Central San Francisco Bay Suspended-Sediment Transport Processes and Comparison of Continuous and Discrete Measurements of Suspended-Solids Concentrations

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Sediments are an important component of the San Francisco Bay estuarine system. Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993). Sediments on the bottom of the bay provide the habitat for benthic communities that can ingest these substances and introduce them into the food web (Luoma and others, 1985). Nutrients, metals, and other substances are stored in bottom sediments and pore water in which chemical reactions occur and which provide an important source and/or sink to the water column (Hammond and others, 1985; Flegal and others, 1991). The transport and fate of suspended sediment is an important factor in determining the transport and fate of the constituents adsorbed on the sediment. Seasonal changes in sediment erosion and deposition patterns contribute to seasonal changes in the abundance of benthic macroinvertebrates (Nichols and Thompson, 1985). Tidal marshes are an ecologically important habitat that were created and are maintained by sedimentation processes (Atwater and others, 1979). In Suisun Bay, the maximum suspended-sediment concentration marks the position of the turbidity maximum, which is a crucial ecological region in which suspended sediment, nutrients, phytoplankton, zooplankton, larvae, and juvenile fish accumulate (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994). Suspended sediments confine the photic zone to the upper part of the water column, and this limitation on light availability is a major control on phytoplankton production in San Francisco Bay (Cloern, 1987; Cole and Cloern, 1987). Suspended sediments also deposit in ports and shipping channels, which must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992).

The objectives of the Central San Francisco Bay suspended-sediment transport-processes study are to estimate which factors determine suspended-solids concentrations (SSC) in Central Bay and to collect time series of SSC data that are appropriate for (1) continuous monitoring of SSC and (2) calibration and validation of numerical models. Potentially important factors include semidiurnal and diurnal tides, the spring/neap cycle, delta discharge, dredging and dredged material disposal, and wind waves.

SSC monitoring sites were established at Point San Pablo in December 1992 and at San Francisco Pier 24 in May 1993 (Figure 1) (Buchanan and Schoellhamer, 1995). At each site, optical backscatterance (OBS) sensors are positioned at mid-depth and near the bottom. The OBS sensors optically measure the amount of material in the water every 15 minutes, and the output of the sensors is converted to SSC with calibration curves developed from analysis of water samples. The sites are serviced every 1 to 5 weeks to clean the sensors, which are susceptible to biological fouling, and to collect water samples for sensor calibration. About half the data collected is invalid, primarily because of sensor fouling. SSC monitoring sites also are located in South San Francisco Bay and Suisun Bay (Figure 1). The sites are operated in cooperation with the U.S. Army Corps of Engineers (Central Bay): the California Regional Water Quality Control Board. San Francisco Bay Region, as part of the Bay Protection and Toxic Cleanup Program (South Bay); and the Interagency Ecological Program (Suisun Bay).

Continuous SSC data can be used to help place the discrete water-quality data collected as part of the Regional Monitoring Program (RMP) into a proper context. Vertical profiles of SSC were collected with an

OBS sensor at 22 sites in the bay three times in 1994 as part of the RMP--February, April, and August. The OBS sensor was calibrated using water samples collected 1 meter below the water surface. Continuous USGS SSC data collected at mid-depth at Point San Pablo during the three RMP water-quality sampling periods are shown in Figure 2.

Delta discharge, the spring/neap tidal cycle, and wind may affect SSC in the estuary. Sediments from the Delta account for 86 percent of the fluvial sediment supply to San Francisco Bay, with the remainder from other smaller watersheds and local runoff (Porterfield, 1980). Because 1994 was a dry year, Delta discharge was low $_{hrms}$, but varied during and between sampling trips (Figure 3). The fortnightly spring/neap tidal cycle can be represented by the root-mean-squared water-surface elevation (hrms), which is determined by squaring the water level measured at Point San Pablo, low-pass filtering with an 11th order Butterworth filter with a cutoff frequency of 0.0271 hr-1, and taking the square root. Larger values of hrms

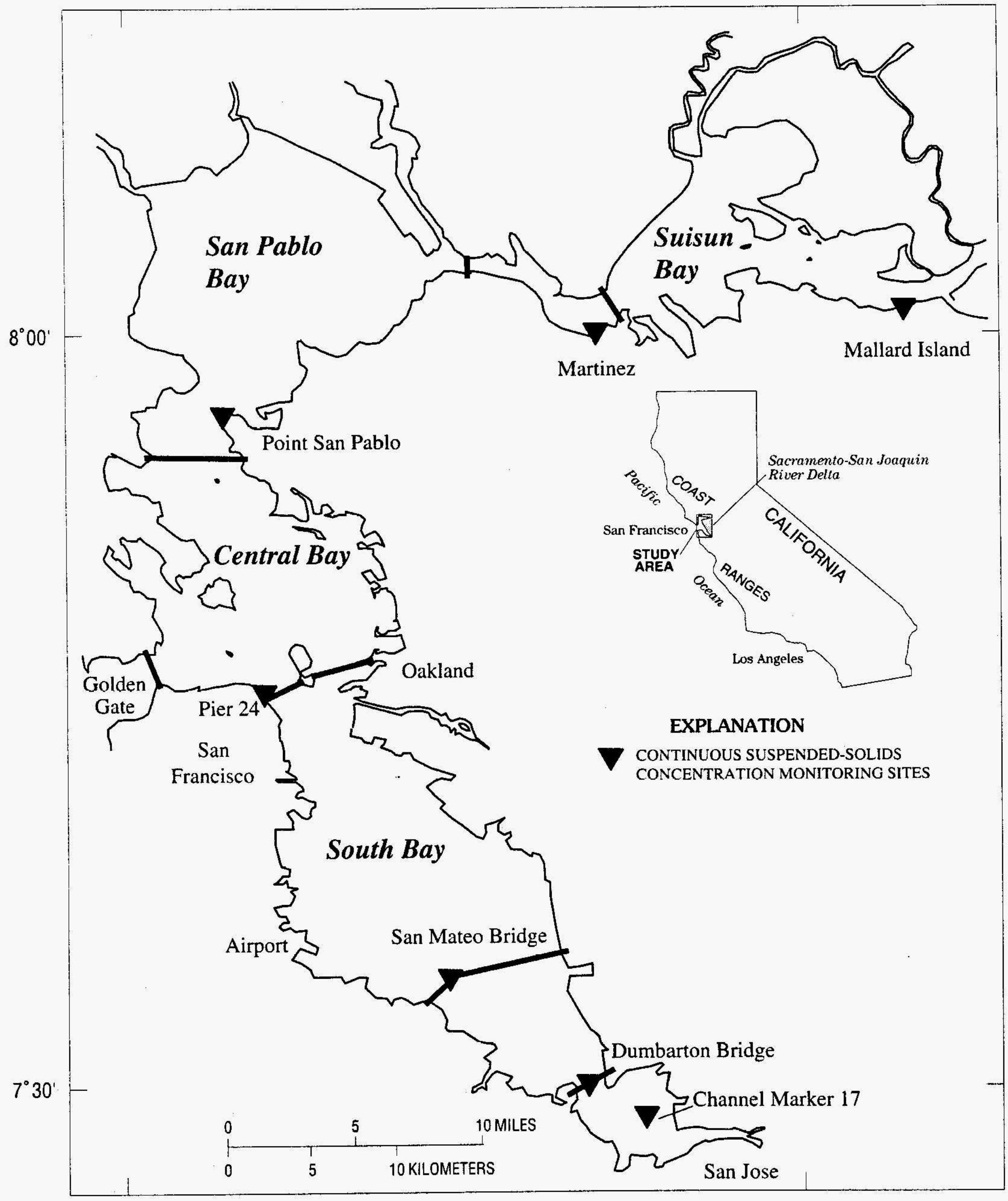

Figure 1. Continuous SSC (suspended-solids concentration) monitoring sites in San Francisco Bay.

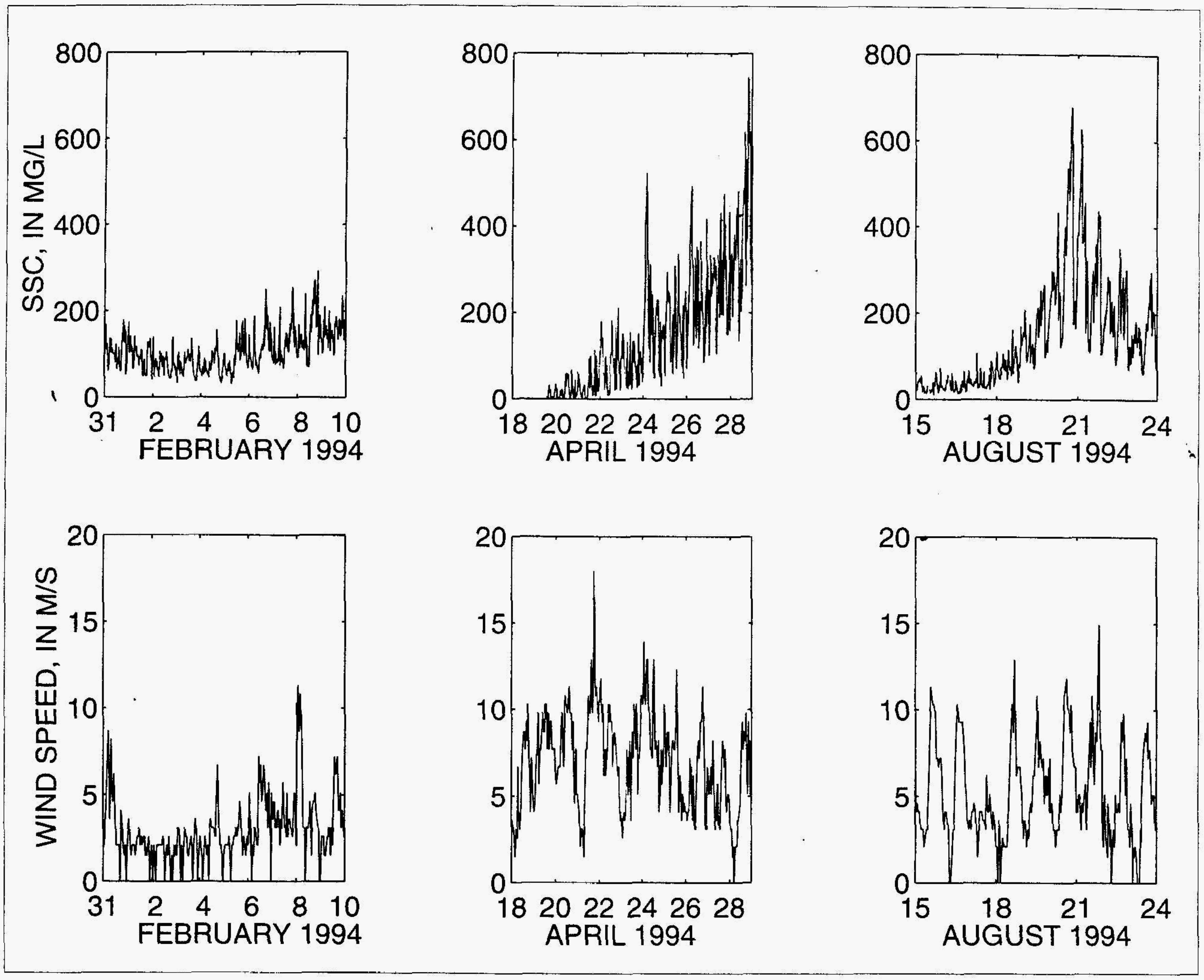

Figure 2. Mid-depth SSC (suspended-solids concentration) at Point San Pablo and wind speed at San Francisco International Airport during the 1994 RMP (Regional Monitoring Program) water-quality sampling trips.

indicate more energetic spring tides, and smaller values indicate weaker neap tides (Figure 4). Wind speed measured at San Francisco International Airport during the three RMP water quality sampling periods are shown in Figure 2. The wind field varies over San Francisco Bay, so these wind data are used as a general indicator of the wind state.

The spring/reap cycle is an important factor affecting SSC at Point San Pablo corresponds with the spring/neap cycle. Approximately 50 percent of the variance of SSC in San Francisco Bay is attributable to the spring/neap cycle, and SSC typically lags the spring/neap cycle by about 2 days (Schoellhamer, 1994; Schoellhamer, in press). The February RMP water-quality data collection started before a strong neap tide and concluded after a spring tide (Figure 4). SSC decreased slightly during the first half of the sampling period and increased slightly afterward (Figure 2). During the April sampling period, tidal energy increased greatly (Figure 3) and SSC at Point San Pablo also increased. The August data-collection period was centered on a weak spring tide, and maximum SSC occurred about one day after the spring tide.Stronger winds in April and August probably increased wind-wave resuspension in shallow water and account for the greater SSC compared to February.

The spring/neap variation in SSC is reflected in the discrete RMP sampling data. The sampling trips started in South and Central Bays, paused for 3 or 4 days, and

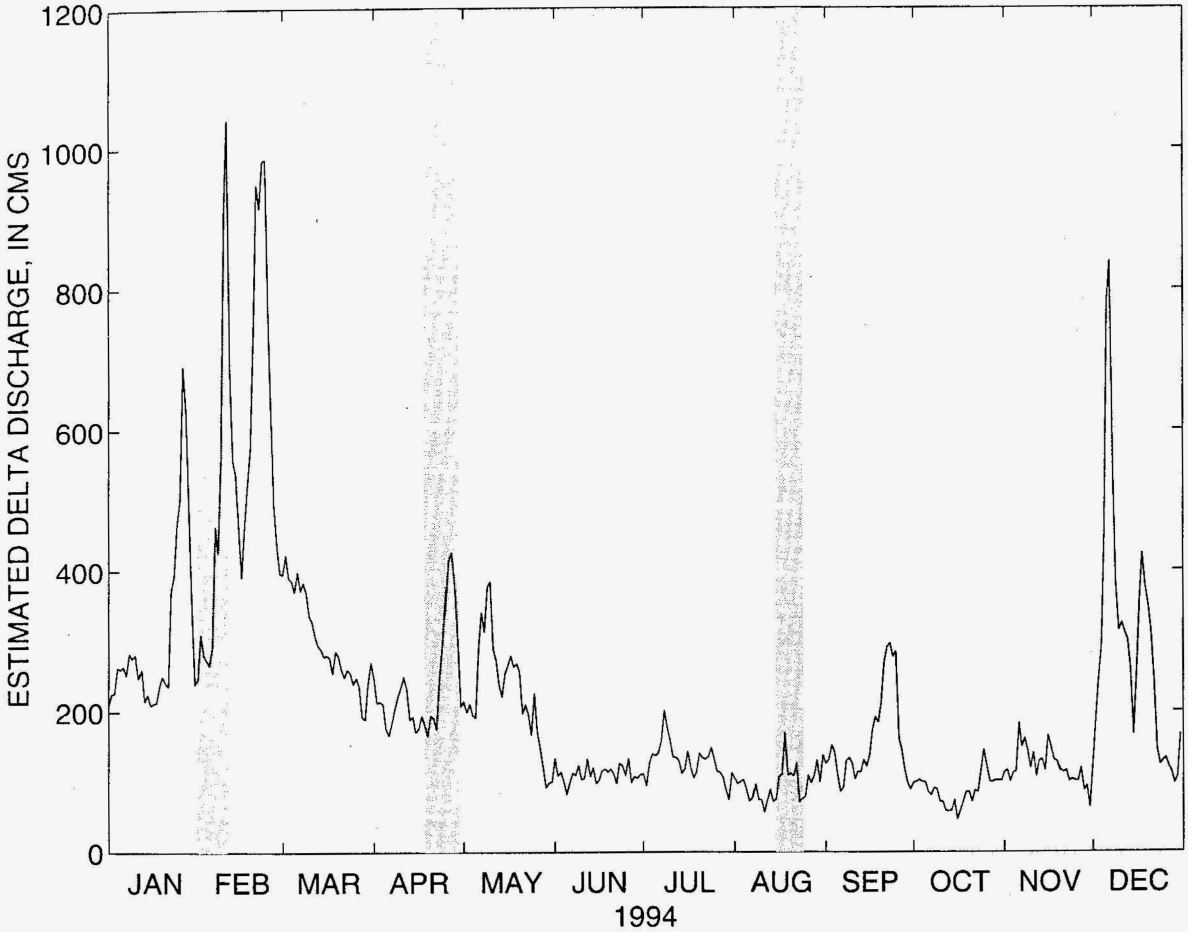

Figure 3. Estimated delta discharge and times of discrete sampling trips in 1994. Duration of RMP (Regional Monitoring Program) sampling trips are indicated by vertical bars.

then concluded in San Pablo and Suisun Bays. The ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays for the discrete data and for the continuous data collected in water year 1994 are given in Table 1. Spring/neap variations are removed from the continuous data by taking the mean of a year-long time series. The greatest ratio (5.6) is for the April discrete data, which is much greater than the ratio from the continuous data collected in water year 1994 (0.7). The spring tide at the end of the sampling period, when San Pablo and Suisun Bays were sampled, increased SSC and the ratio. For the August sampling trip, SSC at Point San Pablo was greater at the end of the sampling period, and the ratio (2.0) was also greater than the continuous data ratio. The SSC spring/neap variation was relatively small during the February sampling trip, and the ratio (0.8) is in good agreement with the continuous data ratio.

Interpretation of the discrete water-quality data is complicated by the spring/neap variation in SSC. For example, the conclusion that SSC in San Pablo and Suisun Bays was greater than in Central and South Bays in 1994 could incorrectly be made from the discrete data because of the relation between sample timing and the spring/neap cycle. A similar conclusion from a spatial comparison of total constituent concentrations may also be incorrect.

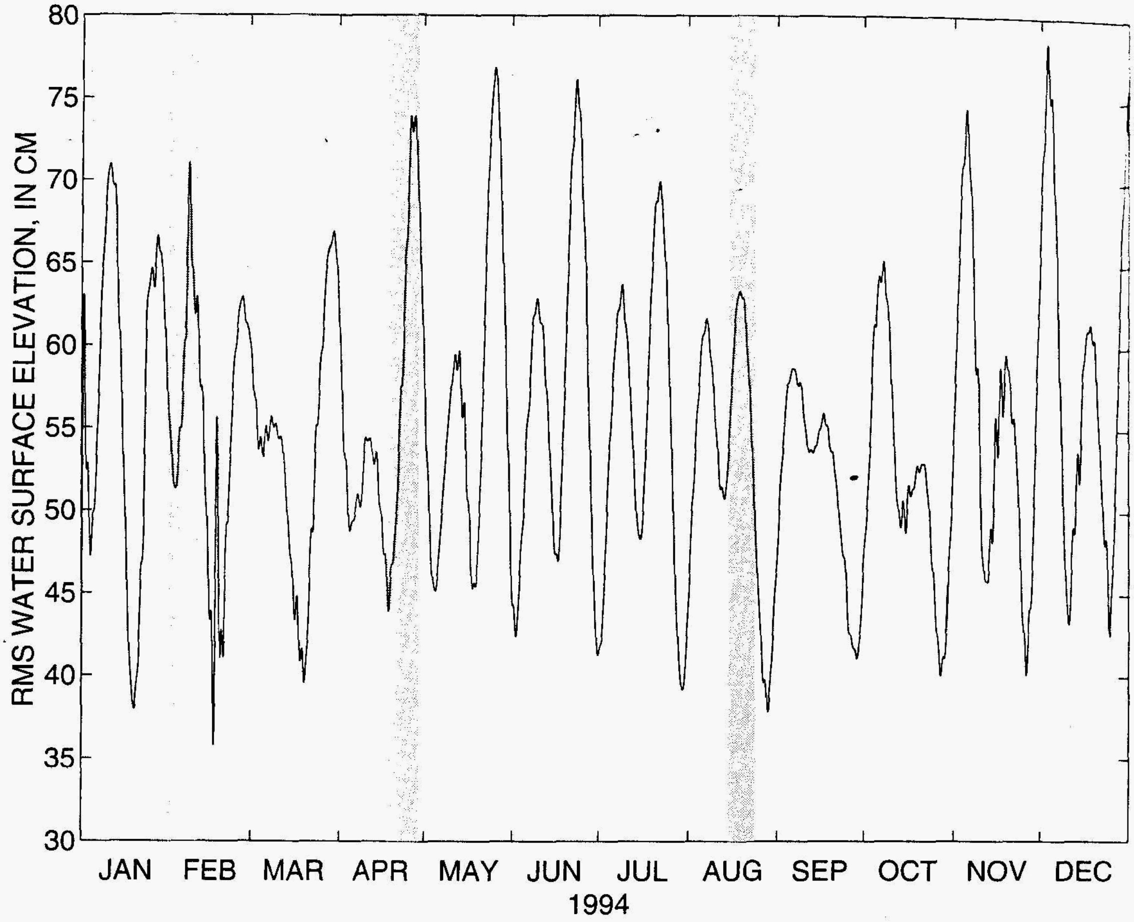

Figure 4. Root-mean-squared (RMS) water-surface elevation (h_{rms}) at Point San Pablo and times of discrete sample trips in 1994. Larger values of h_{rms} indicate spring tides, and smaller values indicate neap tides. Duration of RMP (Regional Monitoring Program) sampling trips are indicated by vertical bars.

Delta discharge was small during 1994 and did not appreciably influence SSC. The maximum discharge was twice as large in 1993 than in 1994. Discharge peaks in February did not noticeably affect SSC at Mallard Island or Martinez. The first increase in delta discharge in February coincided with the collection of discrete samples, but the samples show no obvious influence from the increased discharge. Delta discharge variations had no effect on suspended-solids flux measured at Mallard Island from April 14 to June 20 (Tobin and others, 1995). Thus, Delta discharge is not responsible for the large ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays for the April data set.

Wind and dredged-material disposal did not cause significant variations in SSC at Point San Pablo during the RMP water-quality sampling trips. Wind speed in February was relatively small, and the wind speed in August contains a stronger diurnal (afternoon sea breeze) signal than in April (Figure 2). Winds can generate waves that can resuspend bottom sediments, especially in shallow waters with a large fetch. The seasonal increase in wind speed during the summer increases SSC in South Bay (Schoellhamer, in press).A dredged-material disposal site is located in San Pablo Bay about 3 miles north of point San Pablo. The amounts of disposed material during the February, April, and August. RMP water-quality

Table 1. Ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays

[For continuous data, Point San Pablo, Martinez, and Mallard data collected in water year 1994 are considered to be from San Pablo and Suisun Bays, and mid-depth or near-surface SSC were used. Large ratios for the April and August discrete data are caused by spring tides and large SSC at the end of the sampling period when San Pablo and Suisun Bays samples were collected]

Data set	Ratio
February	0.8
April	5.6
August	2.0
Continuous	0.7

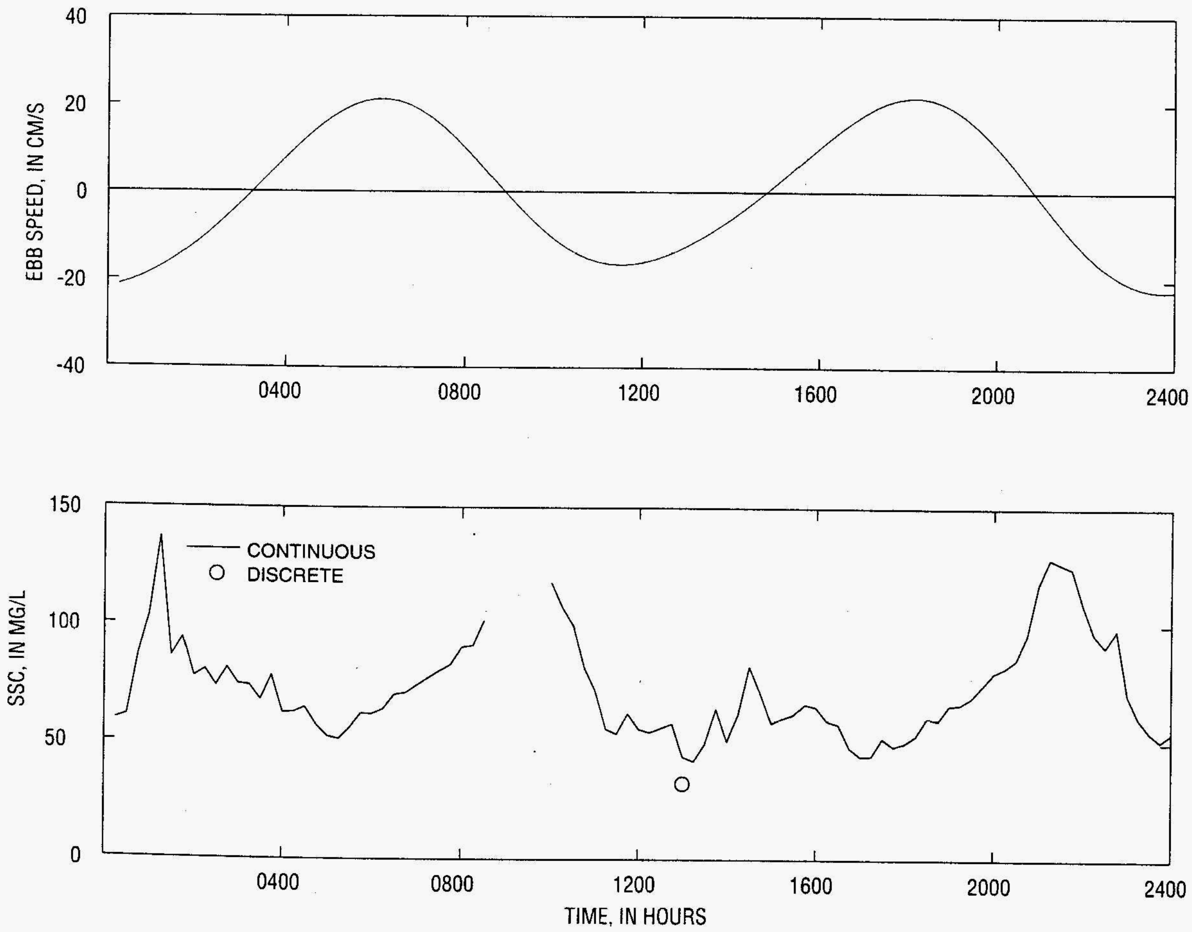

Figure 5. Predicted ebb current speed and measured SSC (suspended-solids concentration) 1 meter above the bed at the Dumbarton Bridge on January 31, 1994. The break in the continuous measurement near 0900 hours is due to temporary fouling of the optical sensor.

sampling trips were 0, 4,750, and 5,000 yd^3, which are relatively small quantities for the site (Tom Gandesbery, California Regional Water Quality Control Board, oral commun., 1995) and did not noticably affect SSC at Point San Pablo.

In addition to the SSC variation associated with the spring/neap cycle, SSC varies with the diurnal and semidiurnal tides. The site with the best data to demonstrate this is the Dumbarton Bridge site because the sampling locations for discrete and continuous data are the closest of any sites in the bay. Figure 5 shows continuous and discrete SSC 1 meter above the bed. These concentrations were measured at the Dumbarton Bridge on January 31, 1994. The discrete measurement was collected at 1300 hours during a floodtide when SSC was relatively low. Two SSC maxima, about two to three times larger than the 1300-hour concentration, occurred at 0900 and 2100 hours, concurrent with slack water after ebb. SSC in South Bay channel typically is greatest at slack after ebb; this indicates a landward gradient of SSC with larger values to the south and in shallower water (Schoellhamer, in press).

SSC can vary greatly during a day, so samples collected only a few hours apart are not a true synoptic sample. For example, if the discrete measurement had been taken 3 hours earlier at 1000 hours, the SSC would have been about double the 1300-hour value.

Table 2. Statistical summary of suspended solids concentration data, San Francisco Bay, water year 1994

[All measurements are given in milligrams per liter. From P.A. Buchanan and others, **U.S.** Geological Survey, written commun., 1995]

Site	Depth	Mean	Median	Lower quartile	Upper quartile
Channel marker 17	Mid-depth	166	135	76.1	222
	Near-bottom	204	145	82.9	256
Dumbarton Bridge	Mid-depth	96.9	85.7	63.0	118
	Near-bottom	133	112	68.0	173
San Mateo Bridge	Mid-depth	62.6	51.7	38.3	73.0
	Near-bottom	95.6	75.7	53.1	118
Pier 24	Mid-depth	42.7	38.4	25.8	54.6
	Near-bottom	45.4	40.0	26.2	60.2
Point San Pablo	Mid-depth	98.5	78.8	45.2	128
	Near-bottom	96.3	77.2	45.4	126
Martinez	Near-surface	56.9	52.4	41.9	66.4
Mallard Island	Near-surface	44.5	42.1	34.0	52.4
	Near-bottom	54.3	51.8	38.9	65.6

In addition to temporal variations of SSC at a site, there are long-term spatial variations in the bay. The mean and median SSC are greatest at channel marker 17, decrease at Dumbarton Bridge and San Mateo Bridge, and are smallest at San Francisco Pier 24 (Table 2) (P.A. Buchanan and others, U.S. Geological Survey, written commun., 1995). Thus, average SSC from continuous data provides further evidence of a landward gradient of increasing suspended solids from Central to South Bays.

In 1995, the Central Bay suspended-sediment transport processes study will continue operation of the existing continuous sites, install an additional site at the Golden Gage Bridge, monitor suspended-sediment transport processes in shallow water, prepare a report summarizing data collected during water year 1994, and continue to analyze the data.

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