SUMMARY OF SUSPENDED-SOLIDS CONCENTRATION DATA, SAN FRANCISCO BAY, CALIFORNIA, WATER YEAR 1994

By Paul A. Buchanan, David H. Schoellhamer, *and* Robert C. Sheipline

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CONVERSION FACTORS, ADDITIONAL ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram

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

$$°F=1.8(°C)+32.$$

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

ABBREVIATIONS

°C	degrees Celsius
L	liter
µm	micrometer
mg/L	milligrams per liter
mL	milliliter

ACRONYMS

AC	alternating current
ADAPS	automated data processing system
DC	direct current
DWR	California Department of Water Resources
GPS	global positioning system
NTU	Nephelometric Turbidity Units
PG&E	Pacific Gas and Electric
PVC	polyvinyl chloride
USGS	U.S. Geological Survey

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Abstract

Suspended-solids concentration data were collected in San Francisco Bay during water year 1994. Optical backscatterance sensors and water samples were used to monitor suspended solids continuously at two sites in Suisun Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. Sensors were positioned at two depths at each site. In addition, a shallow-water instrument package was deployed in South San Francisco Bay three times for periods of several weeks to measure suspended-solids concentration and water velocity. Water samples were collected periodically and were analyzed for concentrations of suspended solids. The results of the analyses were used to calibrate the electrical output of the optical backscatterance sensors. This report presents the data-collection methods used and summarizes the suspended-solids concentration data collected from October 1993 through September 1994. Calibration plots and edited data for each sensor also are presented.

INTRODUCTION

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). The sediments on the bay bottom provide the habitat for benthic communities that can ingest these substances and introduce them into the food web (Luoma and others, 1985). Bottom sediments also are a reservoir of nutrients that contribute to the maintenance of estuarine productivity (Hammond and others, 1985). The transport and fate of suspended sediment are important factors in determining the transport and fate of constituents adsorbed on the sediment. In Suisun Bay, the maximum concentration of suspended solids usually 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 also limit light availability in the bay, which, in turn, limits photosynthesis and primary production (Cloern, 1987; Cole and Cloern, 1987), and deposit in ports and shipping channels, which must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992). The U.S. Geological Survey (USGS), in cooperation with the San Francisco Regional Water Quality Control Board (South San Francisco Bay), the U.S. Army Corps of Engineers (Central San Francisco Bay), and the Interagency Ecological Program (Suisun Bay), is studying the factors that affect suspended-solids concentrations in San Francisco Bay.

Purpose and Scope

This report summarizes suspended-solids concentration data collected by the USGS in San Francisco Bay in water year 1994. Suspended-solids concentrations were monitored continuously at two sites in Suisun Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. A shallow-water instrument package was deployed in South San Francisco Bay three times for periods of several weeks to measure suspended-solids concentration and water velocity.

Complete data for water year 1994 are available from the files of the USGS in Sacramento, California. Data collected in water years 1992 and 1993 are summarized in a report by Buchanan and Schoellhamer (1995).

Study Area

In San Francisco Bay (fig. 1), tides are semidiurnal with a range from about 5.5 ft in Suisun Bay, to 6.5 ft at the Golden Gate and Central San Francisco Bay (Central Bay), to about 10 ft in South San Francisco Bay (South Bay). The tides also have a 14-day spring-neap cycle. Typical tidal currents range from 0.6 ft/s in shallow water to more than 3 ft/s in deep channels (Smith, 1987). Winds are typically strongest during the summer when there is an afternoon onshore sea breeze. Most precipitation occurs from late fall to early spring, and freshwater discharge into the bay is greatest in the spring due to runoff from snowmelt. About 90 percent of the discharge is from the Sacramento–San Joaquin River Delta, which drains the Central Valley of California (Smith, 1987). Delta discharge contains 83 to 86 percent of the fluvial sediments that enter the bay (Porterfield, 1980) and determines the position of the turbidity maximum in Suisun Bay (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994). During wet winters, turbid plumes of water from the delta have extended into South Bay (Carlson and McCulloch, 1974). The bottom sediments are composed of mostly silts and clays in South Bay and in the shallow waters (about 12 ft or less) of Central and Suisun Bays. Silts and sands are present in the deeper parts of Central and Suisun Bays (Conomos and Peterson, 1977). Large tidal velocities, spring tides, and wind waves in shallow water are all capable of resuspending bottom sediments (Powell and others, 1989).

Acknowledgments

The authors gratefully acknowledge the U.S. Coast Guard, California Department of Transportation, California Department of Water Resources (DWR), the San Francisco Port Authority, and the PakTank Corporation for their permission and assistance in establishing the monitoring sites used in this study.

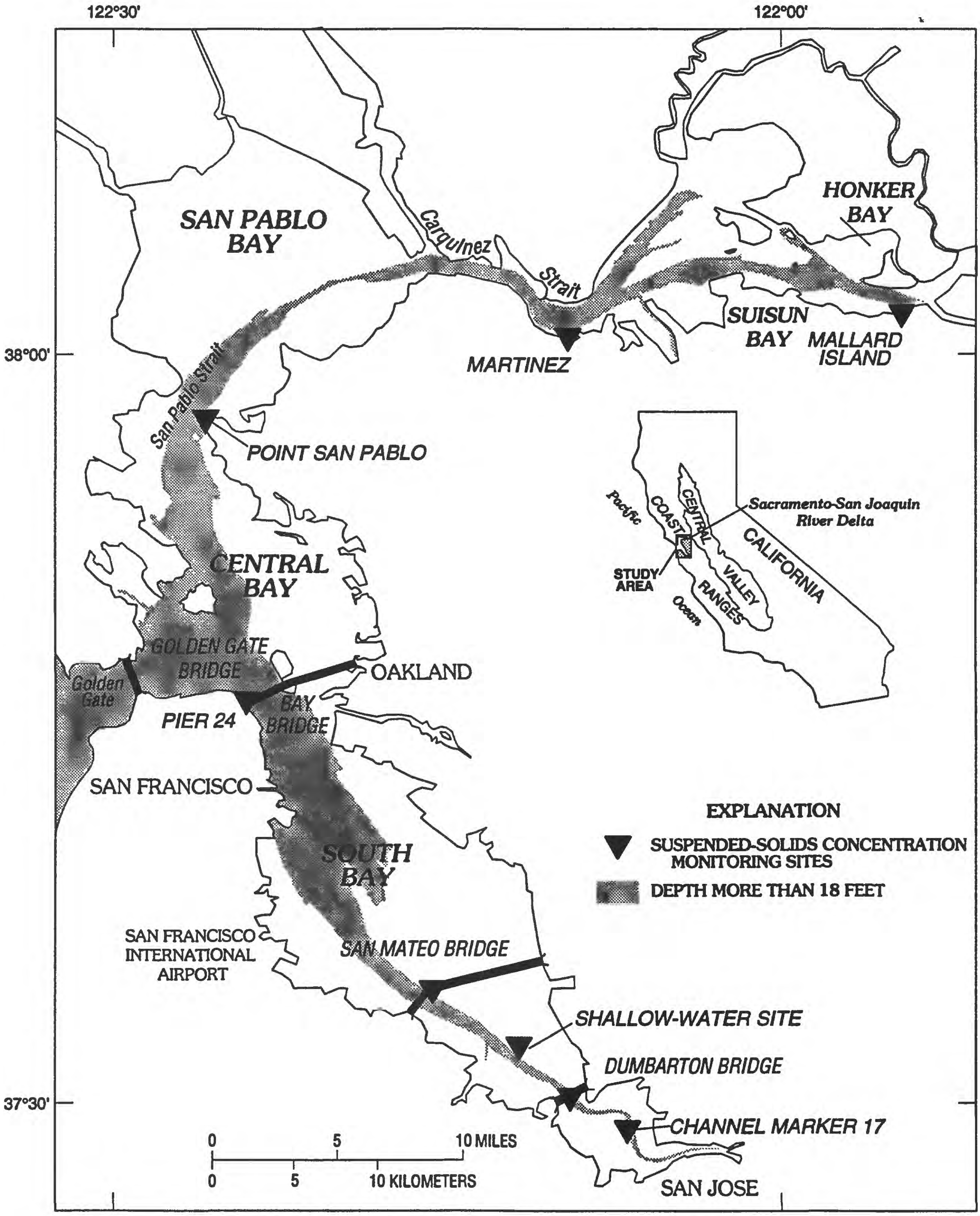

Figure 1. San Francisco Bay study area.

METHODS

Instrument Description and Operation

Optical backscatterance sensors were used to monitor concentrations of suspended solids. An optical backscatterance sensor is a cylinder approximately 7 in. long and 1 in. in diameter with an optical window at one end, a cable connection at the other end, and an encased circuit board (Downing and others, 1981; Downing, 1983). An infrared pulse of light is transmitted through the optical window and is scattered or reflected by particles in front of the window to a distance of about 4 to 8 in. at angles up to 165 degrees. Some of this scattered or reflected light is returned to the optical window where a receiver converts the backscattered light to a voltage output. The voltage output is proportional to the concentration of suspended solids in the water column. Calibration of the sensor output to concentrations of suspended solids will vary depending on the size and optical properties of the suspended solids; therefore, the sensors must be calibrated either in the field or in a laboratory using the same suspended material that is found in the field (Levesque and Schoellhamer, 1995).

The optical sensors were positioned in the water column using polyvinyl chloride (PVC) pipe carriages that were coated with an antifoulant paint to impede biological growth. These carriages were designed to align with the direction of flow and to ride along a stainless steel or Kevlar reinforced nylon suspension line attached to an anchor weight, which allowed the sensors to be raised and lowered easily for servicing. The plane of the optical window was positioned parallel to the direction of flow, and as the carriage and sensor moved with the changing direction of flow, the plane of the window retained its position relative to the direction of flow.

Data acquisition, data storage, and sensor timing were controlled by an electronic data logger. The logger was programmed to power the optical sensors every 15 minutes, collect data every second for 1 minute, and average and store the output voltages. Power was supplied by 12-volt DC, 12-amp-hour gel-cell batteries.

Biological growth interferes with the collection of accurate optical backscatterance data. In water years 1992 and 1993, about half of the data collected was invalidated by fouling (Buchanan and Schoellhamer, 1995). Self-cleaning optical sensors with wipers were deployed at four sites in 1994 to help alleviate the problem of fouling. The wiper probes are similar in size and function to the optical sensors already in use, but the wiper probe has a separate electronics unit, which was used to set the full-scale optical backscatter, expressed in Nephelometric Turbidity Units (NTU). Output from the wiper probe is averaged over a 1-minute period and is stored on a data logger every 15 minutes. Because the unit requires 95 to 130 AC, installation was limited to sites with AC power. The wiper probes and electronic units were installed at two sites in Suisun Bay and at two sites in South Bay. Fouling in Suisun Bay was light compared to that in South and Central Bays, and the wiper probes were effective in keeping the optical ports clean (about 80-percent data recovery). However, fouling at the two sites in South Bay during the summer months was so extreme that the wiper probes were often rendered ineffective by biological growth on the carriage and wiper mechanism.

Optical sensors without self-cleaning wipers required frequent cleaning, but because of the difficulty in servicing some of the monitoring stations, cleaning was done every 1 to 5 (usually 3) weeks. Therefore, about 40 percent of the data collected was invalidated by fouling. Fouling generally was greatest on the sensor closest to the water surface. However, at shallower sites where the upper sensor was set 10 ft above the lower sensor, fouling was about equal on both sensors. Fouling would begin to affect sensor output from 2 days to several weeks after cleaning, depending on the level of biological activity in the bay. Generally, biological fouling was greatest during the spring and summer months.

Suisun Bay Installations

Suspended-solids concentration data were collected at two sites in Suisun Bay: Suisun Bay at Mallard Island and Carquinez Strait at Martinez (fig. 1). Monitoring equipment was installed at both sites in water year 1994.

Mallard Island

Self-cleaning optical sensors were installed at the DWR Mallard Island Compliance Monitoring Station on February 8, 1994 (lat. 38°02'34", long. 121°55'09"). This site is about 5 mi downstream from the confluence of the Sacramento and San Joaquin Rivers and is at the north shore of Mallard Island near the eastern boundary of Honker Bay, an embayment of Suisun Bay (fig. 1). The station was constructed in the early 1980's by DWR on Pacific Gas and Electric (PG&E) property, and, in January 1984, data were first recorded. A quarter-mile-long wooden walkway crosses the sometimes submerged reedbeds of Mallard Island and connects the concrete block house to the levee road.

Sensors were positioned at near-bottom (5 ft above the bottom) and near-surface (3.3 ft below the surface) to coincide with DWR near-bottom electrical conductance and temperature sensors and near-surface pump intake. The pump intake is attached to a float housed inside a 12-in. PVC pipe and draws water from about 3 ft below the surface. DWR near-surface parameters are measured by sensors submerged in flow-through chambers inside the gage house. This allows the USGS to use DWR data for parameters other than turbidity and saves the cost of installing duplicate sets of sensors. DWR also monitors stage, pH, chlorophyll concentration, and meteorological parameters. Mean lower low water depth at this site is about 25 ft.

Data storage is controlled by a data logger connected to a cellular phone and modem. AC power is used to operate both optical sensors and to charge a 12-volt, 12-amp-hour battery that powers the data logger and modem. The instruments are housed inside the gage house. The sensors are suspended from a galvanized support stand attached to the metal railing on the northwest corner of the concrete deck of the station. This stand has two stainless steel lines attached to separate concrete weights, one for the near-bottom and the other for the near-surface sensor. The near-bottom sensor is positioned in a PVC carriage suspended on the stainless steel line by a nylon rope at the specified depth. The near-surface sensor is housed in a PVC carriage that is attached to a float. This float assembly moves up and down the suspension line during tidal cycles, which maintains the near-surface sensor at the same depth as the DWR pump intake. A pressure transducer is positioned on the float assembly at the same level as the sensor and provides data to verify the depth of the near-surface sensor. To prevent sensor cables from being snagged by debris, a counterweight was installed to keep slack cables out of the water.

Martinez

Self-cleaning optical sensors were installed at the DWR Martinez Compliance Monitoring Station on February 8, 1994 (lat. 38°01'40", long. 122°08'22"). This site is at the end of the Martinez Marina fishing pier at the south shore of the Carquinez Strait where it widens into Suisun Bay. The station was constructed in the early 1980's by DWR on City of Martinez property, and, in May 1983, data were first recorded.

Sensors were positioned at near-bottom (5 ft above the bottom) and near-surface (3.3 ft below the surface) to coincide with placement of DWR sensors. Mean lower low water depth at this site is about 31 ft. Data storage, power supplies, and installation descriptions are identical to those for the Mallard Island station with the exception that Martinez does not have a cellular phone or modem and the shelter and deck are wood structures.

Central San Francisco Bay Installations

Suspended-solids concentration data were collected at two sites in Central San Francisco Bay beginning in water year 1993: San Pablo Strait at Point San Pablo and Pier 24 at San Francisco (fig. 1).

Point San Pablo

The USGS maintains a monitoring station at San Pablo Strait on the northern end of the Richmond Terminal no. 4 pier (lat. 37°57'53", long. 122°25'42") on the western side of Point San Pablo. The USGS took over operation of this station in October 1989 from the DWR. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at Point San Pablo on December 1, 1992, and were positioned at near-bottom and mid-depth (3 ft and 13 ft from the bottom). Mean lower low water depth at this site is about 26 ft. Electrical conductance and temperature data (cooperatively funded with DWR) are collected at near-surface and near-bottom points in the water column. Sensor timing and storage are controlled by a data logger connected to a phone line and modem. Water level is recorded using a float-driven, incremental encoder wired into the data logger, and outside water levels are read using a wire-weight gage. A separate data logger controls the optical sensors. AC power is available at this site and is used to charge a 12-volt, 60-amp-hour battery that powers the data loggers and sensors. The instruments are housed in a 5- by 8-ft wooden shelter.

Pier 24

The monitoring station at Pier 24 is on the western end of the San Francisco–Oakland Bay Bridge (lat. 37°47'27", long. 122°23'05"). The USGS took over operation of this station from DWR in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

Optical sensors were installed at the Pier 24 site on May 25, 1993, and were positioned at near-bottom and mid-depth (3 ft and 23 ft above the bottom). Mean lower low water depth at this site is about 41 ft. As at the Point San Pablo site, electrical conductance and temperature data (cooperatively funded with DWR) are collected at near-surface and near-bottom points in the water column. Sensor timing and storage are controlled by a data logger connected to a cellular phone and modem. AC power is available at this site and is used to charge a 12-volt, 12-amp-hour battery that powers the instrumentation. A corrugated steel shelter houses the equipment.

South San Francisco Bay Installations

Suspended-solids concentration data were collected at four sites in South San Francisco Bay (fig. 1). Monitoring stations were installed in water year 1992 at two sites, South San Francisco Bay at channel marker 17 and South San Francisco Bay at San Mateo Bridge. The South San Francisco Bay at Dumbarton Bridge monitoring station was installed in water year 1993. A shallow-water instrument package was deployed three times during water year 1994.

Channel Marker 17

The southernmost monitoring site in South Bay is at Coast Guard channel marker 17 (lat. 37°28'44", long. 122°04'38"). Instrumentation was installed on February 26, 1992, and the optical sensors were positioned at near-bottom and mid-depth (3 ft and 13 ft from the bottom). The mean lower low water depth at this site is about 25 ft. Sensor cables are protected by a 10-ft length of PVC pipe strapped to the channel marker support column. Sensor cables, carriages, and probes are suspended in the water column using a 100-lb weight attached to a 1/4-in. Kevlar reinforced nylon line. The data logger and DC power are housed in a 2- by 2- by 1-ft weather-proof enclosure mounted on the channel marker platform.

Dumbarton Bridge

Suspended-solids concentration monitoring equipment was installed October 21, 1992, at Pier 23 of the Dumbarton Bridge on the west side of the ship channel (lat. 37°30'15", long. 122°07'10"). Optical sensors were deployed at near-bottom and mid-depth (3 ft and 23 ft above the bottom). Mean lower low water depth is about 45 ft. The sensors are suspended between the concrete pier superstructure and the fender boards, an approximate distance of 3 ft. PVC carriages, attached to 1/4-in. Kevlar reinforced nylon line, are anchored to a 100-lb weight and are used to suspend the sensors at the desired depth.

The existing sensors were replaced with self-cleaning sensors on March 3, 1994. The electronic units, data logger and storage module are housed in a 3- by 2- by 1-ft weather-proof shelter mounted on the pier. AC power, which became available on March 17, 1994, supplies the instrumentation.

San Mateo Bridge

The monitoring station on the San Mateo Bridge is at Pier 20 on the east side of the ship channel (lat. 37°35'04", long. 122°14'59"). This station originally was operated by DWR, but the USGS took over operations on October 1, 1989.

The optical sensors were installed on December 23, 1991, and were positioned at near-bottom and mid-depth (3 ft and 23 ft above the bottom). Mean lower low water depth at this site is about 48 ft. The instruments are housed in a wooden shelter on the pier, which is surrounded by a protective fender structure. The sensors are deployed between the pier and the fender, and flow past the sensors is affected to some degree by the pilings and the concrete superstructure. Sensors are suspended in place using PVC carriages and stainless-steel line attached to a 200-lb weight. A separate data logger and modem are used to control sensor timing, data storage, and retrieval. AC power is available at this site, and all instruments are powered by a 12-volt, 60-amp-hour battery with an AC/DC charger and regulator. In addition to suspended-solids concentrations, electrical conductivity and temperature (cooperatively funded with DWR) are monitored at near-surface and near-bottom depths.

The existing sensors were replaced with self-cleaning optical sensors on January 25, 1994. No modifications to the existing equipment were necessary to accommodate the new sensors and electronic units.

Shallow-Water Site

The shallow-water site was located between the San Mateo and Dumbarton Bridges at lat. 37°33'42", long. 122°10'52" (fig. 1). The mean lower low water depth at the site was about 7 ft and fine bottom sediments (<63 μm) were always observed. The instrument was deployed three times during water year 1994. Table 1 gives the deployment dates and sensor elevations above the bay bottom.

Table 1. Deployment dates and sensor elevations above the bay bottom of the shallow-water instrument, South San Francisco Bay, California, water year 1994

Deployment period	Sensor elevations, in feet		
	Velocity	Optical sensor	Pressure
November 23 to December 17, 1993	0.82	1.15	4.10
March 8 to April 7, 1994	0.92	1.25	4.20
August 30 to October 26, 1994	0.98	1.25	4.23

Sediment transport data for the shallow water of South Bay were collected by deploying a submersible instrument package for periods of 3 to 8 weeks. An EG&G ACM3 acoustic current meter was used to collect measurements of water velocity, water depth, water temperature, and suspended-solids concentration. The 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, and an optical sensor was used to measure suspended-solids concentration.

The instrument was programmed to measure property variations at both tidal and wind-wave time scales. Every 15 minutes, output from the sensors was averaged over a 128-second period and stored in order to measure variations over the tidal cycle. Every hour, output from the velocity sensor was stored every 0.5 second over a 128-second period in order to measure the wind-wave properties. Periodic, short, and intensive data collection strategies are called burst sampling and are used to measure high frequency processes that cannot be continuously recorded because of data storage limitations. The variance of velocity (foot squared per second squared) for each burst sample is an approximate measure of the wind-wave energy. For example, a tidal current without wind waves will have a relatively small velocity variance and with large wind waves will have a relatively large velocity variance. Pressure measurements were not burst sampled because the initial deployment indicated that suspended-solids concentration was not responding at wind-wave frequencies. In addition, not collecting burst samples from these sensors decreased data storage requirements and increased the duration of instrument deployments.

The instrument was deployed inside a weighted aluminum frame that rests on the bottom sediment. An acoustic release was attached to concrete weights that were deployed about 50 ft from the instrument and a stainless-steel line ran from the frame to the acoustic release. Differential global positioning system (GPS) was used to record the positions of the instrument and the release, which were not marked at the surface. A locational device was attached to the frame so that it could be located if it were moved. After deployment, water depths were measured and water samples were collected to calibrate the pressure and optical sensors. Pressure measurements were corrected for fluctuations in atmospheric pressure. Pressure measurements are available from the weather station at San Francisco International Airport (fig. 1).

The instrument must be recovered to download data and to clean the optical sensor. To recover the instrument, a transmitter on the recovery boat is used to trigger the acoustic release, which releases a tethered float to the surface. The float is recovered, and the attached line is used to pull up the acoustic release, weights, and one end of the stainless-steel line, which is used to recover the instrument. The release often failed to operate properly, in which case, grappling hooks were dragged behind the recovery boat over the GPS coordinates to snag the deployed equipment.

Water Sample Collection

Until April 1994, water samples were collected using a P-72 point sampler positioned at sensor depth. A P-72 is a torpedo-shaped sampler that has a solenoid that opens and closes the intake, which allows a sample to be collected at a specific depth and for a specific amount of time. A 1-L plastic bottle placed within the sampler was used to collect the water samples. A nylon nozzle with a 1/4-in. opening controls the flow velocity into the sampler.

Water samples were collected before and after the sensors were cleaned. With the optical sensors deployed, the sampler was lowered to the depth of the sensor by a reel and crane assembly. The reel has conductive cable that allows an electrical current to trigger the sampler solenoid. The sampler was kept open long enough to collect at least 200 mL of water, which is the minimum amount needed for analysis of suspended-solids concentration. The sample was then removed from the sampler, marked for identification, and placed in a cooler and chilled to limit biological growth.

San Francisco Bay is a saline environment that frequently corroded the electrical components of the P-72 sampler. A weighted Van Dorn bottle was used as a back-up sampler when the P-72 was inoperable. The Van Dorn bottle is a plastic tube with rubber stoppers at each end that snap shut when triggered by a small weight dropped down the suspension cable.

A comparison test was conducted on March 25, 1994, at Mallard Island using the P-72 and Van Dorn samplers. The results (fig. 2) demonstrated that both samplers collected virtually the same suspended-solids concentration at a given depth and time in the water column. Beginning in April 1994, all water samples for suspended-solids analysis were collected using the Van Dorn sampler.

Samples were sent to the USGS Sediment Laboratory in Salinas, California, for analysis to determine suspended-solids concentration. Each sample was mixed well and a suitable volume was quickly poured into a graduated cylinder. The suspended solids were collected on a 0.45-µm membrane filter, the filter was rinsed to remove salts, and the insoluble material was dried at 103 °C and weighed (Fishman and Friedman, 1989).

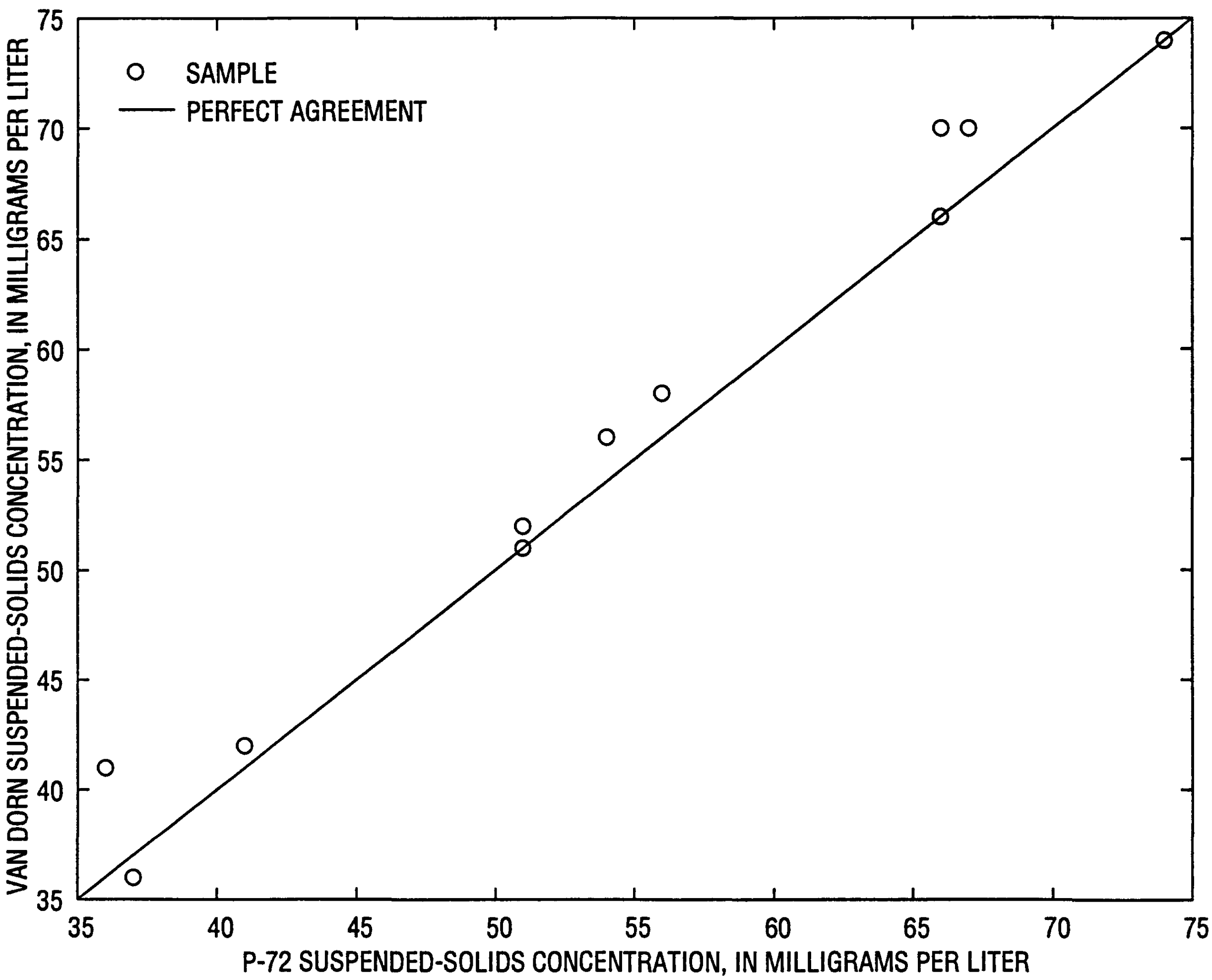

Figure 2. Results of comparison test of P-72 and Van Dorn samplers conducted on March 25, 1994, at Mallard Island, Suisun Bay, California.

Data Processing

Data loggers stored the voltage outputs from the optical sensors every 15 minutes. Recorded data were downloaded from the data logger onto a storage module during site visits by USGS personnel. Raw data from the storage modules were loaded into the USGS's automated data processing system (ADAPS).

The time-series data were retrieved and visually edited to remove invalid data. Invalid data included rapidly increasing voltage outputs and unusually high voltage outputs of short duration. As biological growth occurred on the optical sensors, the voltage output of the sensors increased rapidly. An example time series of raw and edited data is presented in figure 3. After the sensors were cleaned, sensor output decreased discontinuously (fig. 3, April 19, June 8, and June 28). Efforts to correct the invalid data proved to be unsuccessful because the desired signal was sometimes highly variable. Thus, data collected during the period prior to sensor cleaning often were unusable and were removed from the record (fig. 3). Spikes in the data, which are anomalously high voltages probably caused by debris temporarily wrapping around the sensor or by large marine organisms (fish, crabs) on or near the sensor, also were removed from the raw data record (fig. 3).

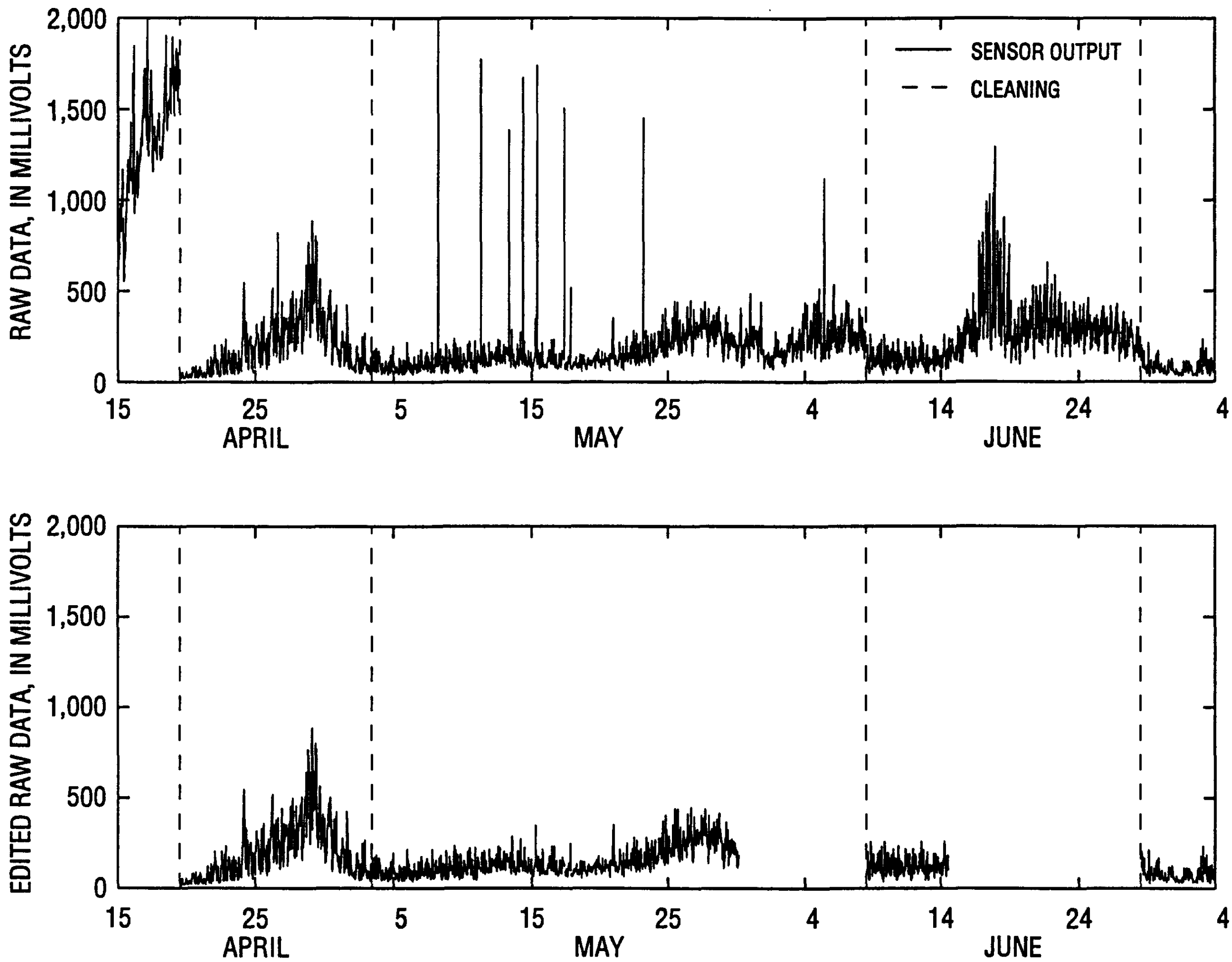

Figure 3. Raw and edited optical backscatterance data, mid-depth sensor, Point San Pablo, Central San Francisco Bay, California.

SENSOR CALIBRATION AND SUSPENDED-SOLIDS CONCENTRATION DATA

Linear regression was used to calibrate sensor output to suspended-solids concentration. The calibration figures, time-series plots of suspended-solids concentration data, and statistical summary table are presented. Calibration figures include the number of samples, correlation coefficient, and root-mean-squared error.

Suisun Bay

Mallard Island

The calibration of the near-surface sensor at Mallard Island had a standard error of 4.50 mg/L (fig. 4), and the near-bottom sensor had a standard error of 3.26 mg/L (fig. 5). Suspended-solids concentration data collected during water year 1994 are presented in figures 6 and 7, and a statistical summary is given in table 2. Data collected by the near-surface sensor were 71.6 percent valid. An abrasion on the near-surface sensor cable caused a loss of data from June 5 to July 8, 1994. A calibration shift of the near-surface sensor in September caused some clipping of lower concentration data. Data collected by the near-bottom sensor were 89.5 percent valid. Missing data in August due to fouling.

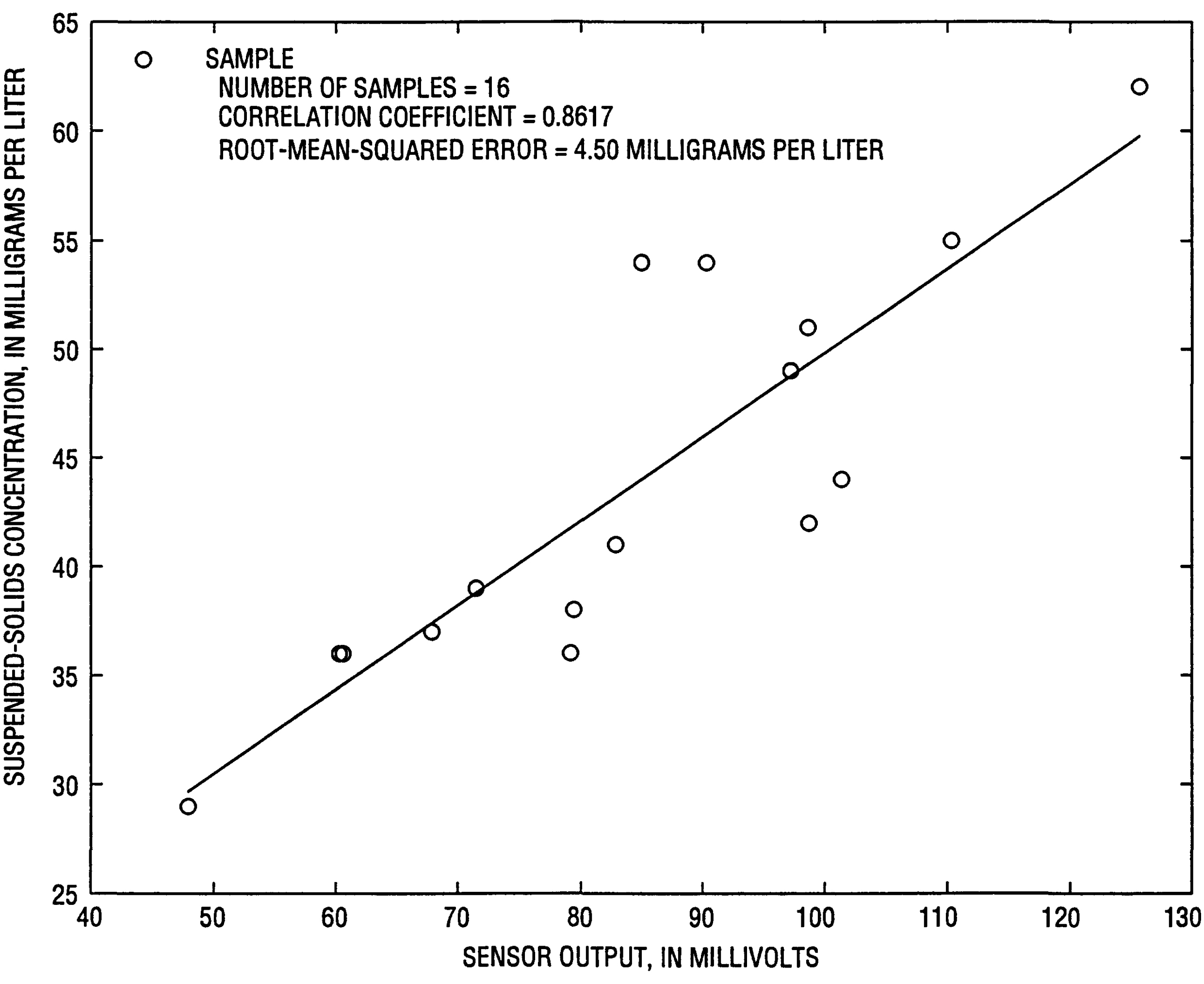

Figure 4. Calibration of near-surface optical backscatterance sensor (with wiper) at Mallard Island, Suisun Bay, California, water year 1994.

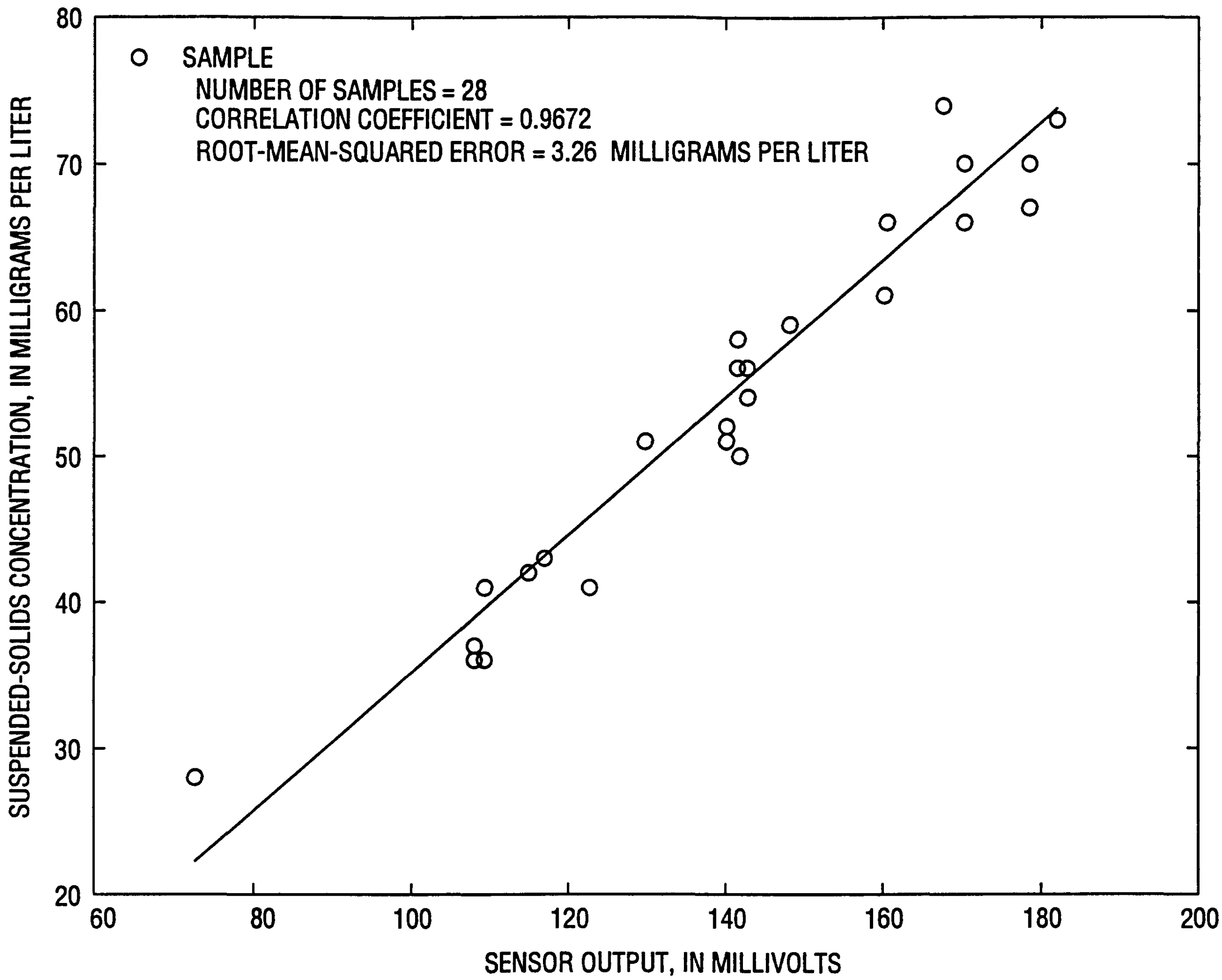

Figure 5. Calibration of near-bottom optical backscatterance sensor (with wiper) at Mallard Island, Suisun Bay, California, water year 1994.

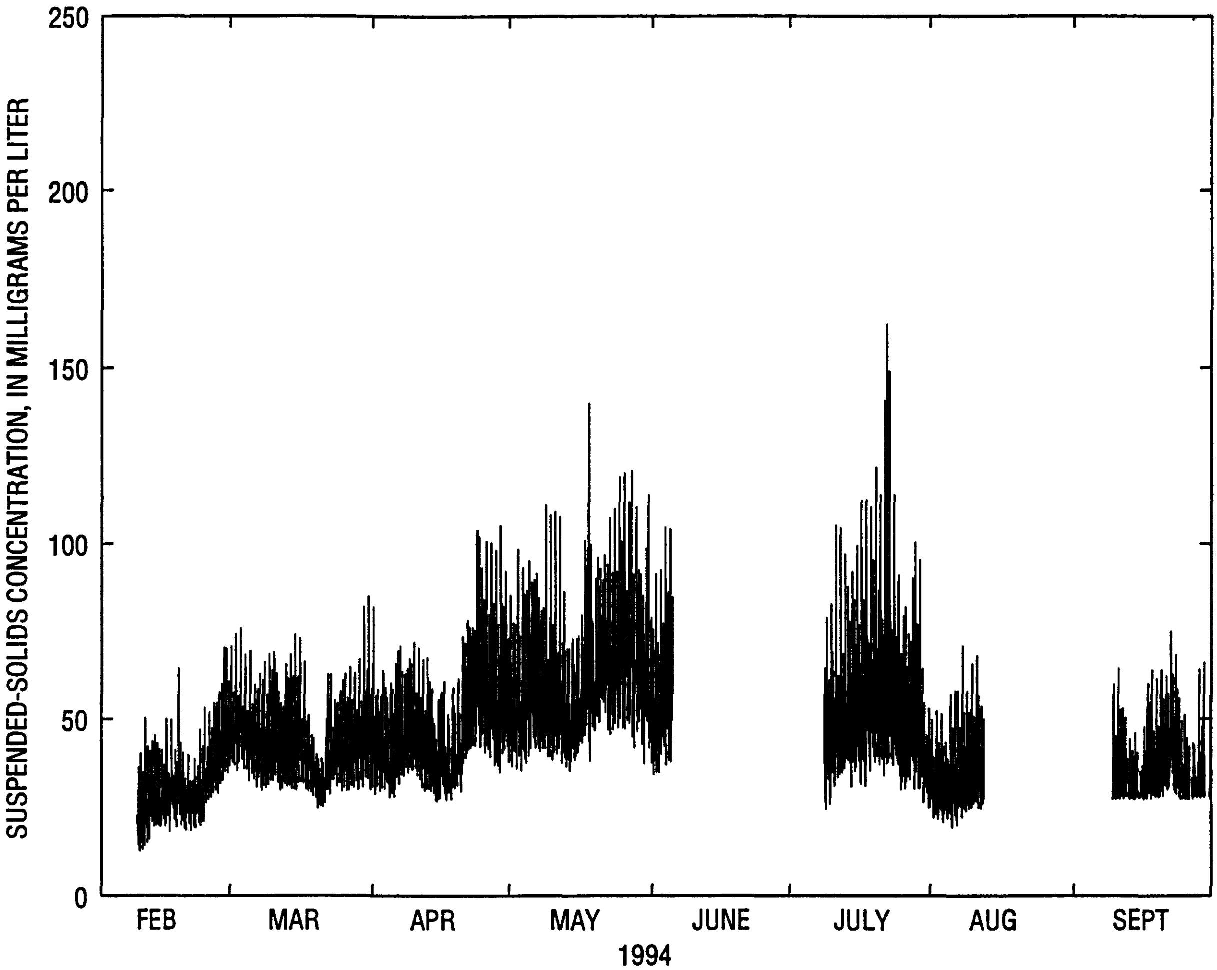

Figure 6. Time series of near-surface suspended-solids concentration calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 1994.

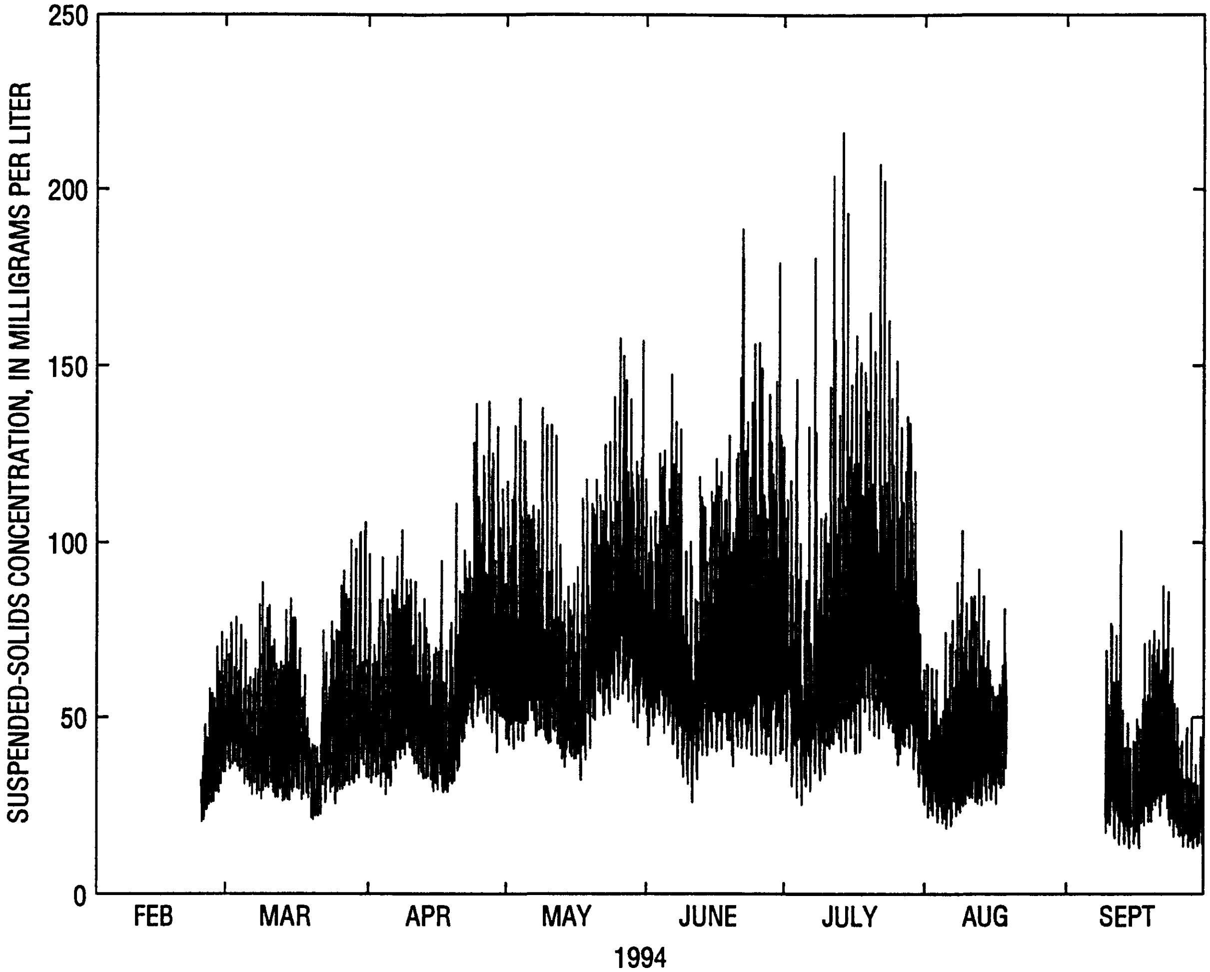

Figure 7. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 1994.

Table 2. Statistical summary of suspended-solids concentration data, Suisun Bay and Central and South San Francisco Bays, California, water year 1994

[All measurements are in milligrams per liter]

Site	Depth	Mean	Median	Lower quartile	Upper quartile
Mallard Island	Near-surface	44.5	42.1	34.0	52.4
	Near-bottom	54.3	51.8	38.9	65.6
Martinez	Near-surface	56.9	52.4	41.9	66.4
Point San Pablo	Mid-depth	98.5	78.8	45.2	128
	Near-bottom	96.3	77.2	45.4	126
Pier 24	Mid-depth	42.7	38.4	25.8	54.6
	Near-bottom	45.4	40.0	26.2	60.2
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

Martinez

Calibration of the near-surface sensor at Martinez had a standard error of 6.24 mg/L (fig. 8). Data from the near-bottom sensor were not used because of local circulation patterns and a nearby mudflat. During floodtides, output from the near-bottom sensor was poorly correlated with independent optical sensor measurements made slightly north of the site (Tobin and others, 1995). Suspended-solids concentration data collected during water year 1994 are presented in figure 9, and a statistical summary is given in table 2. Data collected by the near-surface sensor were 78.3 percent valid.

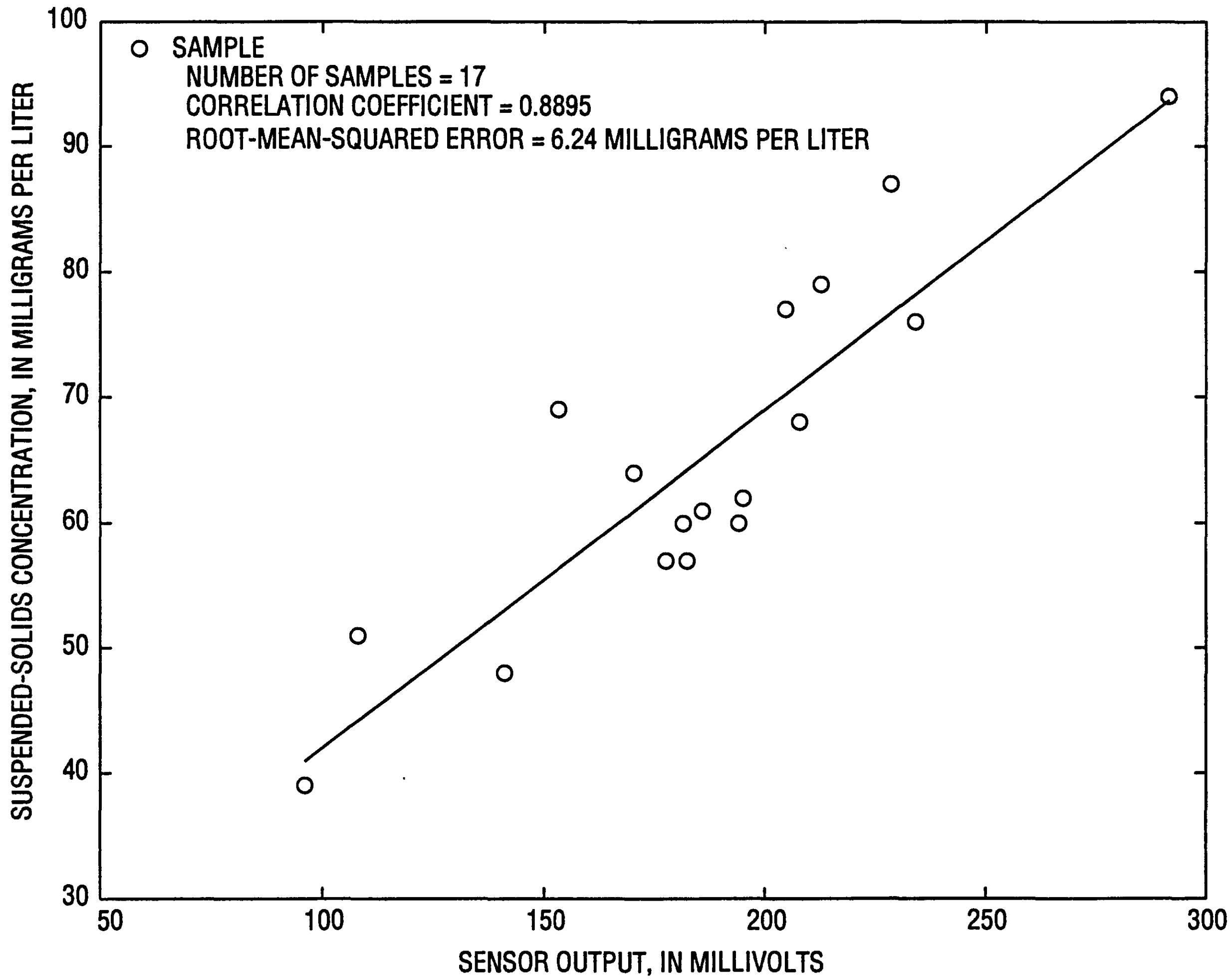

Figure 8. Calibration of near-surface optical backscatterance sensor (with wiper) at Martinez, Suisun Bay, California, water year 1994.

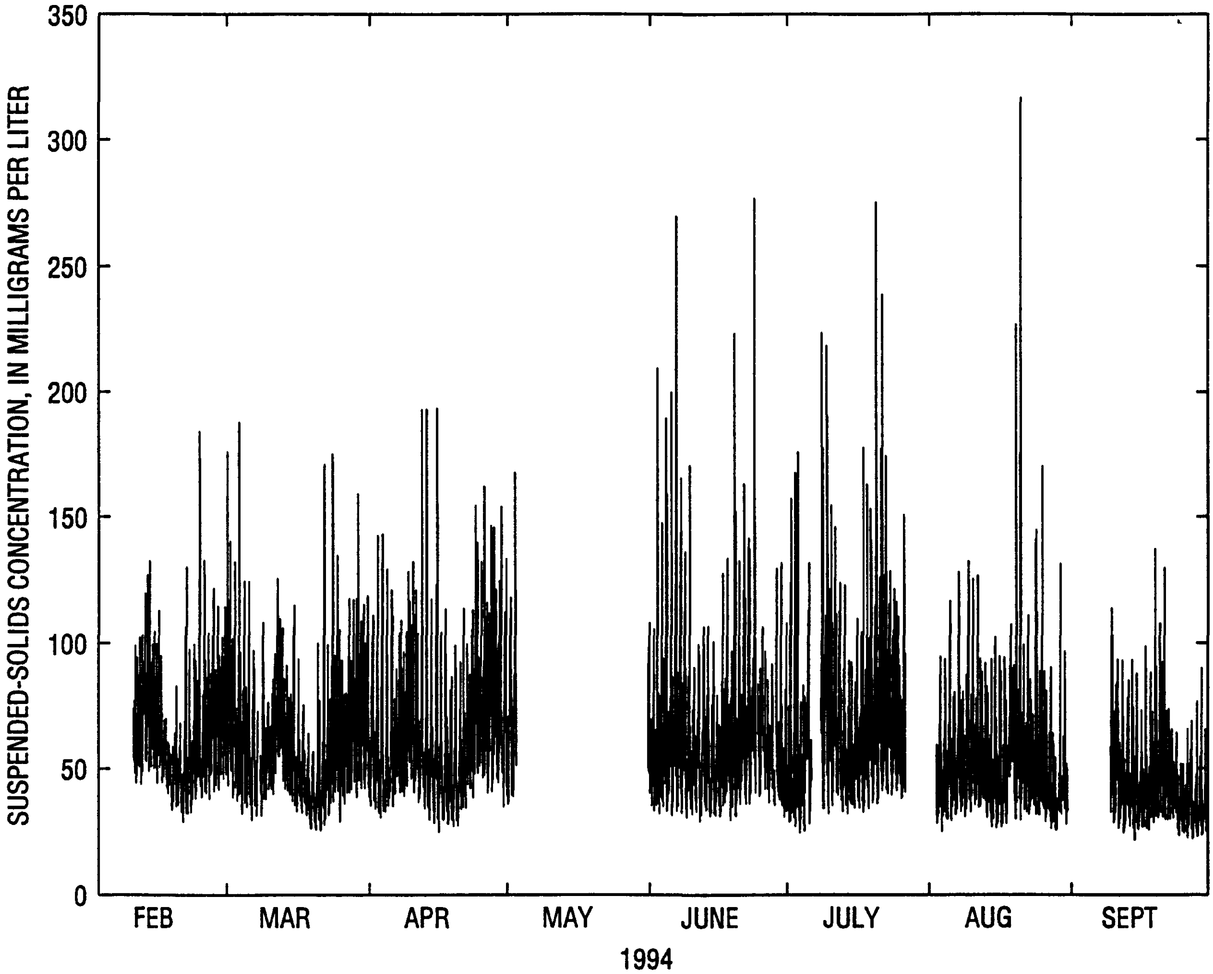

Figure 9. Time series of near-surface suspended-solids concentration calculated from sensor readings at Martinez, Suisun Bay, California, water year 1994.

Central San Francisco Bay

Point San Pablo

Calibration of the mid-depth sensor at Point San Pablo had a standard error of 25.1 mg/L (fig. 10), and calibration of the near-bottom sensor had a standard error of 35.3 mg/L (fig. 11). Suspended-solids concentration data collected during the 1994 water year are presented in figures 12 and 13. A statistical summary is presented in table 2. Data collected by the mid-depth sensor were 65.9 percent valid, and data collected by the near-bottom sensor were 77.4 percent valid. Missing data were due to fouling.

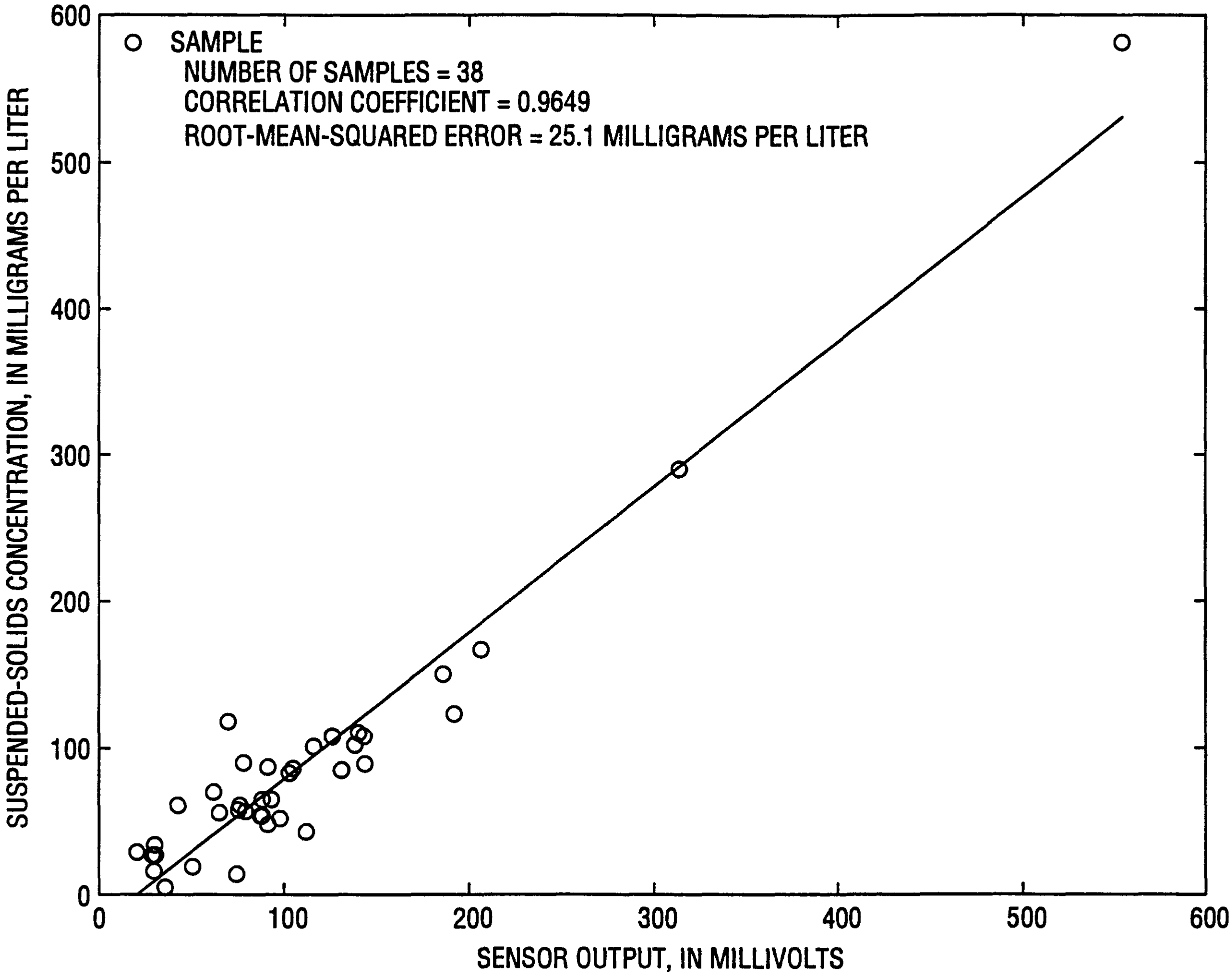

Figure 10. Calibration of mid-depth optical backscatterance sensor at Point San Pablo, Central San Francisco Bay, California, water year 1994.

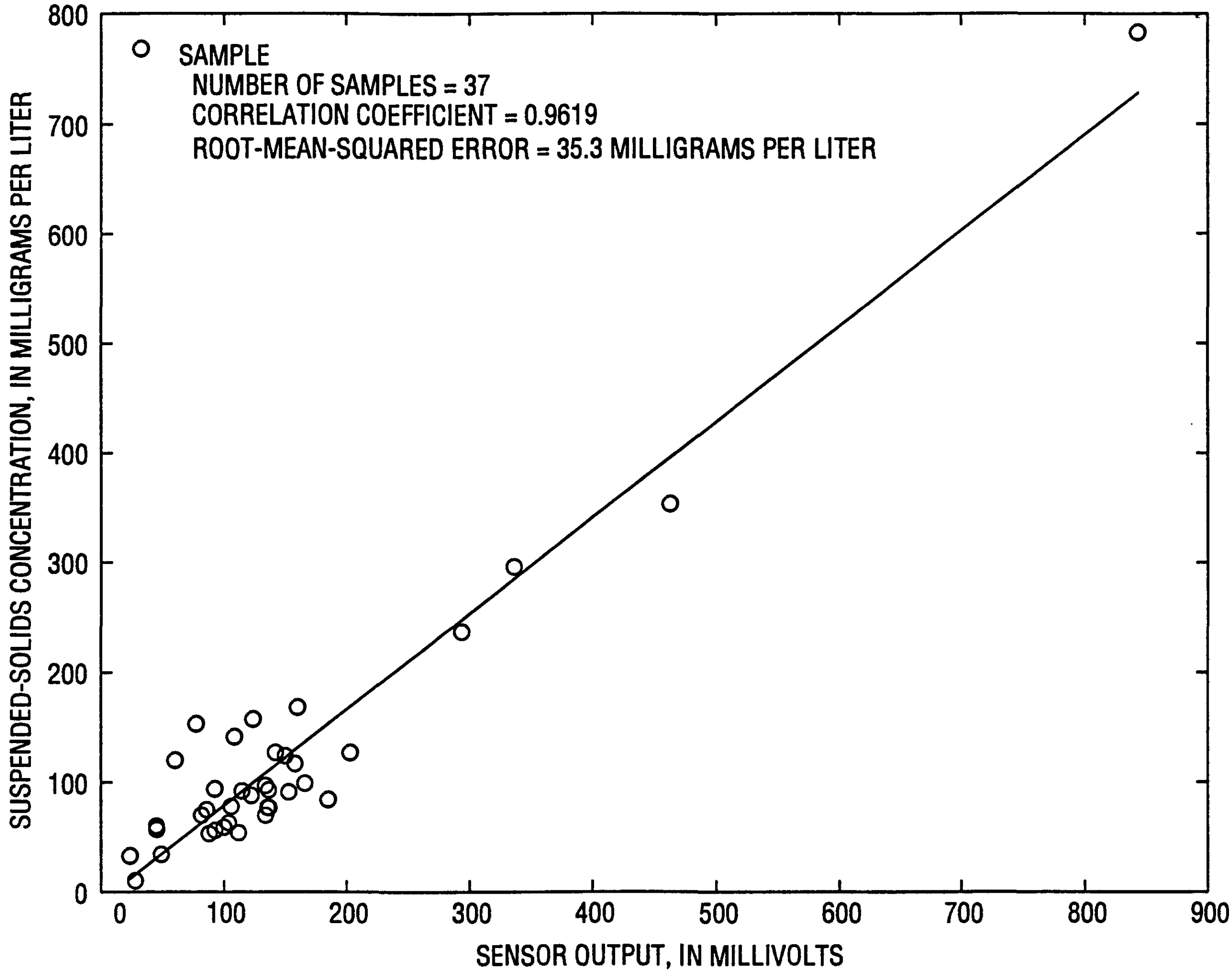

Figure 11. Calibration of near-bottom optical backscatterance sensor at Point San Pablo, Central San Francisco Bay, California, water year 1994.

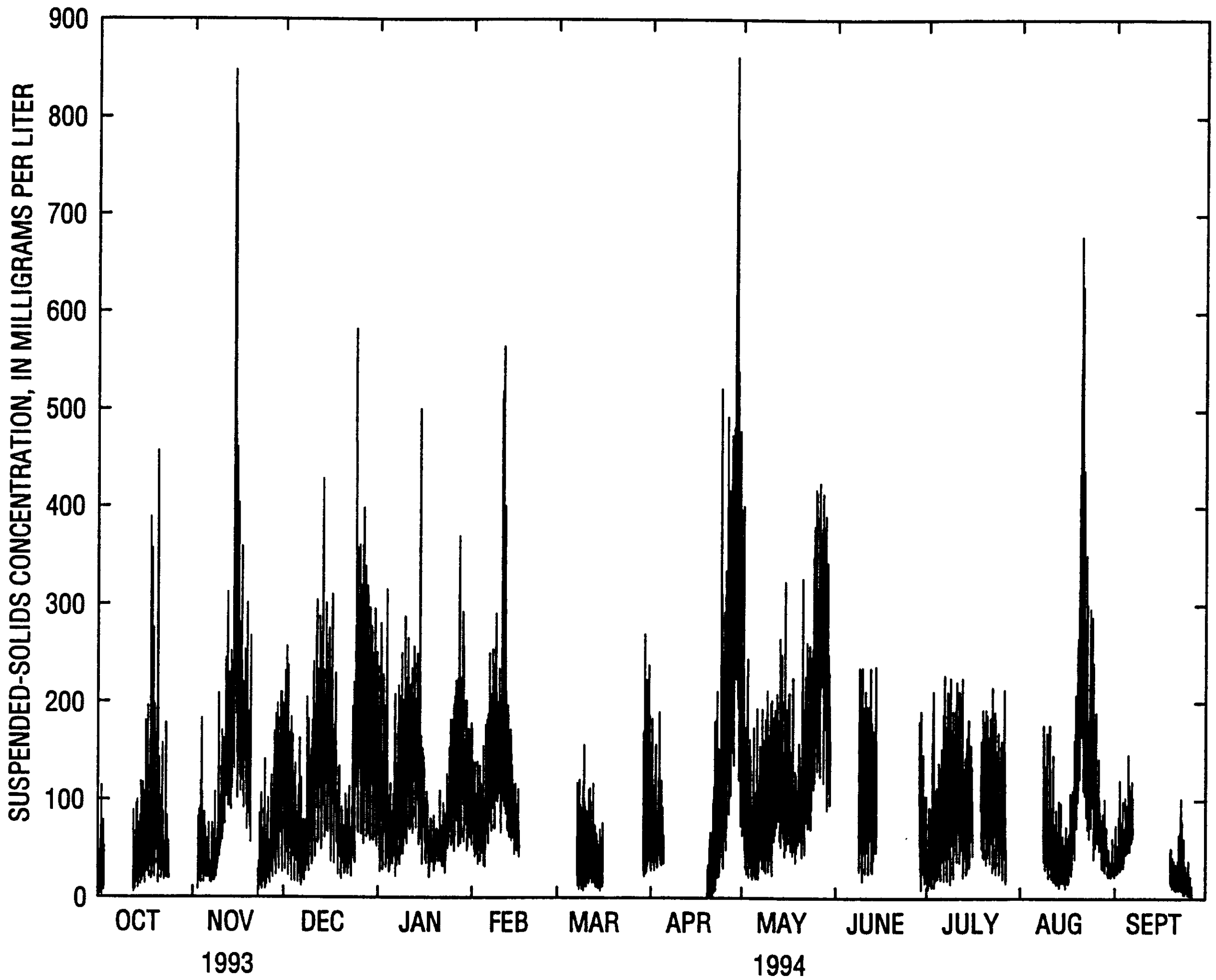

Figure 12. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 1994.

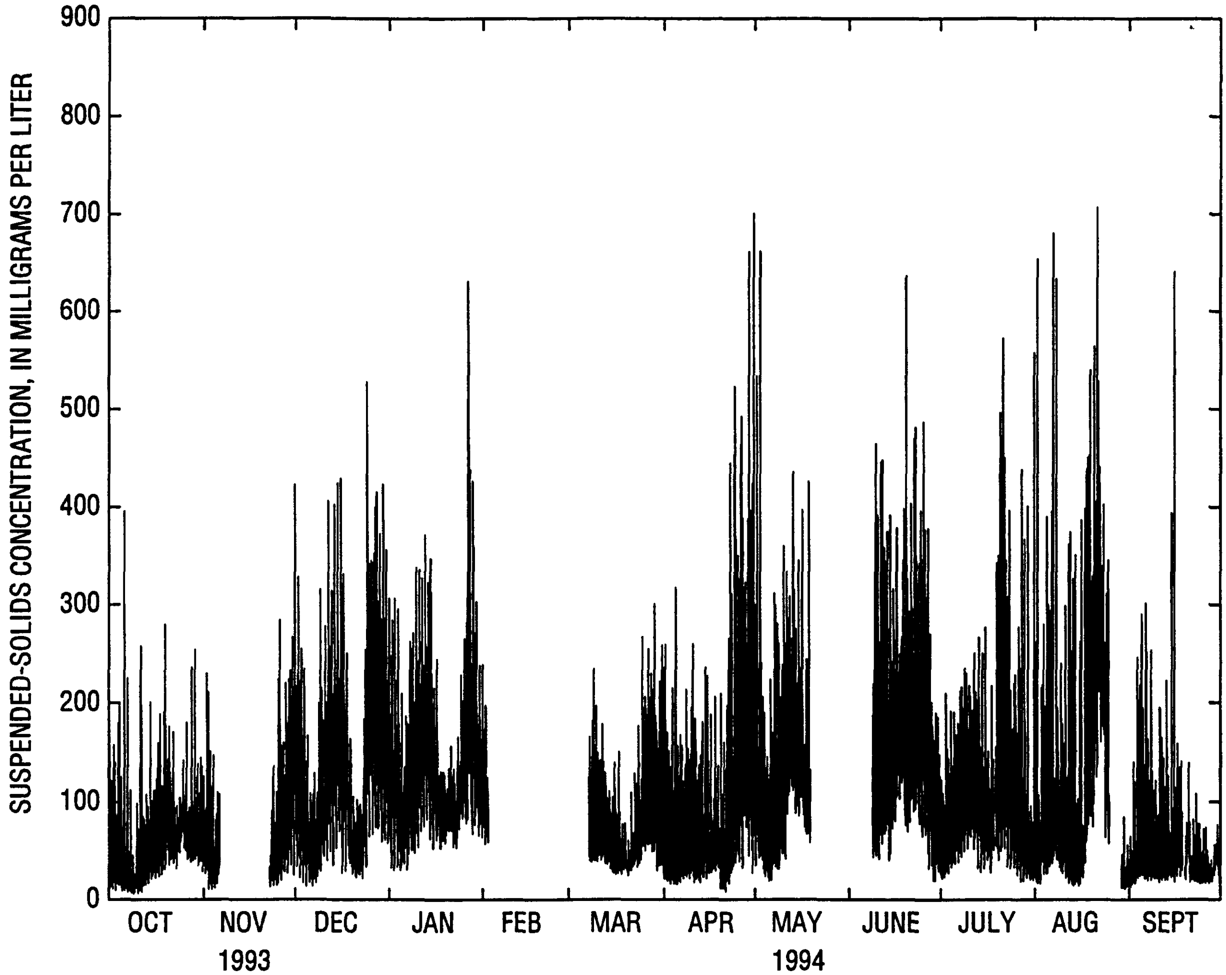

Figure 13. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 1994.

Pier 24

Calibration of the mid-depth sensor at Pier 24 had a standard error of 10.3 mg/L (fig. 14), and calibration of the near-bottom sensor had a standard error of 12.7 mg/L (fig. 15). Suspended-solids concentration data collected during water year 1994 are presented in figures 16 and 17, and a statistical summary is given in table 2. Data collected by the mid-depth sensor were 35.4 percent valid, and data collected by the near-bottom sensor were 45.9 percent valid. Missing data were due to fouling.

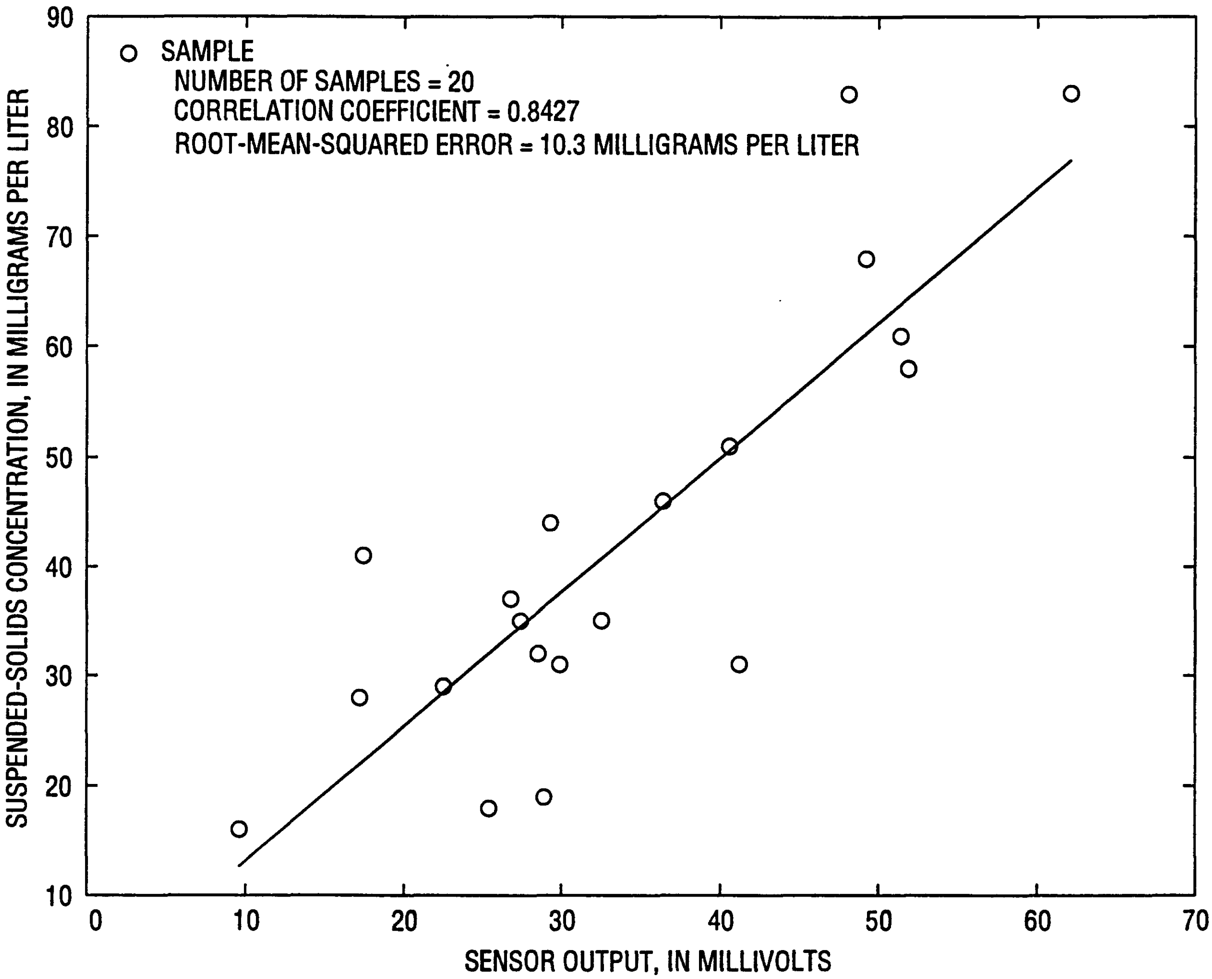

Figure 14. Calibration of mid-depth optical backscatterance sensor at Pier 24, Central San Francisco Bay, California, water year 1994.

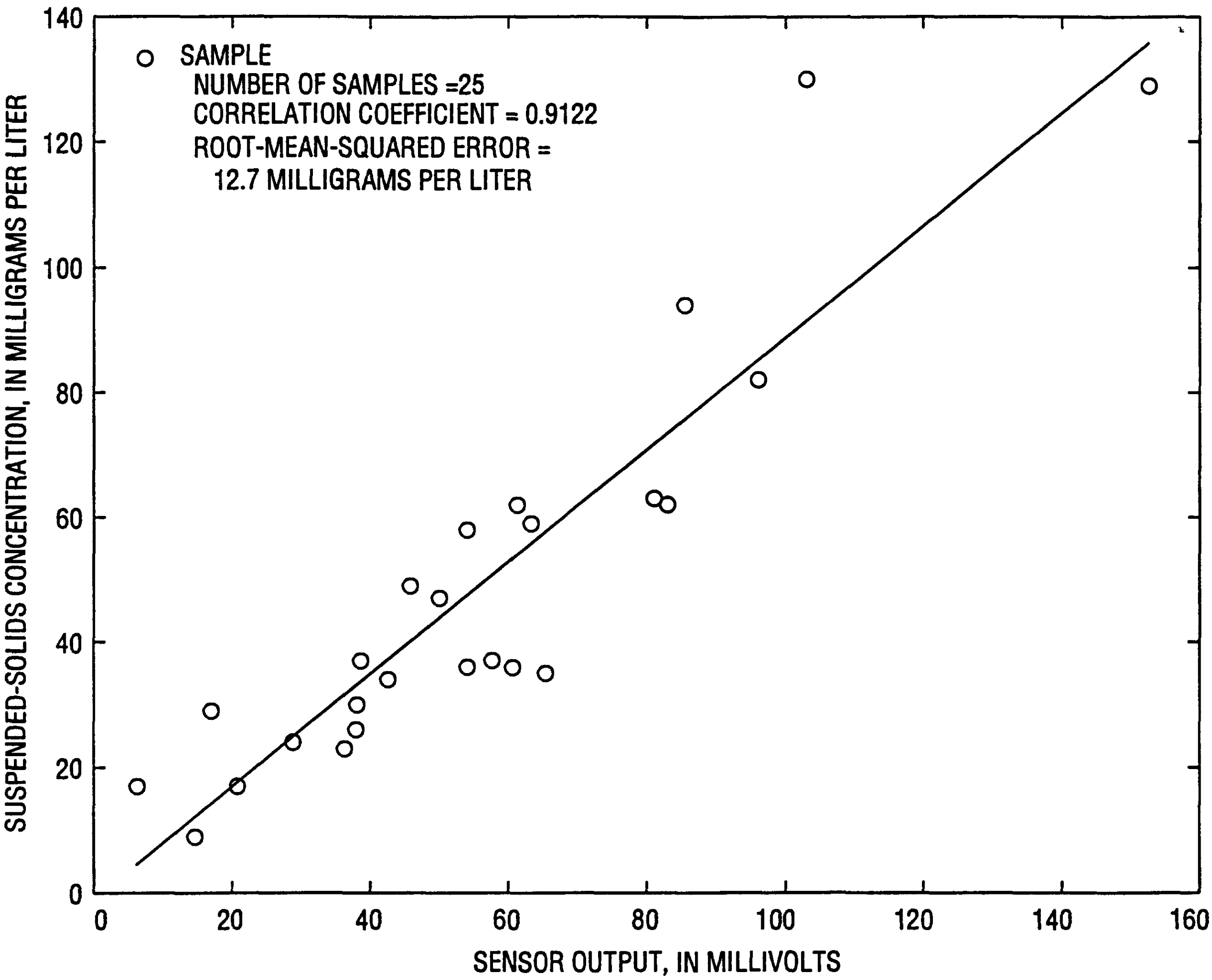

Figure 15. Calibration of near-bottom optical backscatterance sensor at Pier 24, Central San Francisco Bay, California, water year 1994.

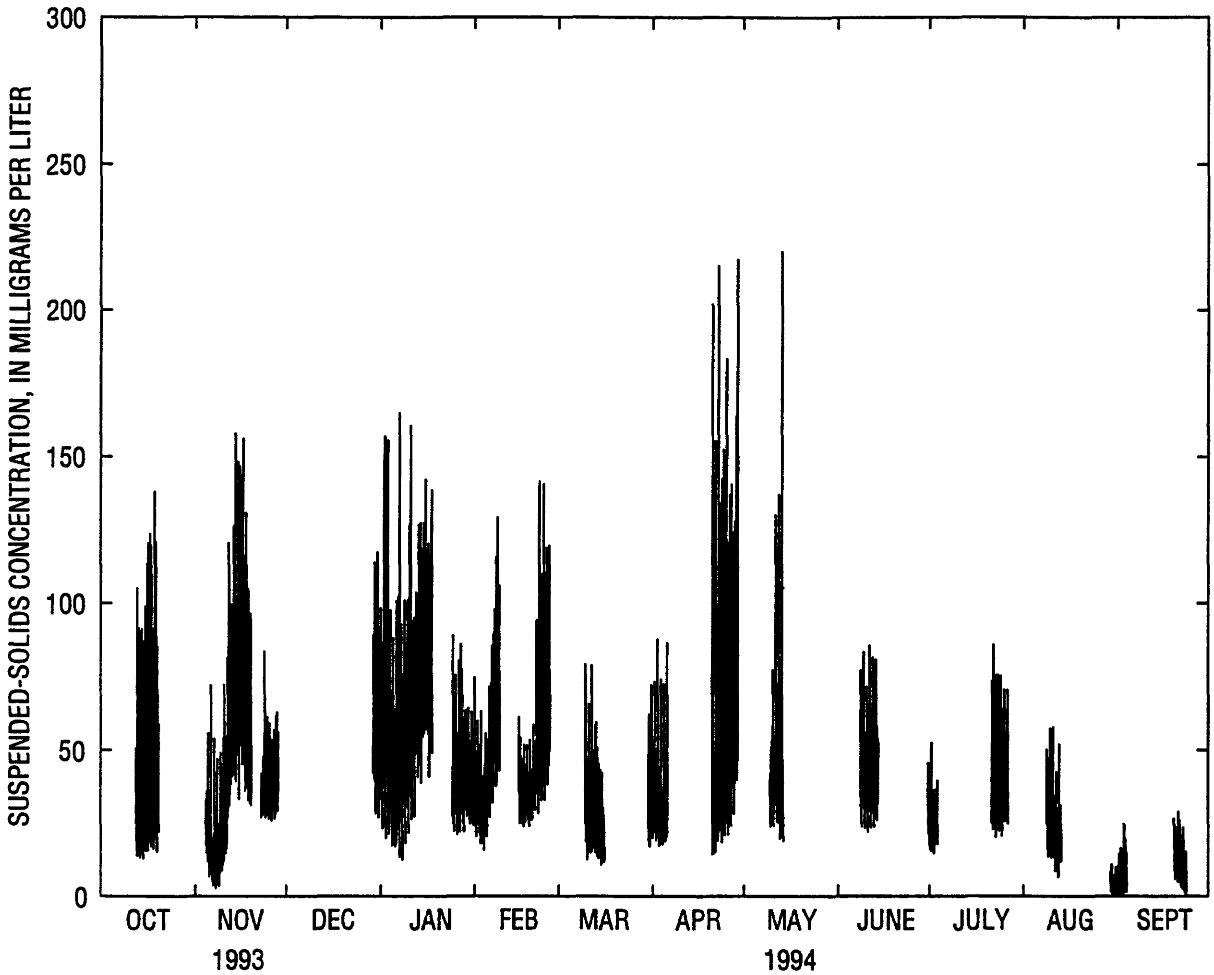

Figure 16. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 1994.

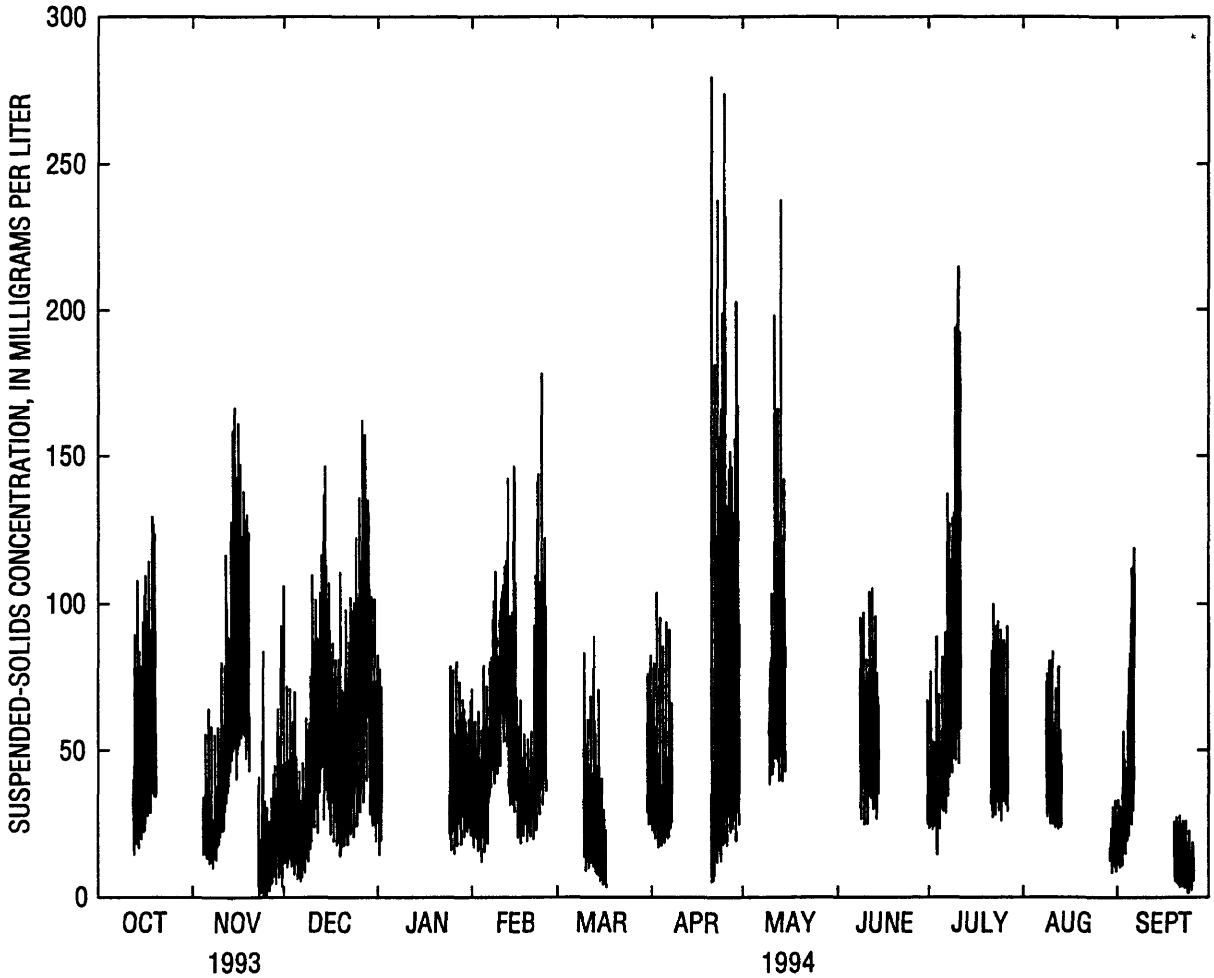

Figure 17. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 1994.

South San Francisco Bay

Channel Marker 17

Calibration of the mid-depth sensor at channel marker 17 had a standard error of 18.4 mg/L (fig. 18), and the calibration of the near-bottom sensor had a standard error of 20.1 mg/L (fig. 19). Suspended-solids concentration data collected during water year 1994 are presented in figures 20 and 21, and a statistical summary is given in table 2. Data collected by the mid-depth sensor were 66.6 percent valid, and data collected by the near-bottom sensor were 75.1 percent valid. Most missing data were due to fouling. Spikes recorded by both sensors during floodtides, believed to be caused by sensor cables twisting around the suspension line, were deleted from the data.

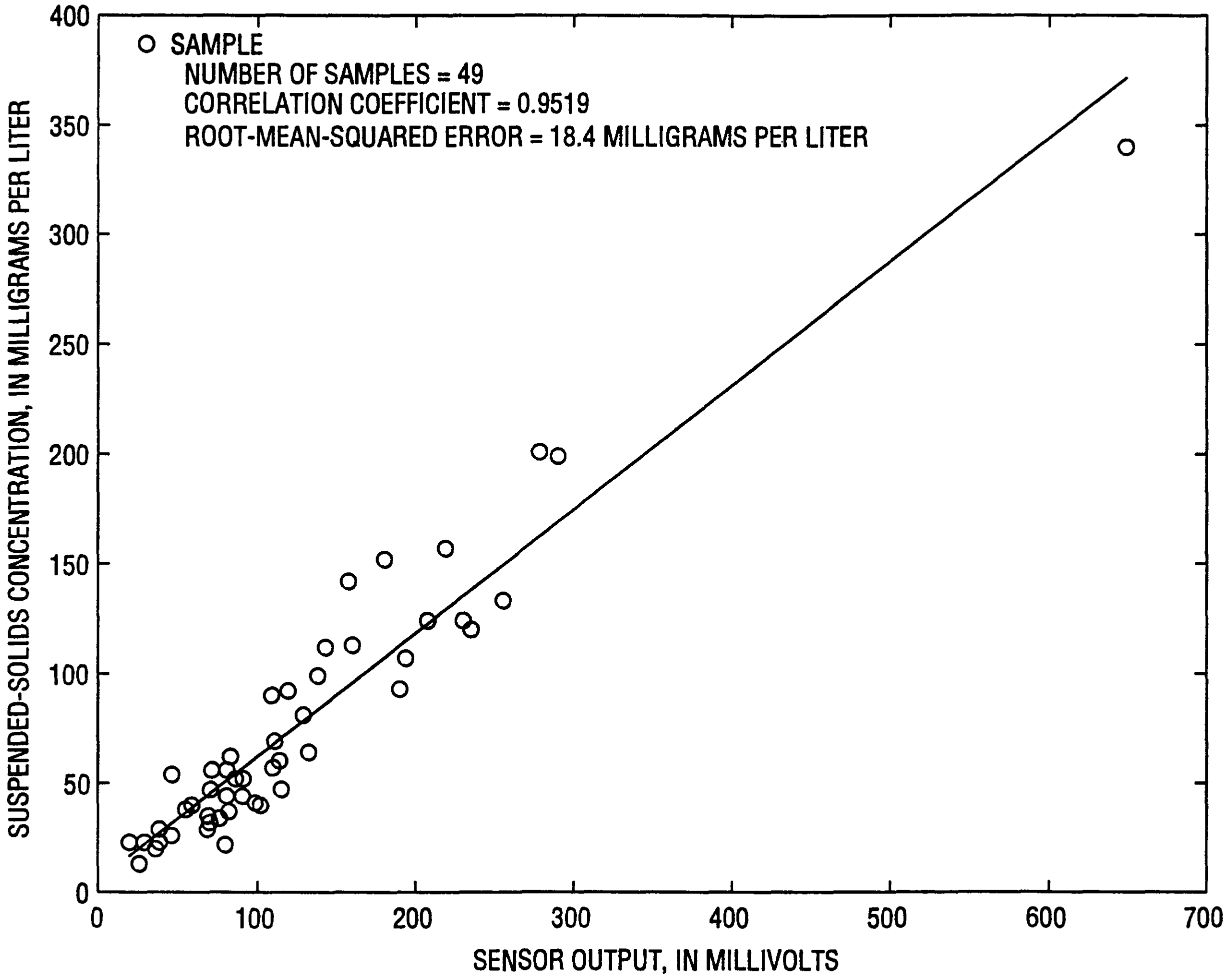

Figure 18. Calibration of mid-depth optical backscatterance sensor at channel marker 17, South San Francisco Bay, California, water year 1994.

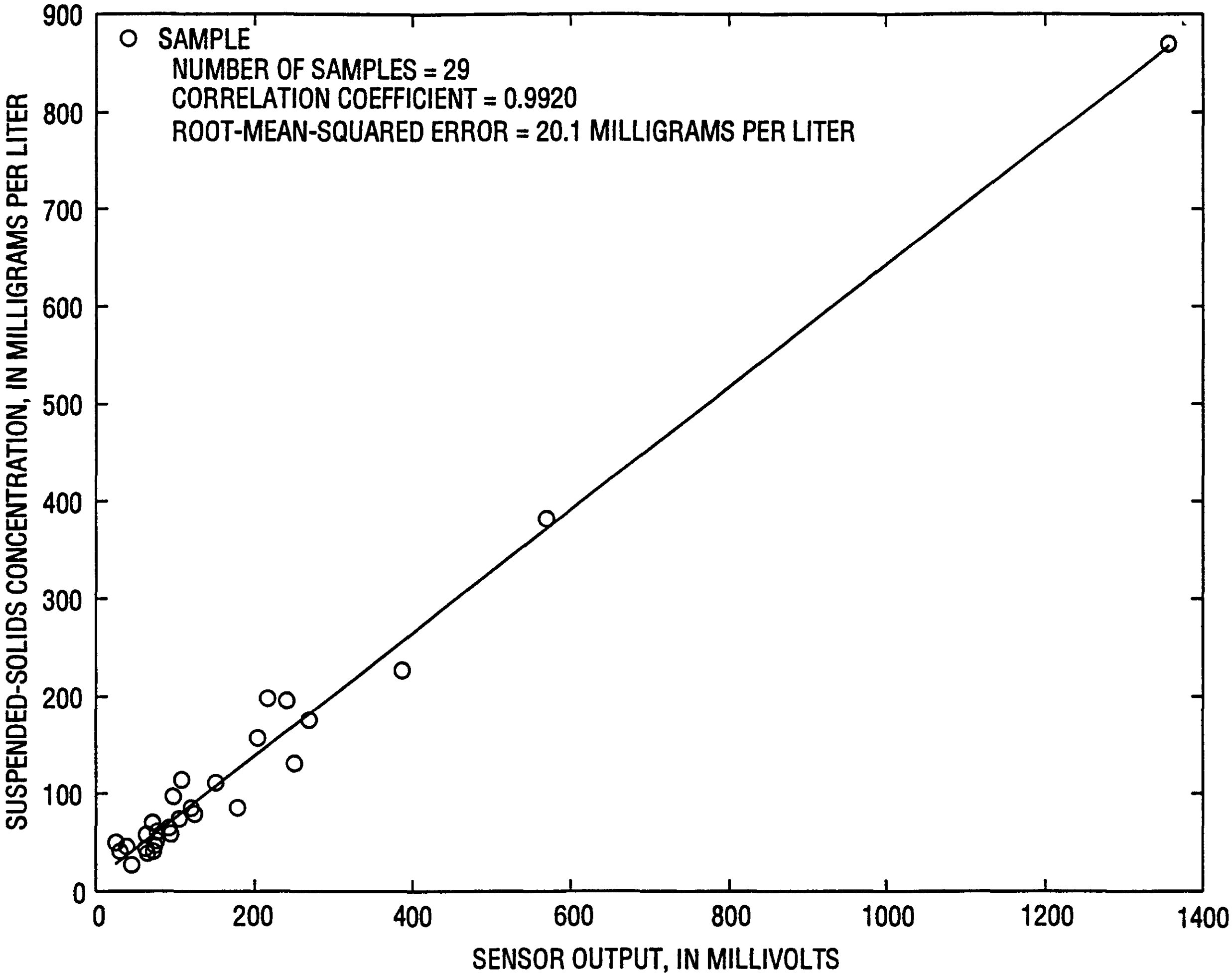

Figure 19. Calibration of near-bottom optical backscatterance sensor at channel marker 17, South San Francisco Bay, California, water year 1994.

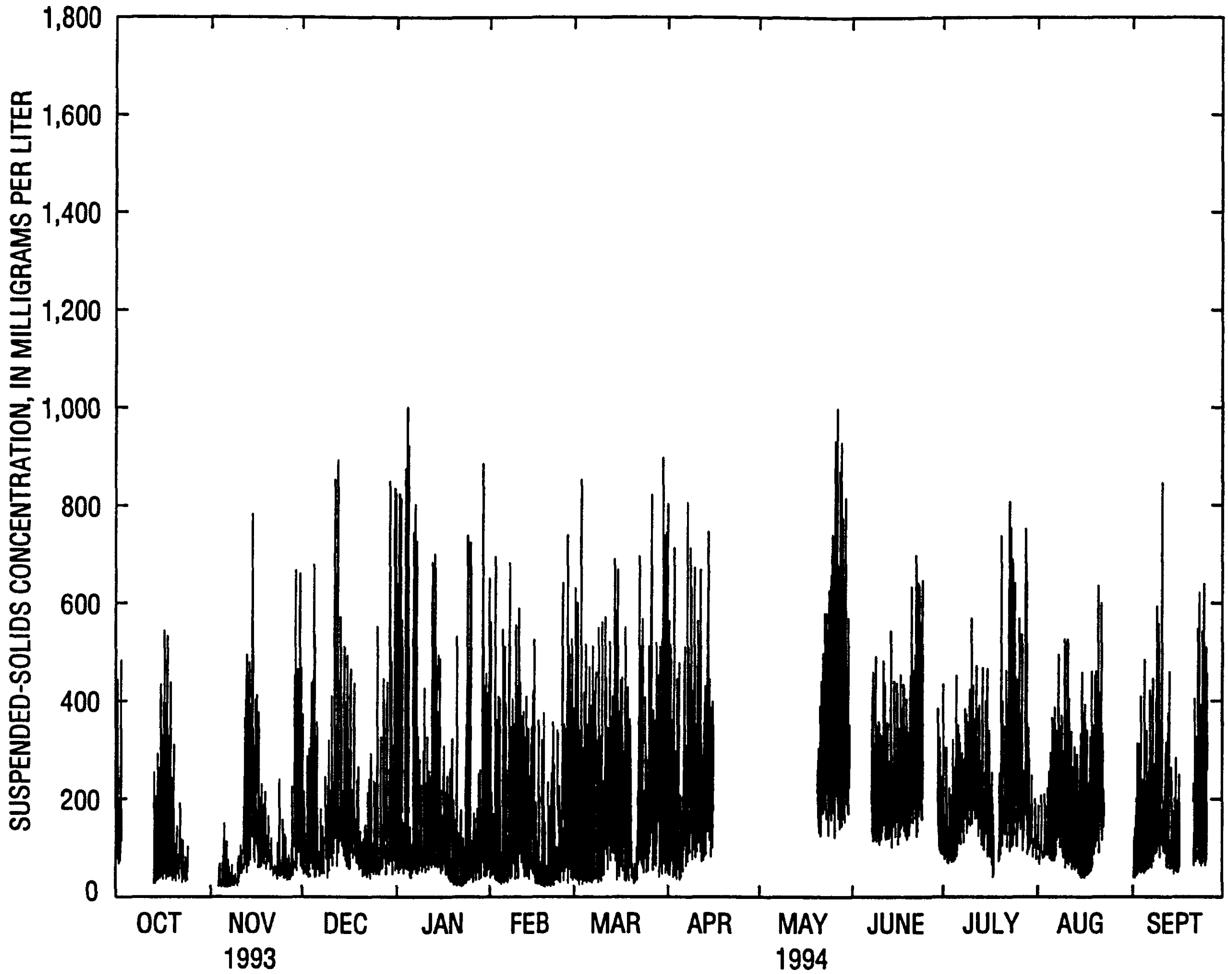

Figure 20. Time series of mid-depth suspended-solids concentration calculated from sensor readings at channel marker 17, South San Francisco Bay, California, water year 1994.

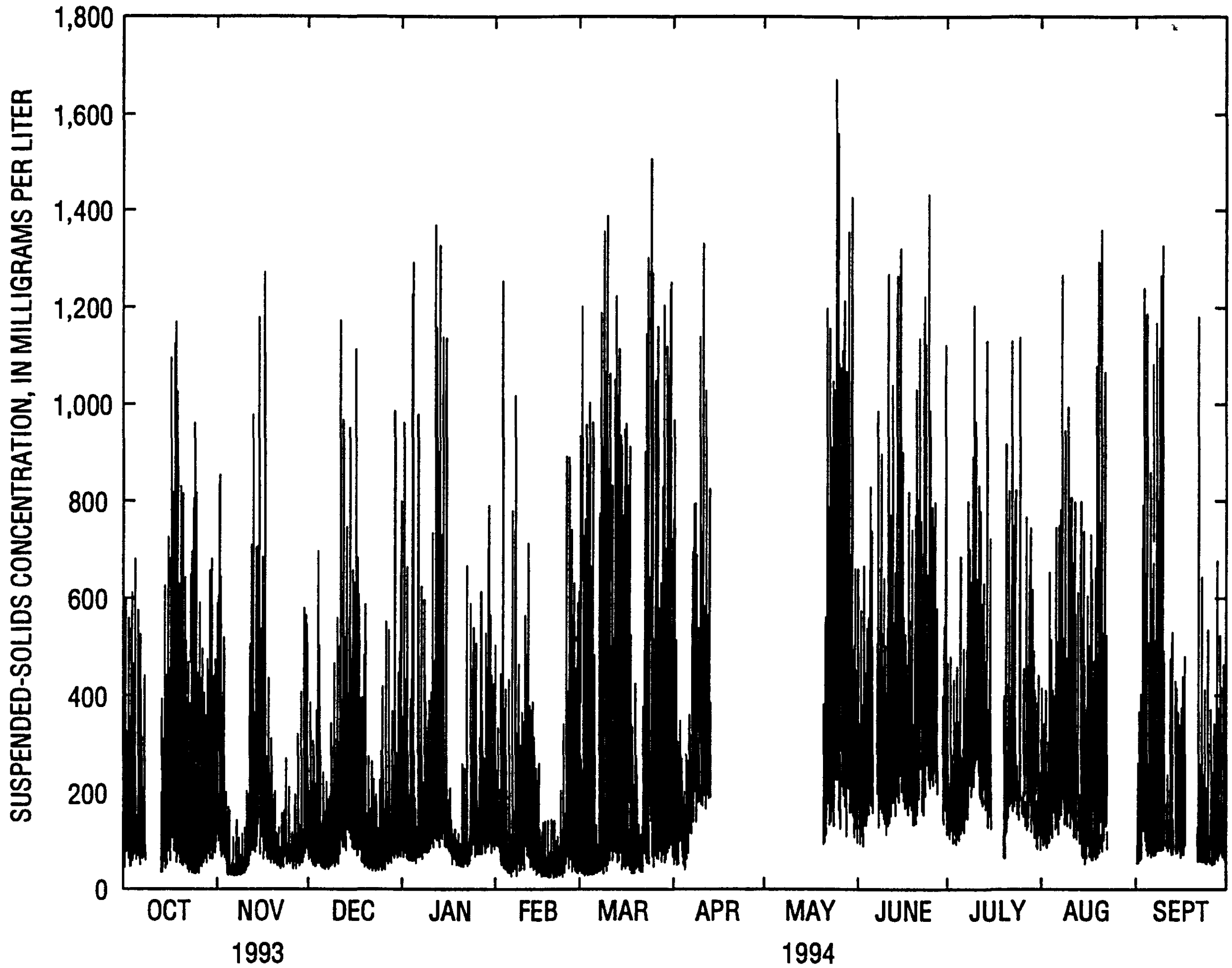

Figure 21. Time series of near-bottom suspended-solids concentration calculated from sensor readings at channel marker 17, South San Francisco Bay, California, water year 1994.

Dumbarton Bridge

Calibration of the mid-depth sensor at the Dumbarton Bridge, in operation until March 3, 1994, had a standard error of 14.3 mg/L (fig. 22), and calibration of the mid-depth wiper probe, in operation from March 17 to September 30, 1994, had a standard error of 17.4 mg/L (fig. 23). Calibration of the near-bottom sensor, in operation until March 3, 1994, had a standard error of 20.1 mg/L (fig. 24), and calibration of the near-bottom wiper probe, in operation from March 17 to September 30, 1994, had a standard error of 11.5 mg/L (fig. 25). Suspended-solids concentration data collected during water year 1994 are presented in figures 26 and 27, and a statistical summary is given in table 2. From March 17 to April 7, the maximum limit of the electronic unit was set at 100 NTU, and all data in excess of 100 NTU were lost. On April 7, the limit was raised to 1,000 NTU. Data collected by the mid-depth sensors were 37.6 percent valid, and data collected by the near-bottom sensors were 43.8 percent valid. Most missing data were the result of fouling.

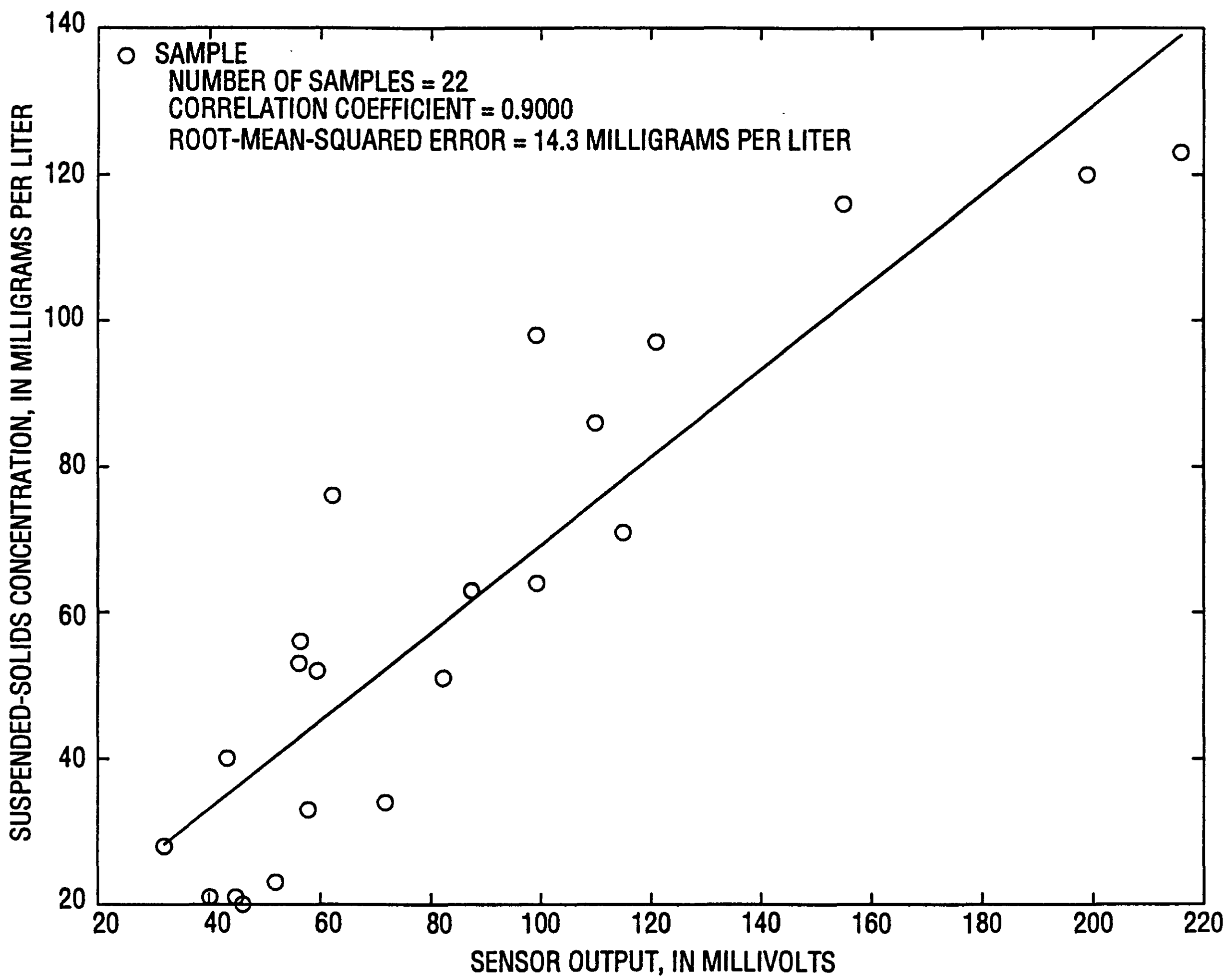

Figure 22. Calibration of mid-depth optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, until March 3, water year 1994.

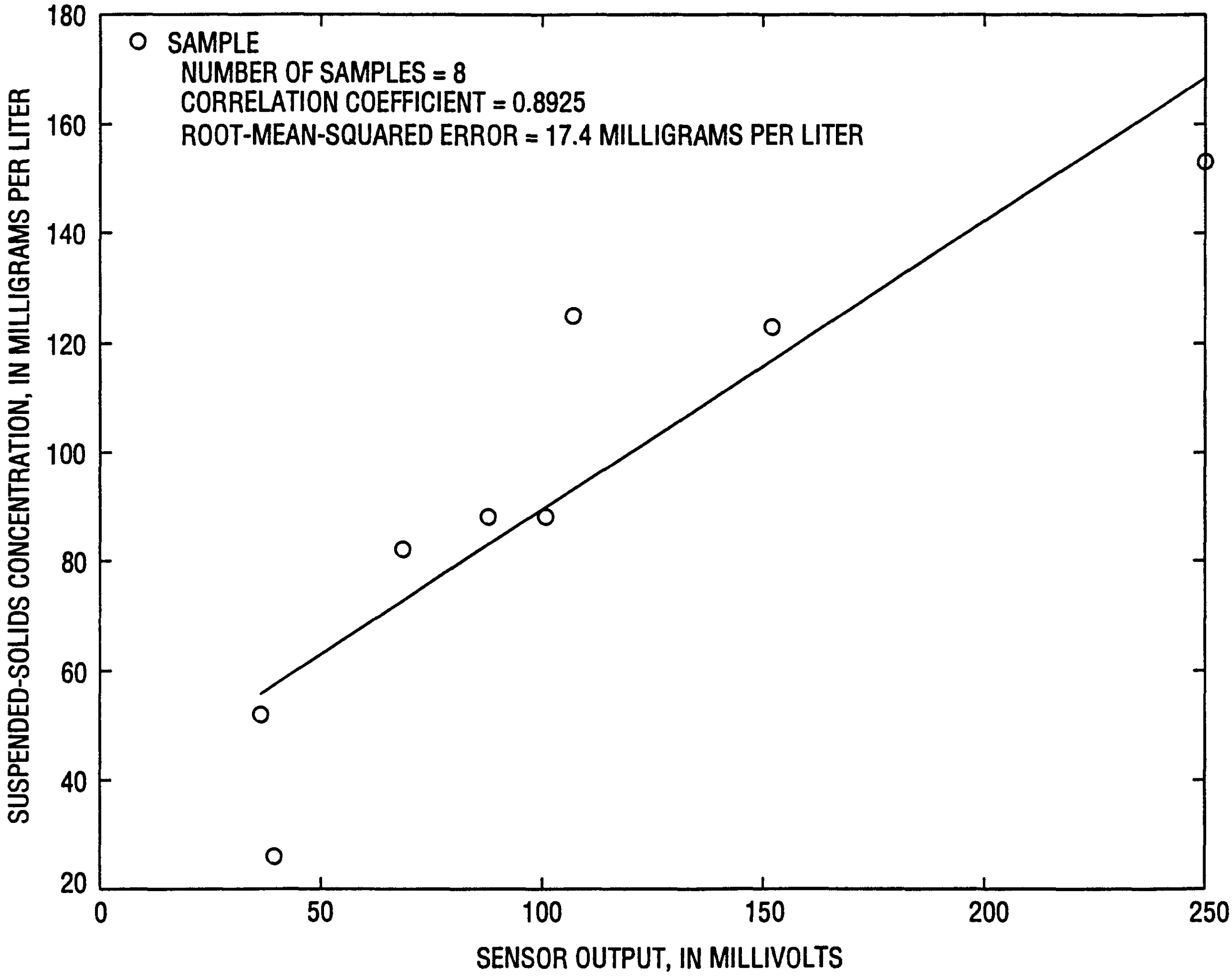

Figure 23. Calibration of mid-depth optical backscatterance sensor (with wiper) at Dumbarton Bridge, South San Francisco Bay, California, from March 17 to September 30, water year 1994.

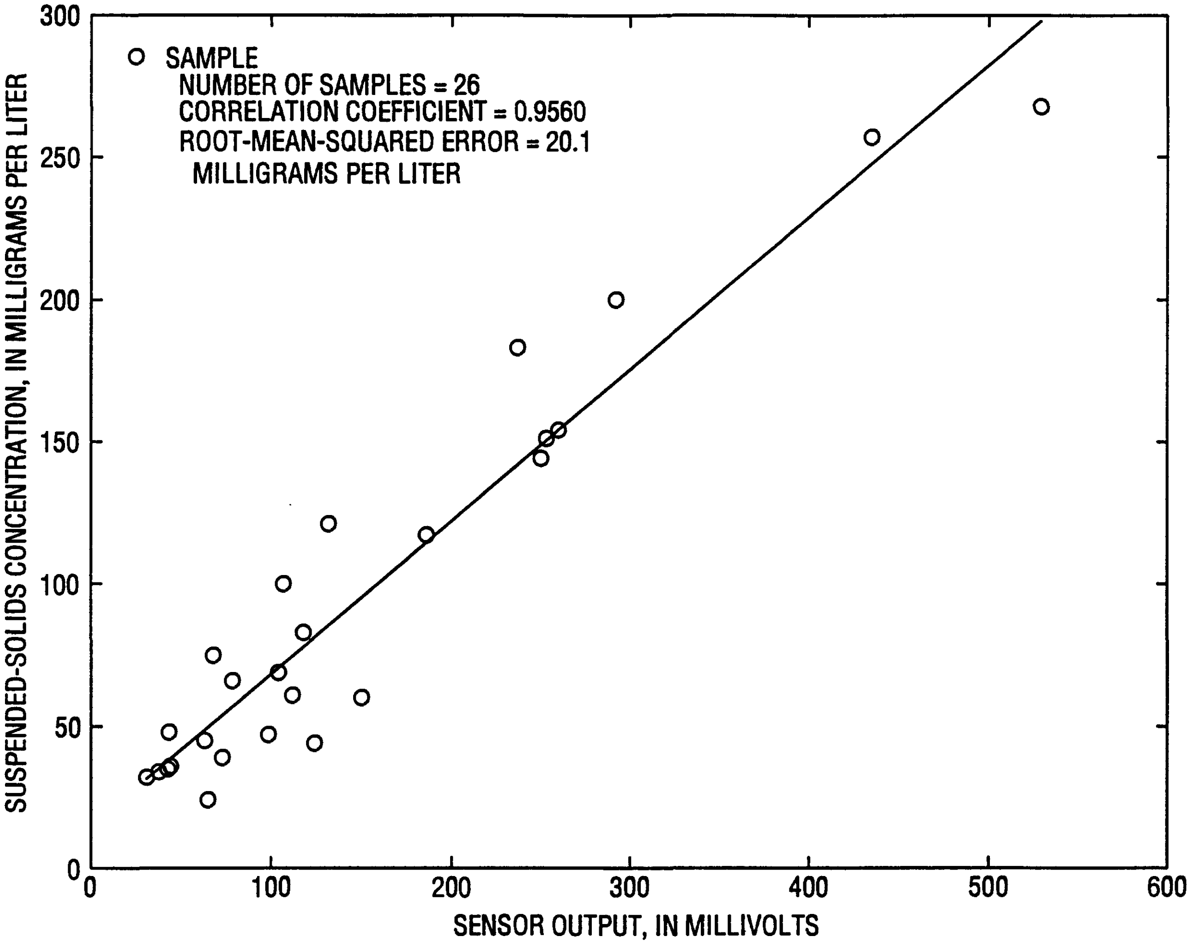

Figure 24. Calibration of near-bottom optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, until March 3, water year 1994.

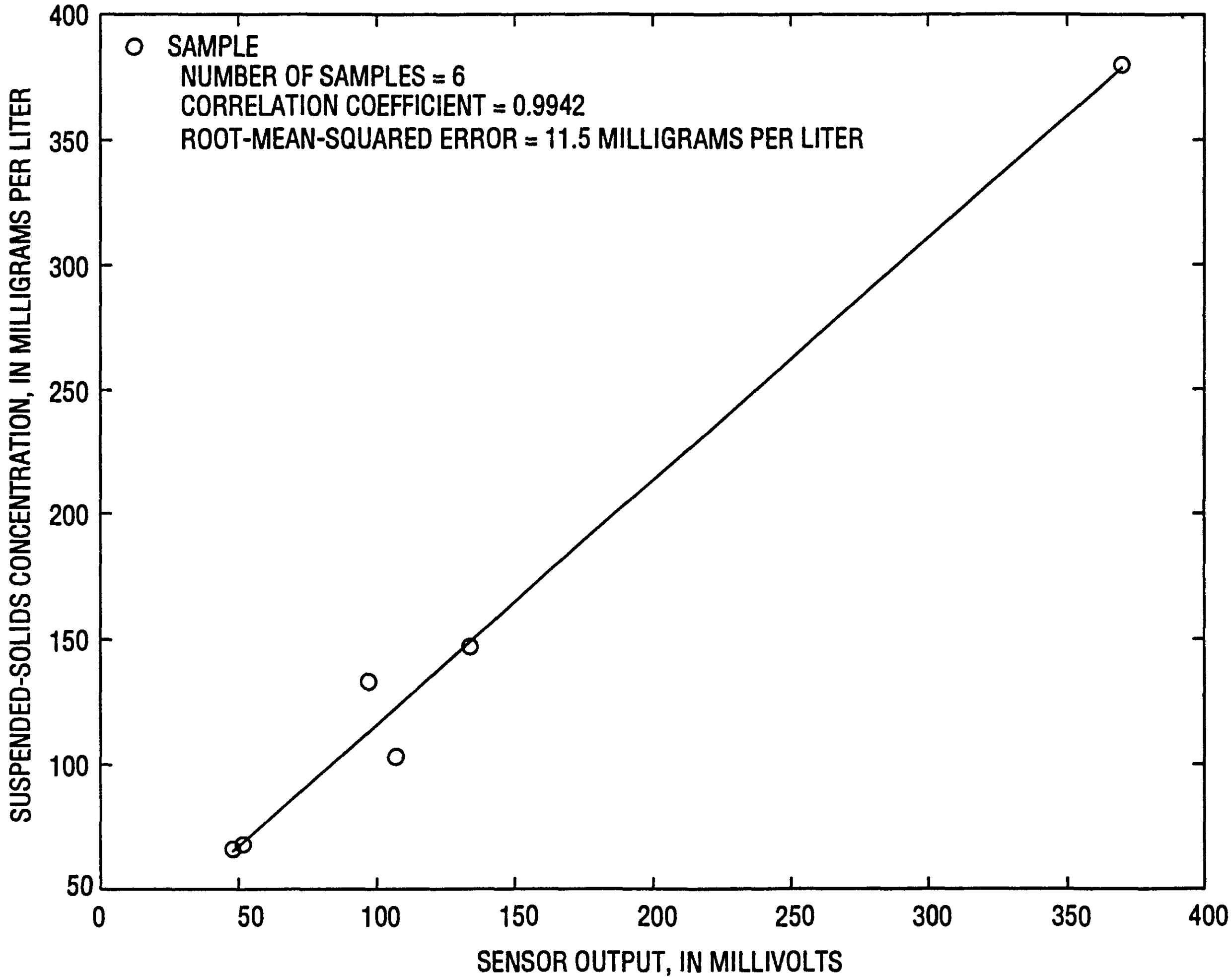

Figure 25. Calibration of near-bottom optical backscatterance sensor (with wiper) at Dumbarton Bridge, South San Francisco Bay, California, from March 17 to September 30, water year 1994.

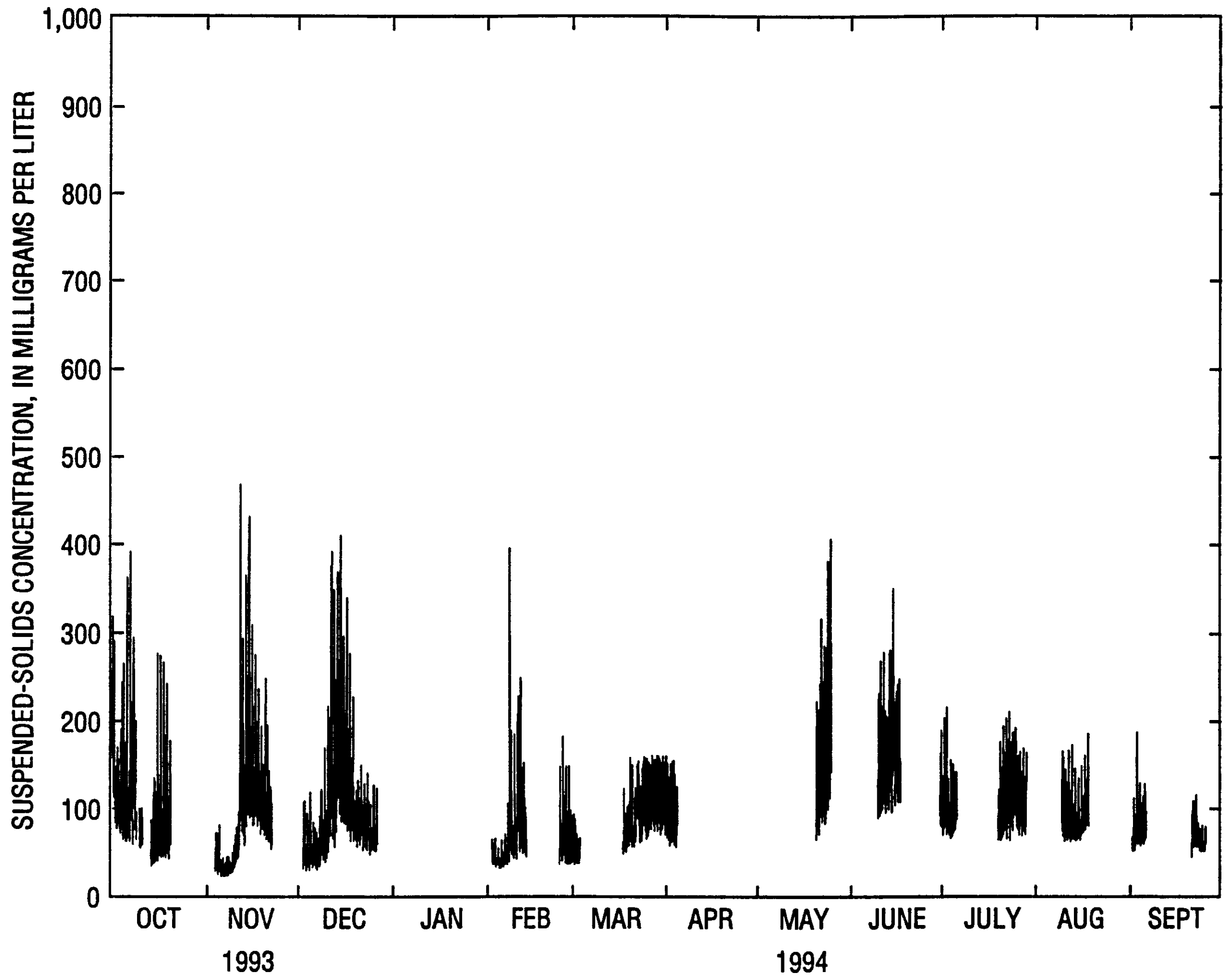

Figure 26. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 1994.

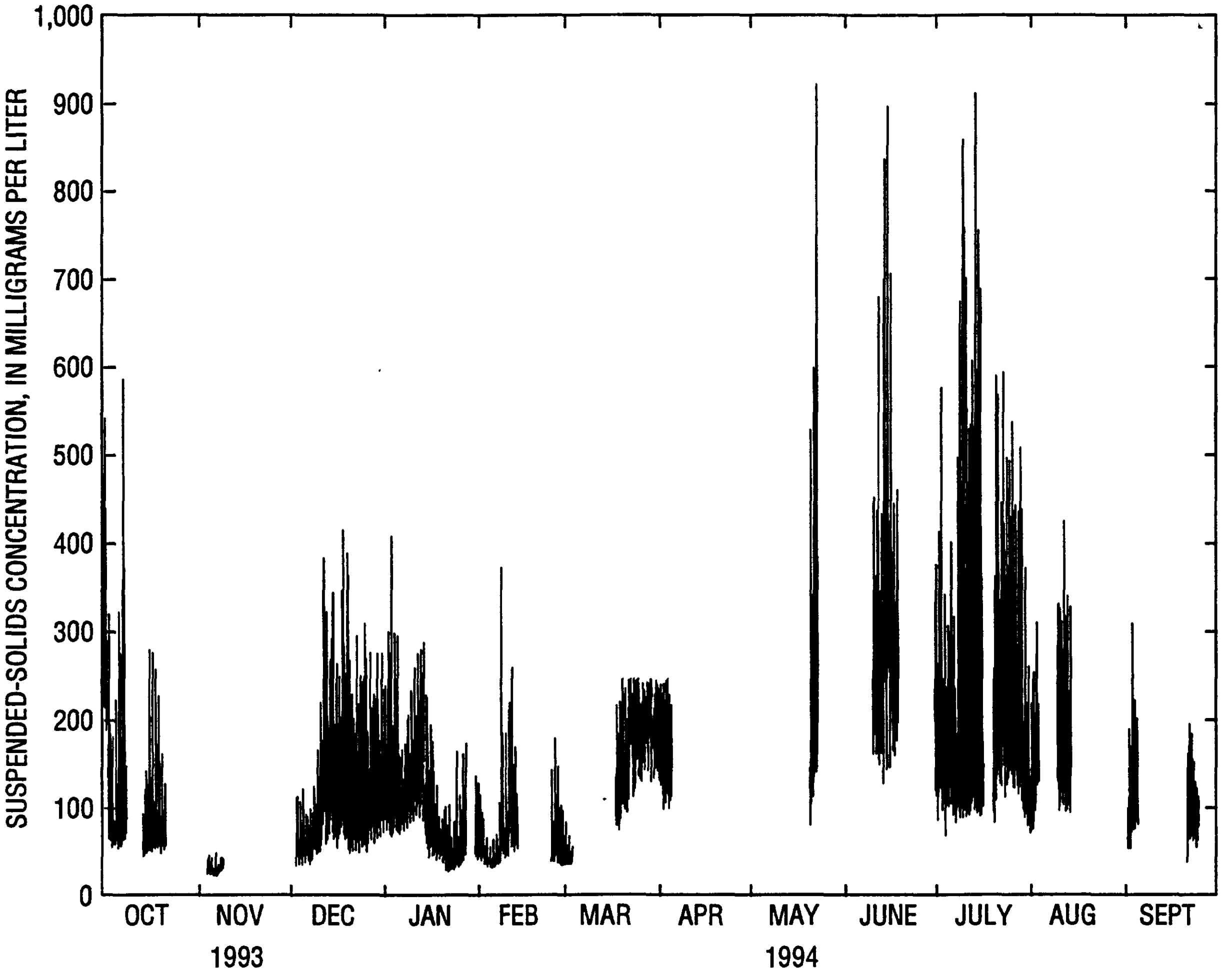

Figure 27. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 1994.

San Mateo Bridge

Calibration of the mid-depth sensor at San Mateo Bridge, in operation until January 25, 1994, had a standard error of 10.8 mg/L (fig. 28), and calibration of the wiper probe, in operation from January 25 to September 30, 1994, had a standard error of 5.69 mg/L (fig. 29). Calibration of the near-bottom sensor, in operation until January 25, 1994, had a standard error of 15.3 mg/L (fig. 30), and calibration of the near-bottom wiper probe, in operation from January 25 to September 30, 1994, had a standard error of 34.0 mg/L (fig. 31). Suspended-solids concentration data collected during water year 1994 are presented in figures 32 and 33, and a statistical summary is given in table 2. Data collected by the mid-depth sensors were 36.3 percent valid, and data collected by the near-bottom sensors were 39.1 per-cent valid. From January 25 to April 26, the maximum limit of the electronic unit was set to 100 NTU, and data in excess of 100 NTU were lost. From April 26 to July 1, 1994, the maximum limit was set to 500 NTU, and data in excess of 500 NTU were lost. On July 1, 1994, the limit was raised to 1,000 NTU. The mid-depth sensor became inoperable on July 1, 1994, and no data were collected until the unit was reinstalled on October 6, 1994.

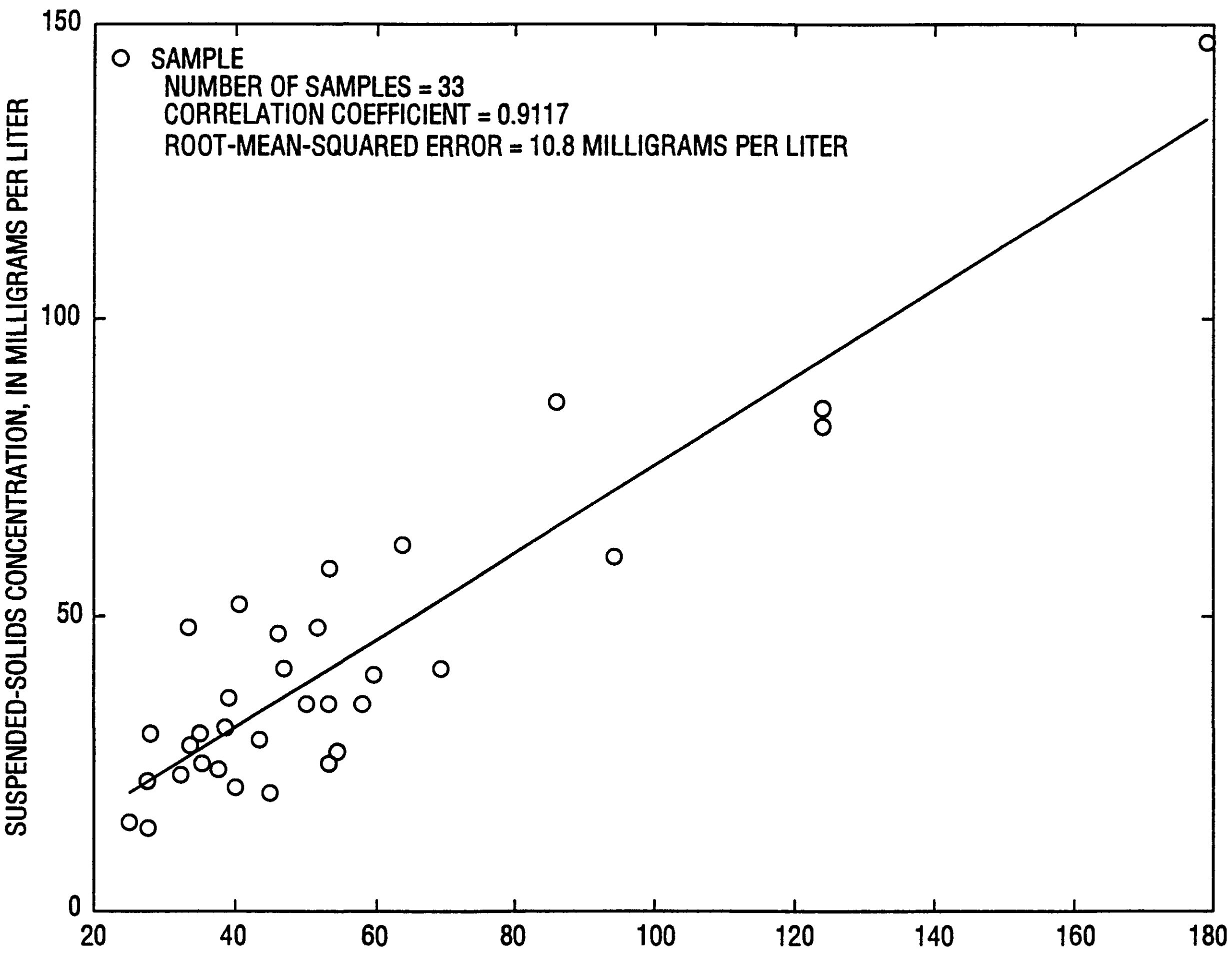

Figure 28. Calibration of mid-depth optical backscatterance sensor at San Mateo Bridge, South San Francisco Bay, California, until January 25, water year 1994.

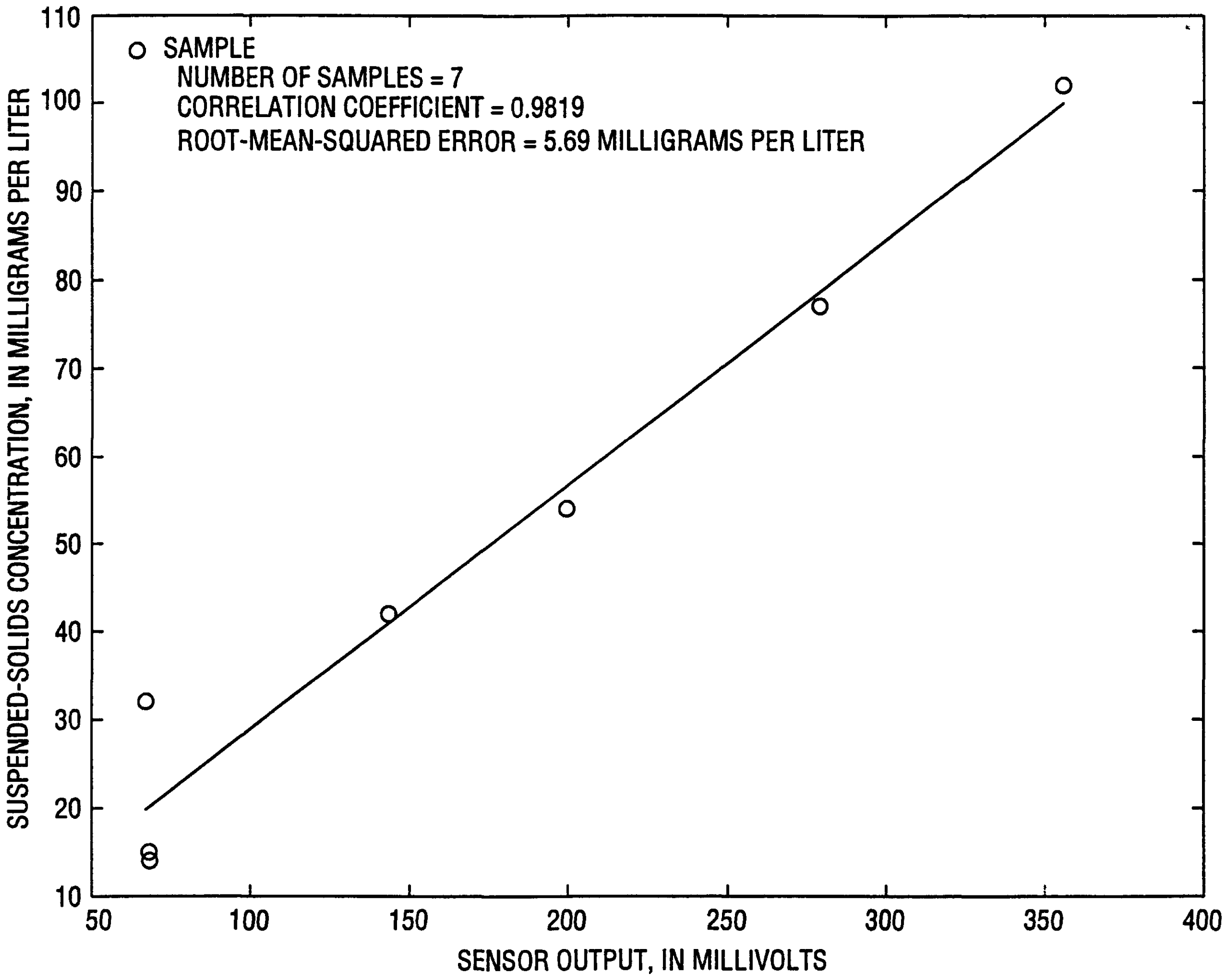

Figure 29. Calibration of mid-depth optical backscatterance sensor (with wiper) at San Mateo Bridge, South San Francisco Bay, California, after January 25, water year 1994.

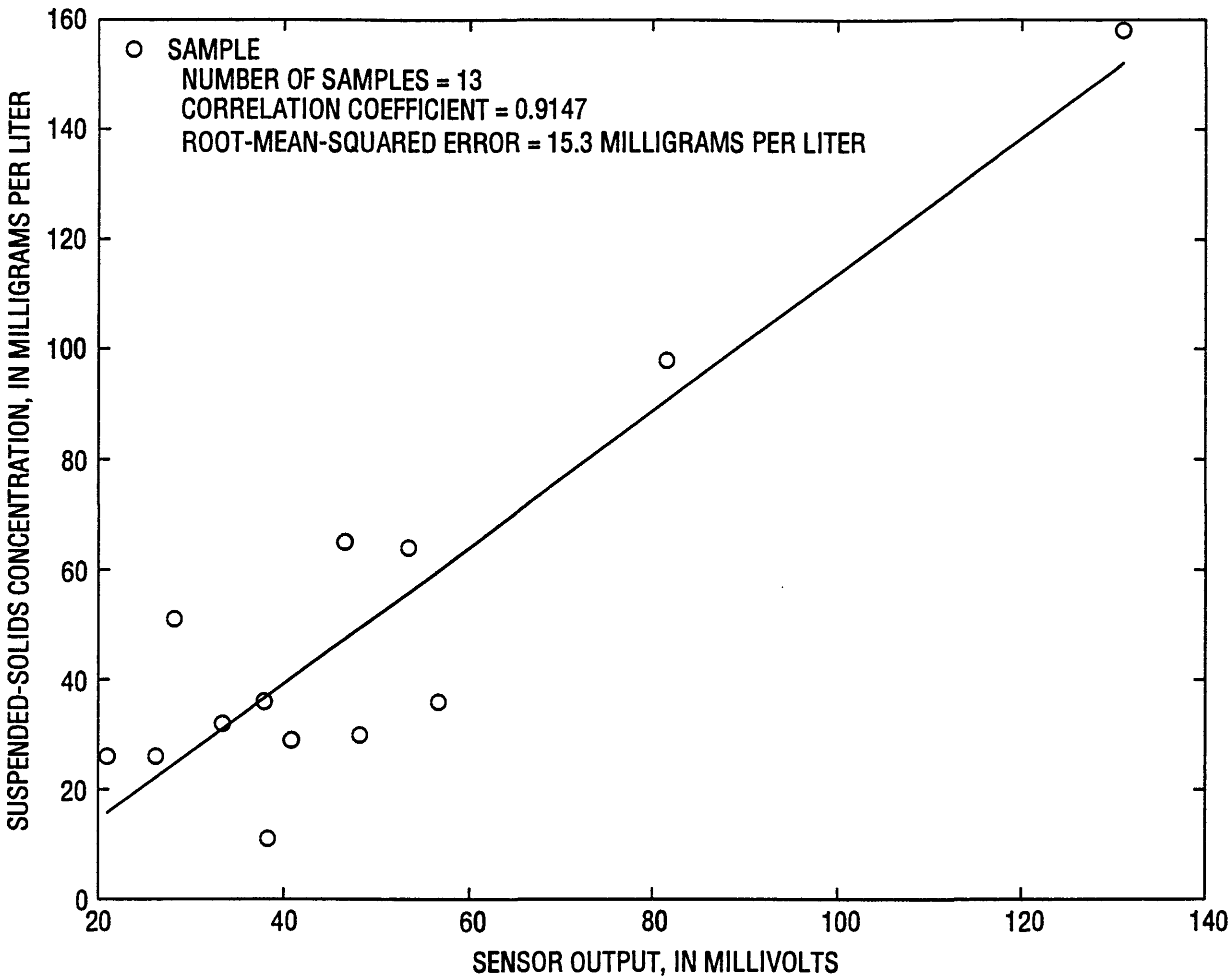

Figure 30. Calibration of near-bottom optical backscatterance sensor at San Mateo Bridge, South San Francisco Bay, California, until January 25, water year 1994.

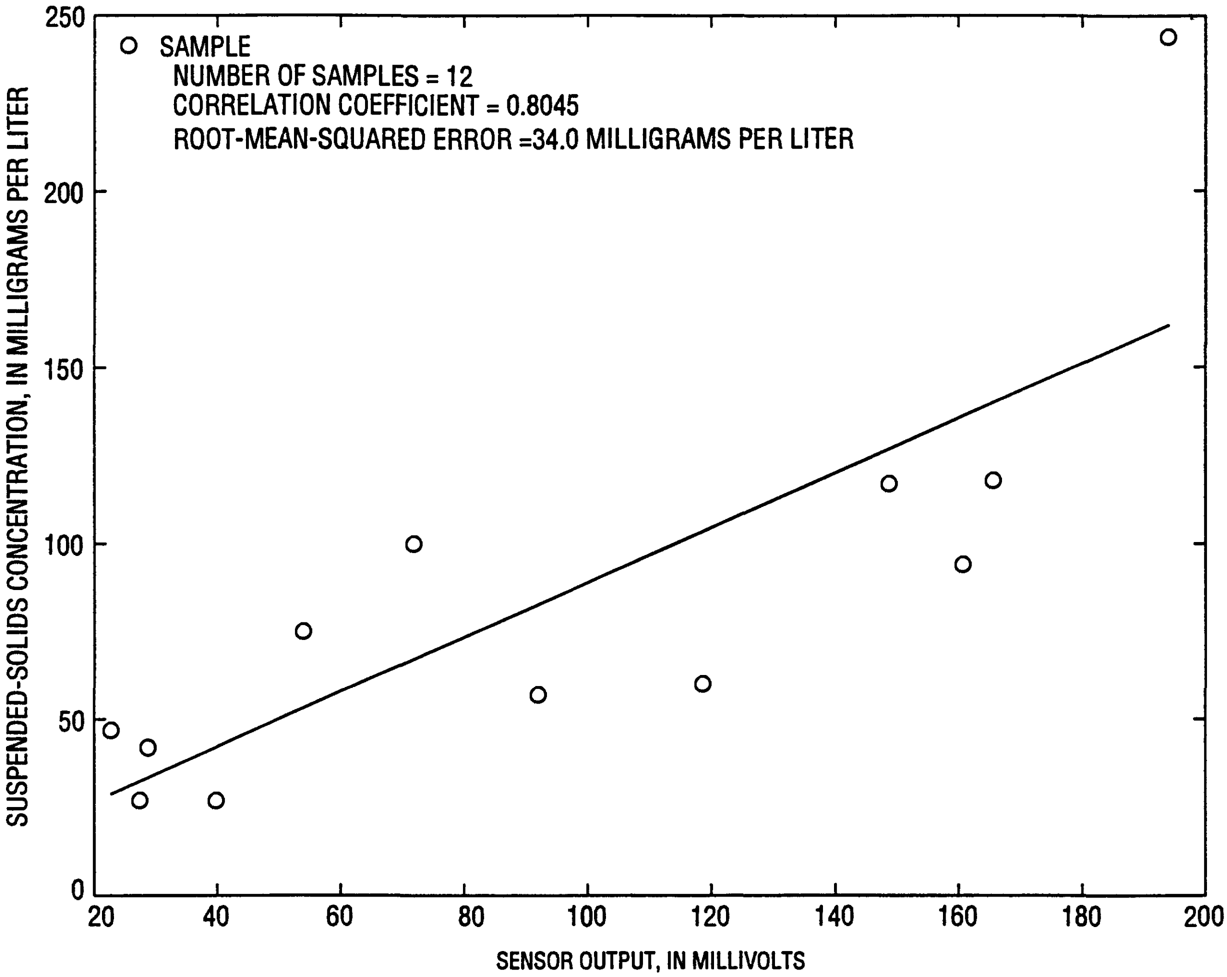

Figure 31. Calibration of near-bottom optical backscatterance sensor (with wiper) at San Mateo Bridge, South San Francisco Bay, California, after January 25, water year 1994.

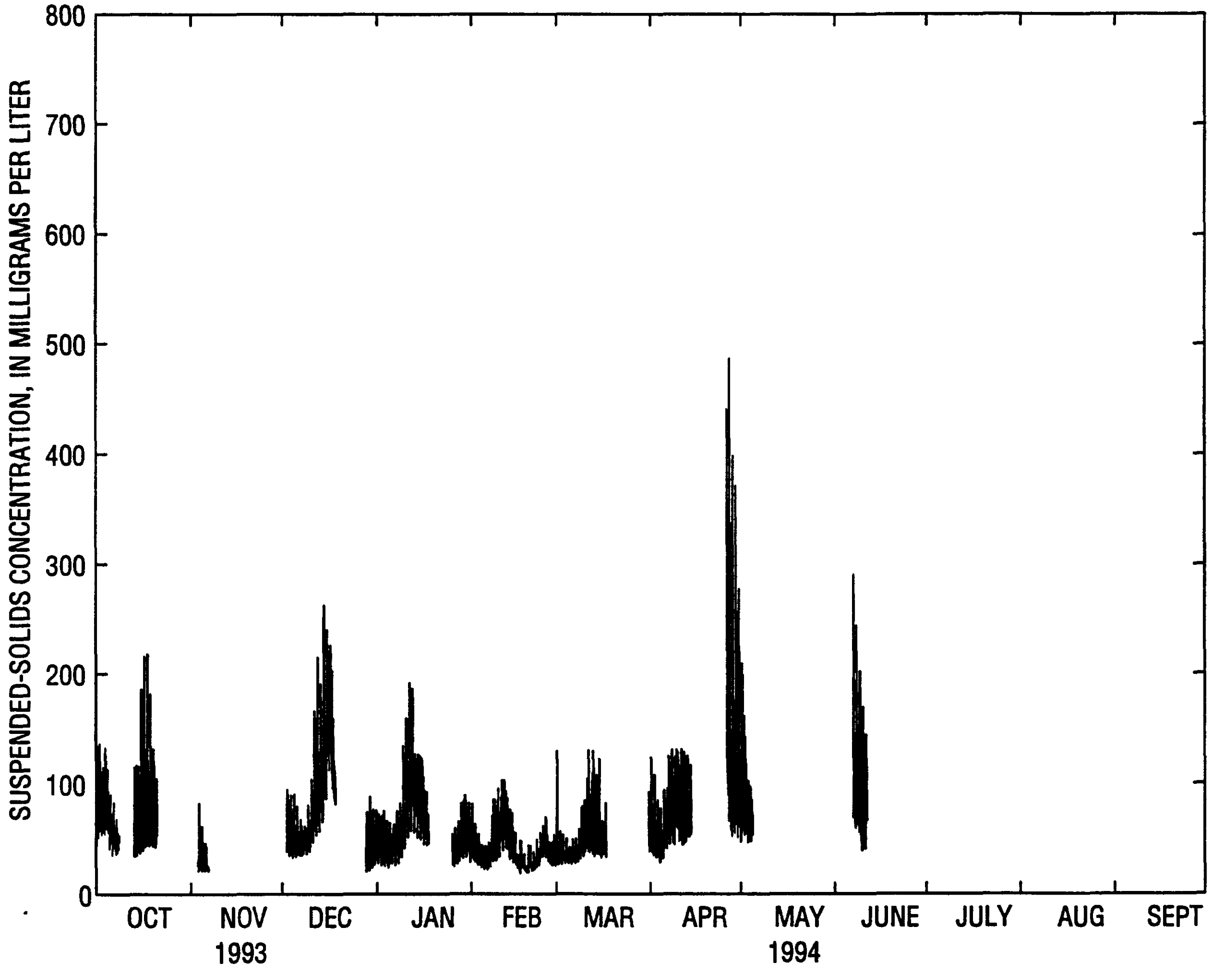

Figure 32. Time series of mid-depth suspended-solids concentration calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 1994.

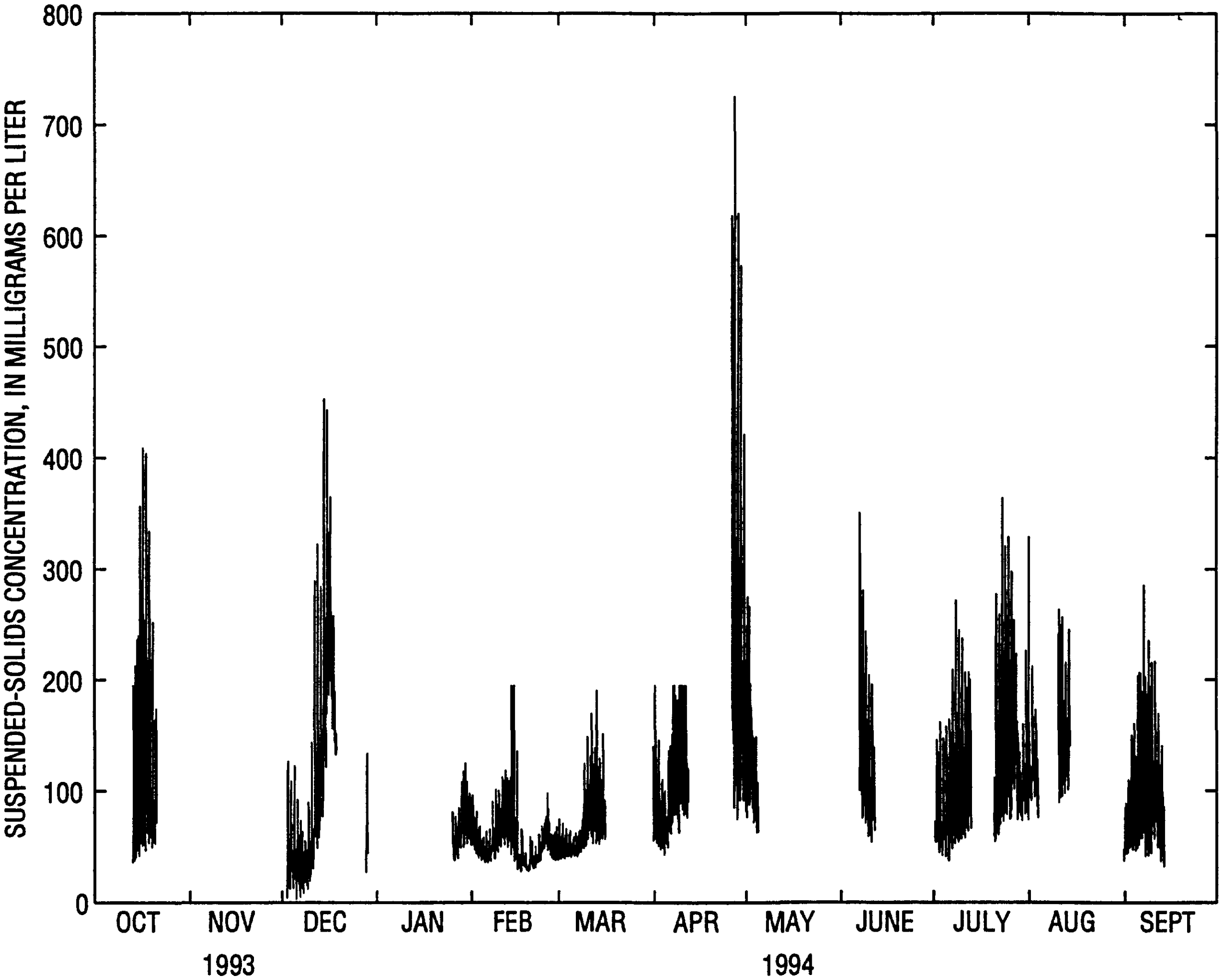

Figure 33. Time series of near-bottom suspended-solids concentration calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 1994.

November 23 to December 17, 1993

The instrument was deployed at the shallow-water site (fig. 1) in South Bay on November 23, 1993. Sensor elevations above the bay bottom are given in table 1. An attempt to service the instrument on December 8, 1993, was unsuccessful, and the instrument was recovered on December 17. Data were successfully collected from 1130 hours on November 23 to 2245 hours on December 15 when the instrument data storage was filled. The optical sensor calibration for the November deployment is presented in figure 34. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration are presented in figure 35. The sensor was slightly fouled when recovered, and a water sample collected on December 2 was used to correct the sensor output.

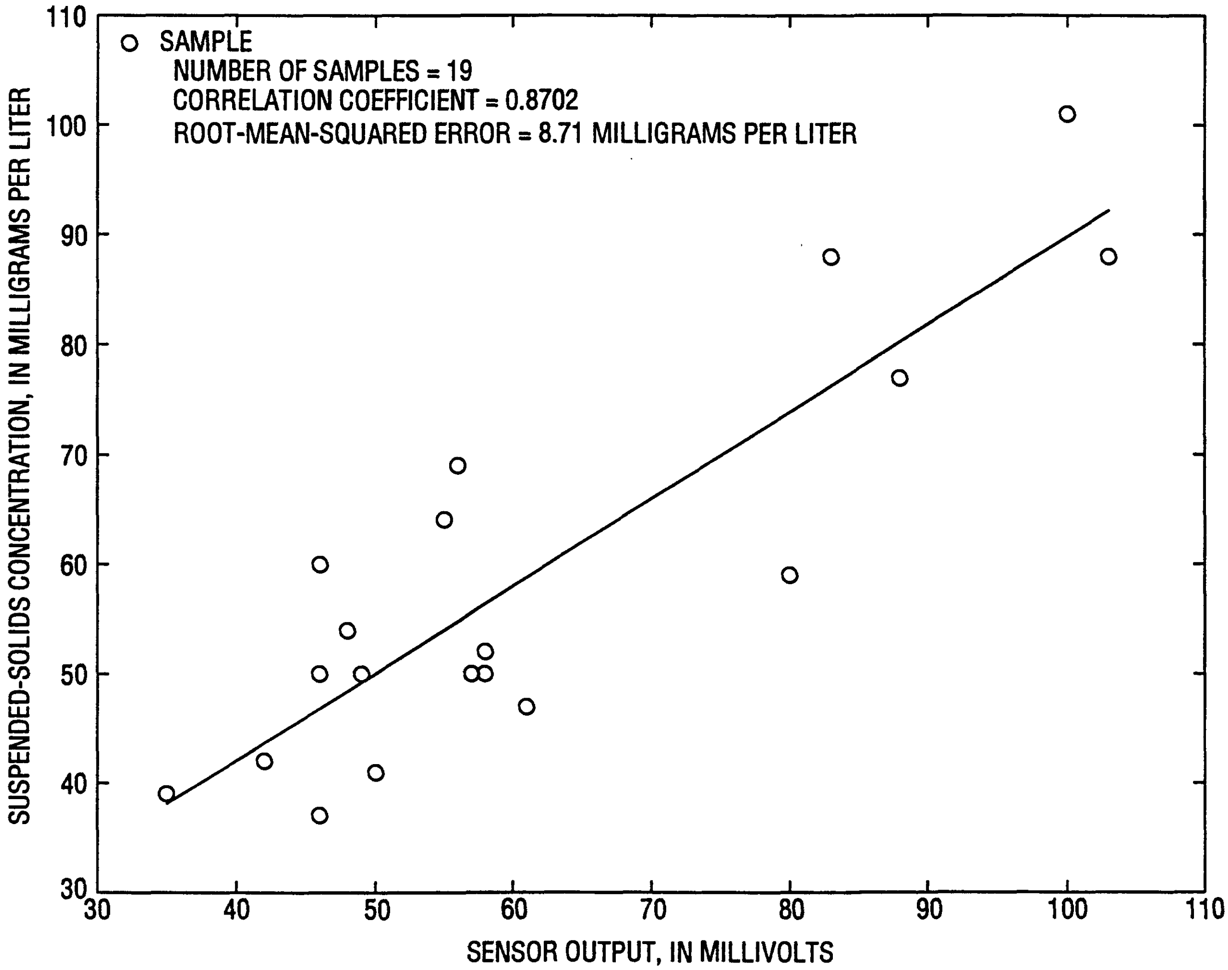

Figure 34. Calibration of optical backscatterance sensor at shallow-water site, South San Francisco Bay, California, November 23 to December 15, 1993, and March 8 to April 7, 1994.

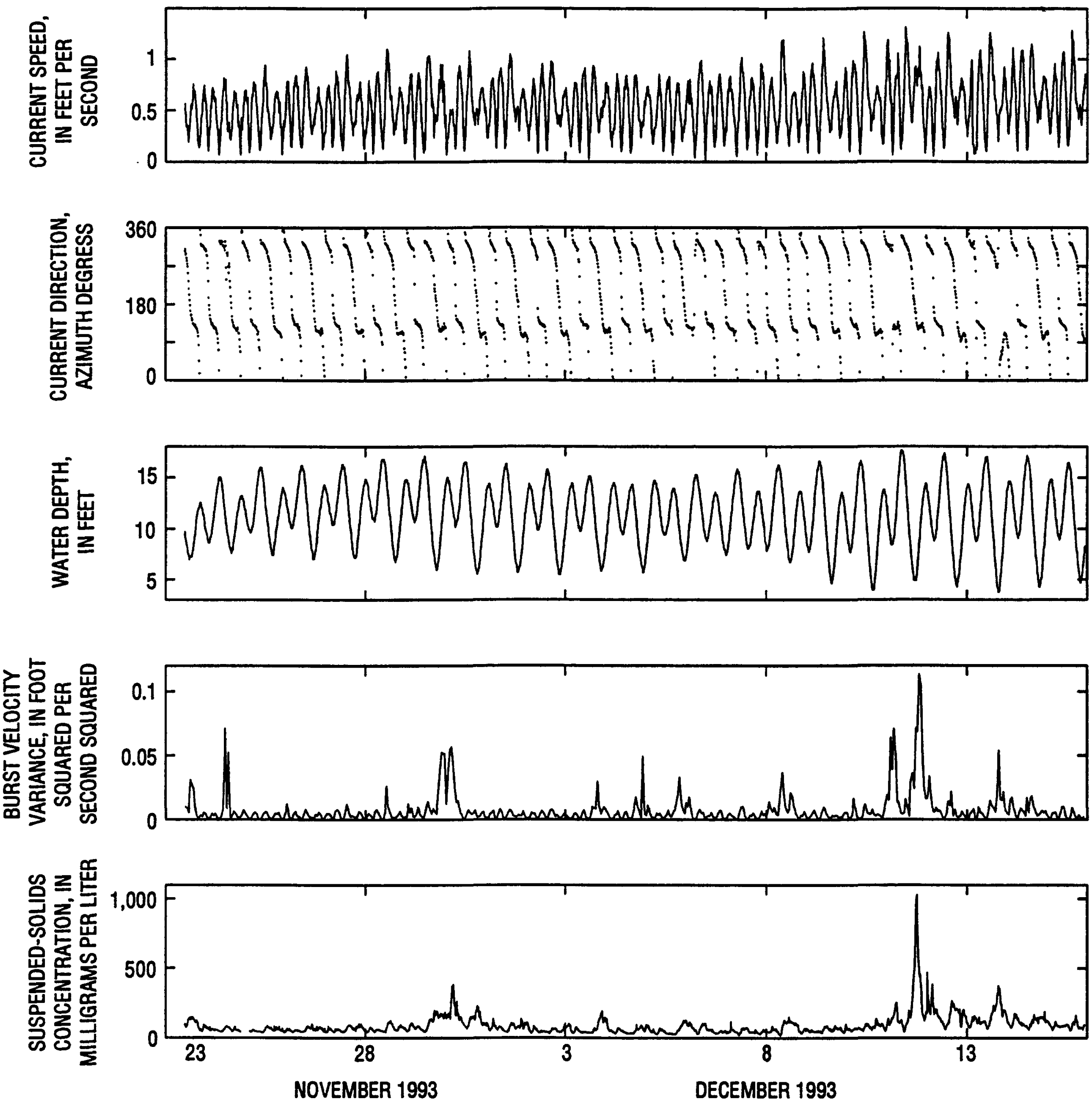

Figure 35. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration at shallow-water site, South San Francisco Bay, California, November 23 to December 15, 1993.

March 8 to April 7, 1994

The instrument was deployed on March 8, serviced on March 22, and recovered on April 7. Sensor elevations above the bay bottom are given in table 1, and calibration of the optical sensor for the March deployment is shown in figure 34. Data were successfully collected from 1045 hours on March 8 to 1045 hours on March 22. The instrument failed to operate after servicing on March 22 because of a programming error. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration are presented in figure 36.

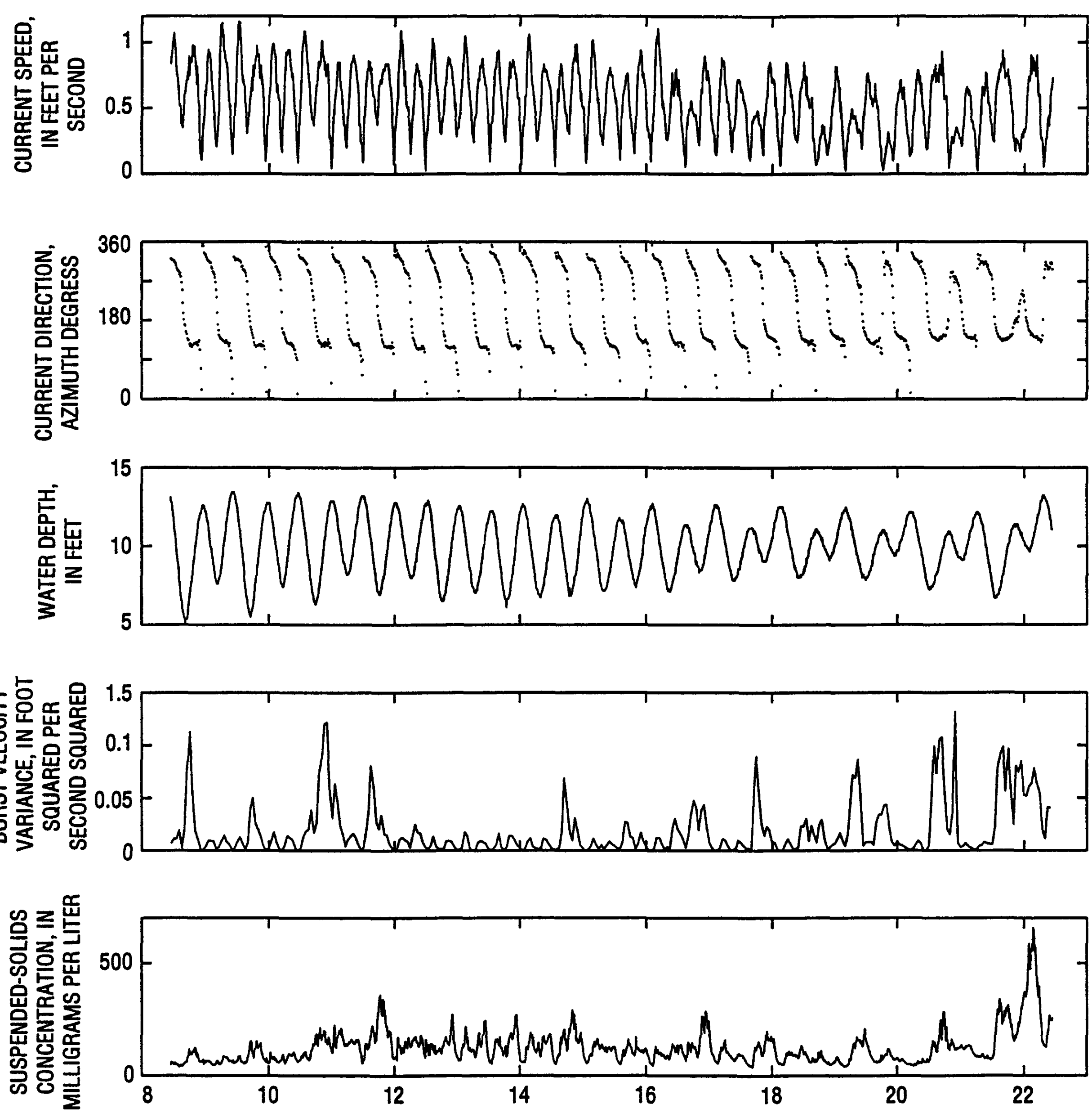

Figure 36. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration at shallow-water site, South San Francisco Bay, California, March 8 to March 22, 1994.

August 30 to October 26, 1994

The instrument was deployed on August 30, serviced on September 14 and 29, and recovered on October 26. Sensor elevations are given in table 1. The optical sensor used during previous deployments was replaced prior to this deployment. Calibration of the replacement sensor is given in figure 37. Calibration samples are available only for low concentrations, so calibration is significant only at the 93.3-percent level and may be inaccurate for higher concentrations. Data were successfully collected from 1015 hours on August 30 to 0100 hours on October 19. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration data are presented in figure 38. The optical sensor was lightly fouled when serviced on September 14 and 29 and heavily fouled when recovered on October 26.

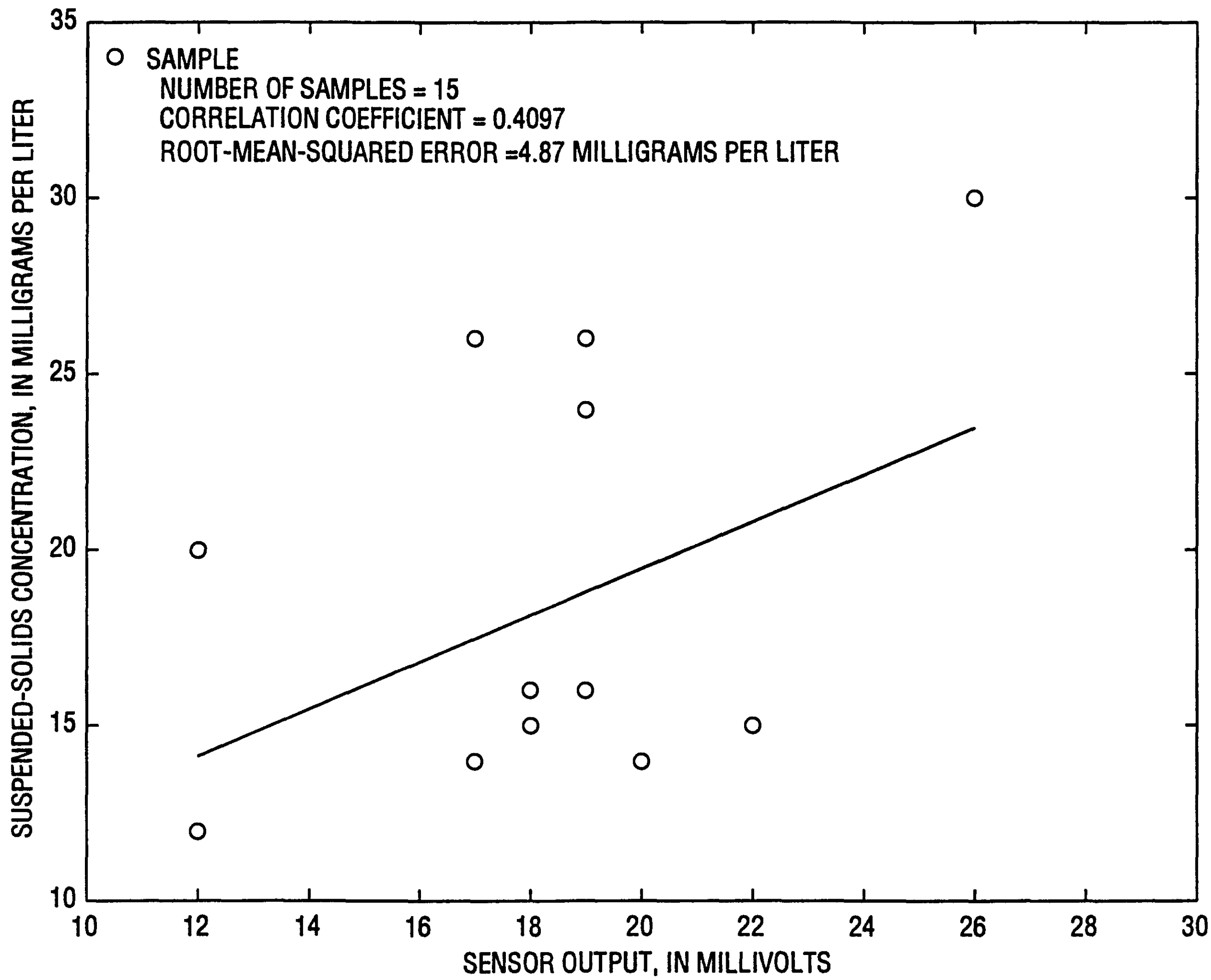

Figure 37. Calibration of optical backscatterance sensor at shallow-water site, South San Francisco Bay, California, August 30 to October 26, 1994.

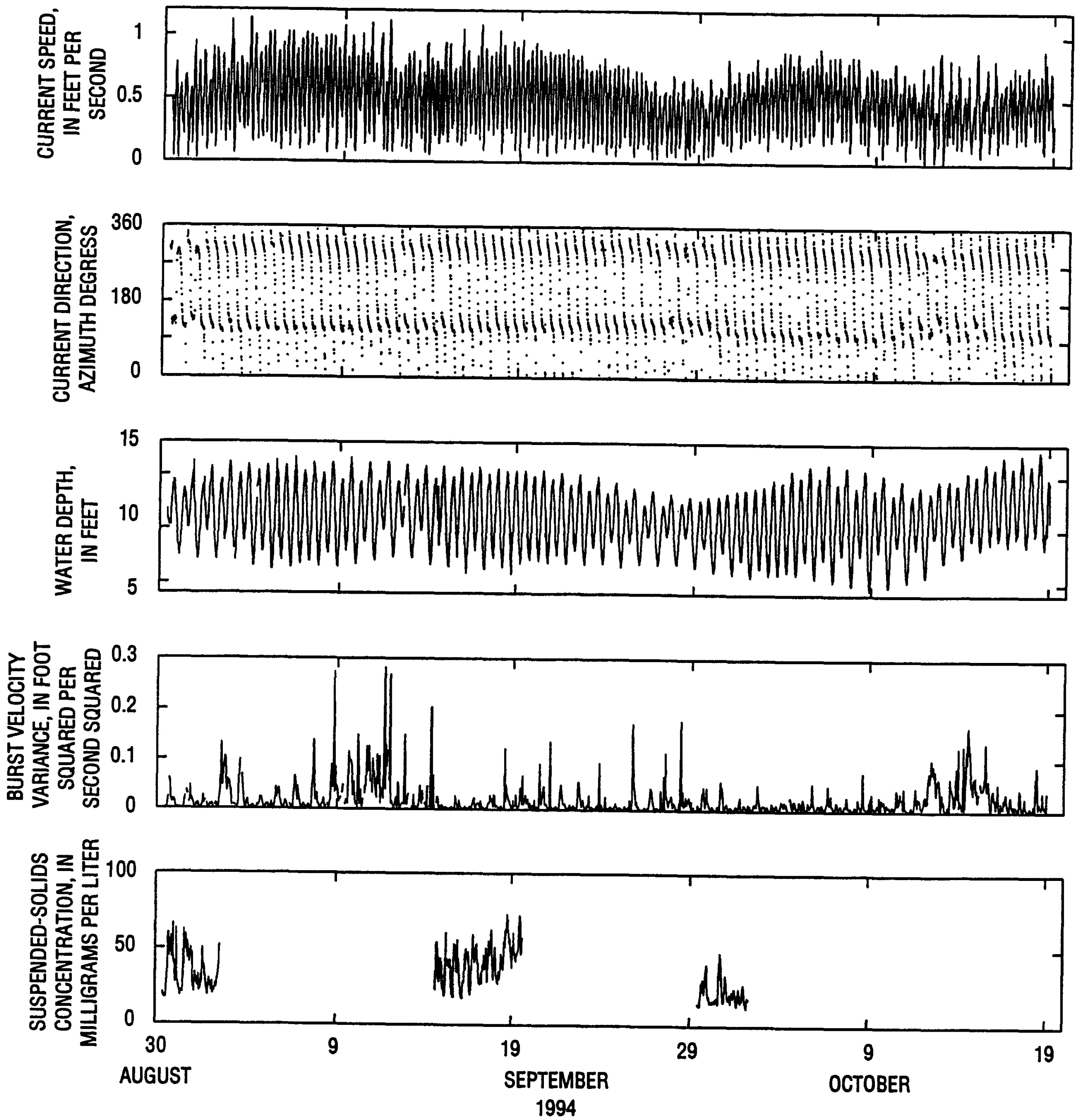

Figure 38. Current speed, current direction, water depth, burst velocity variance, and suspended-solids concentration at shallow-water site, South San Francisco Bay, California, August 30 to October 19, 1994.

SUMMARY

Suspended-solids concentration data were collected by the U.S. Geological Survey (USGS) at two sites in Suisun Bay, two sites in Central San Francisco Bay, and four sites in South San Francisco Bay during water year 1994. Two types of optical backscatterance sensors, controlled by an electronic data logger, were used to monitor suspended solids. Water samples were collected to calibrate the electrical output of the optical sensors to suspended-solids concentration, and the recorded data were recovered and edited. Biological growth can foul optical sensors, and about half the data was invalidated by fouling. Complete data are available from the files of the USGS in Sacramento, California.

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