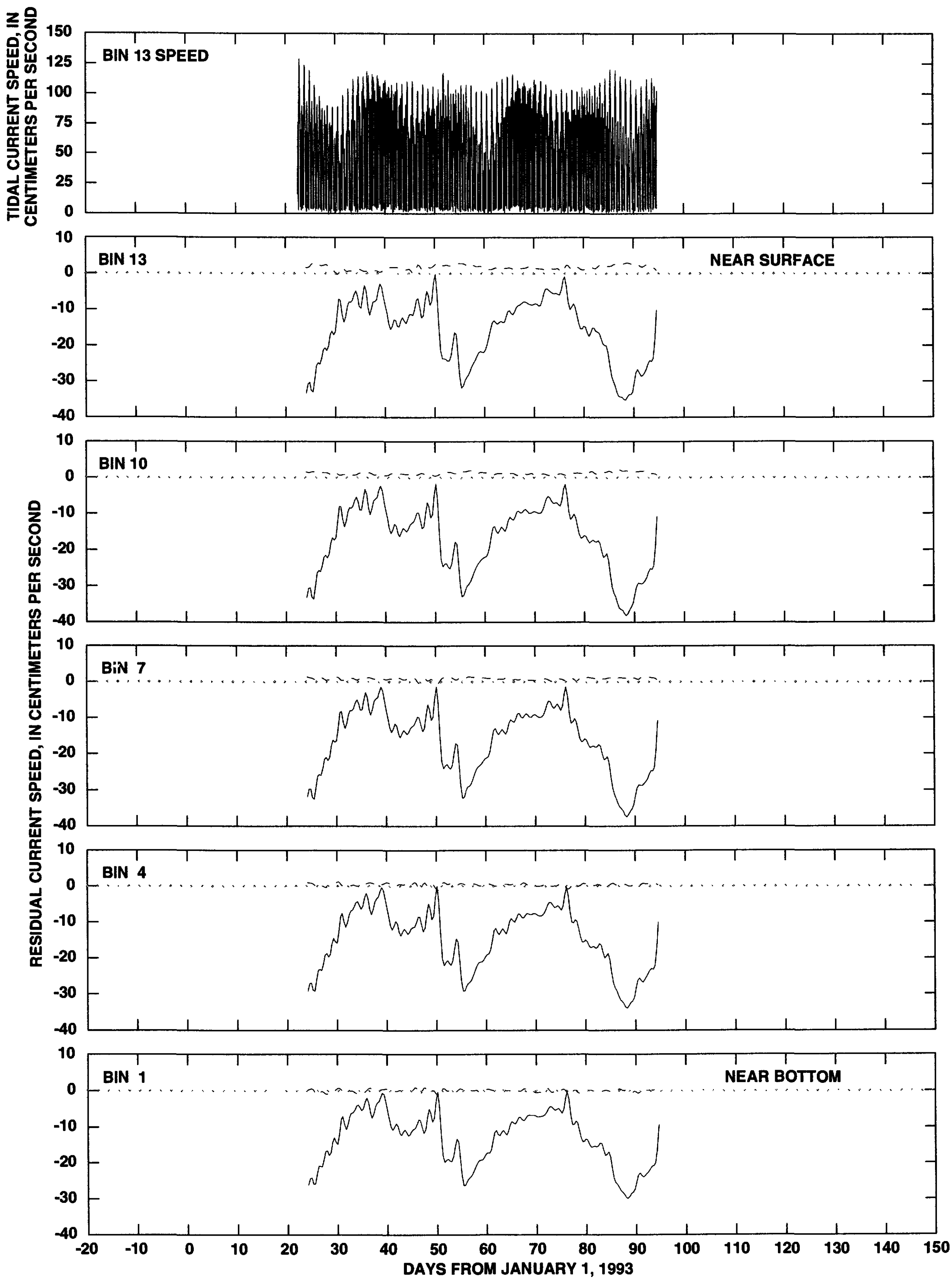

Figure I8. Longitudinal and transverse residual current speed, station MAL, January 22 through April 4, 1993, first deployment, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 98.9°. (Solid) streamwise speed, positive upstream; (dash) transverse speed.

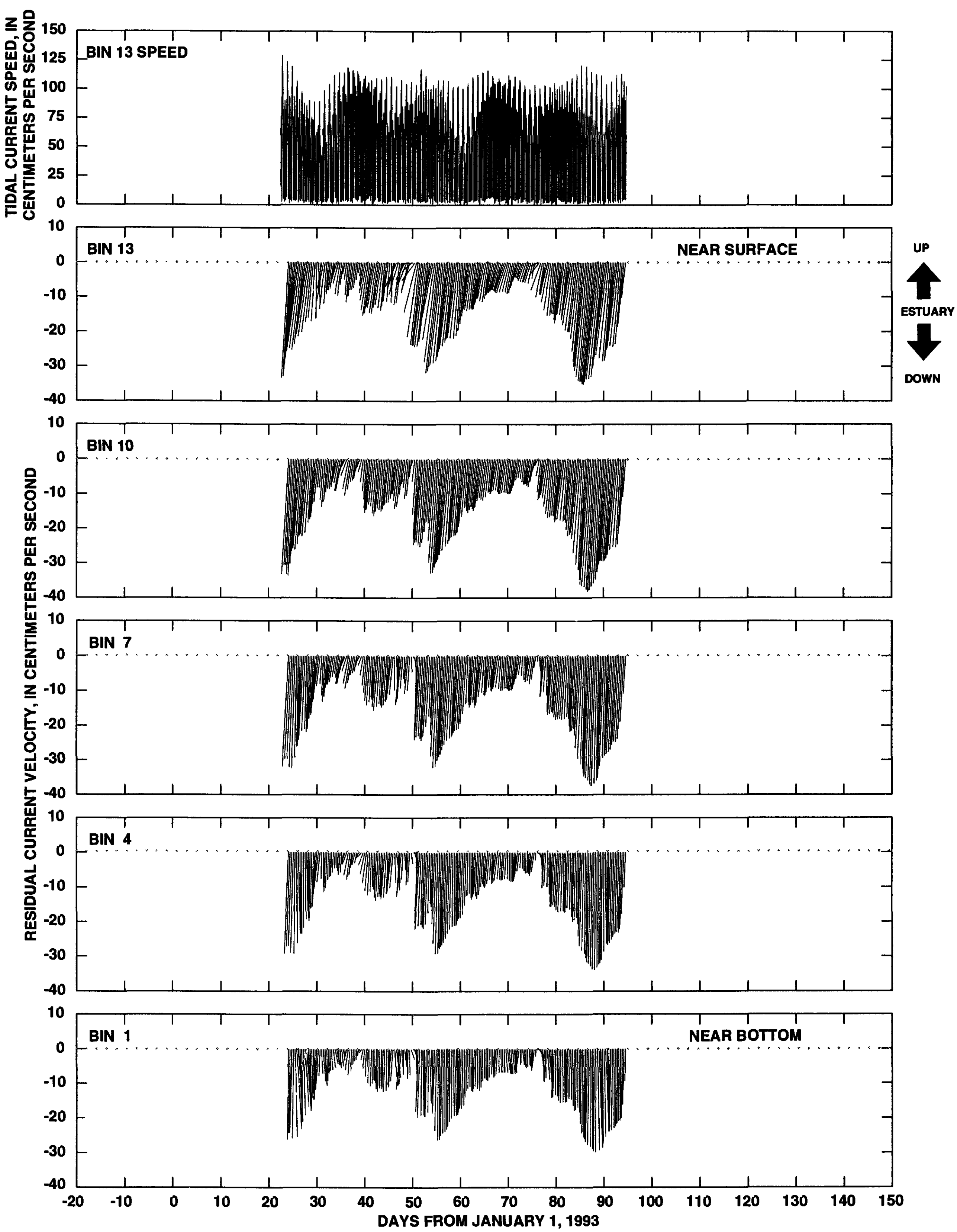

Figure 19. Residual current speed, station MAL, January 22 through April 4, 1993, first deployment, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 98.9°. Sticks angled to the left imply positive transverse velocity.

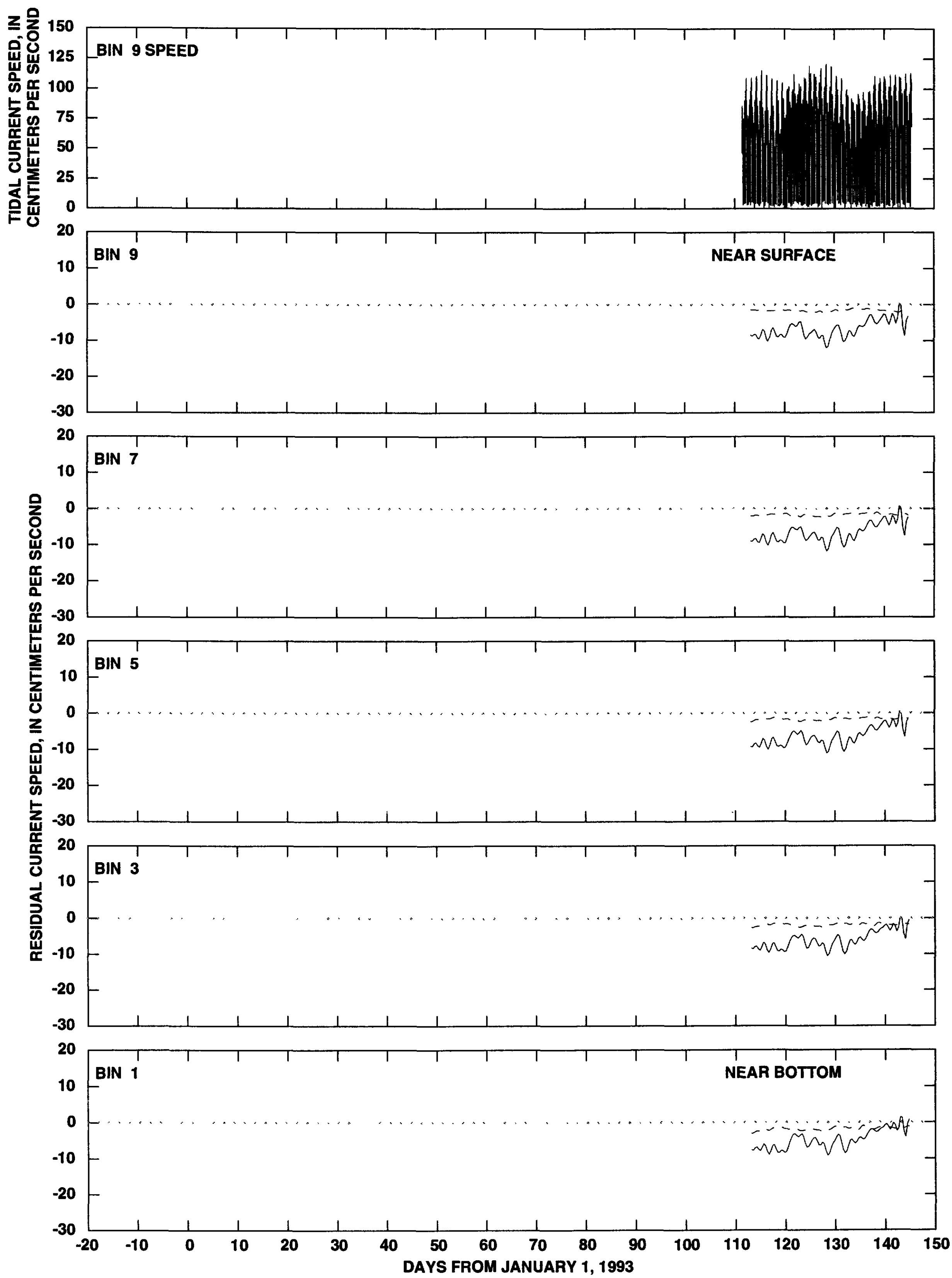

Figure I10. Longitudinal and transverse residual current speed, station MAL, April 21 through May 26, 1993, second deployment, Suisun Bay, California. Tidal current speed at BIN 9 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 98.9°. (Solid) streamwise speed, positive upstream; (dash) transverse speed.

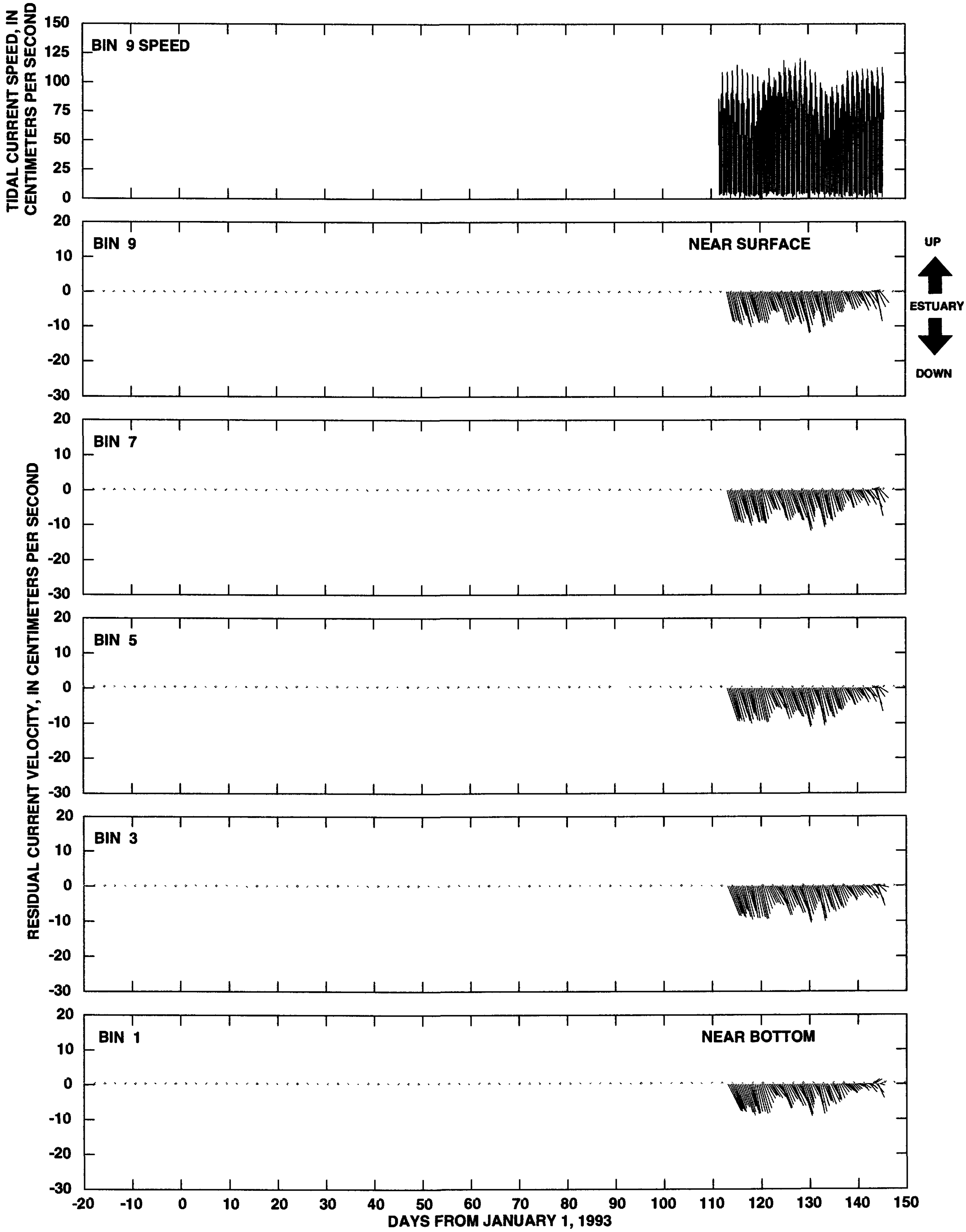

Figure I11. Residual current speed, station MAL, April 21 through May 26, 1993, second deployment, Suisun Bay, California. Tidal current speed at BIN 9 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 98.9°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table I1. Harmonic analysis results for sea level, station MAL, January 1 through May 31, 1993, Suisun Bay, California

Time-series mean: 345.29745
Standard deviation: 13.20063
Harmonic constants: No tidal inference

Tidal symbol	Cycles (per day)	Mean amplitude (centimeters)	Local epoch (degrees)	Modified epoch (degrees)
Q_1	0.89324	2.36108	140.87222	155.59930
O_1	.92954	15.02599	142.66891	153.04102
M_1	.96645	1.18732	196.83206	202.77490
P_1	.99726	7.86955	163.22626	165.47119
K_1	1.00274	26.40720	157.96706	159.55490
J_1	1.03903	.71617	206.40314	203.63599
μ_2	1.86455	1.05384	234.88737	254.97449
N_2	1.89598	8.37524	32.46967	48.78461
ν_2	1.90084	1.68981	40.71109	56.44321
M_2	1.93227	44.39536	60.78455	72.74451
L_2	1.96857	3.15198	70.14828	77.75323
T_2	1.99726	.93386	4.75132	8.91262
S_2	2.00000	8.79323	73.09050	76.92326
K_2	2.00548	4.25465	61.31689	64.49258
M_4	3.86455	1.56218	25.33795	49.25781
Mk_3	2.93501	2.24478	136.70966	150.25745

Table I2. Harmonic analysis results for velocity, station MAL, January 21 through April 4, 1993, BIN 1 near-bottom BIN (first deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 1
Station: MAL (first deployment)
Start time of the series (local): Year, 1993; Month, 1; Day, 22; Hour, 10:27
Time meridian: 120°W
Station position: 38°02′33″N/121°54′59″W
Record length: 138 M2 Cycle: 10285 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	13.15	0.12	100.5	103.7	127.1	Counter-clockwise
K_1	19.37	.23	100.0	116.9	197.4	Counter-clockwise
N_2	14.01	.25	100.1	16.0	194.4	Clockwise
M_2	63.56	.33	99.7	40.3	328.8	Counter-clockwise
S_2	17.20	.11	100.3	47.3	313.8	Counter-clockwise
M_4	4.90	.17	90.2	81.4	297.5	Clockwise

Root-mean-square speed (cm/s):	53.18
Standard deviation, U series (cm/s):	13.05
Standard deviation, V series (cm/s)	3.04
Tidal form number:	0.40
Spring tidal current maximum (cm/s):	113.27
Neap tidal current maximum (cm/s):	40.14
Principal current direction (deg. T):	99.91

Table I3. Harmonic analysis results for velocity, station MAL, January 21 through April 4, 1993, BIN 9 near-surface BIN (first deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 9
Station: MAL (first deployment)
Start time of the series (local): Year, 1993; Month, 1; Day, 22; Hour, 10:27
Time meridian: 120°W
Station position: 38°02′33″N/121°54′59″W
Record length: 138 M2 Cycle: 10285 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	17.20	0.02	101.2	102.3	127.1	Counter-clockwise
K_1	25.08	.01	101.3	116.6	197.4	Clockwise
N_2	18.26	.08	101.0	15.3	194.4	Clockwise
M_2	83.52	.48	100.9	39.9	328.8	Clockwise
S_2	22.32	.12	100.7	47.2	313.8	Clockwise
M_4	6.31	.09	99.4	80.9	297.5	Clockwise

Root-mean-square speed (cm/s):	69.42
Standard deviation, U series (cm/s):	16.46
Standard deviation, V series (cm/s)	3.55
Tidal form number:	0.40
Spring tidal current maximum (cm/s):	148.12
Neap tidal current maximum (cm/s):	53.31
Principal current direction (deg. T):	100.99

Table I4. Harmonic analysis results for velocity, station MAL, April 21 through May 26, 1993, BIN 1 near-bottom BIN (second deployment) Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 1
Station: MAL (second deployment)
Start time of the series (local): Year, 1993; Month, 4; Day, 21; Hour, 11:31
Time meridian: 120°W
Station position: 38°02′33″N/121°54′59″W
Record length: 64 M2 Cycle: 4770 data points

Tidal symbol	Major axis (cm/s)	Minor axos (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	10.05	0.36	95.8	94.5	44.3	Counter-clockwise
K_1	27.67	.08	96.6	93.6	301.1	Clockwise
N_2	11.42	.13	96.5	1.2	131.8	Counter-clockwise
M_2	70.16	.05	96.5	38.9	349.6	Counter-clockwise
S_2	10.87	.10	97.2	24.2	345.6	Clockwise
M_4	3.96	.02	90.3	49.2	339.1	Clockwise

Root-mean-square speed (cm/s):	56.70
Standard deviation, U series (cm/s):	12.35
Standard deviation, V series (cm/s)	2.60
Tidal form number:	0.47
Spring tidal current maximum (cm/s):	118.75
Neap tidal current maximum (cm/s):	41.67
Principal current direction (deg. T):	96.52

Table I5. Harmonic analysis results for velocity, station MAL, April 21 through May 26, 1993, BIN 13 near-surface BIN (second deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 13
Station: MAL (second deployment)
Start time of the series (local): Year, 1993; Month, 4; Day, 21; Hour, 11:31
Time meridian: 120°W
Station position: 38°02′33″N/121°54′59″W
Record length: 64 M2 Cycle: 4770 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	14.37	0.18	96.1	93.0	44.3	Clockwise
K_1	35.07	.09	97.5	89.7	301.1	Counter-clockwise
N_2	14.52	.19	98.4	357.9	131.8	Counter-clockwise
M_2	89.80	.25	98.3	37.0	349.6	Clockwise
S_2	14.51	.20	97.6	22.2	345.6	Counter-clockwise
M_4	3.34	.37	108.9	34.1	339.1	Clockwise

Root-mean-square speed (cm/s):	70.82
Standard deviation, U series (cm/s):	14.90
Standard deviation, V series (cm/s)	3.64
Tidal form number:	0.47
Spring tidal current maximum (cm/s):	153.76
Neap tidal current maximum (cm/s):	54.59
Principal current direction (deg. T):	97.82

APPENDIX J—STATION MART

Station Name: **MART**
(Near Martinez)
Position: Lat 38° 01' 40" N
Long 122° 08' 22" W
Depth: 8.0 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t :	Schnieder	RM25 C	DWR monitoring
CT_b :	Foxboro	872	DWR monitoring

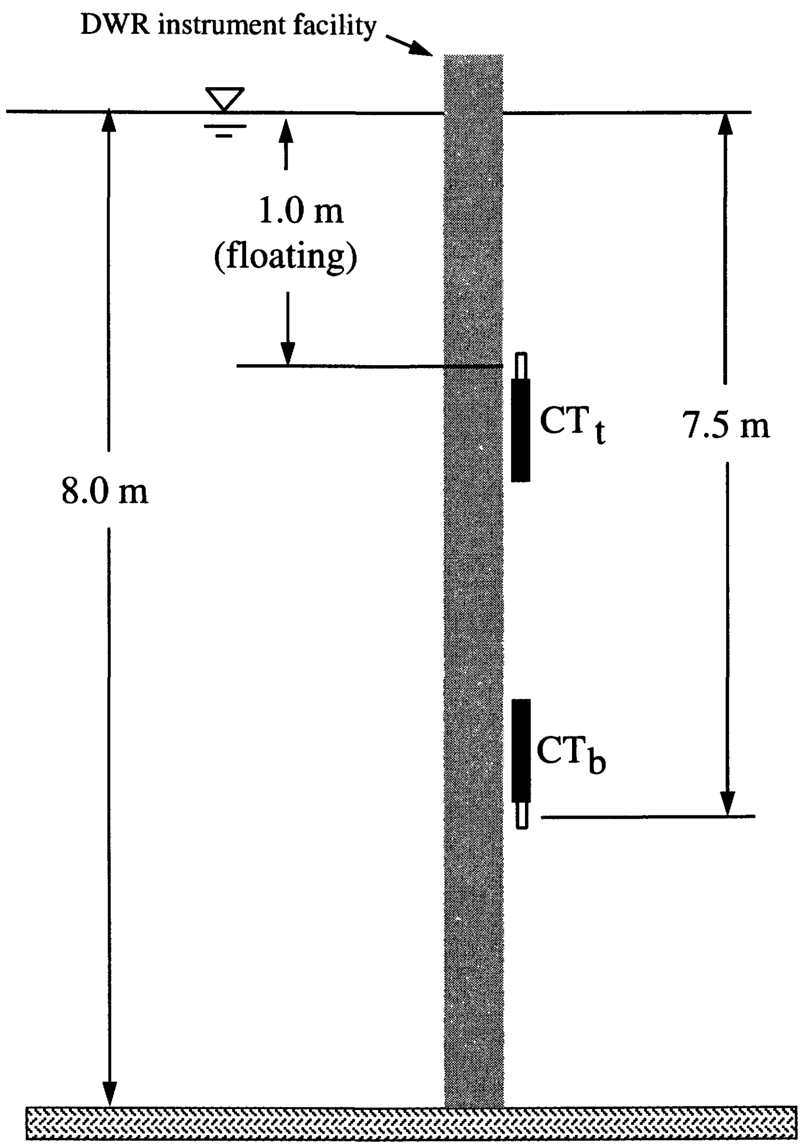

Figure J1. Configuration of instrument deployment, station MART, Suisun Bay, California. m, meters; MLLW, mean lower low water; DWR, California Department of Water Resources.

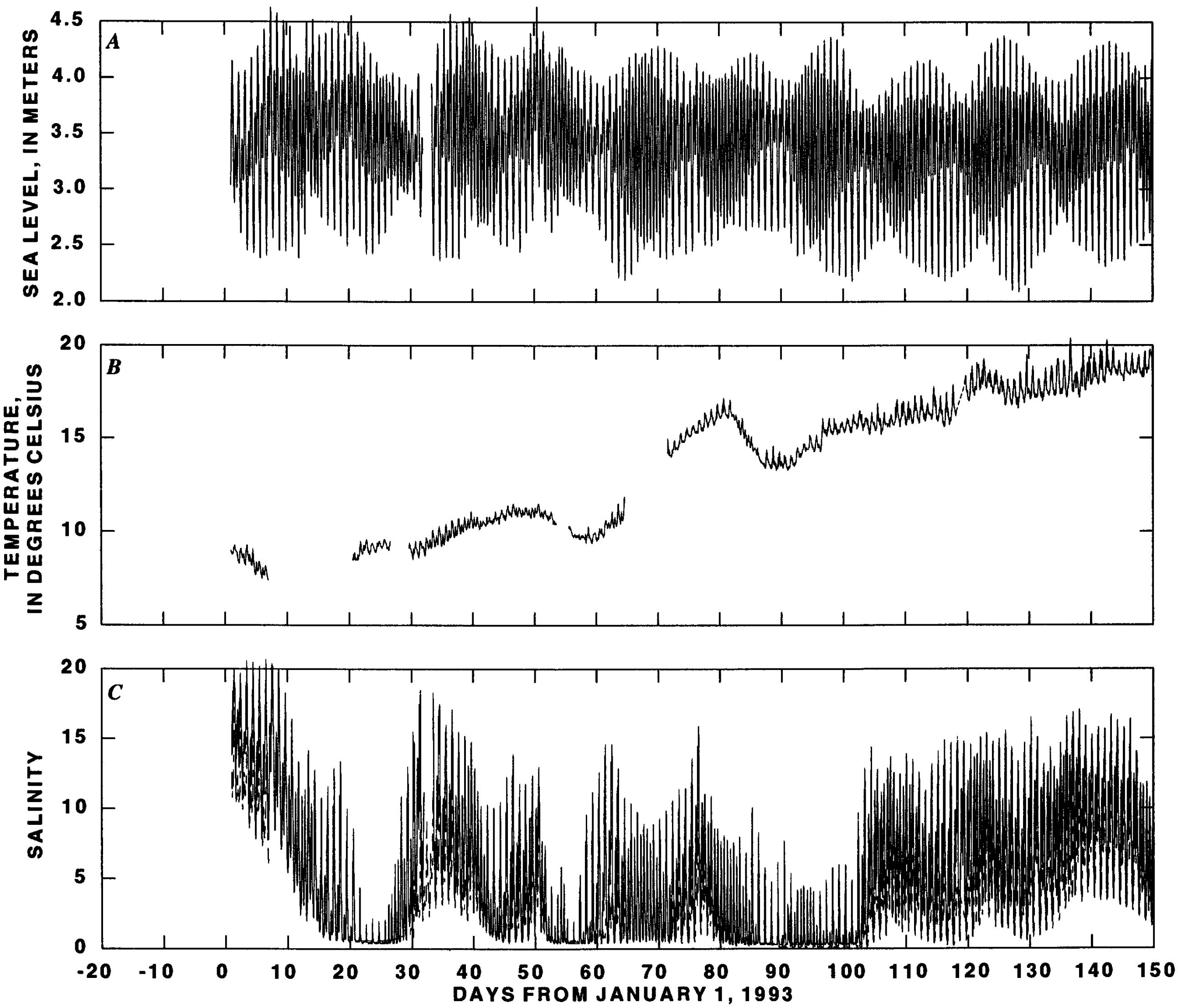

Figure J2. Time-series plots of ***A***, sea level; ***B***, salinity; and ***C***, temperature, station MART, January 1 through May 31, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 0.9 meters.

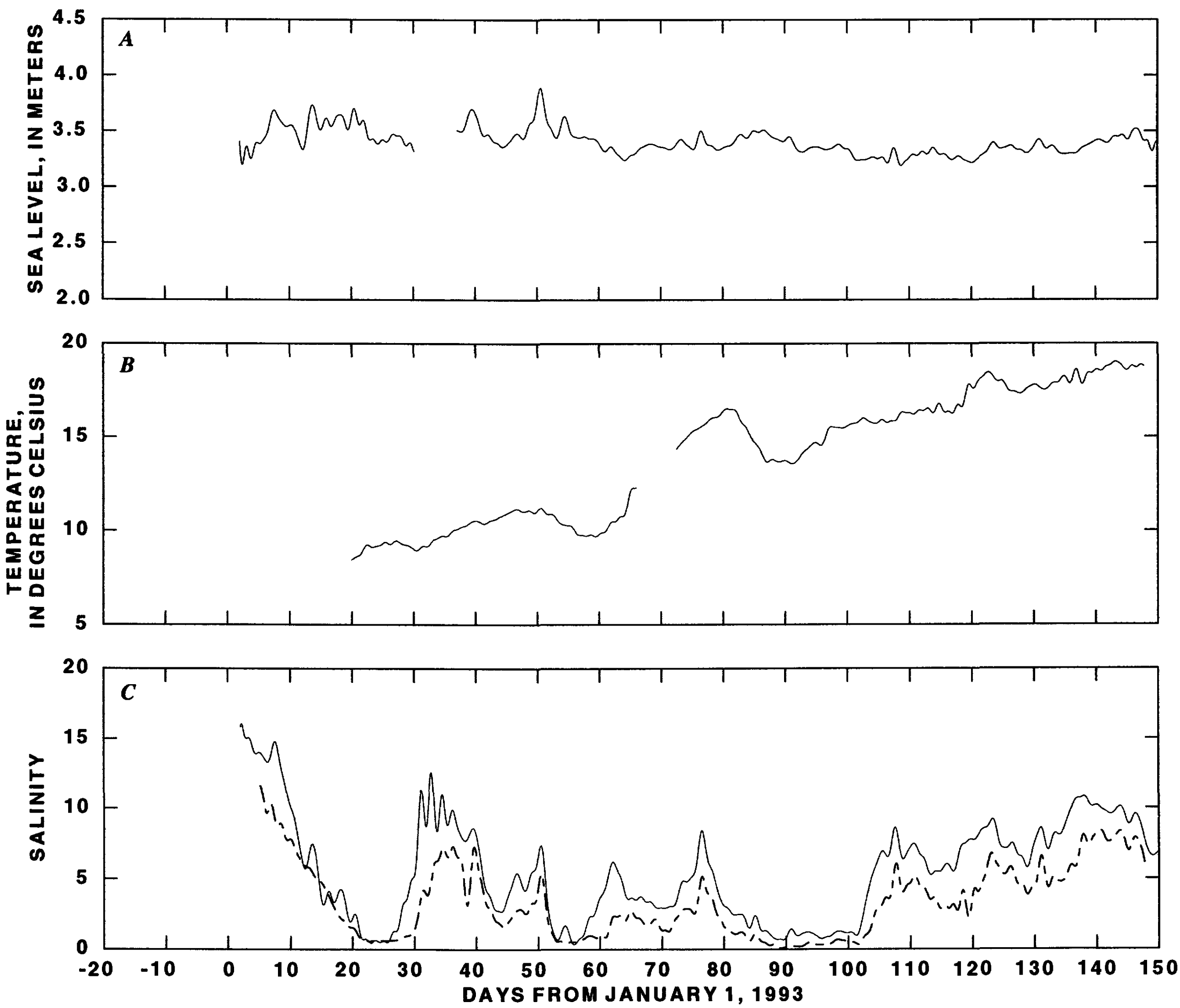

Figure J3. Time-series plots of low-pass-filtered ***A***, sea level; ***B***, salinity; and ***C***, temperature, station MART, January 1 through May 31, 1993, Suisun Bay, California. (Solid) near-bed sensor, (dashed) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 0.9 meters.

Table J1. Harmonic analysis results for sea level, station MART, January 1 through May 31, 1993, Suisun Bay, California

Time series mean: 340.81918
Standard deviation: 12.43273
Harmonic constants: No tidal inference

Tidal symbol	Cycles (per day)	Mean amplitude (centimeters)	Local epoch (degrees)	Modified epoch (degrees)
Q_1	0.89324	3.09195	113.75066	128.70081
O_1	.92954	19.44003	118.85883	129.45398
M_1	.96645	1.13722	158.61737	164.78326
P_1	.99726	9.83238	140.97922	143.44720
K_1	1.00274	32.55415	134.41988	136.23077
J_1	1.03903	1.43976	176.55435	174.01025
μ_2	1.86455	.80638	243.16161	263.69482
N_2	1.89598	11.44629	356.20206	12.96310
ν_2	1.90084	2.15025	4.29681	20.47504
M_2	1.93227	57.13730	25.75327	38.15933
L_2	1.96857	2.64401	25.61752	33.66858
T_2	1.99726	1.28871	296.65485	301.26224
S_2	2.00000	12.37480	40.03300	44.31187
K_2	2.00548	5.00026	25.01321	28.63501
M_4	3.86455	.79808	277.69427	302.50635
Mk_3	2.93501	1.33353	90.54248	104.75943

APPENDIX K—STATION MID

Station Name: **MID**
(Near Middle Ground)
Position: Lat 38° 03' 30" N
Long 121° 58' 48" W
Depth: 9.8 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t :	Hydrolab	4	12/11/92 (-20) - 03/27/93 (86)
CT_b :	Hydrolab	3	12/11/92 (-20) - 02/10/93 (41)
CT_b :	Hydrolab	1	03/16/93 (75) - 05/25/93 (145)
ADCP :	RDI	1161	01/22/93 (22) - 05/25/93 (145)

CT Sensors serviced: 01/12/93 (12), 02/10/93 (41), 03/16/93 (75), 04/19/93 (109), 05/12/93 (132)

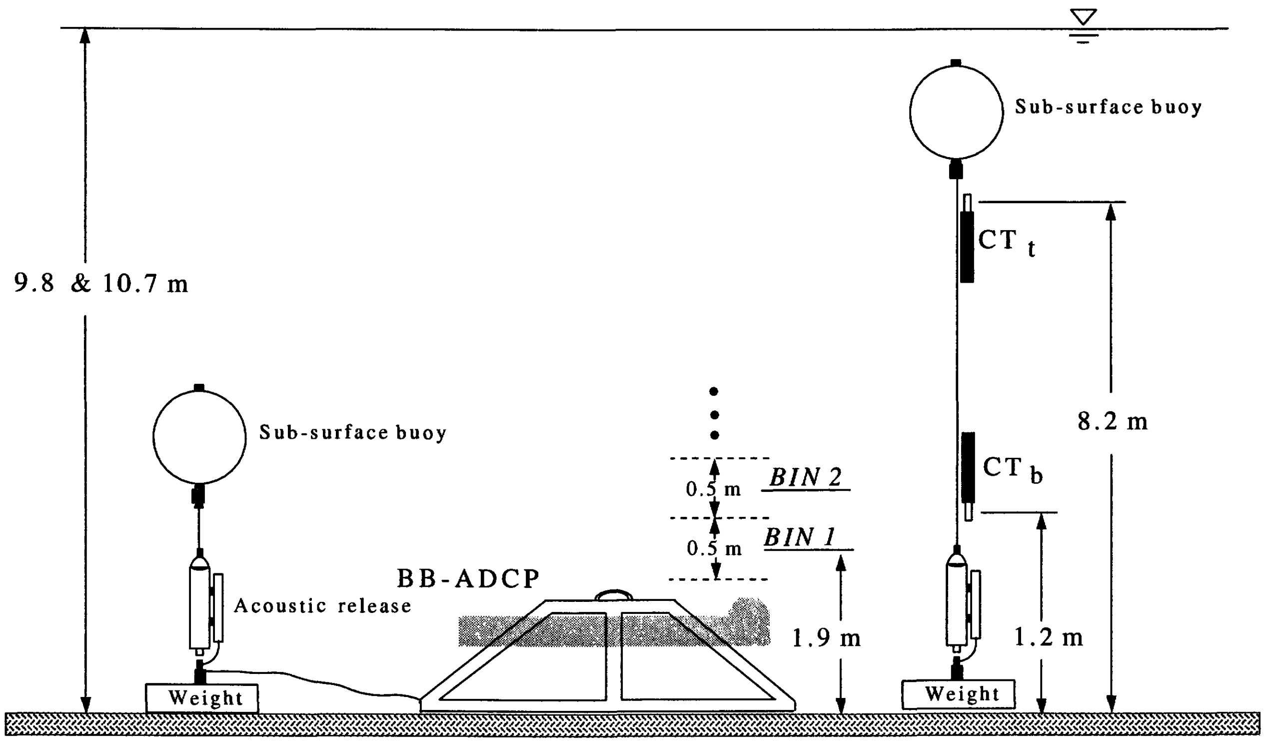

Figure K1. Configuration of instrument deployment, station MID, December 11, 1992, through May 25, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water; BB-ADCP, broad-band acoustic Doppler current profiler.

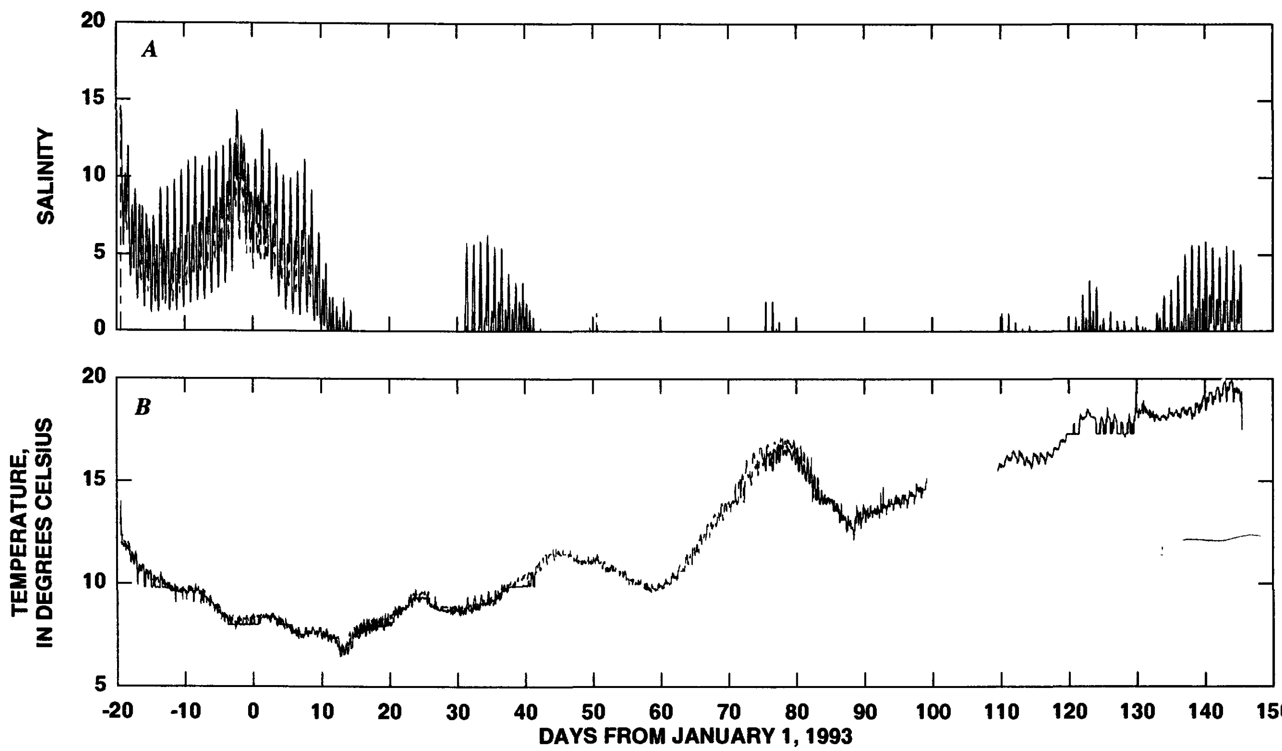

Figure K2. Time-series plots of ***A***, salinity; and ***B***, temperature, station MID, December 12, 1992, through May 25, 1993, Suisun Bay, California. (Solid) bottom sensor, (dashed) top sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

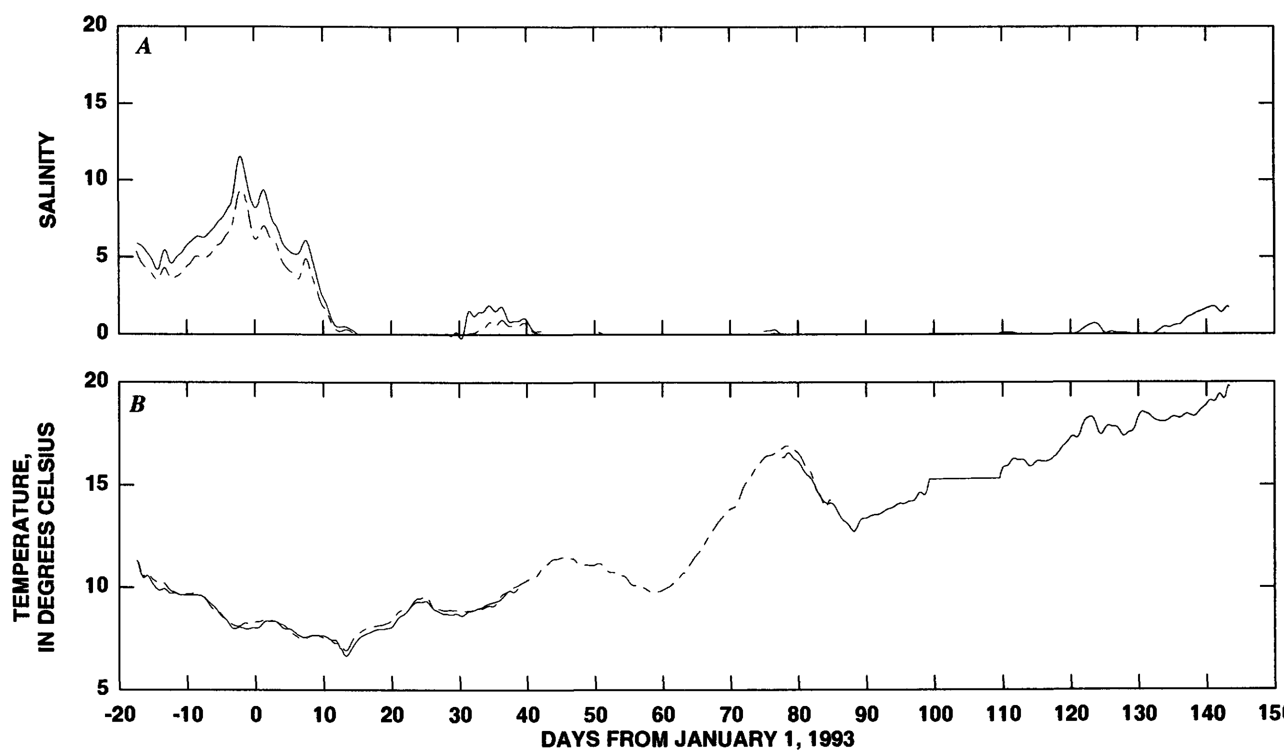

Figure K3. Time-series plots of low-pass-filtered ***A***, salinity; and ***B***, temperature, station MID, December 12, 1992, through May 25, 1993, Suisun Bay, California. (Solid) bottom sensor, (dashed) top sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

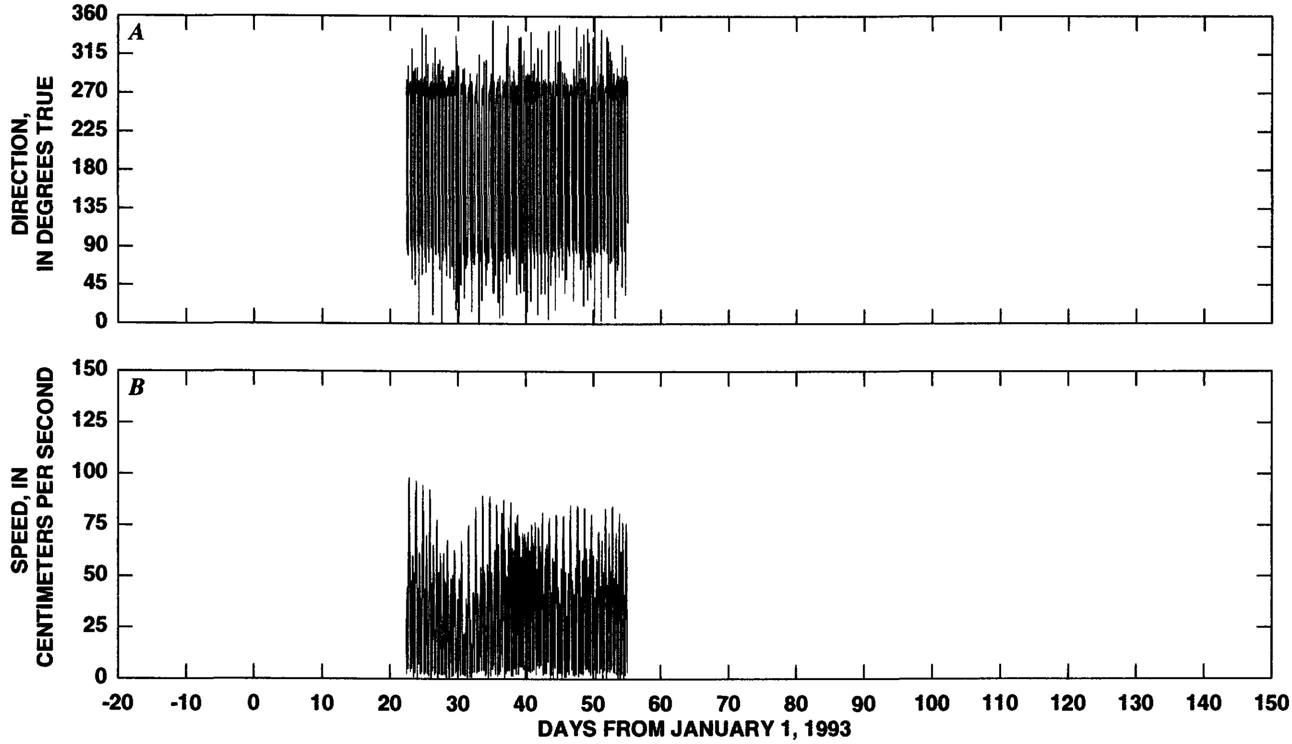

Figure K4. Time-series plots of tidal current speed, station MID, January 22 through February 24, 1993, BIN 1 near-bottom BIN, first deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

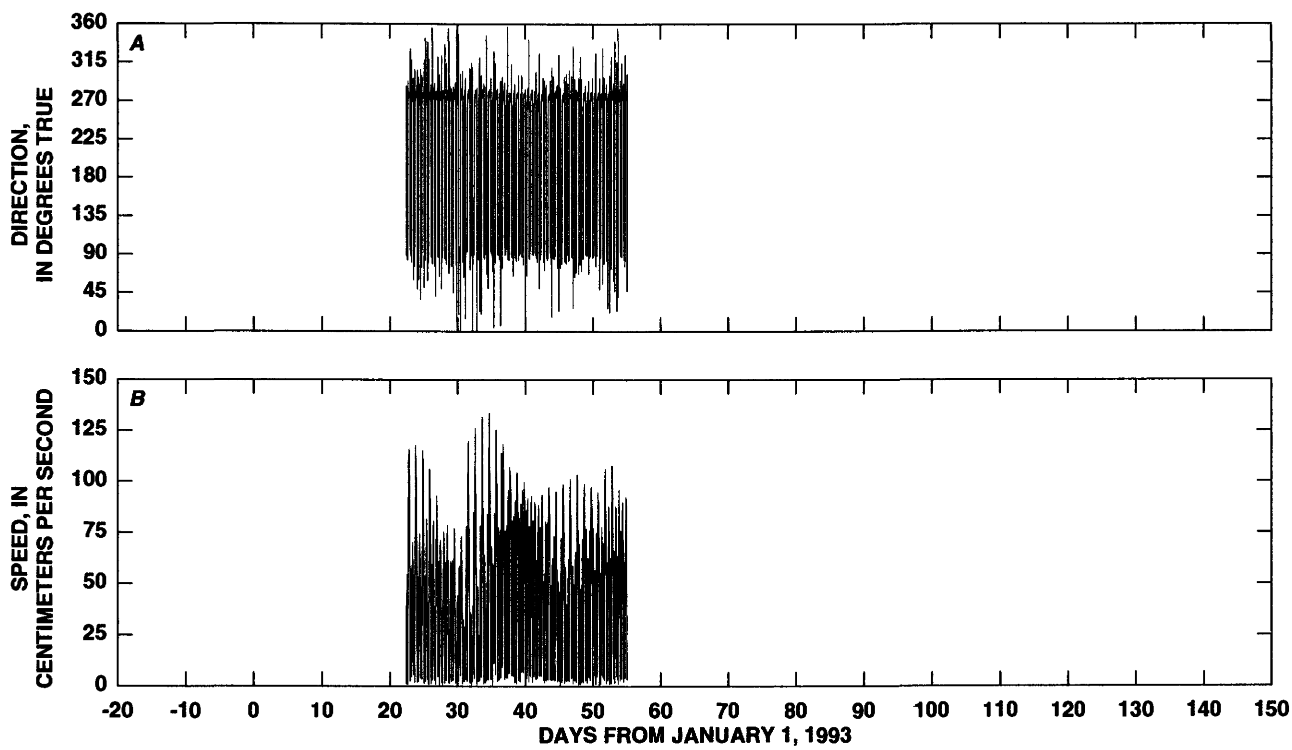

Figure K5. Time-series plots of tidal current speed, station MID, January 22 through February 24, 1993, BIN 13 near-surface BIN, first deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

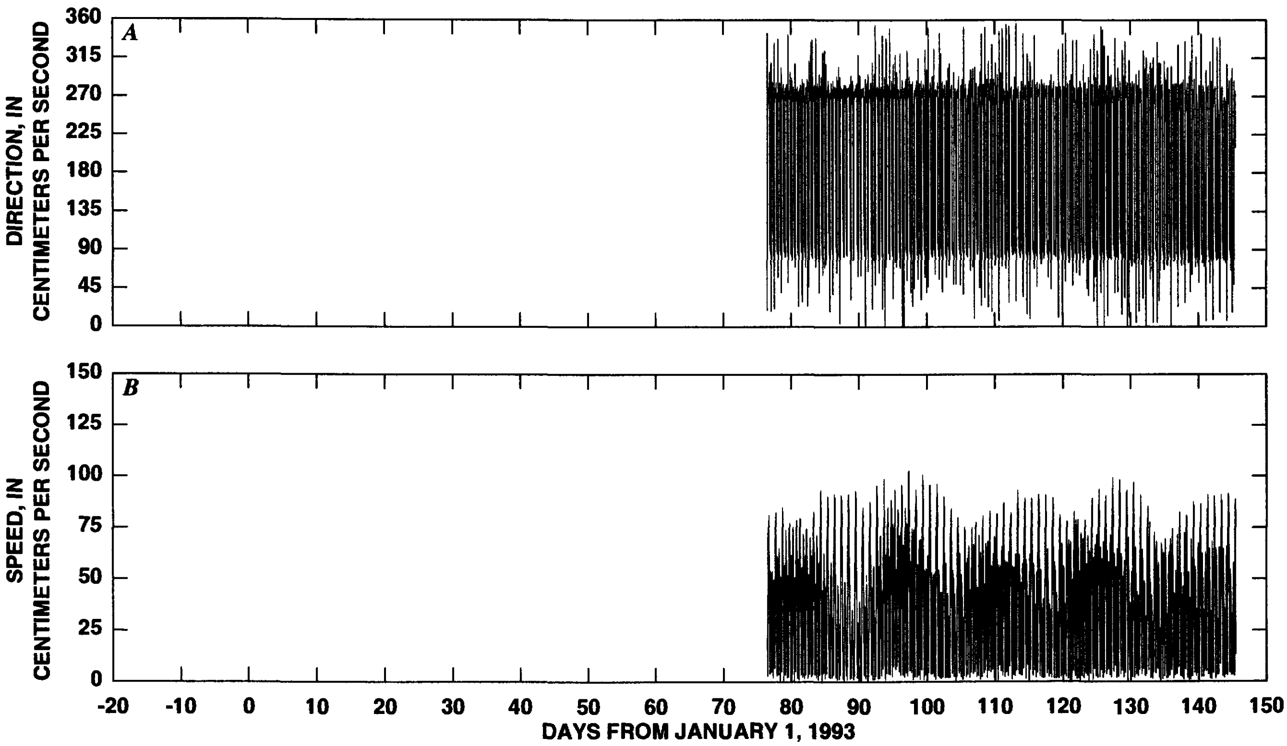

Figure K6. Time-series plots of tidal currents, station MID, March 17 through May 25, 1993, BIN 1 near-bottom BIN, second deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

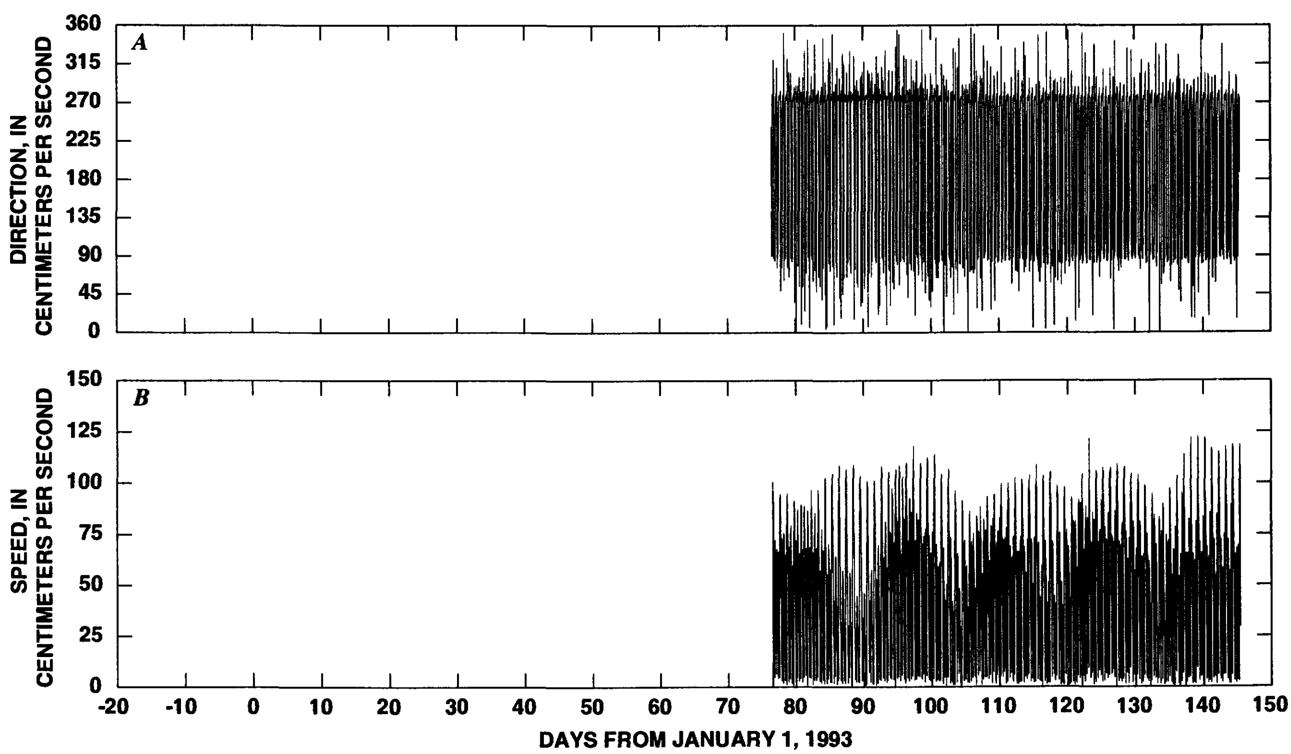

Figure K7. Time-series plots of tidal currents, station MID, March 17 through May 25, 1993, BIN 13 near-surface BIN, second deployment, Suisun Bay, California. BIN refers to a discrete measurement location in the vertical.

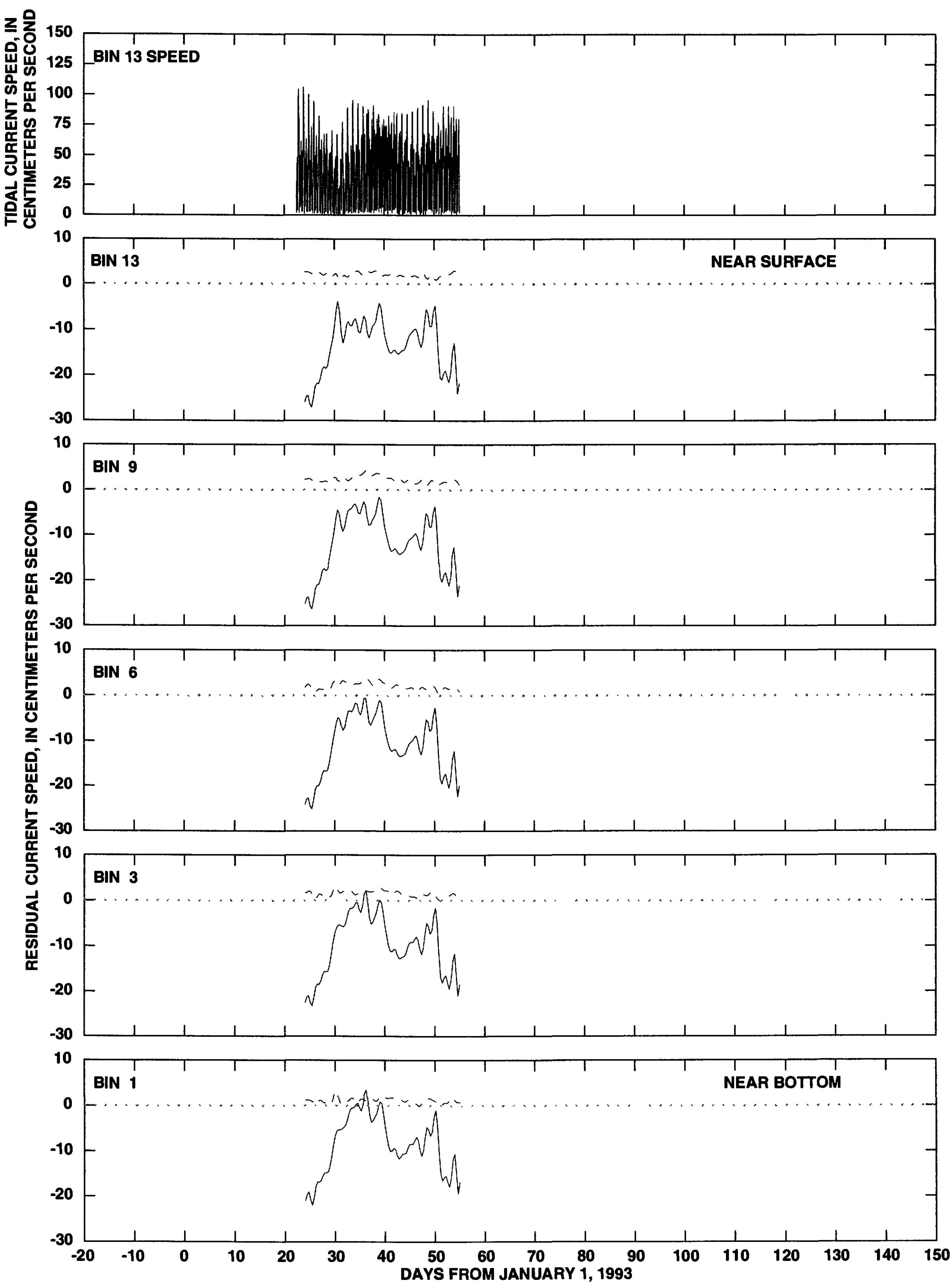

Figure K8. Longitudinal (solid) and transverse (dashed) residual currents, station MID, January 22 through February 24, 1993, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. Principal direction is 94.2°. BIN refers to a discrete measurement location in the vertical.

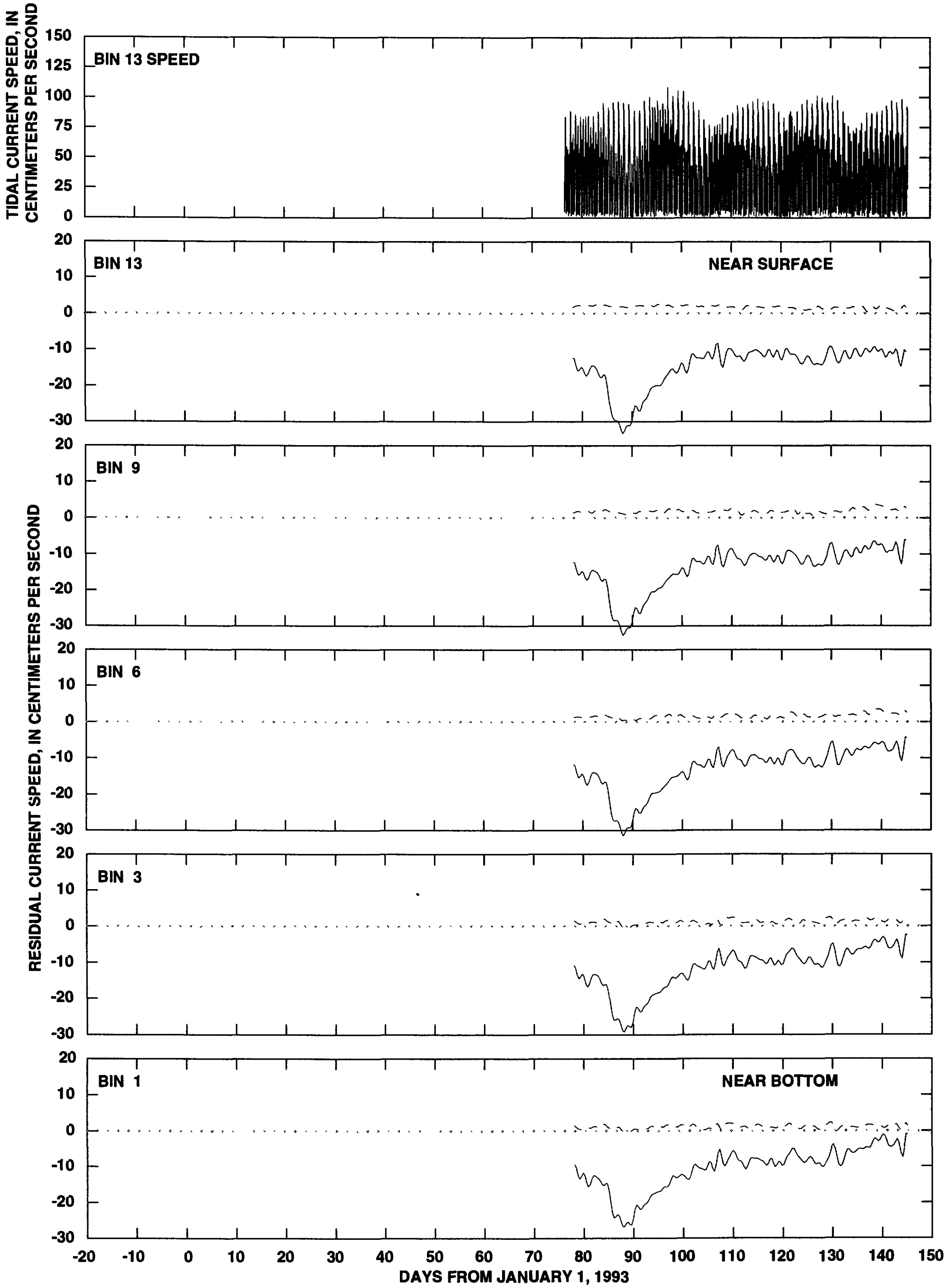

Figure K9. Longitudinal (solid) and transverse (dashed) residual currents, station MID, March 17 through May 25, 1993, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. Principal direction is 94.2°. BIN refers to a discrete measurement location in the vertical.

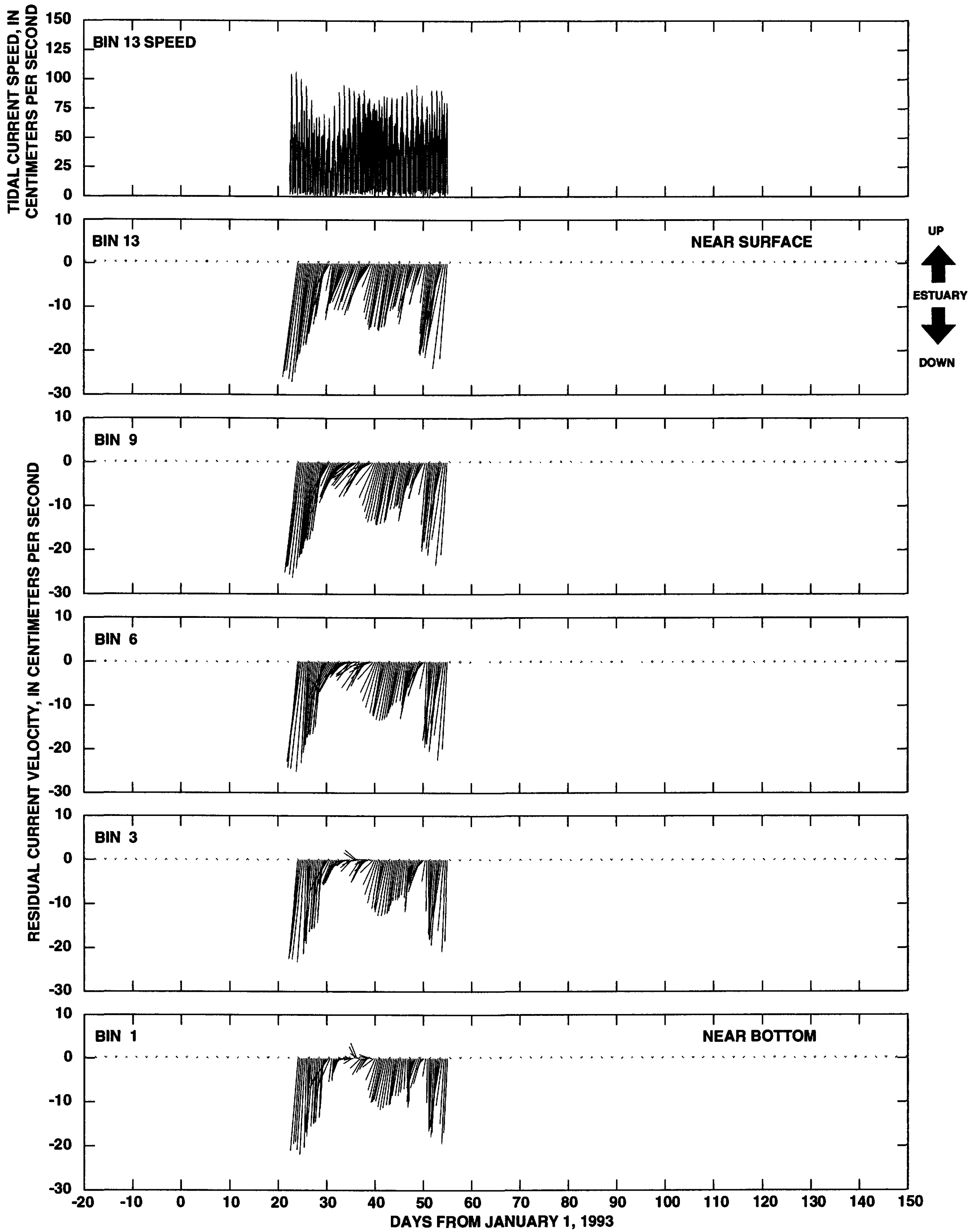

Figure K10. Residual currents, station MID, January 22 through February 24, 1993, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 94.2°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

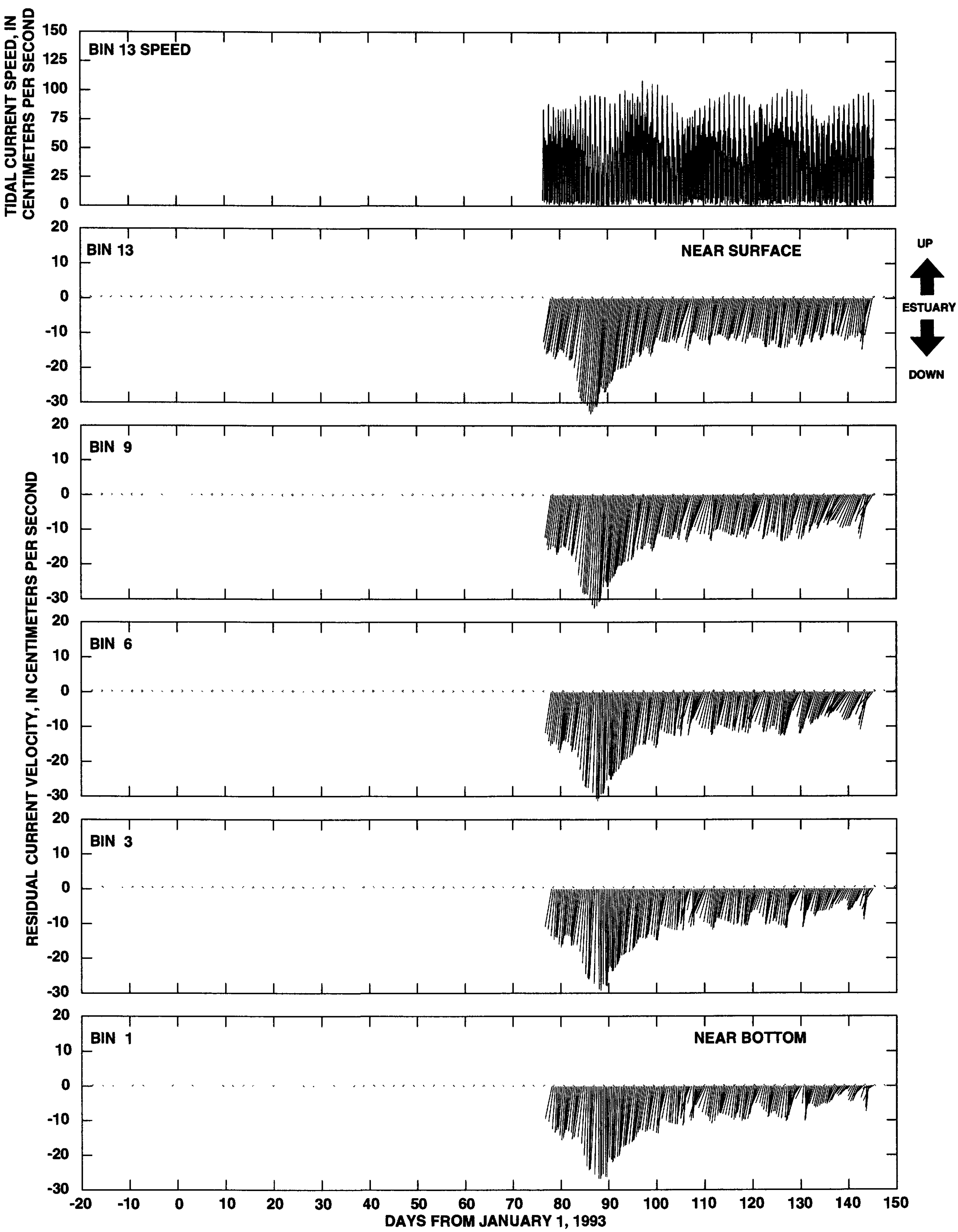

Figure K11. Residual currents, station MID, March 17 through May 25, 1993, Suisun Bay, California. Tidal current speed at BIN 13 near-surface BIN is shown in top panel for reference. BIN refers to a discrete measurement location in the vertical. Principal direction is 94.2°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table K1. Harmonic analysis results for velocity, station MID, January 22 through February 24, 1993, BIN 1 near-bottom BIN (first deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 1
Station: MID (first deployment)
Start time of the series (local): Year, 1993; Month, 1; Day, 22; Hour, 7:58
Time meridian: 120°W
Station position: 38°03′31″N/121°58′48″W
Record length: 62 M2 Cycle: 4621 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	12.21	0.01	93.3	114.7	92.6	Clockwise
K_1	18.75	.00	92.5	127.1	160.1	Counter-clockwise
N_2	9.42	.84	87.2	14.9	123.9	Counter-clockwise
M_2	48.16	.49	92.1	39.4	256.9	Clockwise
S_2	12.37	.39	93.4	53.8	239.4	Clockwise
M_4	1.93	.82	107.1	44.2	153.8	Counter-clockwise

Root-mean-square speed (cm/s):	41.74
Standard deviation, U series (cm/s):	10.75
Standard deviation, V series (cm/s)	3.69
Tidal form number:	0.51
Spring tidal current maximum (cm/s):	91.48
Neap tidal current maximum (cm/s):	29.25
Principal current direction (deg. T):	92.53

Table K2. Harmonic analysis results for velocity, station MID, January 22 through February 24, 1993, BIN 13 near-surface BIN (first deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 13
Station: MID (first deployment)
Start time of the series (local): Year, 1993; Month, 1; Day, 22; Hour, 9.28
Time meridian: 120°W
Station position: 38°03′31″N/121°58′48″W
Record length: 62 M2 Cycle: 4621 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	16.26	0.24	95.8	110.2	113.5	Clockwise
K_1	25.07	.22	95.7	121.8	182.7	Clockwise
N_2	14.84	.68	94.5	17.6	166.5	Clockwise
M_2	66.33	.86	95.3	36.5	300.4	Clockwise
S_2	15.06	.13	94.4	46.8	284.4	Clockwise
M_4	3.74	.26	83.4	82.2	240.7	Counter-clockwise

Root-mean-square speed (cm/s):	56.66
Standard deviation, U series (cm/s):	12.14
Standard deviation, V series (cm/s)	3.41
Tidal form number:	0.51
Spring tidal current maximum (cm/s):	122.71
Neap tidal current maximum (cm/s):	42.46
Principal current direction (deg. T):	95.36

Table K3. Harmonic analysis results for velocity, station MID, March 17 through May 25, 1993, BIN 1 near-bottom BIN (second deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 1
Station: MID (second deployment)
Start time of the series (local): Year, 1993; Month, 3; Day, 17; Hour, 10.51
Time meridian: 120°W
Station position: 38°03′31″N/121°58′48″W
Record length: 132 M2 Cycle: 9838 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	10.13	0.13	94.0	92.3	202.7	Counter-clockwise
K_1	19.92	.11	92.6	93.4	256.6	Clockwise
N_2	10.28	.10	93.5	358.6	343.4	Clockwise
M_2	53.04	.11	91.8	39.2	103.5	Clockwise
S_2	12.04	.25	90.4	26.3	325.5	Clockwise
M_4	2.13	.99	106.7	36.5	206.9	Counter-clockwise

Root-mean-square speed (cm/s):	44.97
Standard deviation, U series (cm/s):	10.52
Standard deviation, V series (cm/s)	3.43
Tidal form number:	0.46
Spring tidal current maximum (cm/s):	95.12
Neap tidal current maximum (cm/s):	31.21
Principal current direction (deg. T):	92.03

Table K4. Harmonic analysis results for velocity, station MID, March 17 through May 25, 1993, BIN 13 near-surface BIN (second deployment), Suisun Bay, California

[BIN refers to a discrete measurement location in the vertical. cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

BIN number: 13
Station: MID (second deployment)
Start time of the series (local): Year, 1993; Month, 3; Day, 17; Hour, 10.51
Time meridian: 120°W
Station position: 38°03′31″N/121°58′48″W
Record length: 132 M2 Cycle: 9838 data points

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
O_1	13.36	0.40	94.6	93.2	202.7	Clockwise
K_1	24.46	.24	93.8	88.1	256.6	Clockwise
N_2	12.32	.19	93.5	358.2	343.4	Clockwise
M_2	67.80	1.41	94.0	37.3	103.5	Clockwise
S_2	14.87	.26	94.9	22.6	325.5	Clockwise
M_4	2.95	.40	79.1	69.2	206.9	Counter-clockwise

Root-mean-square speed (cm/s):	57.14
Standard deviation, U series (cm/s):	12.36
Standard deviation, V series (cm/s)	3.38
Tidal form number:	0.46
Spring tidal current maximum (cm/s):	120.50
Neap tidal current maximum (cm/s):	41.83
Principal current direction (deg. T):	94.13

APPENDIX L—STATION RYER

Station Name: **RYER**
(Between Roe and Ryer Islands)
Position: Lat 38° 04' 24" N
Long 122° 01' 25" W
Depth: 7.0 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
V:	Endeco	43	01/13/93 (13) - 05/26/93 (146)

Sensors serviced: 02/11/93 (42), 03/15/93 (74), 04/20/93 (110)

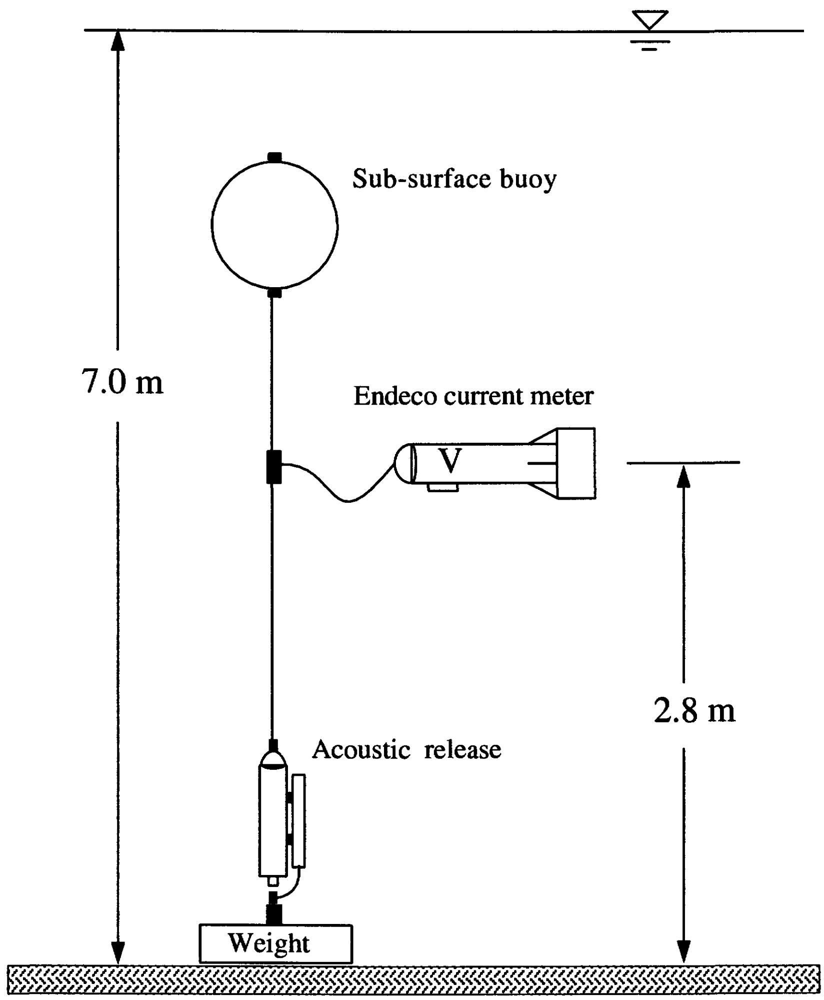

Figure L1. Configuration of instrument deployment, station RYER, January 13 through May 26, 1993, Suisun Bay, California. m, meters; MLLW, mean lower low water.

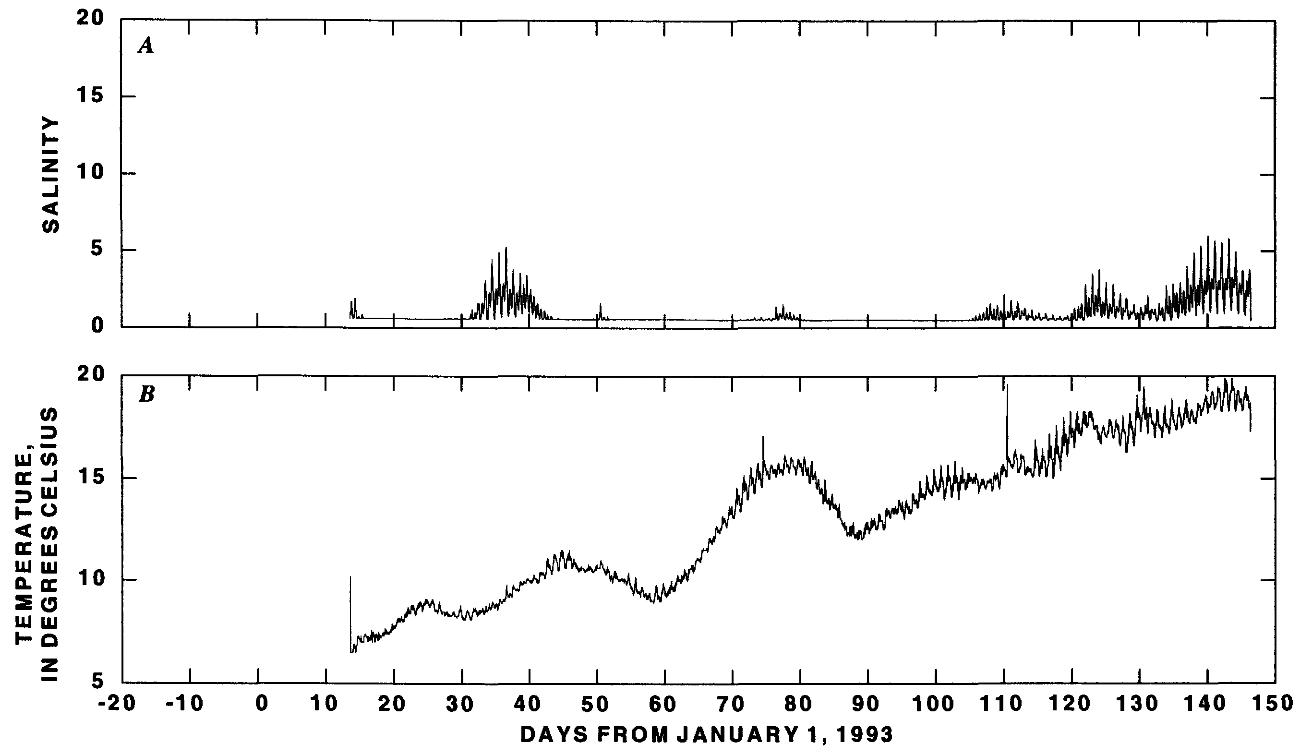

Figure L2. Time-series plots of ***A***, salinity; and ***B***, temperature, station RYER, January 13 through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

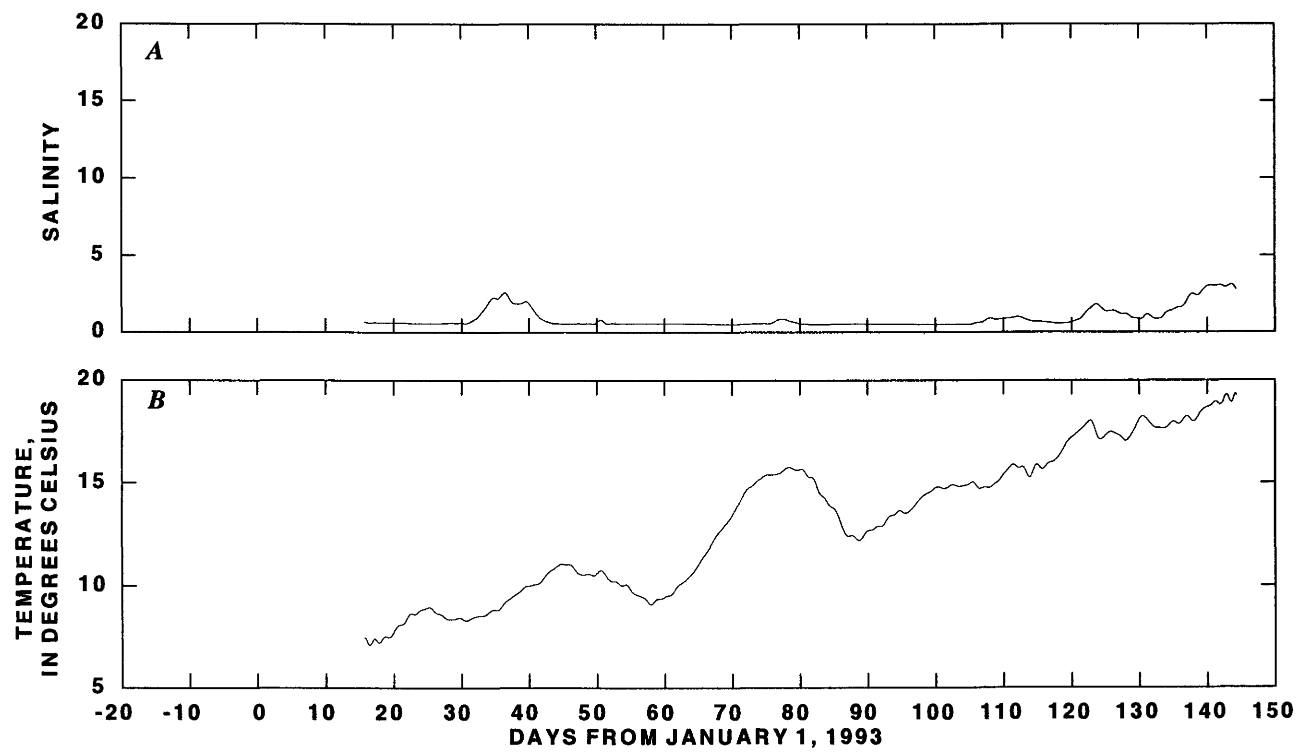

Figure L3. Time-series plots of low-pass-filtered ***A***, salinity; and ***B***, temperature, station RYER, January 13 through May 26, 1993, Suisun Bay, California. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993).

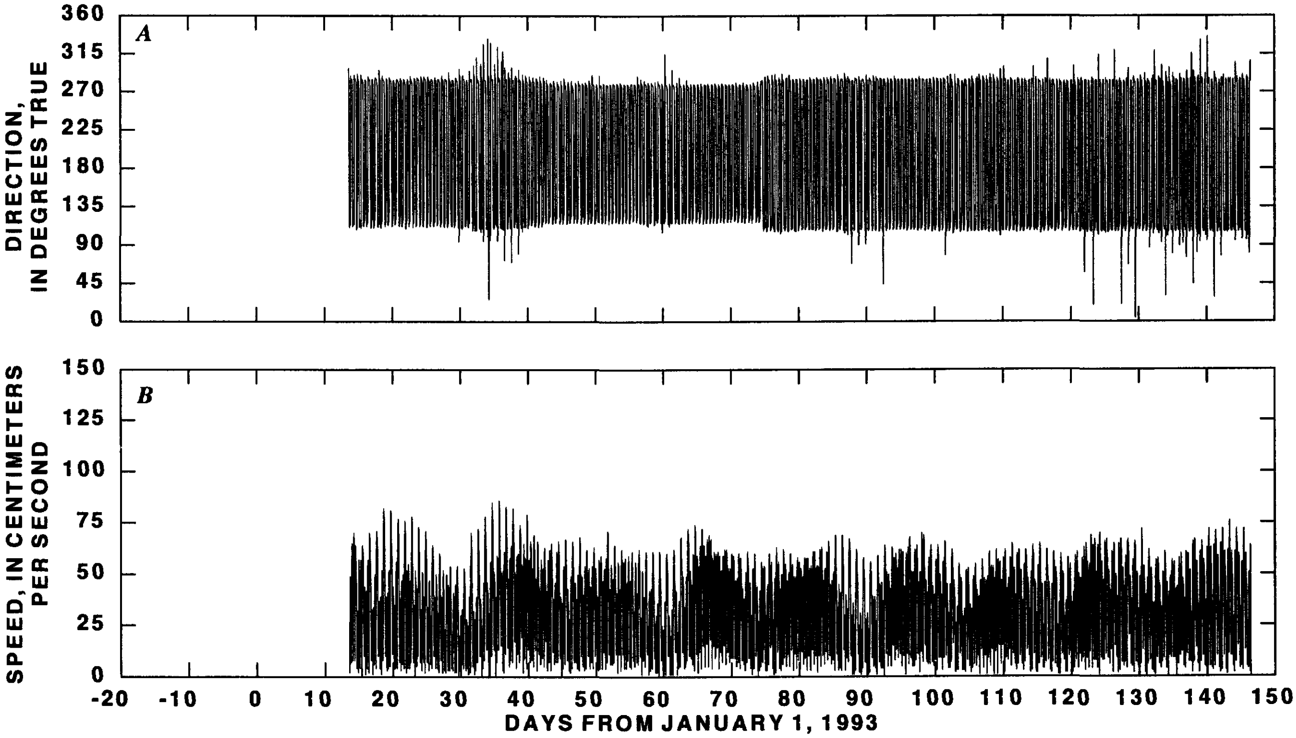

Figure L4. Time-series plots of ***A***, current direction and ***B***, speed, station RYER, January 13 through May 26, 1993, Suisun Bay, California.

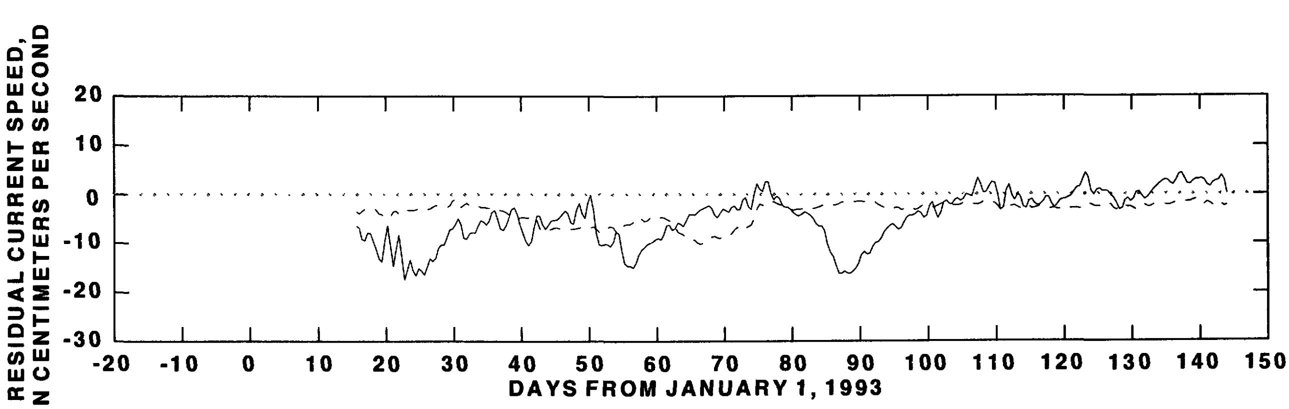

Figure L5. Longitudinal (solid) and transverse (dashed) residual currents, station RYER, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 105.7°.

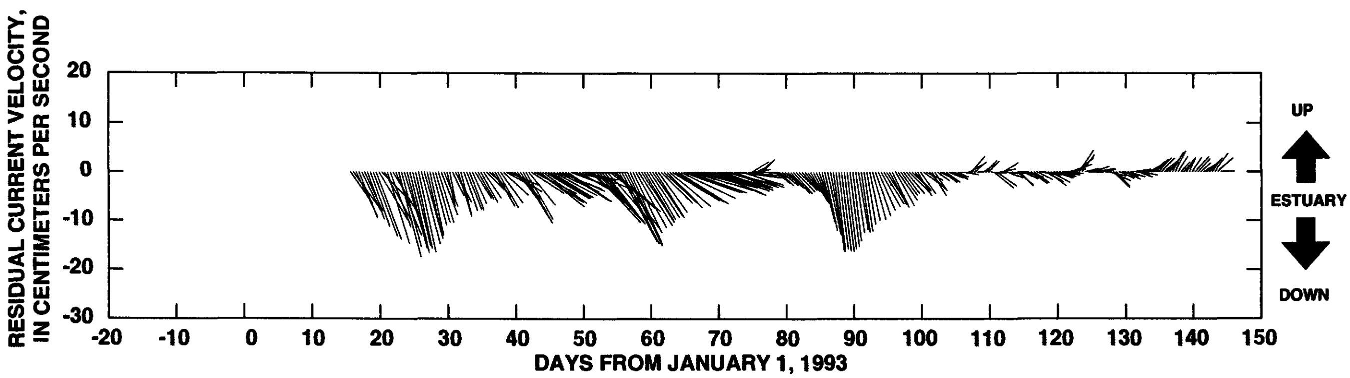

Figure L6. Residual currents, station RYER, January 13 through May 26, 1993, Suisun Bay, California. Principal direction is 105.7°. Sticks angled to the left imply positive transverse velocity. Up estuary, landward; down estuary, seaward.

Table L1. Harmonic analysis results for velocity, station RYER, January 13 through May 26, 1993, Suisun Bay, California

[cm/s, centimeters per second; deg. T, degrees true; deg, degrees; E, equilibrium argument]

Tidal symbol	Major axis (cm/s)	Minor axis (cm/s)	Direction (deg. T)	Phase (deg)	E (deg)	Rotation
Q_1	1.80	0.02	104.4	91.7	19.4	Clockwise
O_1	10.04	.15	102.0	93.1	37.8	Counter-clockwise
M_1	.96	.11	106.5	154.8	234.9	Counter-clockwise
P_1	4.87	.16	106.9	116.2	179.4	Counter-clockwise
K_1	18.44	.28	105.7	101.5	234.3	Counter-clockwise
J_1	.63	.11	108.8	136.5	256.9	Clockwise
μ_2	2.16	.12	103.2	189.5	145.6	Counter-clockwise
N_2	7.93	.03	110.5	357.7	257.9	Counter-clockwise
ν_2	2.22	.45	110.5	335.4	164.0	Counter-clockwise
M_2	46.87	.88	106.9	23.7	276.3	Counter-clockwise
L_2	4.49	.19	105.3	57.2	108.6	Counter-clockwise
T_2	3.09	.56	107.6	268.6	34.8	Clockwise
S_2	8.53	.38	103.3	36.1	45.0	Counter-clockwise
K_2	4.50	.06	110.2	4.3	288.3	Counter-clockwise
M_4	1.13	.11	118.3	26.6	192.6	Counter-clockwise
Mk_3	3.10	.31	114.7	148.3	150.6	Clockwise

Root-mean-square speed (cm/s):	40.31
Standard deviation, U velocity (cm/s):	11.57
Standard deviation, V velocity (cm/s)	4.45
Tidal form number:	0.51
Spring tidal current maximum (cm/s):	83.88
Neap tidal current maximum (cm/s):	29.95
Principal current direction (deg. T):	105.70

APPENDIX M—STATION WICK

Station Name: **WICK**
(Wickland Oil Pier)

Position: Lat 38° 03' 30" N
Long 122° 14' 24" W

Depth: 15.2 m (MLLW)

	Manufacturer	*Serial Number*	*Deployment Dates*
CT_t:	YSI 33	N/A	Continuous Monitoring
CT_b:	YSI 33	N/A	Continuous Monitoring

CT Sensors servicedMonthly.

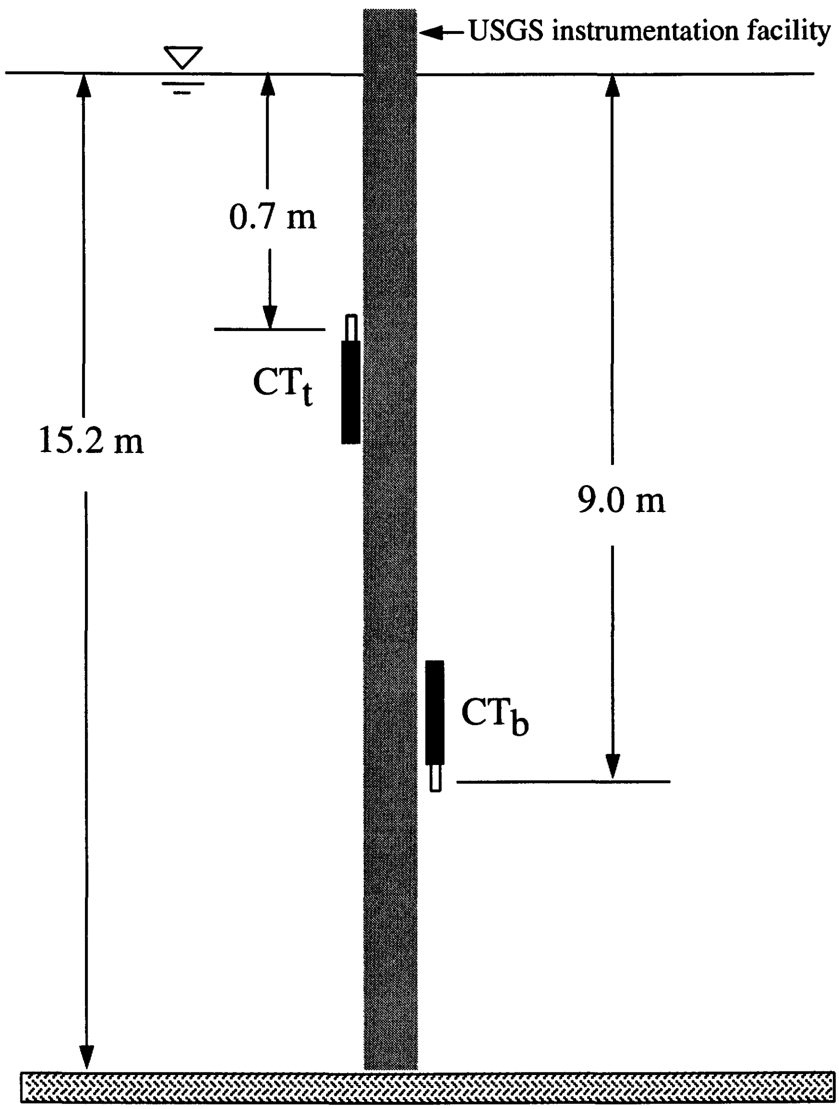

Figure M1. Configuration of instrument deployment, station WICK, Suisun Bay, California. m, meters; MLLW, mean lower low water; USGS, U.S. Geological Survey.

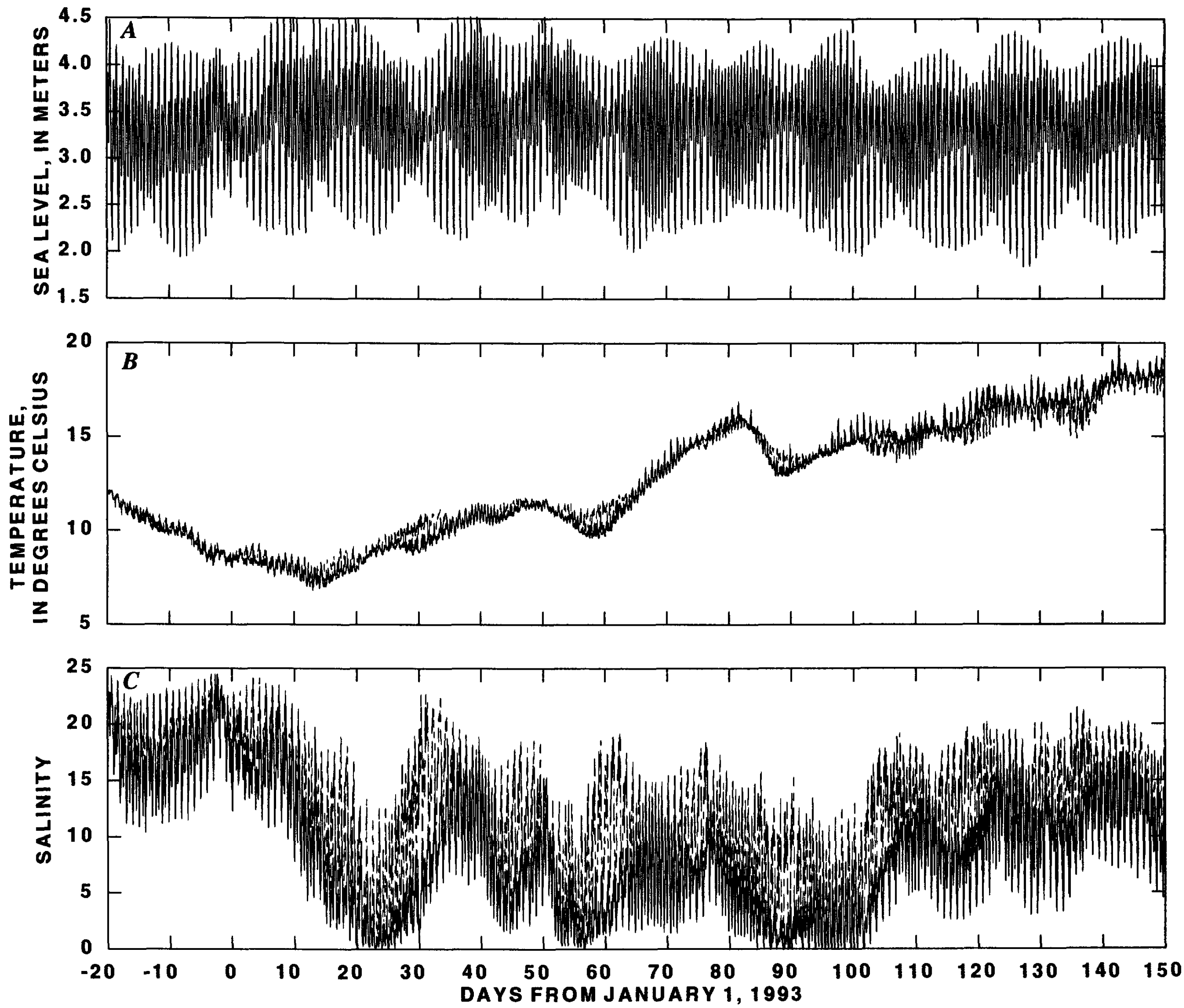

Figure M2. Time-series plots of ***A***, sea level; ***B***, temperature; and ***C***, salinity, station WICK, January 1 through May 31, 1993, Suisun Bay, California. (Dashed) near-bed sensor, (solid) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 3 meters.

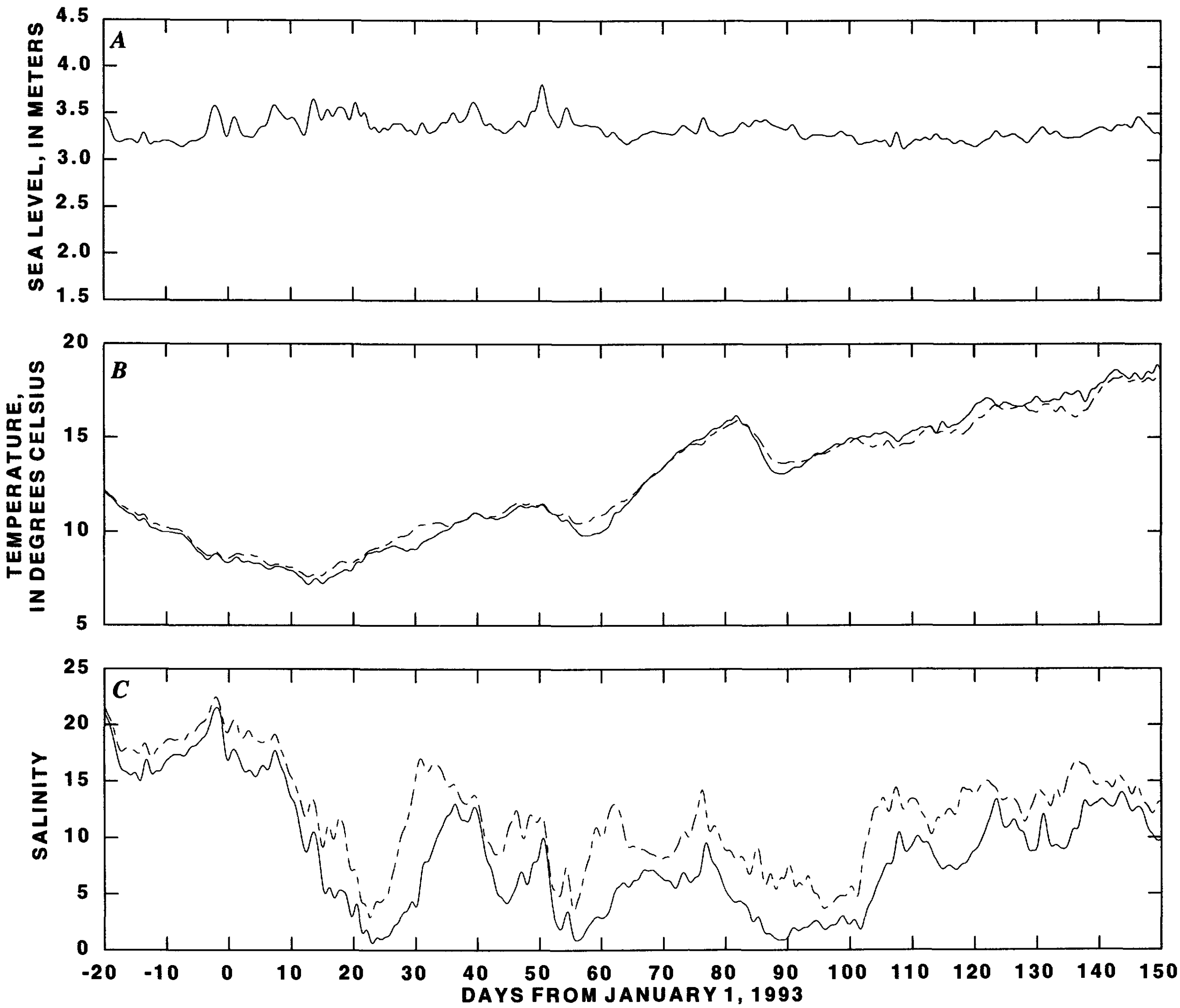

Figure M3. Time-series plots of low-pass-filtered ***A***, sea level; ***B***, temperature; and ***C***, salinity, station WICK, January 1 through May 31, 1993, Suisun Bay, California. (Dashed) near-bed sensor, (solid) near-surface sensor. Salinities in this report are presented without units because salinity is a conductivity ratio; therefore, it has no physical units (Millero, 1993). Sea level is referenced to NGVD 1929 plus an additional 3 meters.

Table M1. Harmonic analysis results for sea level, station WICK, January 1 through May 31, 1993, Suisun Bay, California

Time series mean: 333.12036
Standard deviation: 12.51263
Harmonic constants: No tidal inference

Tidal symbol	Cycles (per day)	Mean amplitude (centimeters)	Local epoch (degrees)	Modified epoch (degrees)
Q_1	0.89324	3.58222	105.03391	120.08461
O_1	.92954	21.76246	109.37360	120.06931
M_1	.96645	1.25335	163.65189	169.91833
P_1	.99726	9.96132	131.34125	133.90977
K_1	1.00274	35.36189	124.69118	126.60263
J_1	1.03903	1.29143	159.38092	156.93738
μ_2	1.86455	1.50110	198.63435	219.36868
N_2	1.89598	12.84715	341.42178	358.38394
ν_2	1.90084	2.89436	354.27020	10.64954
M_2	1.93227	64.63815	8.98224	21.58942
L_2	1.96857	3.21594	23.71585	31.96802
T_2	1.99726	1.19556	291.47369	296.28220
S_2	2.00000	14.17680	24.16451	28.64449
K_2	2.00548	5.34257	8.54758	12.37048
M_4	3.86455	1.85211	182.57671	297.79100
Mk_3	2.93501	.57907	102.45724	116.97586

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