Summary of Suspended-Solids Concentration Data, San Francisco Bay, California, Water Year 1997

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Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	.3048	meter
foot per second (ft/s)	.3048	meter per second
mile (mi)	1.609	kilometer
pound (lb)	.4536	kilogram

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

$$°F = (1.8 \times °C) + 32.$$

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.

Mean lower low water (MLLW): The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. The National Tidal Datum Epoch is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values.

Abbreviations

Ah	ampere hour
μm	micrometer
mg/L	milligram per liter
mV	millivolt
V	volt

Acronyms

AC	alternating current
ADAPS	automated data-processing system
DC	direct current
DWR	California Department of Water Resources
NOAA	National Oceanic and Atmospheric Administration
NTU	Nephelometric Turbidity Units
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 1997 (October 1, 1996–September 30, 1997). Optical backscatterance sensors and water samples were used to monitor suspended solids at two sites in Suisun Bay, three sites in Central San Francisco Bay, and three sites in South San Francisco Bay. Sensors were positioned at two depths at most sites. 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 1996 through September 1997 (water year 1997). Calibration plots and plots of edited data for each sensor also are presented.

INTRODUCTION

Sediments are an important component of the San Francisco Bay estuarine system. Bottom sediments provide the habitat for benthic organisms and are a reservoir of nutrients that contribute to the maintenance of estuarine productivity (Hammond and others, 1985). Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993; Flegal and others, 1996). Benthic organisms can ingest these substances and introduce them into the food web (Luoma and others, 1985; Brown and Luoma, 1995; Luoma, 1996).

The transport and fate of suspended sediments are important factors in determining the transport and fate of constituents adsorbed on the sediments. In Suisun Bay, the maximum concentration of suspended sediment usually marks the position of the turbidity maximum, which is a crucial ecological region in which suspended sediments, nutrients, phytoplankton, zooplankton, larvae, and juvenile fish accumulate (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994; Schoellhamer and Burau, 1998).

Suspended sediments limit the availability of light in the bay, which, in turn, limits photosynthesis and primary phytosynthetic carbon production (Cole and Cloern, 1987; Cloern, 1987, 1996). Suspended sediments also deposit in ports and shipping channels, which then 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 and the U.S. Army Corps of Engineers, 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 during water year 1997 (October 1, 1996–September 30, 1997). Suspended-solids concentrations were monitored at two sites in Suisun Bay, three sites in Central San Francisco Bay, and three sites in South San Francisco Bay.

This report is the latest in a series summarizing suspended-solids concentration data collected in San Francisco Bay, which began in water year 1992 (Buchanan and Schoellhamer, 1995, 1996, 1998; Buchanan and others, 1996). These data have been used by Tobin and others (1995) to study suspended-solids flux at Mallard Island in Suisun Bay; by Schoellhamer (1996) to study the factors that affect suspended-solids concentration in South San Francisco Bay; by Lacy and others (1996) to study suspended-solids flux in South San Francisco Bay; by Schoellhamer (1997) to estimate the temporal variation of trace elements; by Jennings and others (1997) to determine an optimum sampling strategy for sediment-associated pesticides in Suisun Bay; by Schoellhamer and Burau (1998); and in a study by Ruhl and Schoellhamer (USGS, oral commun., 1999) to compare suspended-solids concentrations in the shallow waters of Suisun Bay and at Mallard Island; and by Oltmann and others (1999) to study sediment inflow from the Sacramento-San Joaquin River Delta to Suisun Bay at Mallard Island. Suspended-solids concentration data for water year 1997 are available from the files of the USGS in Sacramento, California.

Study Area

San Francisco Bay (fig. 1) is comprised of several major subembayments; Suisun Bay, San Pablo Bay, Central San Francisco Bay (Central Bay), and South San Francisco Bay (South Bay). In San Francisco Bay, tides are semidiurnal (two high and two low tides per day) with a range from about 5.5 feet (ft) in Suisun Bay, to 6.5 ft at the Golden Gate and Central Bay, to about 10 ft in South Bay. The tides also have a 14-day spring-neap cycle. Typical tidal currents range from 0.6 feet per second (ft/s) in shallow water to more than 3 ft/s in deep channels (Smith, 1987). Winds typically are strongest during the summer when there is an afternoon onshore sea breeze. Most precipitation occurs from late autumn to early spring, and freshwater discharge into the bay is greatest in the spring as a result of 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).

Discharge from the delta contains 83–86 percent of the fluvial sediments that enter the bay (Porterfield, 1980). During wet winters, turbid plumes of water from the delta have extended into South Bay (Carlson and McCulloch, 1974). The bottom sediments in South Bay and in the shallow water (about 12 ft or less) of Central, San Pablo, and Suisun Bays are composed mostly of silts and clays. Silts and sands are present in the deeper parts of Central, San Pablo, and Suisun Bays and in Carquinez Strait (Conomos and Peterson, 1977). Large tidal velocities, spring tides, and wind waves in shallow water all are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 1996).

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, the PakTank Corporation, and the Golden Gate Bridge, Highway and Transportation District, for their permission and assistance in establishing the monitoring sites used in this study.

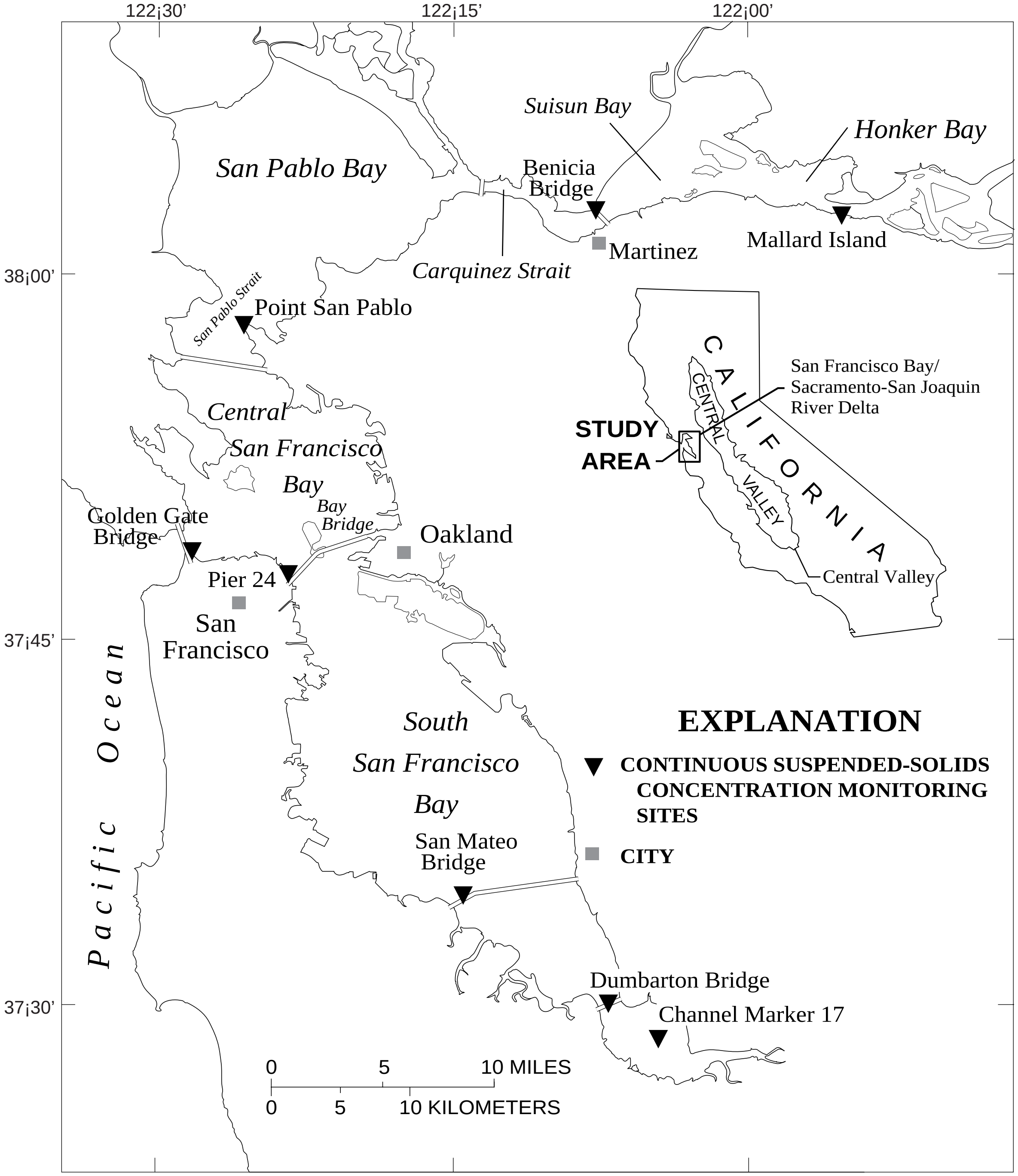

Figure 1. San Francisco Bay study area, California.

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). A high-intensity infrared emitting diode produces a beam through the optical window, which is scattered or reflected by particles that are about 0.2–12 in. in front of the window. A detector (four photodiodes) receives backscatter from 140–165° (D & A Instrument Company, 1991). 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 at the depth of the sensor. Calibration of the sensor voltage output to concentrations of suspended solids will vary according to the size and optical properties of the suspended solids; therefore, the sensors must be calibrated either in the field or a laboratory using suspended material from 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 then average and store the output voltage for that 1-minute period. Power was supplied by 12-volt (V) direct current (DC) 12-ampere hour (Ah) gel-cell batteries.

Biological growth interferes with the collection of accurate optical backscatterance data. Self-cleaning optical sensors with wipers were deployed at four sites during water year 1994 to help alleviate the problem of fouling. The self-cleaning probes are similar in size and function to the other optical sensors that were used in the study, but each self-cleaning probe has a separate electronics unit that sets the resolution and maximum reading, which is expressed in Nephelometric Turbidity Units (NTU). The voltage output from the electronics unit is proportional to the concentration of suspended solids in the water column at the depth of the sensor. Suspended-solids concentrations, calculated from the output of side-by-side sensors with and without the self-cleaning function, are virtually identical (Buchanan and Schoellhamer, 1998, fig. 4). Because the self-cleaning sensor requires 95-130-V alternating current (AC), installation was limited to sites with AC power. The self-cleaning probes and electronic units were installed at two sites in Suisun Bay and at two sites in South Bay. Fouling in Suisun Bay was minor compared with that in South Bay, and the self-cleaning probes were effective in keeping the optical ports clean (about 70 percent data recovery during water year 1996). However, fouling at the two sites in South Bay during the summer was so extreme that the self-cleaning probes often were rendered ineffective by biological growth on the carriage and wiper mechanism (about 35 percent data recovery during water year 1995). During water year 1995, all self-cleaning probes deployed in South Bay failed because of salt crystals forming on an O-ring, resulting in water leakage into the units. To address the leakage problem, the design was modified by the manufacturer. In water year 1996, an updated version of the self-cleaning probe was deployed at the Dumbarton Bridge site in South Bay but failed within the first month of operation. Thereafter, the self-cleaning probes only were used at the less saline Mallard Island site in Suisun Bay.

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 1-5 (usually 3) weeks. Overall, about 40 percent of the collected data were invalidated by fouling. Fouling generally was greatest on the sensor closest to the water surface. However, at shallower sites (mean lower low water depth less than 30 feet) 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.

On-site checks of sensor accuracy were performed using a 100-NTU turbidity solution prepared from a 4,000-NTU formazin standard. Formazin is an aqueous suspension of an insoluble polymer and is specified as the primary turbidity standard by the American Society for Testing and Materials. The 100-NTU solution is prepared by diluting a 4,000-NTU stock standard with high-purity water in a clean, white, sealable bucket. At the field site, the cleaned sensors are immersed in the standard and the voltage output is recorded on the station log. Monitoring sensor performance in a known standard during a period of time aids in identifying output drift or sensor malfunction.

Suisun Bay Installations

Suspended-solids concentration data were collected at two sites in Suisun Bay; Mallard Island and Carquinez Strait at Benicia Bridge (fig. 1). Monitoring equipment was installed at the Mallard Island site during water year 1994, and the Benicia Bridge site was established during water year 1996. The monitoring site at the Martinez Marina fishing pier was discontinued in water year 1996 because the data from the Benicia Bridge were considered more representative of suspended-solids concentration in the Carquinez Strait area of Suisun Bay (Buchanan and Schoellhamer, 1998).

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 miles (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 Company property, and water-quality data were first recorded at the station in January 1984. A 1/4-mi wooden walkway crosses the sometimes submerged reedbeds of Mallard Island and connects the concrete block instrument shelter 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 the near-surface pump intake. The pump intake is attached to a float that is housed inside a 12-in. PVC pipe and the intake draws water from about 3 ft below the surface. DWR near-surface parameters are measured by sensors that are submerged in flow-through chambers inside the instrument shelter. This configuration saves the cost of installing duplicate sets of sensors and enables the USGS to use DWR data for parameters other than turbidity, such as stage, pH, chlorophyll concentration, and meteorology. 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 operates both optical sensors and charges a 12-V, 12-Ah battery that powers the data logger and modem. The data logger and peripheral equipment are housed in the instrument shelter. The sensors are suspended from a galvanized support stand that is attached to metal railing on the station’s northwest concrete deck. The support stand has two stainless-steel lines attached to separate concrete weights; one line for the near-bottom sensor and one line for the near-surface sensor. The near-bottom sensor is attached to a PVC carriage suspended on the stainless-steel line by a nylon rope at the specified depth. The near-surface sensor is attached to a PVC carriage that is built onto 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.

Benicia Bridge

Suspended-solids concentration monitoring equipment was installed March 15, 1996, at the Benicia Bridge (lat. 38°02’42”, long. 122°07’32”). This site is located on Pier 7 of the Benicia Bridge, north of the main ship channel (fig. 1). The National Oceanic and Atmospheric Administration (NOAA) operates salinity sensors and an acoustic Doppler current profiler near this site. Optical sensors without the self-cleaning function were deployed at near-bottom and near-surface (25 ft and 74 ft above the bottom) to coincide with the elevations of the NOAA sensors. The average mean lower low water depths near the pier are about 60 ft; however, the depths immediately surrounding the pier are about 20 ft greater. The near-bottom sensor was set 25 ft above the bottom to collect data representative of the average mean lower low water depth. The sensors are suspended between the concrete pier superstructure and the fender boards, which are approximately 1 ft apart. PVC carriages attached to 1/4-in. stainless-steel line are anchored to a 125-pound (lb) weight and are used to suspend the sensors at the desired depth. AC power charges a 12-V, 12-Ah battery that powers the data logger and sensors. The data logger and peripheral equipment are housed in a 3×2×1-ft plastic weather-proof shelter mounted on the pier.

Central San Francisco Bay Installations

Suspended-solids concentration data were collected at three sites in Central Bay during water year 1997; Point San Pablo, Pier 24, and the south tower of the Golden Gate Bridge (fig. 1).

Point San Pablo

The USGS maintains a monitoring site 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 site from the DWR in October 1989. 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. Sensor timing and storage are controlled by a data logger. A separate data logger that is connected to a phone line and modem controls the collection of specific conductance and temperature data (cooperatively funded by DWR and the USGS) and water levels. Specific conductance and temperature data are collected at near-bottom and near-surface points in the water column (near-bottom and near-surface depths are sampled to define the largest stratification). Water level is recorded using a float-driven, incremental encoder that is wired into the data logger, and outside water levels are read during site visits using a wire-weight gage. AC power charges a 12-V, 60-Ah battery that powers the data loggers and sensors. The data loggers and peripheral equipment are housed in a 5×8×8-ft wooden shelter.

Pier 24

The monitoring site at Pier 24 is on the western end of the San Francisco-Oakland Bay Bridge (lat. 37°47’27”, long. 122°23’05”) (fig. 1). 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, specific-conductance and temperature data (cooperatively funded by DWR and the USGS) are collected at near-bottom and near-surface points in the water column. Sensor timing and storage are controlled by a data logger connected to a cellular phone and modem. AC power charges two 12-V, 12-Ah batteries that power the instrumentation. The data logger and peripheral equipment are housed in a corrugated steel shelter.

Golden Gate Bridge

The monitoring site on the Golden Gate Bridge is located on the north side of the south tower fender wall (lat. 37°49'06", long. 122° 28'18") (fig. 1). The south tower is 1,125 ft from the San Francisco shore and marks the southern edge of the main channel. The site was established on October 27, 1994, but was not operational until water year 1996 because of numerous complications.

The optical sensors originally were deployed at two points in the water column (5 ft and 45 ft above the bottom). However, the near-bottom sensor cables were destroyed several times, probably by the remains of forming material used in the construction of the pier footing that jutted out into the water column and snagged the cables. Beginning in water year 1996, the optical sensor was deployed at the mid-depth position only. Mean lower low water depth at this site is about 75 ft and increases to a maximum depth of 378 ft in the main channel. Sensors were suspended in place using PVC carriages and 3/8-in. stainless-steel line attached to a 600-lb railroad wheel. A data logger and modem are used to control sensor timing, data storage, and retrieval. Instruments are powered by a 12-V, 60-Ah battery with an AC/DC charger and regulator. In addition to suspended-solids concentrations, specific conductance and temperature (cooperatively funded by DWR and the USGS) are monitored at near-surface depth. The data logger and peripheral equipment are housed in a 6×6×8-ft fiberglass shelter on the pier footing.

South San Francisco Bay Installations

Suspended-solids concentration data were collected at three sites in South Bay (fig. 1). Monitoring sites were installed during water year 1992 at two sites in South Bay: Channel Marker 17 and San Mateo Bridge. The Dumbarton Bridge site was installed during water year 1993.

Channel Marker 17

The southernmost monitoring site in South Bay is at the 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). Mean lower low water depth at this site is about 25 ft. Sensor cables were protected by a 10-ft PVC pipe strapped to the channel marker support column until the PVC pipe began causing abrasions on the sensor cables. On February 20, 1997, the strapping was removed from the channel marker support column and the sensor cables, which were still protected by the length of PVC, hung freely from the channel marker platform. Sensor cables, carriages, and probes are suspended in the water column with a 100-lb weight attached to a 1/4-in. Kevlar-reinforced nylon line. The data logger and 12-V, 12-Ah batteries are housed in a 2×2×1-ft plastic weather-proof shelter mounted on the channel marker platform.

Dumbarton Bridge

Suspended-solids concentration monitoring equipment was installed on 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") (fig. 1). Optical sensors were deployed at near-bottom and mid-depth (4 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 its surrounding protective fender boards, a space approximately 3 ft wide. PVC carriages attached to 1/4-in. Kevlar-reinforced nylon line are anchored to a 100-lb weight and suspend the sensors at the desired depth. AC power charges a 12-V, 12-Ah battery that powers the instrumentation. The data logger and peripheral equipment are housed in a 3×2×1-ft plastic weather-proof shelter mounted on the pier.

San Mateo Bridge

The monitoring site 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”) (fig. 1). This station originally was operated by DWR, but the USGS took over operations in October 1989. Data collected prior to October 1, 1989, can be obtained from DWR.

The optical sensors were installed on December 23, 1991, and were positioned at near-bottom and mid-depth (8 ft and 29 ft above the bottom). Mean lower low water depth at this site is about 48 ft. The data loggers and peripheral equipment are housed in an 8×6×8-ft 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 data logger is used to control sensor timing, data storage, and retrieval. In addition to suspended-solids concentrations, specific conductance and temperature (cooperatively funded by DWR and the USGS), which are controlled by a separate data logger and modem, are monitored at near-bottom and near-surface depths. AC power charges a 12-V, 60-Ah battery that powers the data loggers and sensors.

Water-Sample Collection

Water samples, used to calibrate optical sensors, were collected using a horizontally positioned Van Dorn sampler before and after the sensors were cleaned. The Van Dorn sampler is a plastic tube with rubber stoppers at each end that snap shut when triggered by a small weight dropped down a suspension cable. The Van Dorn sampler was lowered to the depth of the sensor by a reel and crane assembly and triggered while the sensor was collecting data. Then, the water sample was removed from the sampler, marked for identification, and placed in a cooler and chilled to limit biological growth. The suspended-solids concentration of water samples collected with a Van Dorn sampler and a P-72 point sampler, used until water year 1994, were compared and found to be virtually identical (Buchanan and others, 1996, fig. 2).

An auto-sampler was used during water year 1997 to help calibrate the near-bottom sensor at Dumbarton Bridge. The auto-sampler is a programmable peristaltic pump with 1/4-in. plastic tubing capable of collecting 24 separate samples. The auto-sampler tubing was deployed at the depth of the sensor by strapping the tubing to the sensor cables. The auto-sampler was programed to collect samples hourly while the sensor was collecting data.

Samples were sent to the USGS Sediment Laboratory in Salinas, California, for analysis to determine suspended-solids concentration. Suspended solids include all particles in the sample; the suspended sediment (material that settles to the bottom of the sample bottle), and buoyant particles that do not settle. Each sample was filtered through a 0.45-micrometer membrane filter, the filter was rinsed to remove salts, and the insoluble material was dried at 103°C and weighed (Fishman and Friedman, 1989). The difference between suspended-solids concentration and suspended-sediment concentration for San Francisco Bay water probably is small.

Data Processing

Data loggers stored the voltage outputs from the optical sensors at 15-minute intervals. Recorded data were downloaded from the data logger onto a storage module during site visits. Raw data from the storage modules were loaded into the USGS automated data-processing system (ADAPS).

The time-series data were retrieved from ADAPS and edited using MATLAB software to remove invalid data. Invalid data included rapidly increasing voltage outputs and unusually high voltage outputs of short duration. As biological growth accumulated on the optical sensors, the voltage output of the sensors increased. An example time series of raw and edited optical backscatterance data from water year 1994 is presented in figure 2. After the sensors were cleaned, sensor output immediately decreased (fig. 2; 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. 2). Spikes in the data, which are anomalously high voltages probably caused by debris temporarily wrapped around the sensor or by large marine organisms (fish, crabs) on or near the sensor, also were removed from the raw data record (fig. 2). Sometimes, incomplete cleaning of a sensor would cause a small constant shift in sensor output that could be corrected using water-sample data.

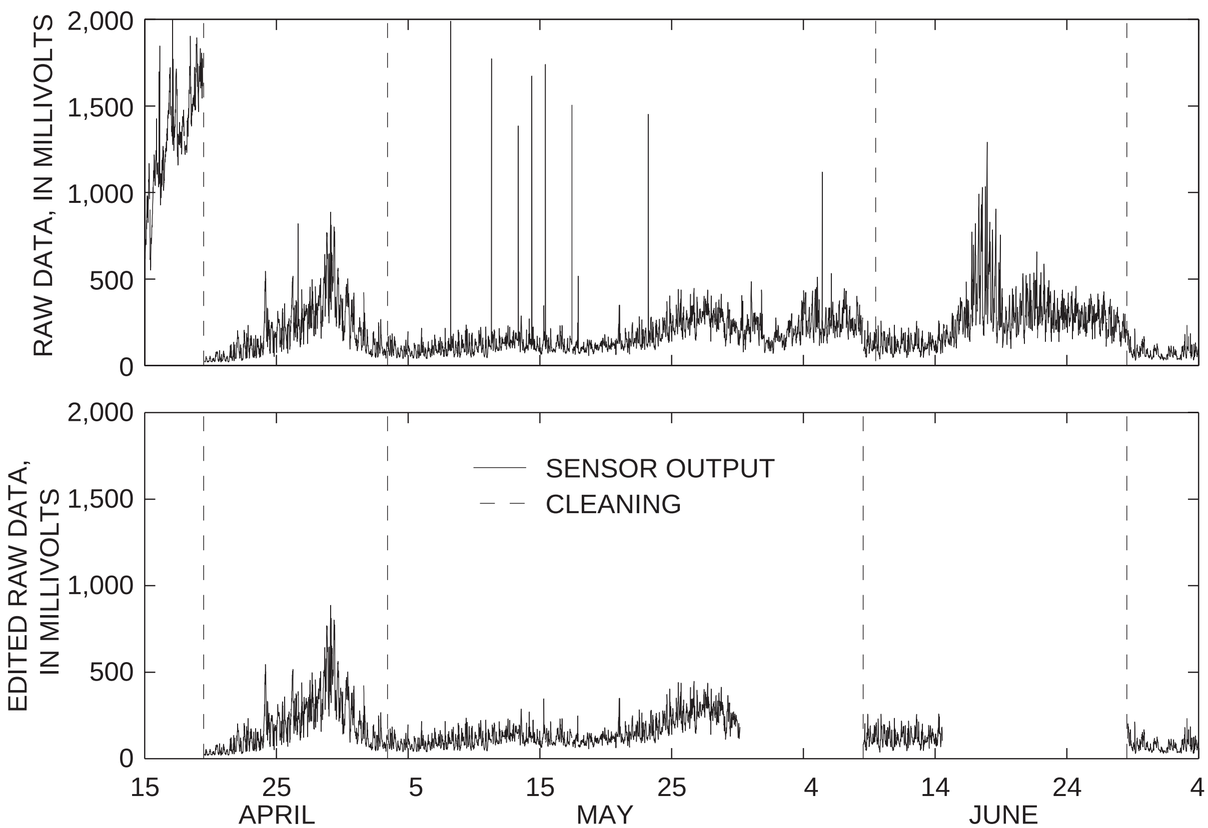

Figure 2. Raw and edited optical backscatterance data, mid-depth sensor, Point San Pablo, Central San Francisco Bay, California, water year 1994 (Buchanan and others, 1996). MV, millivolt.

SENSOR CALIBRATION AND SUSPENDED-SOLIDS CONCENTRATION DATA

The output from the optical sensors was converted to suspended-solids concentration using linear regression equations. A statistical summary of the calculated suspended-solids concentrations, and the percentage of valid data collected by optical backscatterance sensors at each site is presented in tables 1 and 2, respectively. This section of the report also includes the linear regression (calibration) plots for optical sensor output [in millivolts (mV)] versus suspended-solids concentration, in milligrams per liter (mg/L). The linear regression plots include the number of samples (data points), correlation coefficient, squared correlation coefficient, regression significance level, and root-mean-squared error. Finally, the time-series plots of suspended-solids concentration data are shown for each site.

Table 1. Statistical summary of suspended-solids concentration data, Suisun Bay and Central and South San Francisco Bays, California, water year 1997

[All measurements are in milligrams per liter. Lower quartile is 25th percentile; upper quartile is 75th percentile]

Site	Depth	Mean	Median	Lower quartile	Upper quartile
Mallard Island	Near-surface	48	40	28	60
	Near-bottom	54	44	28	69
Benicia Bridge	Near-surface	77	64	48	94
	Near-bottom	137	123	78	173
Point San Pablo	Mid-depth	112	77	49	132
	Near-bottom	144	105	72	170
Pier 24	Mid-depth	28	27	19	34
	Near-bottom	47	36	24	55
Golden Gate Bridge	Mid-depth	17	16	13	21
Channel Marker 17	Mid-depth	168	119	65	223
	Near-bottom	207	125	53	269
Dumbarton Bridge	Mid-depth	122	106	79	143
	Near-bottom	177	133	82	212
San Mateo Bridge	Mid-depth	58	45	26	75
	Near-bottom	59	47	31	71

Table 2. Percentage of valid data collected by optical backscatterance sensors, Suisun Bay, and Central and South San Francisco Bays, California, water year 1997

Site	Depth	Percent valid data
Mallard Island	Near-surface	78
	Near-bottom	72
Benicia Bridge	Near-surface	66
	Near-bottom	65
Point San Pablo	Mid-depth	72
	Near-bottom	76
Pier 24	Mid-depth	46
	Near-bottom	71
Golden Gate Bridge	Near-surface	41
Channel Marker 17	Mid-depth	51
	Near-bottom	53
Dumbarton Bridge	Mid-depth	55
	Near-bottom	54
San Mateo Bridge	Mid-depth	39
	Near-bottom	44

Suisun Bay

Mallard Island

Data were not collected from March 16–26, 1997, because power lines were stolen by vandals. A temporary battery-powered optical sensor without the self-cleaning function was used to collect near-surface suspended-solids concentration data from March 26 to June 2, 1997. The calibration of this sensor had a standard error of 1.8 mg/L (RMS; fig. 3) and was developed using water samples collected during its deployment. AC power was restored on June 2, 1997, and the self-cleaning probes were brought back on line. The calibration of the near-surface self-cleaning probe had a standard error of 5.6 mg/L (RMS; fig. 4) and was calibrated from samples collected from December 9, 1994, through September 30, 1997, excluding flood samples collected from January through March 1995 and January through February 1997. The calibration of the near-bottom self-cleaning sensor had a standard error of 10.0 mg/L (RMS; fig. 5) and was calibrated from samples collected from April 20, 1995, through September 30, 1997, excluding flood samples collected from January through February 1997. Flood waters caused a small shift in the calibration of the near-surface and near-bottom sensors from January 3 to February 5, 1997 (figs. 6 and 7). The calibration of the near-surface self-cleaning sensor used during flood conditions was developed with 18 samples collected during the floods of water year 1995 and 4 samples collected in water year 1997 and had a standard error of 18 mg/L (RMS; fig. 6). The calibration of the near-bottom self-cleaning sensor used during flood conditions was developed with nine samples collected during the floods of water year 1995 and four samples collected during water year 1997 and had a standard error of 6.9 mg/L (RMS: fig. 7). Between January 2–3 and February 5–25, the slope and intercept of the flood and normal calibration curves for both sensors were interpolated to transition smoothly between the two calibrations. Suspended-solids concentration data collected during water year 1997 are presented in figures 8 and 9.

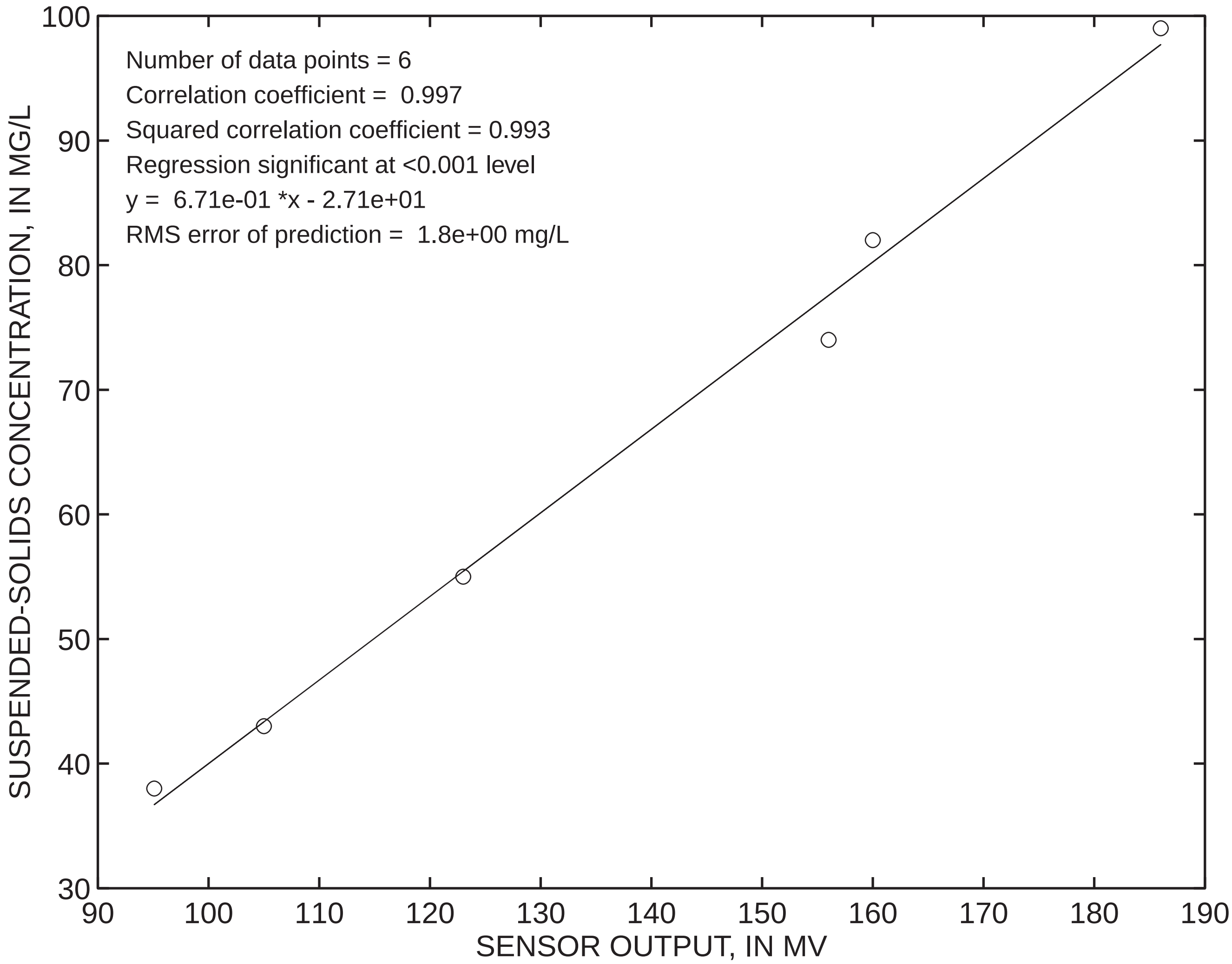

Figure 3. Calibration of the near-surface optical backscatterance sensor at Mallard Island, Suisun Bay, California, March 26–June 2, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

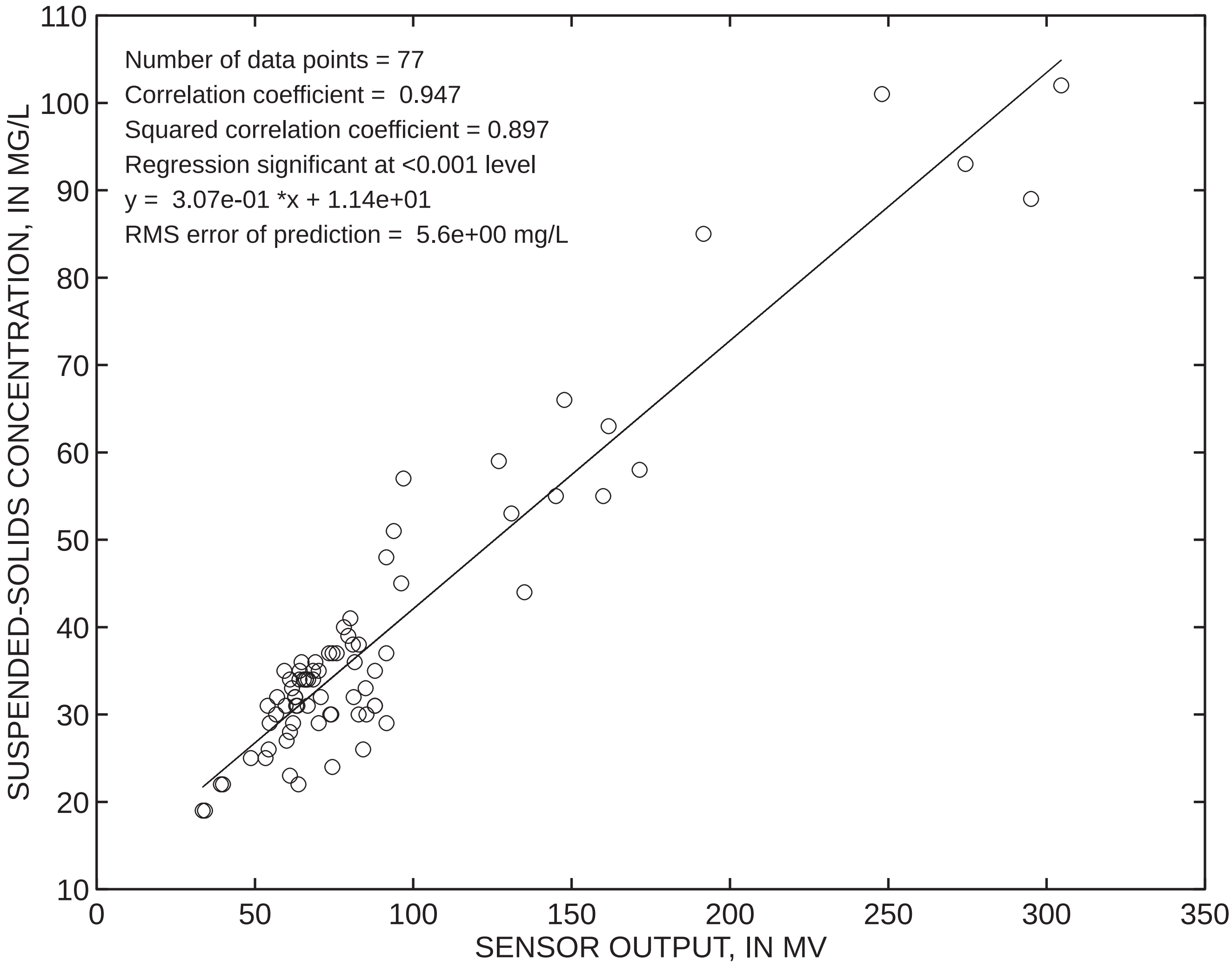

Figure 4. Calibration of near-surface optical backscatterance sensor (with wiper) at Mallard Island, Suisun Bay, California, October 1–January 2, February 25–March 16, and June 2–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

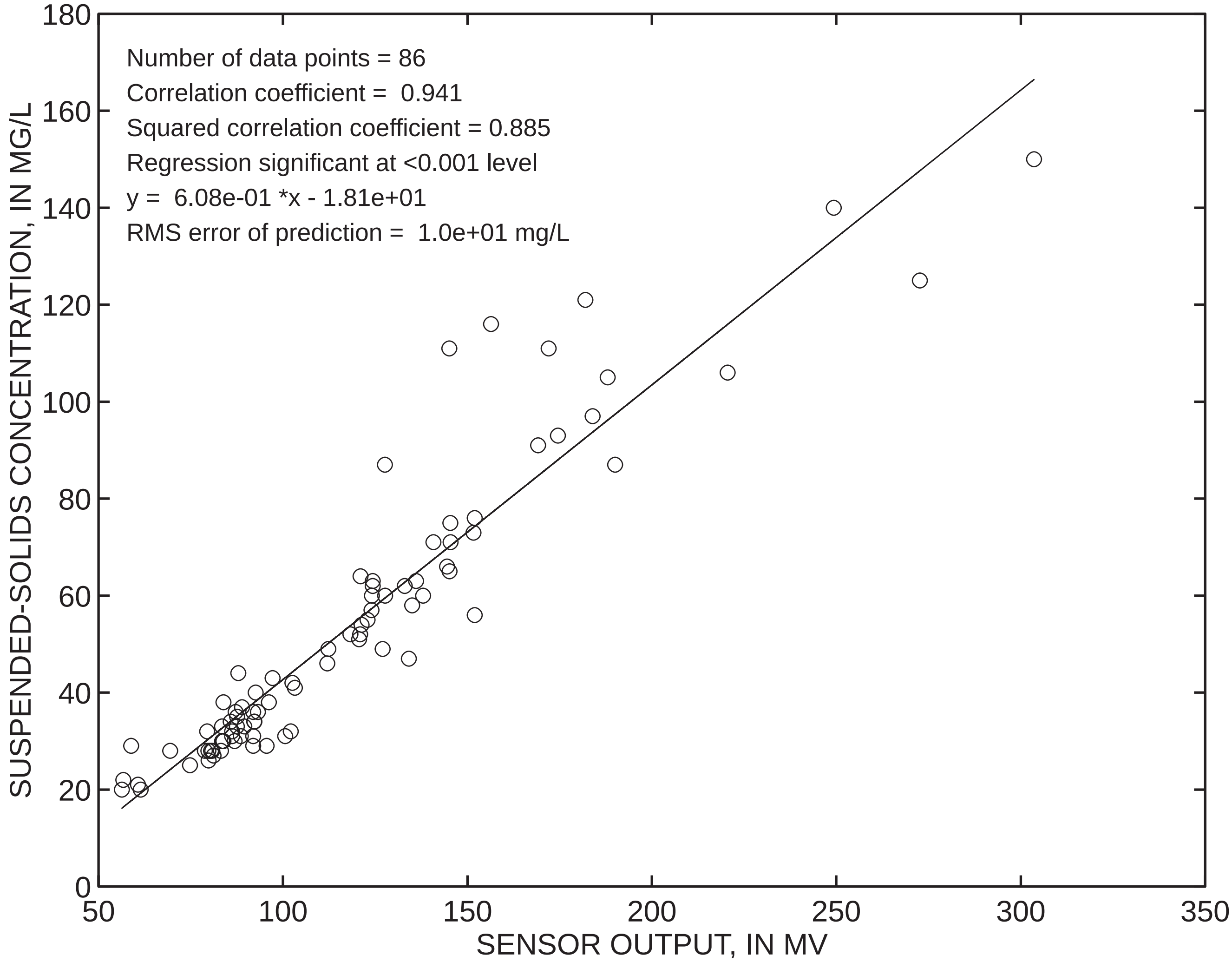

Figure 5. Calibration of near-bottom optical backscatterance sensor (with wiper) at Mallard Island, Suisun Bay, California, October 1–January 2, and February 25–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

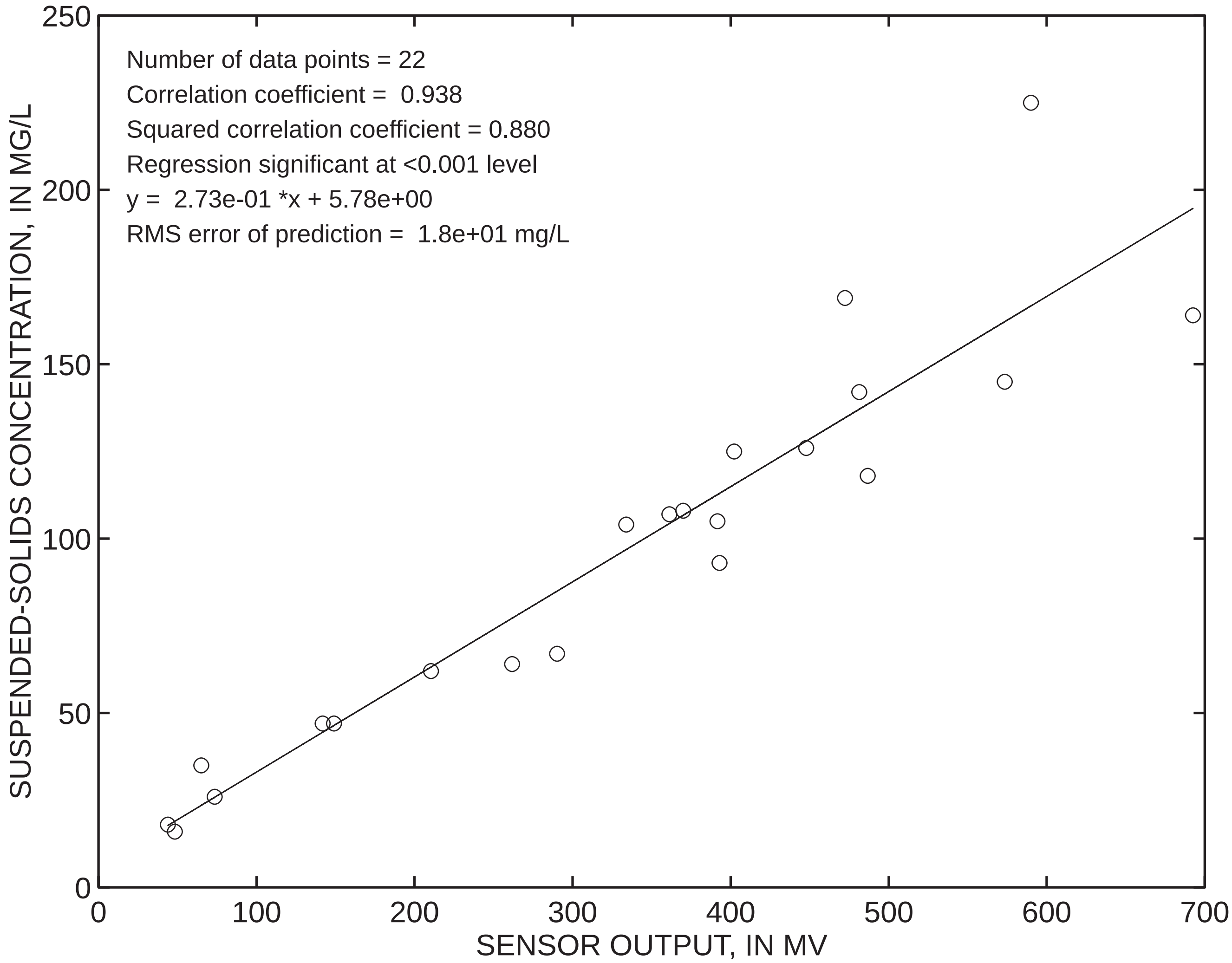

Figure 6. Calibration of near-surface optical backscatterance sensor (with wiper) during flood at Mallard Island, Suisun Bay, California, January 3–February 5, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

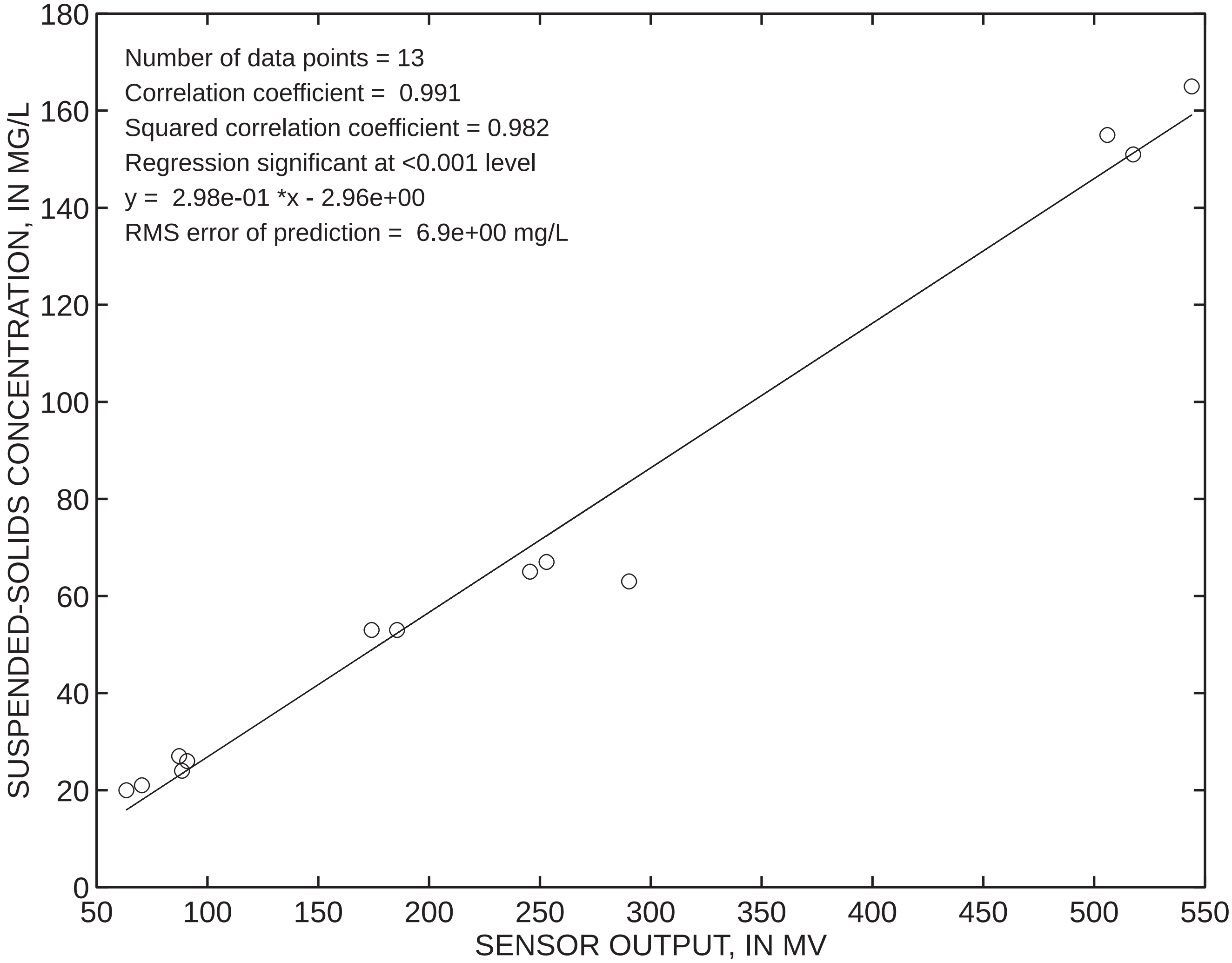

Figure 7. Calibration of near-bottom optical backscatterance sensor (with wiper) during flood at Mallard Island, Suisun Bay, California, January 3–February 5, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

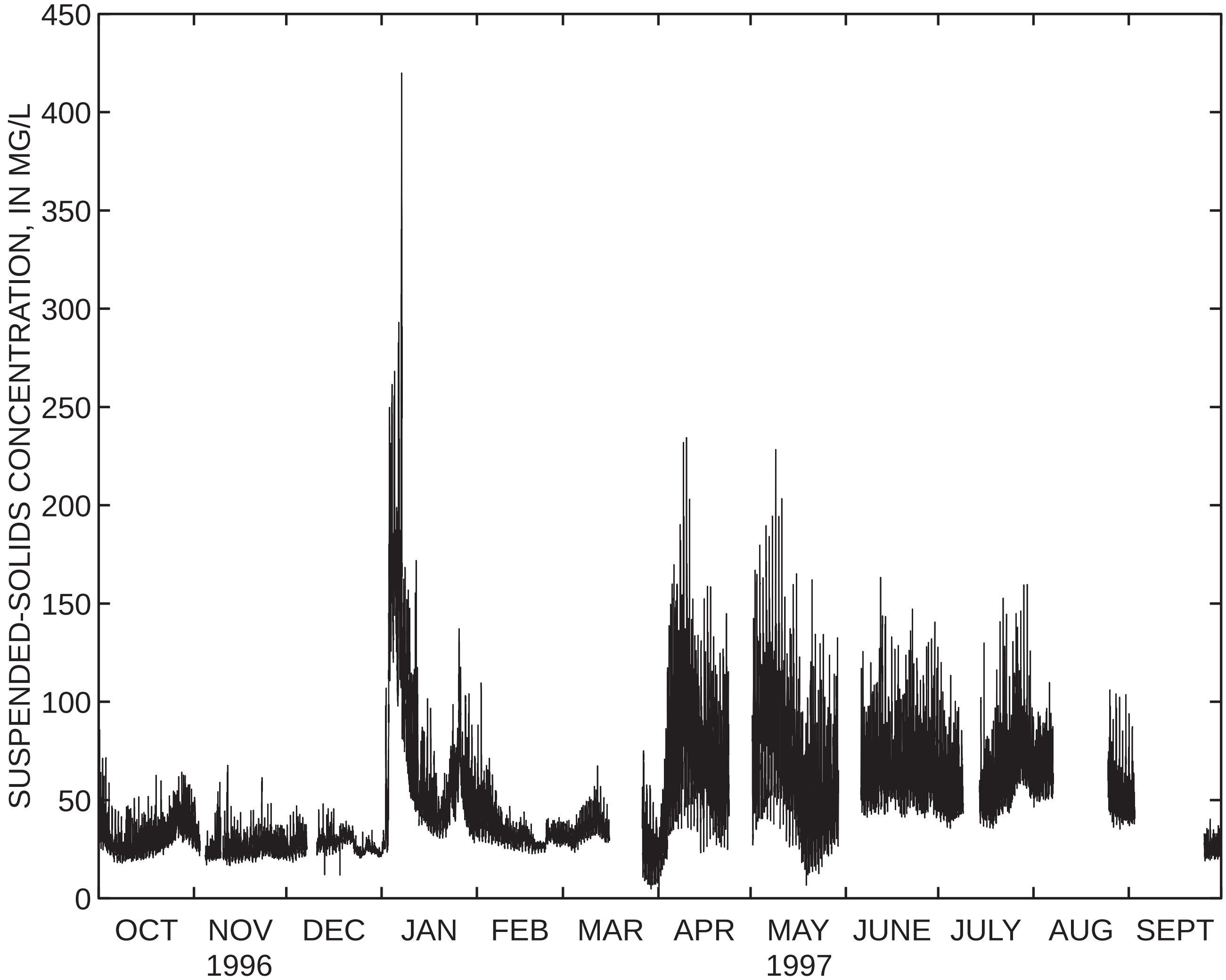

Figure 8. Time series of near-surface suspended-solids concentration calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 1997. Mg/L, milligrams per liter.

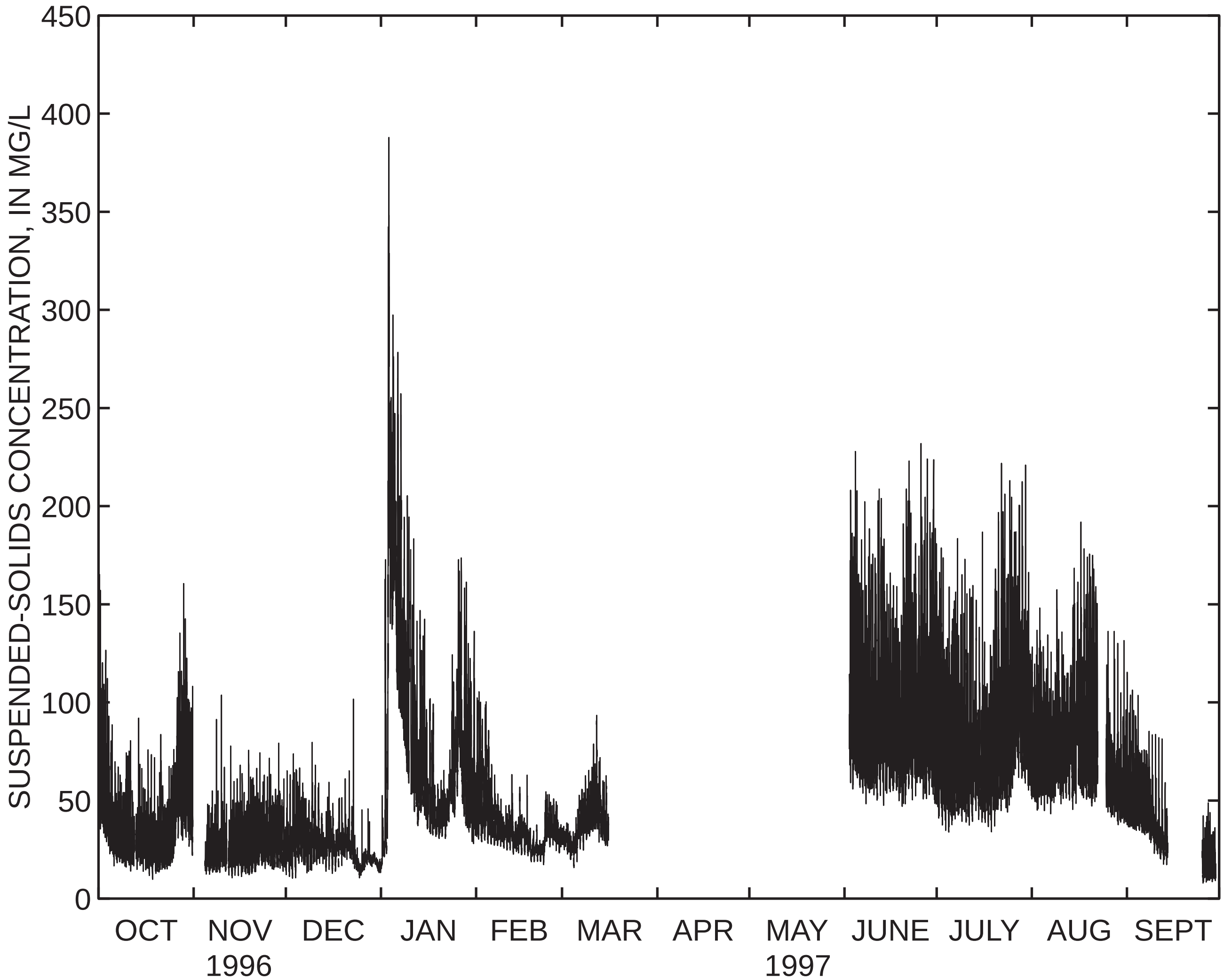

Figure 9. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 1997. Mg/L, milligrams per liter.

Benicia Bridge

Sensors without the self-cleaning function were deployed on May 14, 1996. The calibration of the near-surface sensor had a standard error of 14.0 mg/L (RMS; fig. 10). The calibration of the near-bottom sensor from May 14, 1996, until March 5, 1997, had a standard error of 43 mg/L (RMS; fig. 11). The gain on the near-bottom sensor was set too high, and some high suspended-solids concentration values were off the scale of the sensor, causing clipping of high suspended-solids concentrations from the time series until March 5, 1997, when the gain was reset. A second calibration was used for the near-bottom sensor from March 5, 1997, through the end of water year 1997 and had a standard error of 23 mg/L (RMS; fig. 12). The suspension cable broke sometime in early September 1997 resulting in invalid data until September 30, 1997, when the cable was replaced and the sensors redeployed. Suspended-solids concentration data collected during water year 1997 are presented in figures 13 and 14.

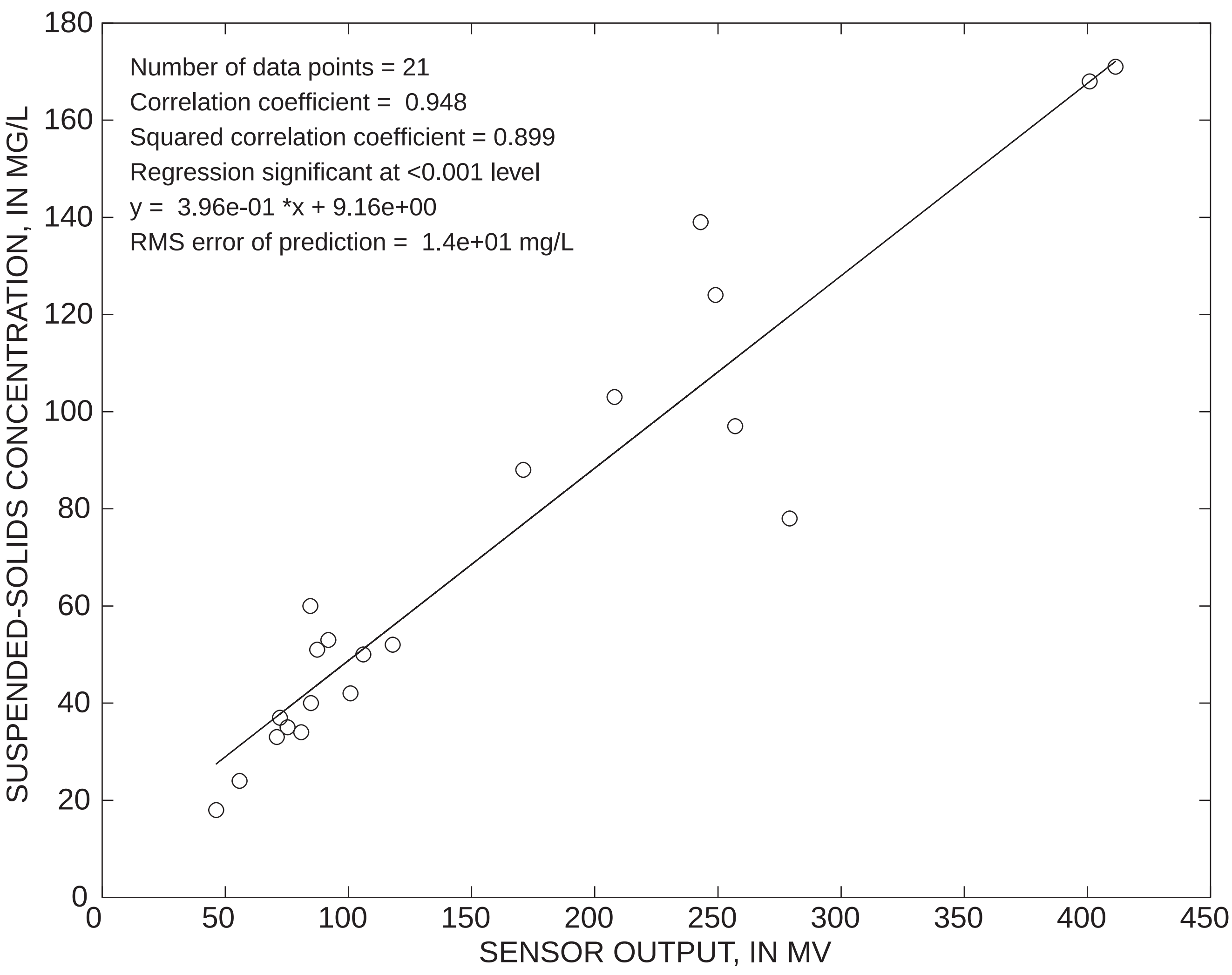

Figure 10. Calibration of near-surface optical backscatterance sensor at Benicia Bridge, Suisun Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

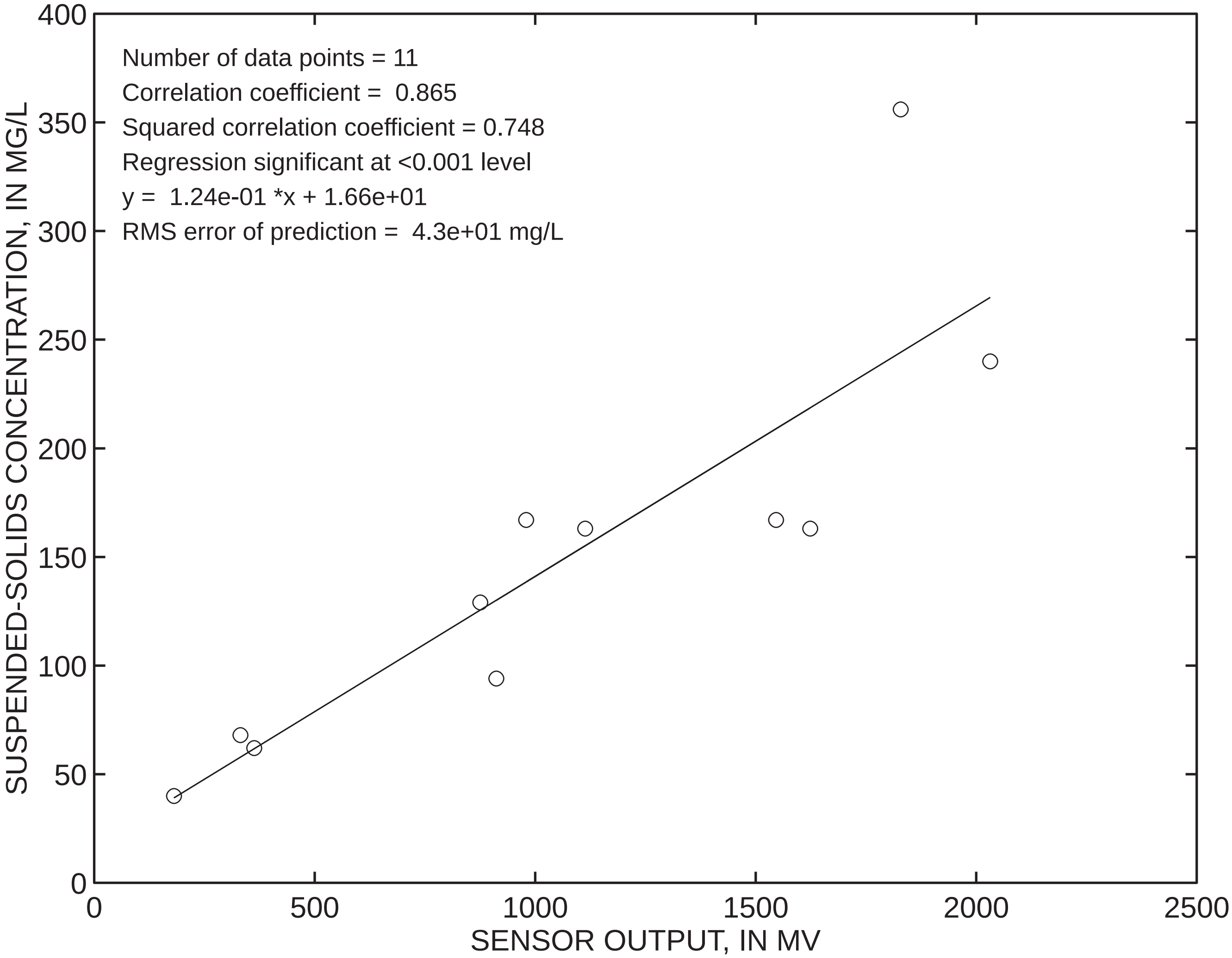

Figure 11. Calibration of near-bottom optical backscatterance sensor at Benicia Bridge, Suisun Bay, California, October 1–March 4, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

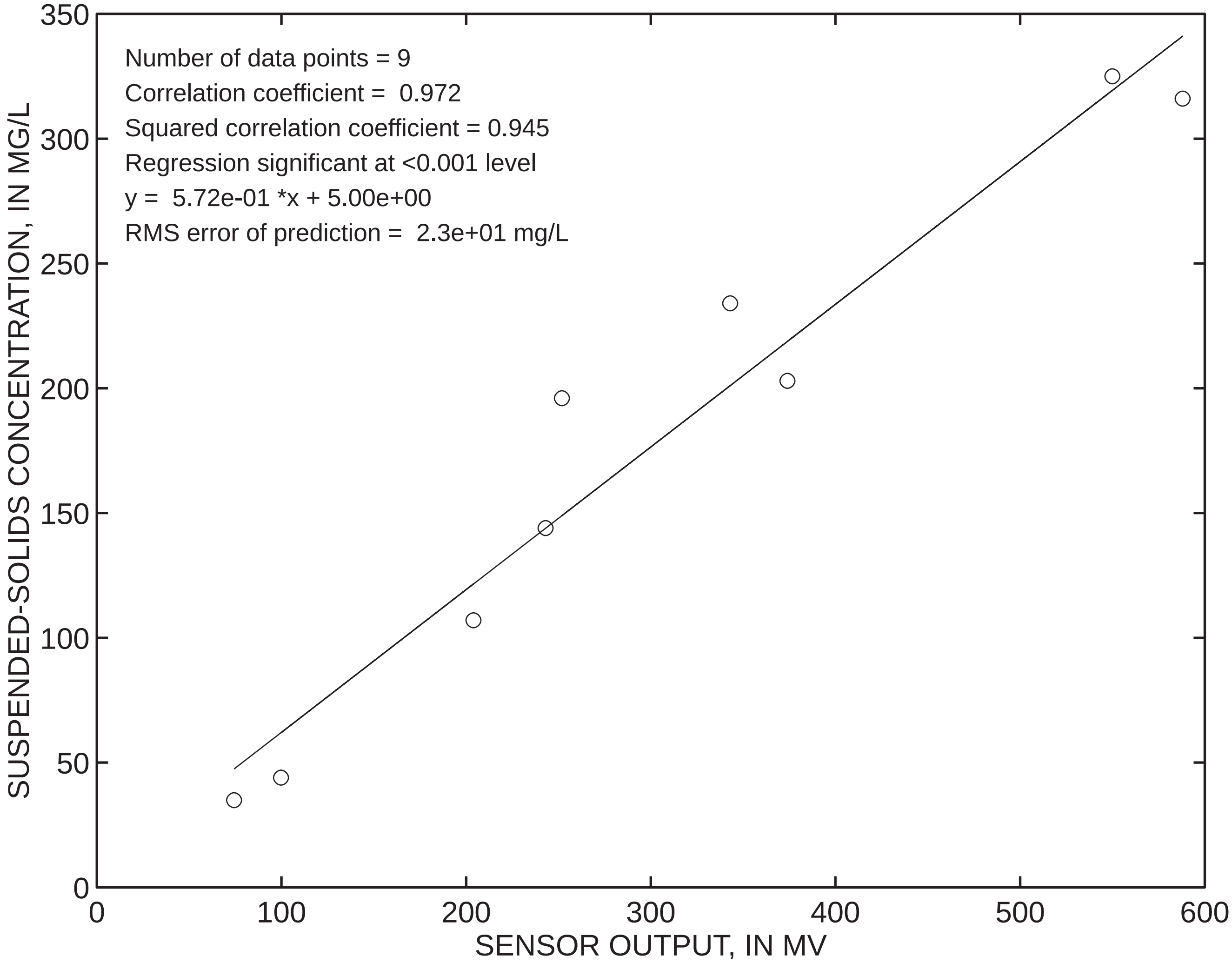

Figure 12. Calibration of near-bottom optical backscatterance sensor at Benicia Bridge, Suisun Bay, California, March 5-September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

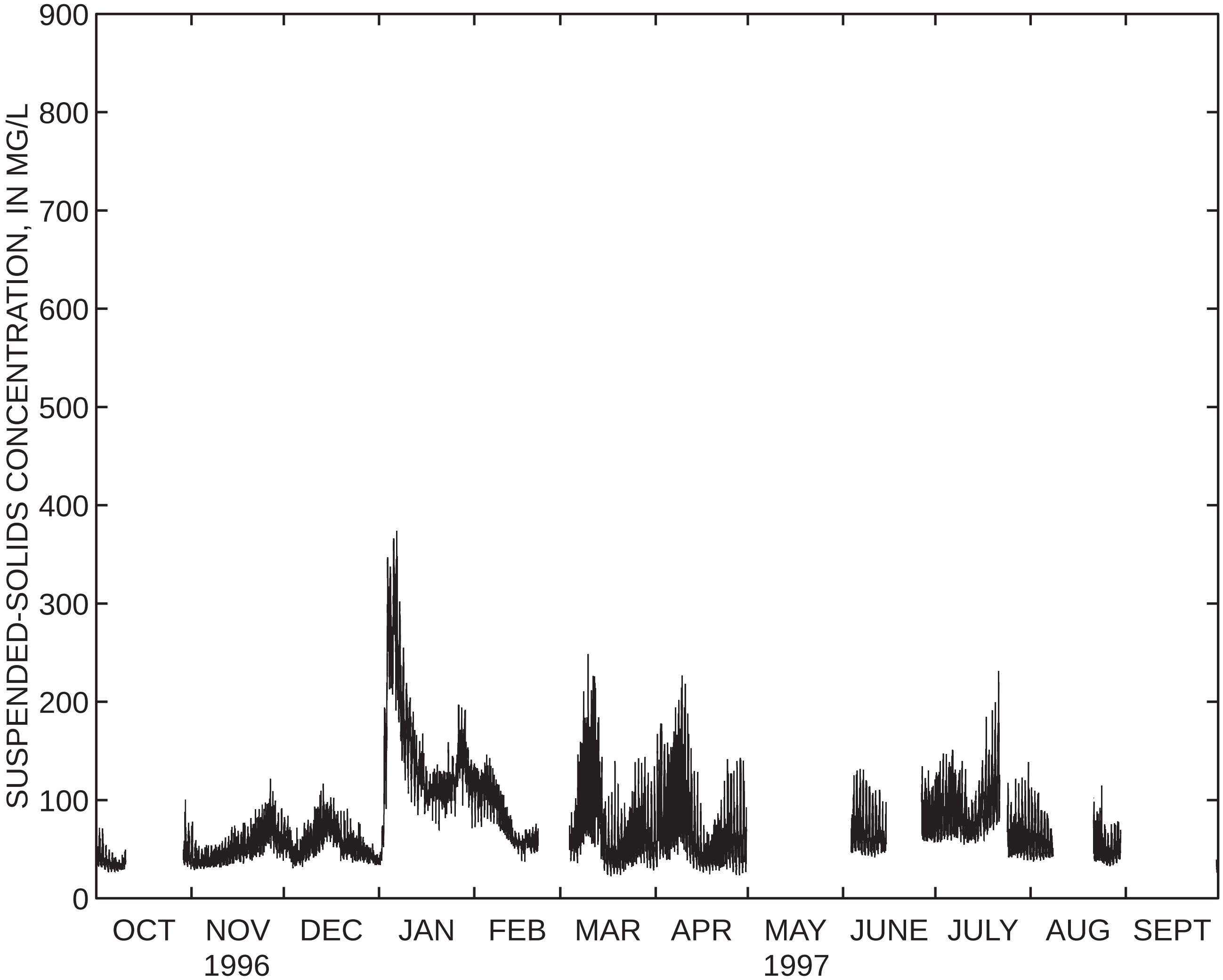

Figure 13. Time series of near-surface suspended-solids concentration calculated from sensor readings at Benicia Bridge, Suisun Bay, California, water year 1997. Mg/L, milligrams per liter.

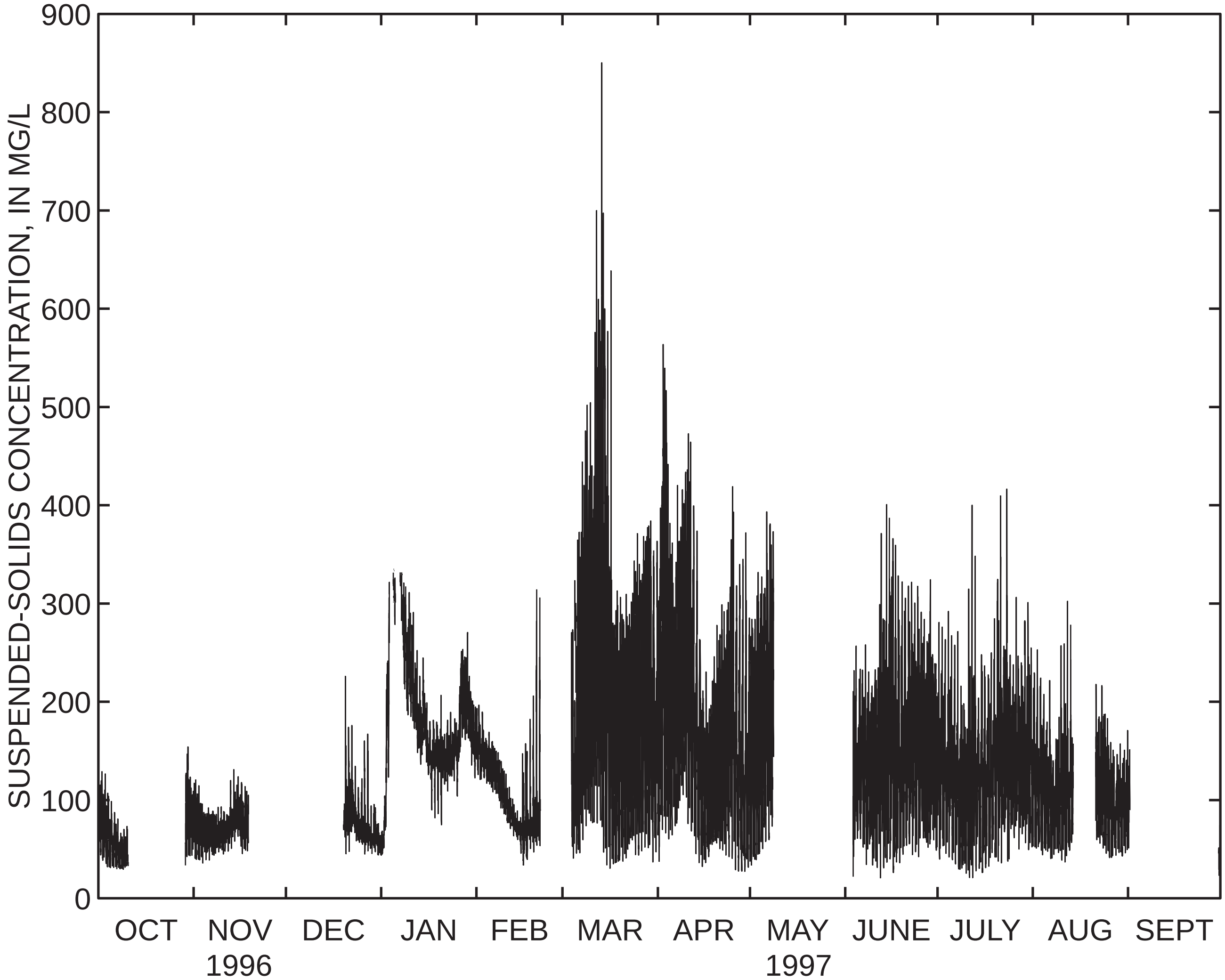

Figure 14. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Benicia Bridge, Suisun Bay, California, water year 1997. Mg/L, milligrams per liter.

Central San Francisco Bay

Point San Pablo

The calibration of the mid-depth sensor was developed using water samples collected from August 15, 1995, through water year 1997 and had a standard error of 18 mg/L (RMS; fig. 15). A -50-mV shift to the record, calculated from water sample data not shown on figure 15, was applied from August 25 through September 30, 1997, to correct for a shift in sensor output. The calibration of the near-bottom sensor was developed using water samples collected from August 15, 1995, through water year 1997 and had a standard error of 46 mg/L (RMS; fig. 16). Suspended-solids concentration data collected during water year 1997 are presented in figures 17 and 18.

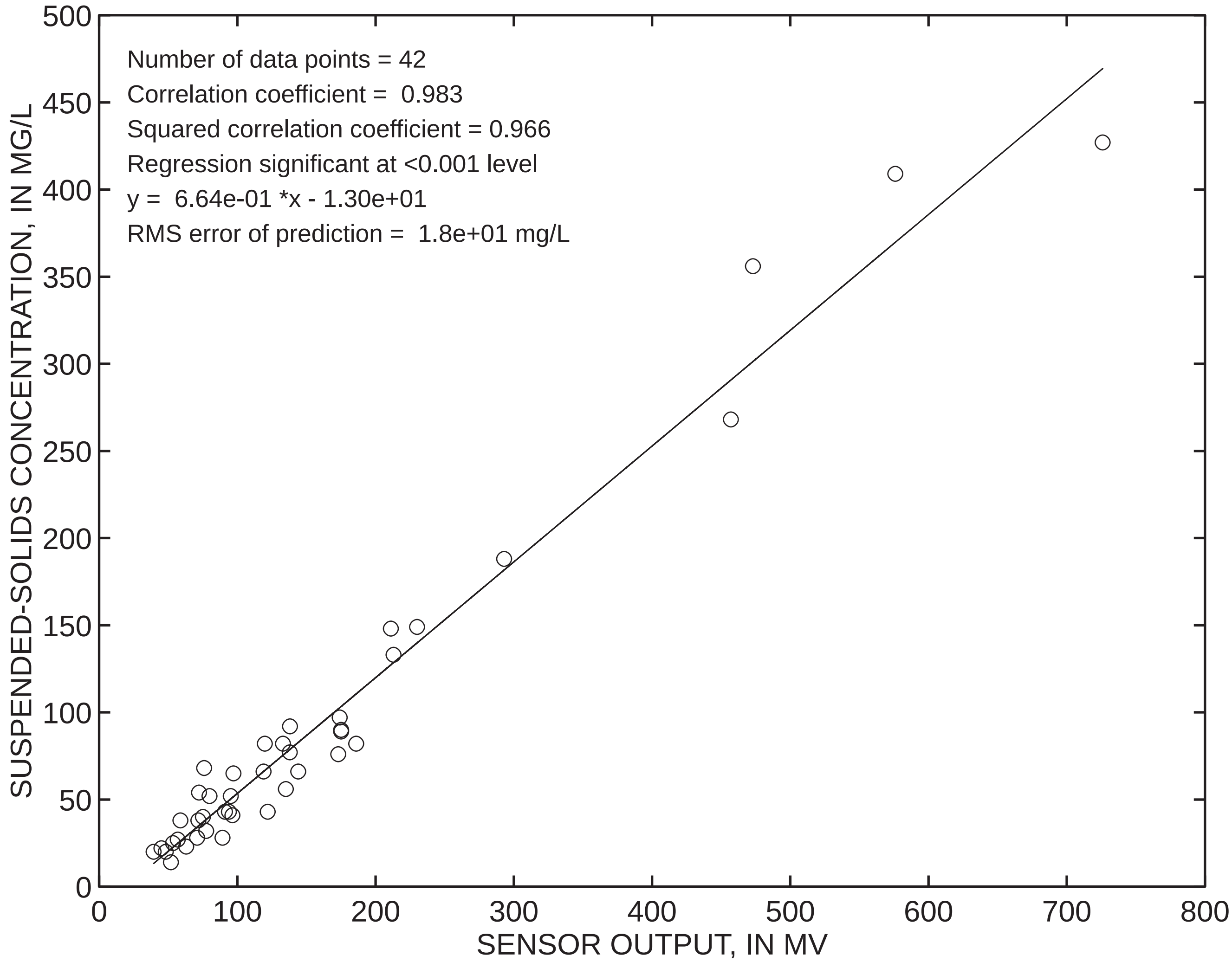

Figure 15. Calibration of mid-depth optical backscatterance sensor at Point San Pablo, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolts.

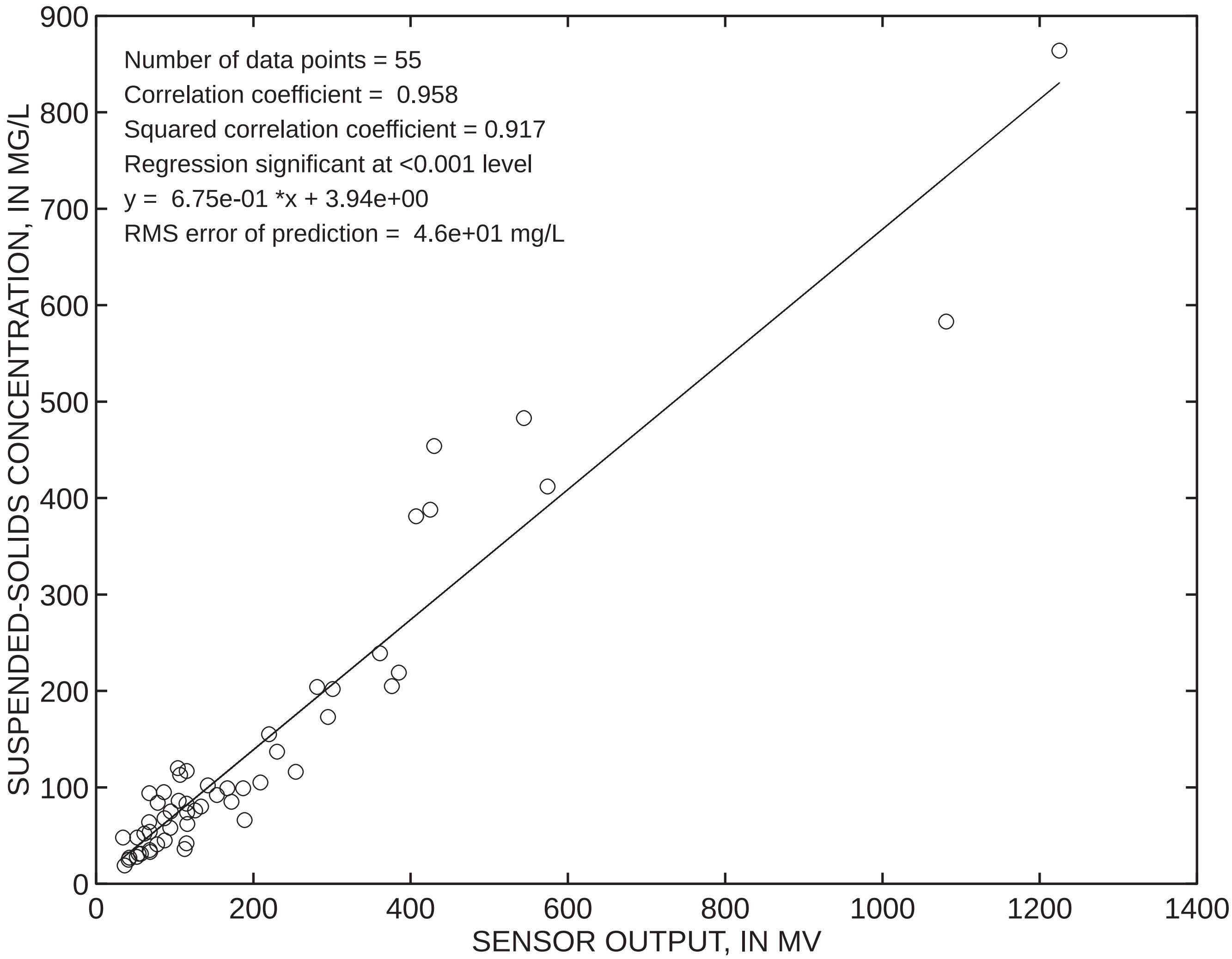

Figure 16. Calibration of near-bottom optical backscatterance sensor at Point San Pablo, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

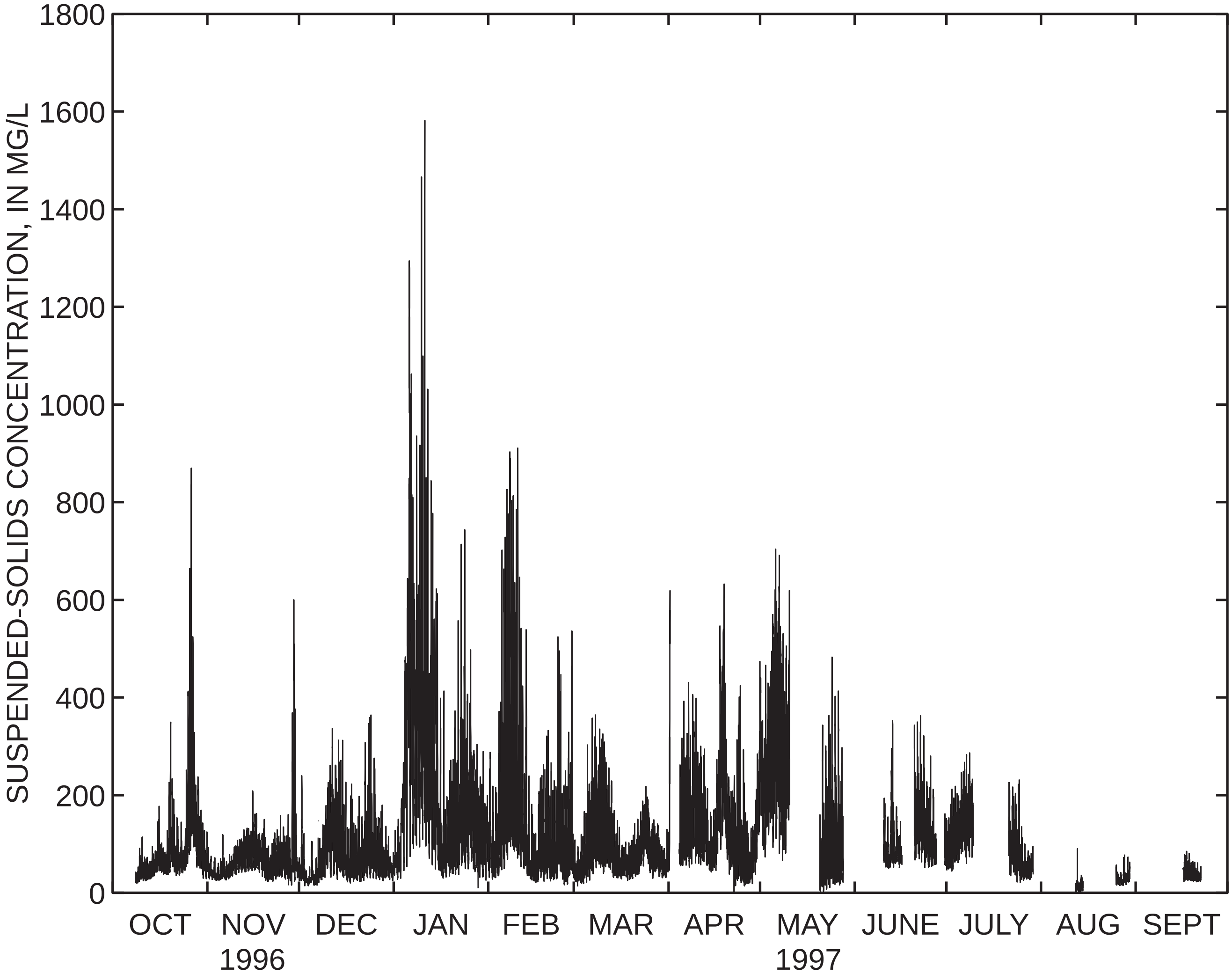

Figure 17. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

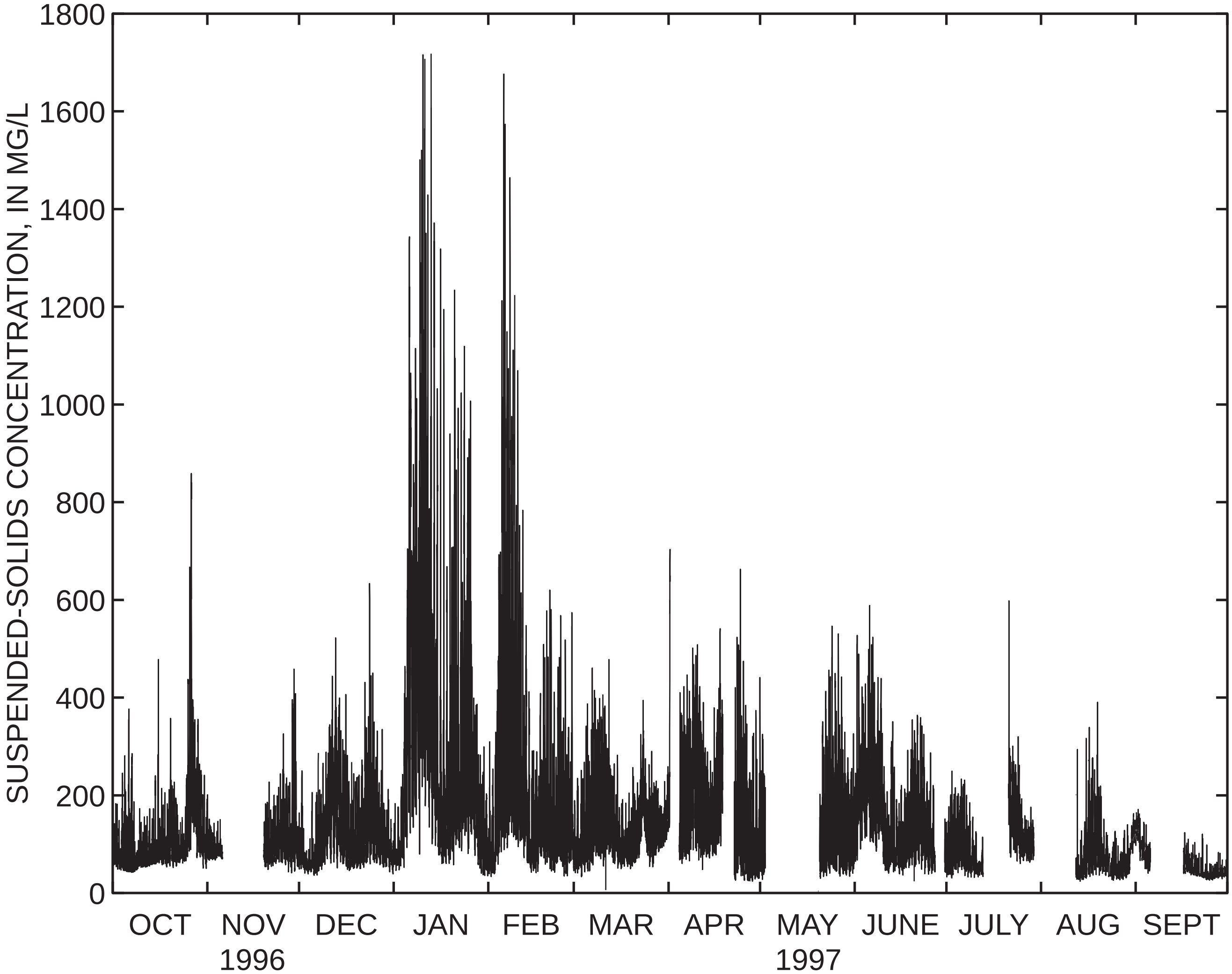

Figure 18. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

Pier 24

Calibration of the mid-depth sensor was developed from water samples collected from April 1996 through water year 1997 and had a standard error of 8.2 mg/L (RMS; fig. 19). Shifts to the mid-depth record, calculated from water-sample data not shown on figure 19, were applied during the following periods to correct for shifts in sensor output: 34 mV, October 29–November 21, 1996; 17 mV, June 4–30, 1997; 34 mV, June 30–July 21, 1997; and -60 mV, September 17–30, 1997. Calibration of the near-bottom sensor was developed from water samples collected from June 22, 1995, through water year 1997 and had a standard error of 19 mg/L (RMS; fig. 20). Suspended-solids concentration data collected during water year 1997 are presented in figures 21 and 22.

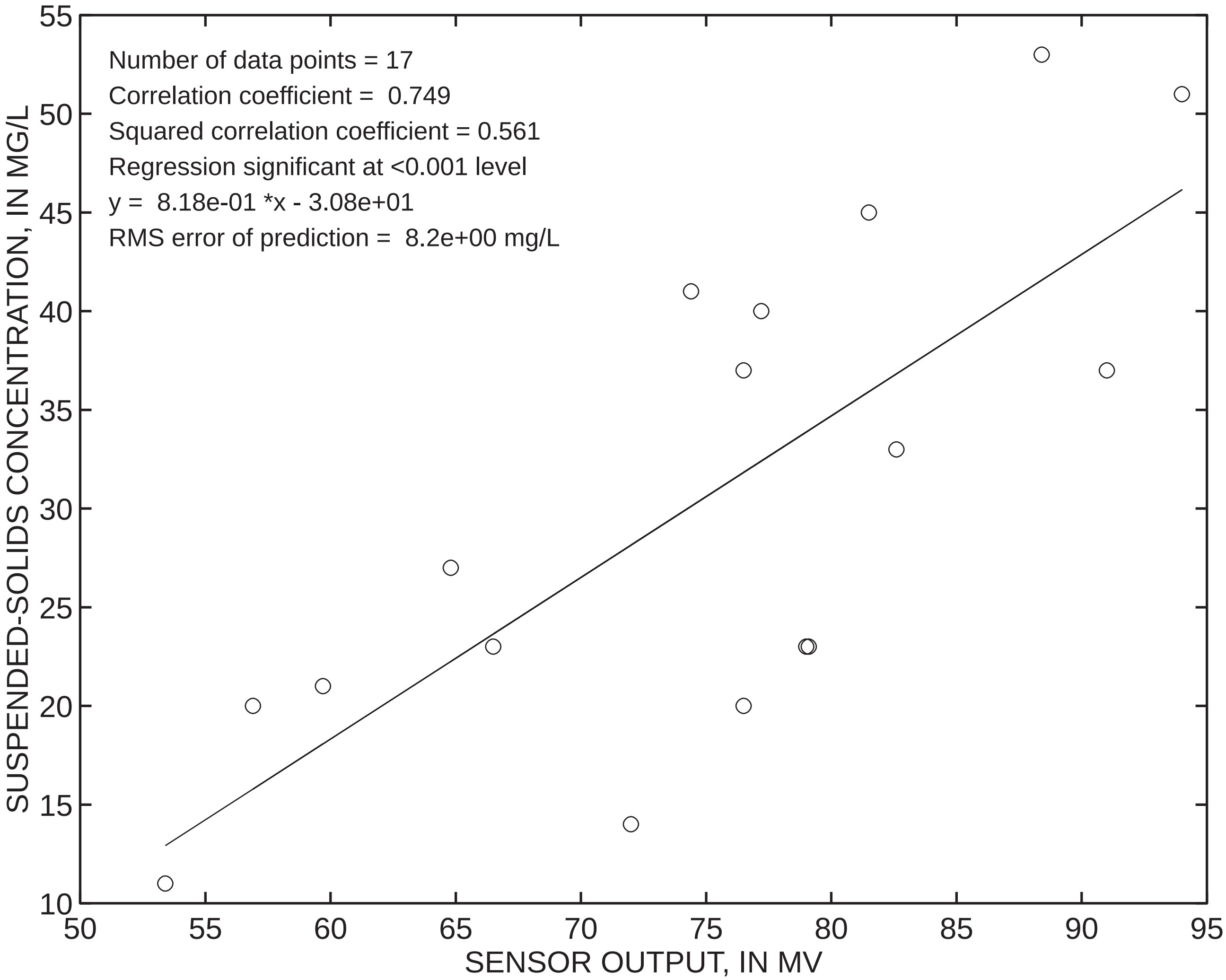

Figure 19. Calibration of mid-depth optical backscatterance sensor at Pier 24, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

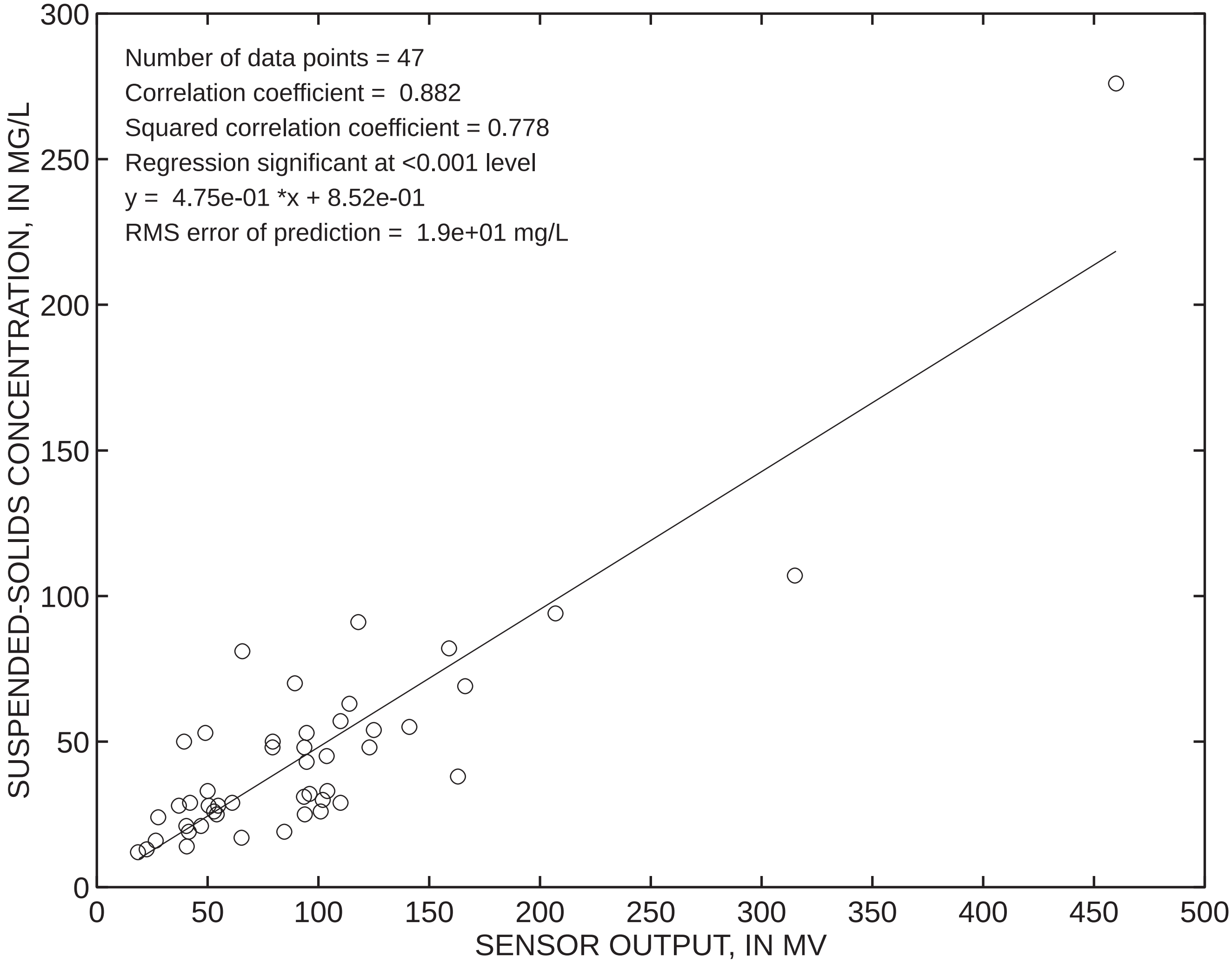

Figure 20. Calibration of near-bottom optical backscatterance sensor at Pier 24, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

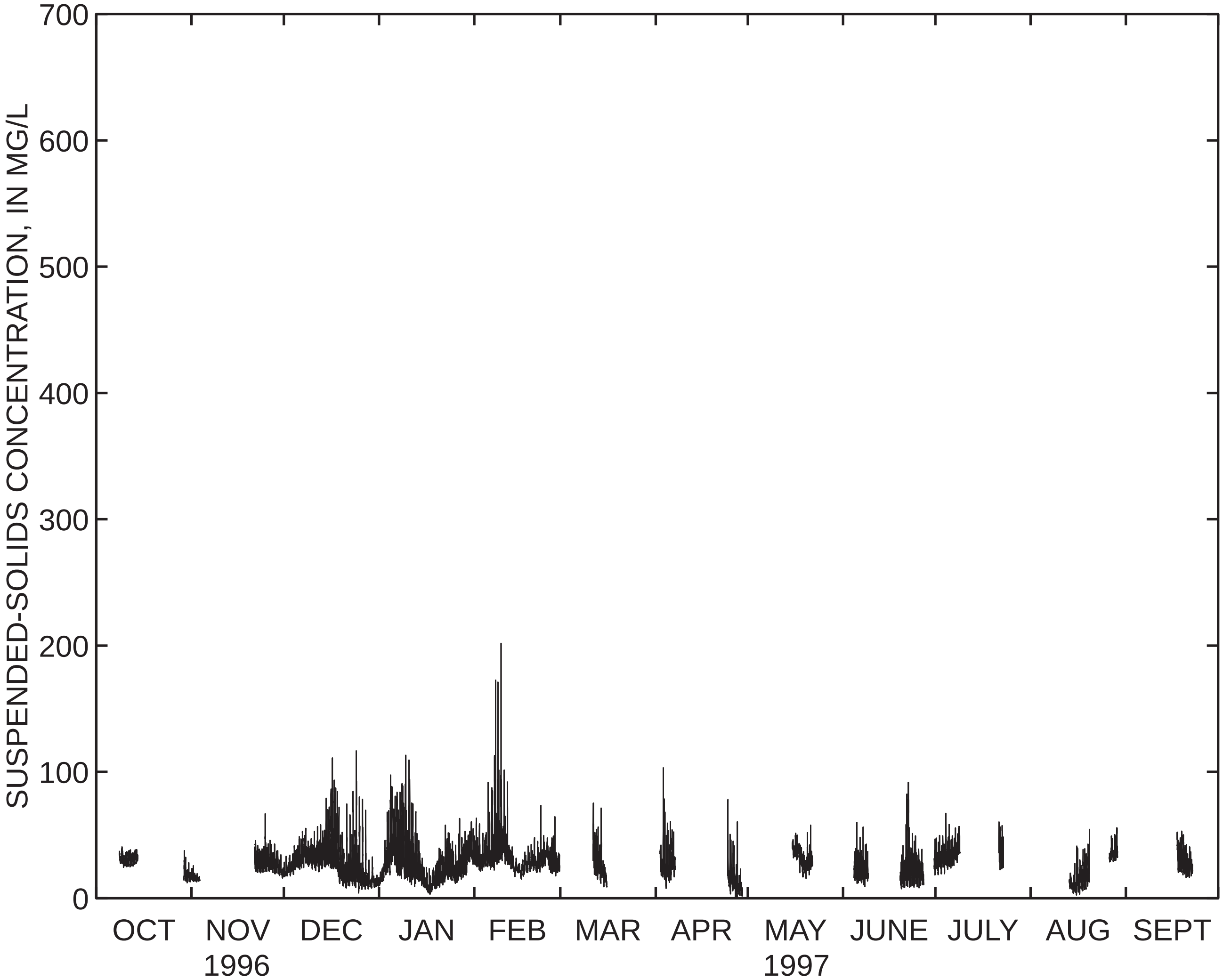

Figure 21. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

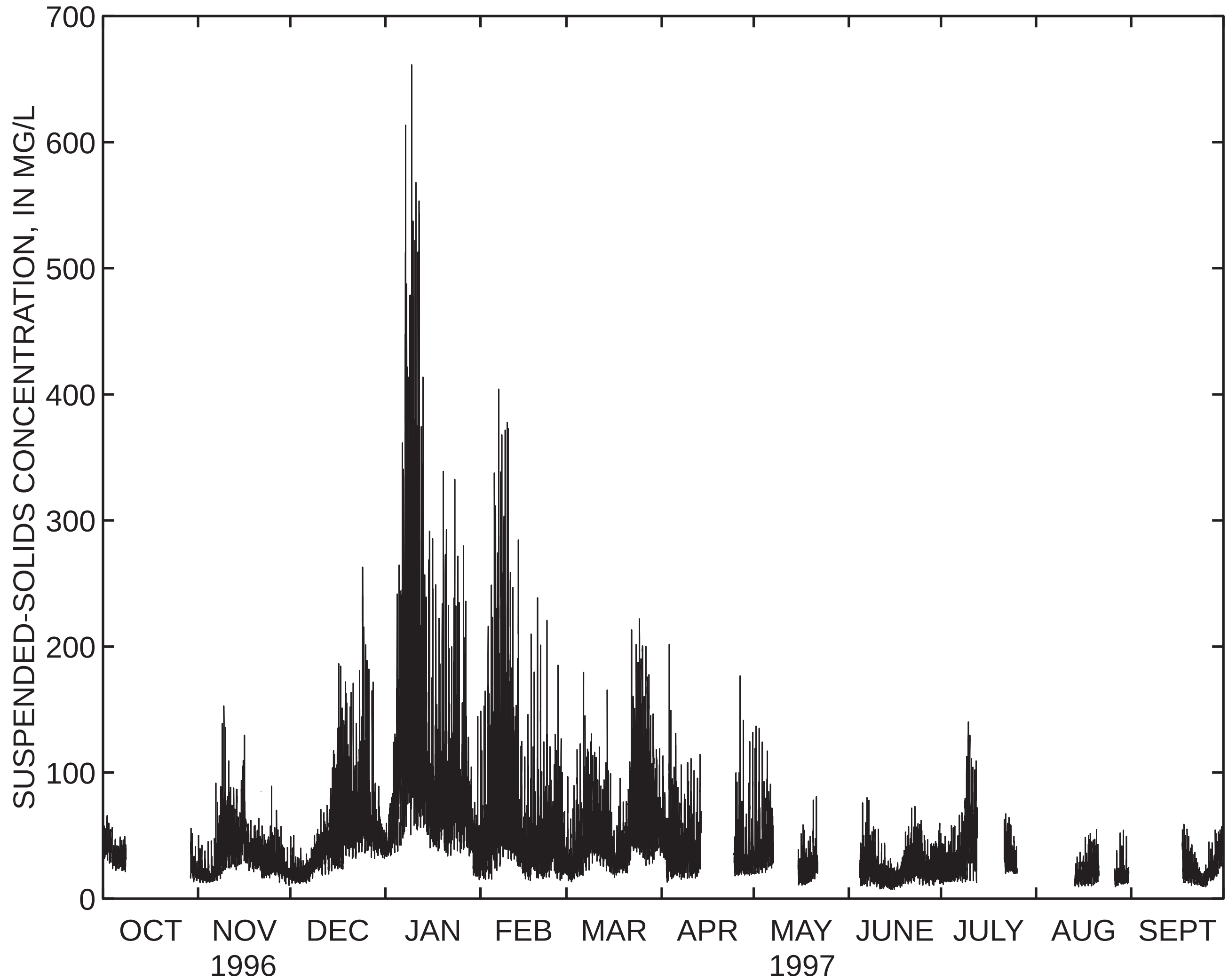

Figure 22. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

Golden Gate Bridge

Suspended-solids concentration data proved difficult to collect at the South Tower of the Golden Gate Bridge. The suspension cable broke on November 10, 1996, and was replaced February 21, 1997. The optical sensor in use from April 2, 1996, through March 14, 1997, was calibrated using one sample from water year 1996 (collected after severe fouling in September 1996 caused a shift in the sensor) and five samples collected during water year 1997 and had a standard error of 1.8 mg/L (RMS; fig. 23). A shift of -7 mV to the record, calculated from water-sample data not shown on figure 23, was applied from October 14 through November 1, 1996, to correct for a shift in sensor output. A tugboat towing a barge snagged the suspension cable and weight on March 4, 1997, lifting them out of position. The sensor was removed from the water March 4, 1997, and redeployed on March 14, 1997, when the suspension weight was found to have resettled into its former position. After redeployment, the sensor was recording inordinately high values (the sensor probably was damaged when the weight and cable were lifted out of position) and was replaced. The record from October 1, 1996, to March 4, 1997, is considered poor due to the few calibration samples over a small range of concentrations. A replacement sensor deployed on March 14, 1997, was calibrated using 15 water samples and had a standard error of 3.8 mg/L (RMS; fig. 24). Suspended-solids concentration data collected during water year 1997 are presented in figure 25.

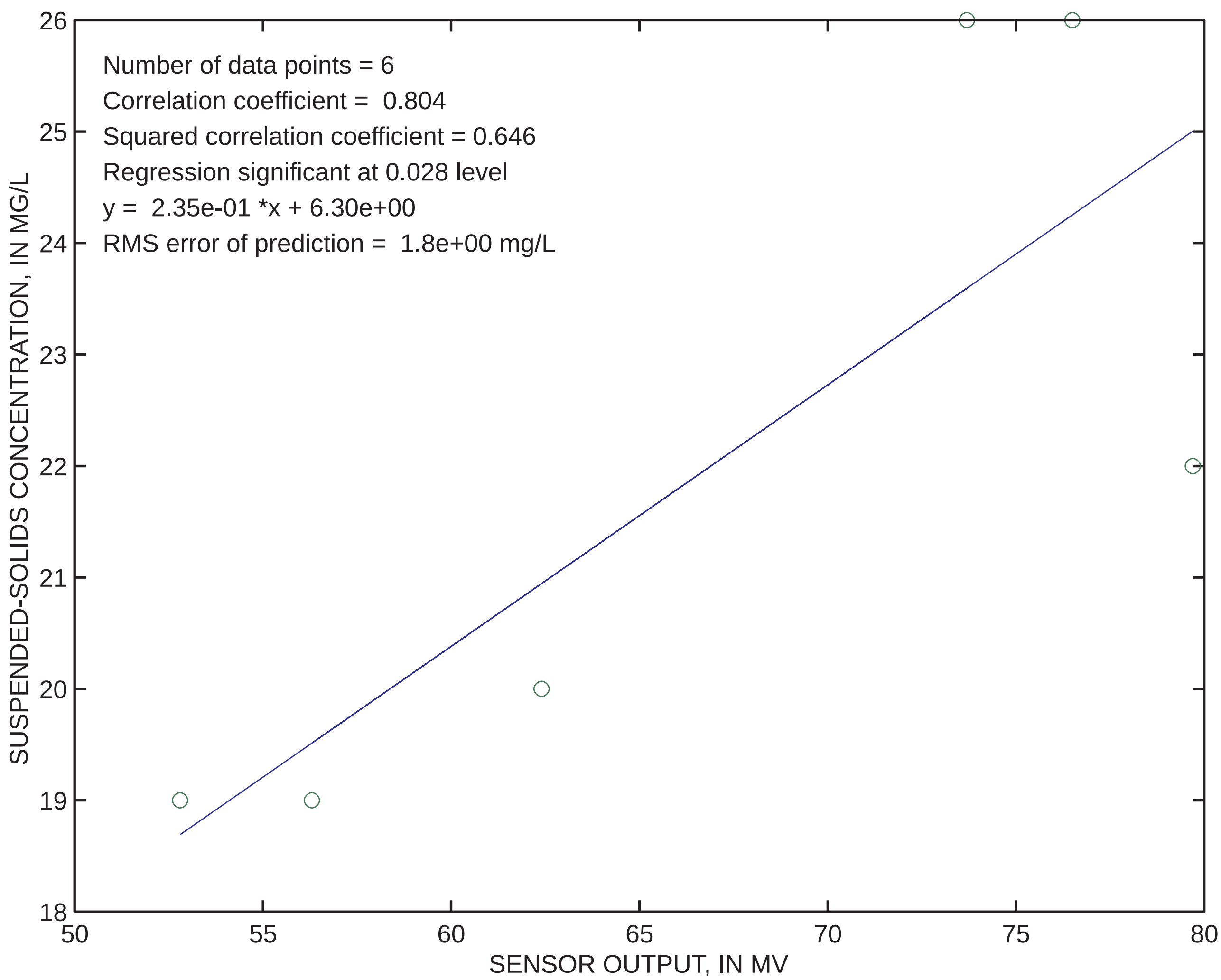

Figure 23. Calibration of mid-depth optical backscatterance sensor at Golden Gate Bridge, Central San Francisco Bay, California, October 1–March 4, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

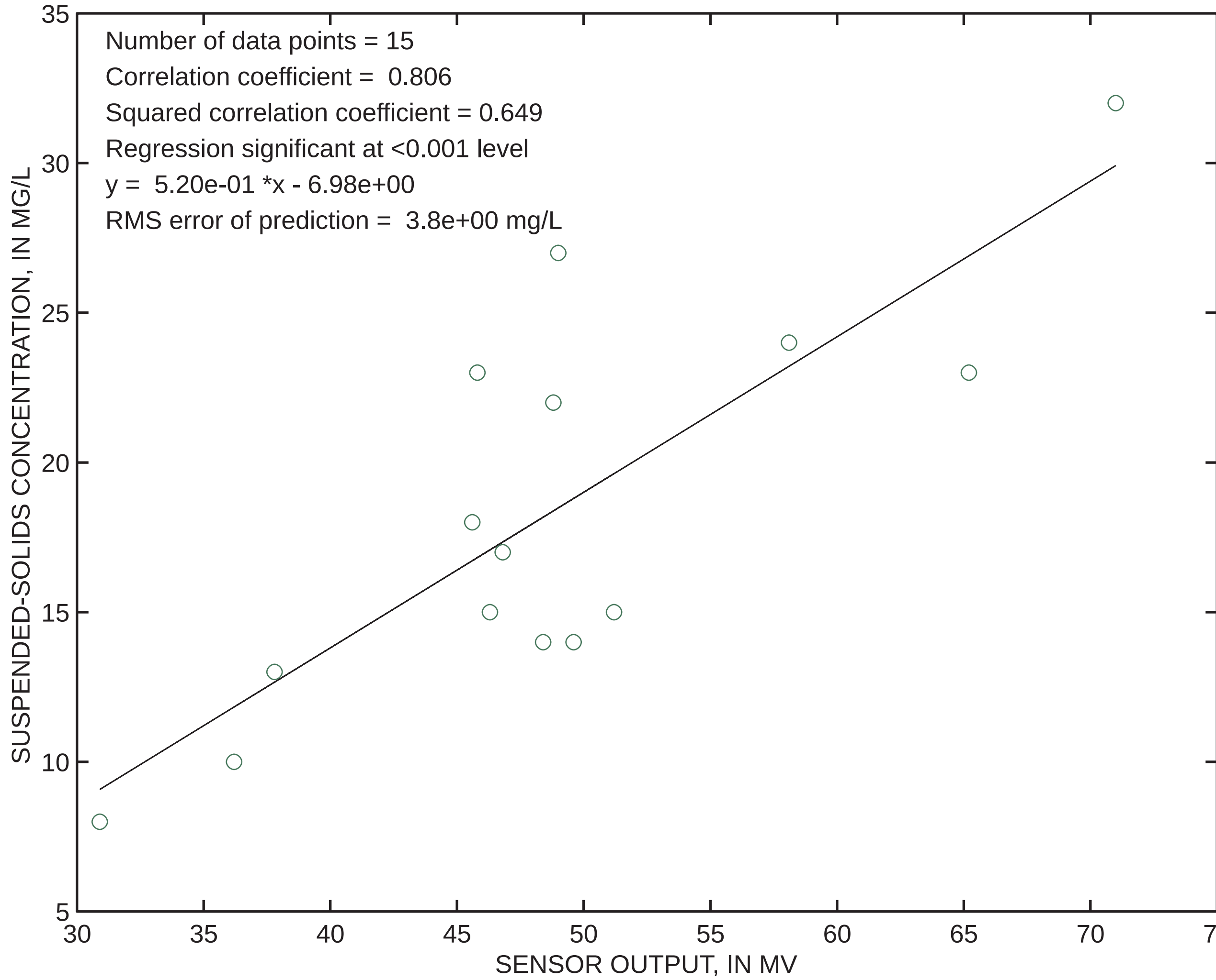

Figure 24. Calibration of mid-depth optical backscatterance sensor at Golden Gate Bridge, Central San Francisco Bay, California, March 14–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

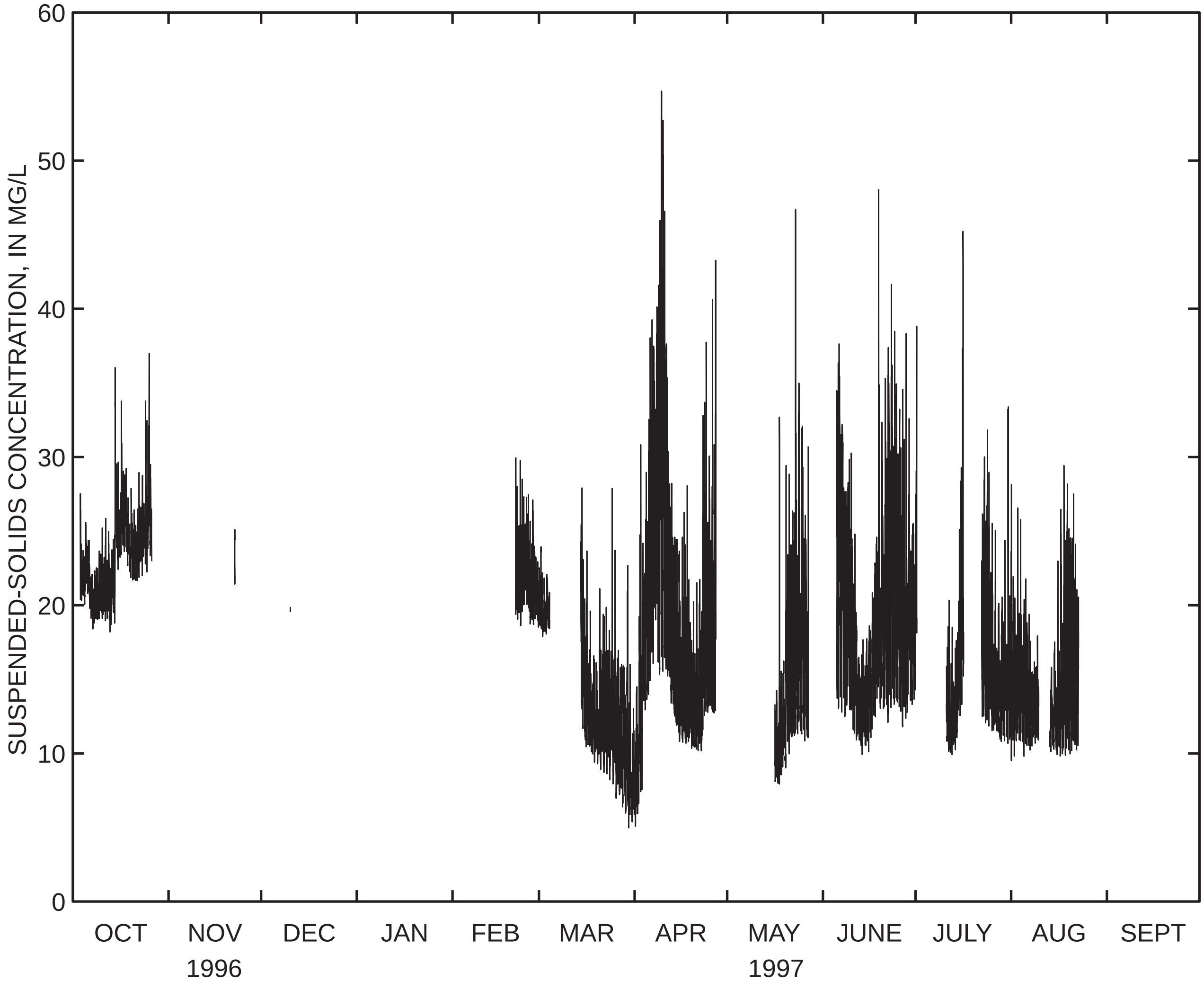

Figure 25. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Golden Gate Bridge, Central San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

South San Francisco Bay

Channel Marker 17

The calibration of the mid-depth sensor prior to January 30, 1997, was based on water samples collected from May 9, 1996, through January 10, 1997, and had a standard error of 23 mg/L (RMS; fig. 26). The gain on this sensor was mistakenly set high enough that suspended-solids concentrations often saturated the sensor, which could measure a maximum concentration of approximately 520 mg/L. Data logger problems caused a loss of data from January 30 through February 26, 1997, at which time the sensor cables were replaced and the gain reset on the mid-depth sensor. The calibration of the mid-depth sensor from February 26 through September 30, 1997, was based on 14 samples and had a standard error of 22 mg/L (RMS; fig. 27). The calibration of the near-bottom sensor was based on water samples collected during water years 1995-97 and had a standard error of 53 mg/L (RMS; fig. 28). Suspended-solids concentration data collected during water year 1997 are presented in figures 29 and 30.

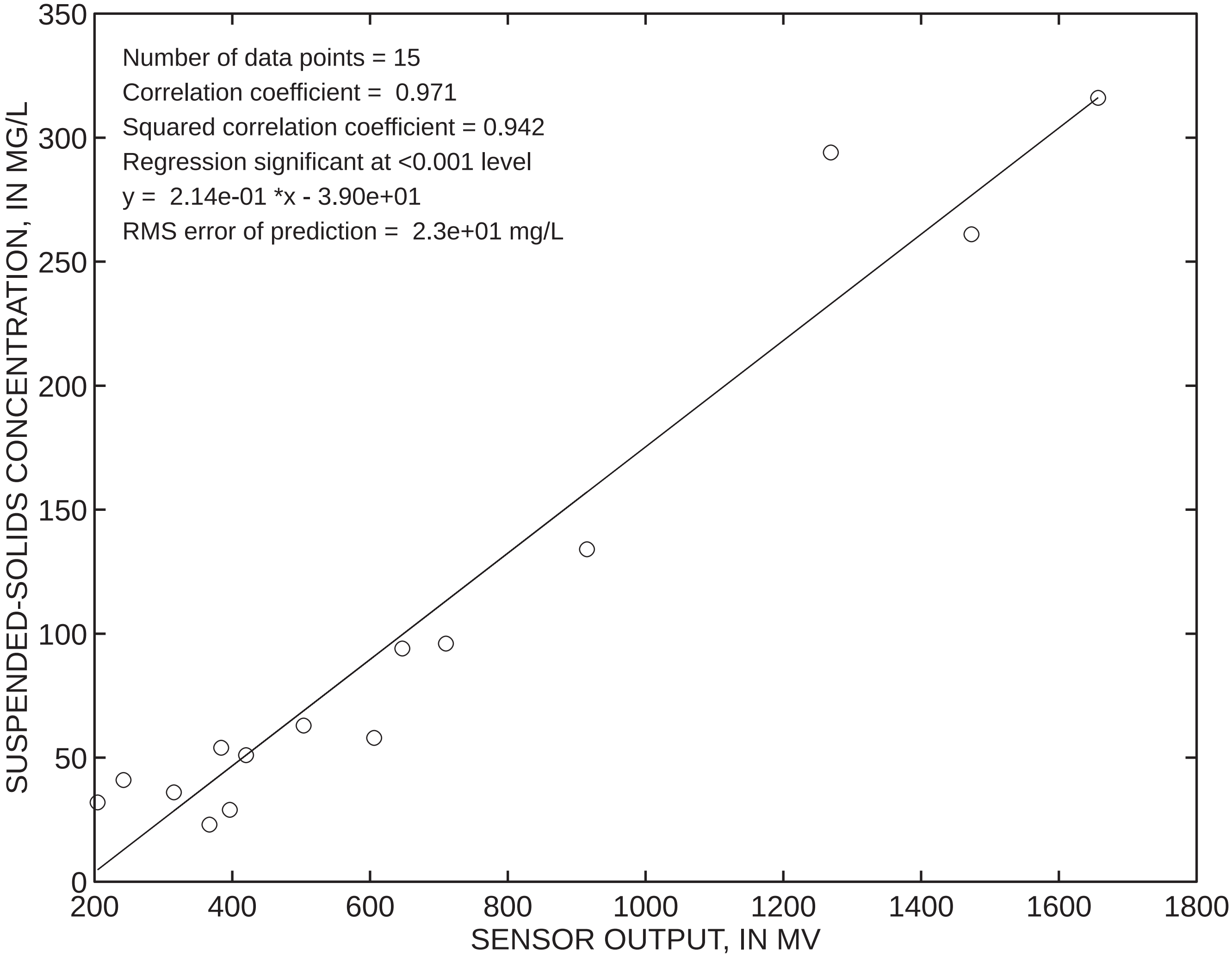

Figure 26. Calibration of mid-depth optical backscatterance sensor at Channel Marker 17, South San Francisco Bay, California, October 1–January 10, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

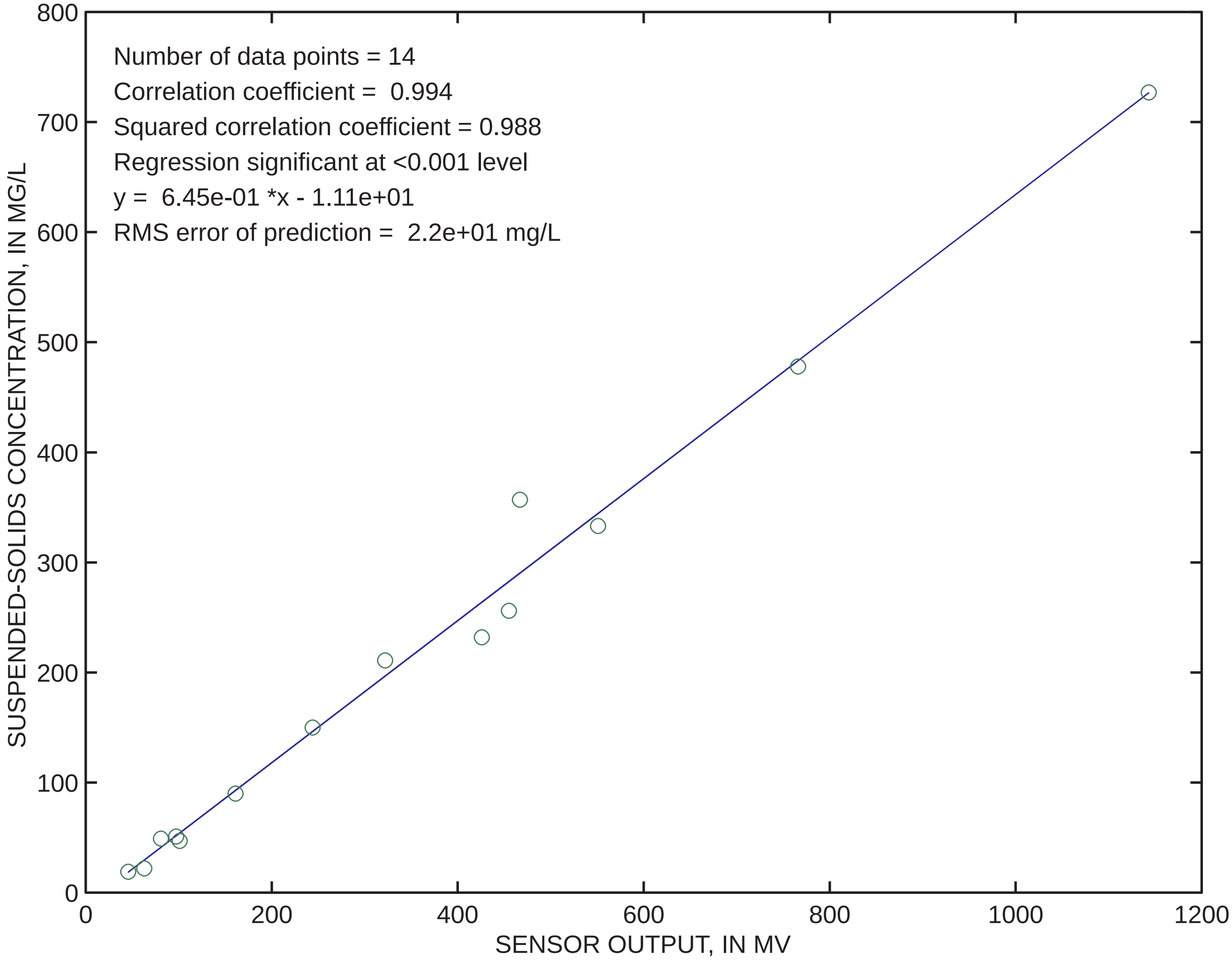

Figure 27. Calibration of mid-depth optical backscatterance sensor at Channel Marker 17, South San Francisco Bay, California, February 26–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

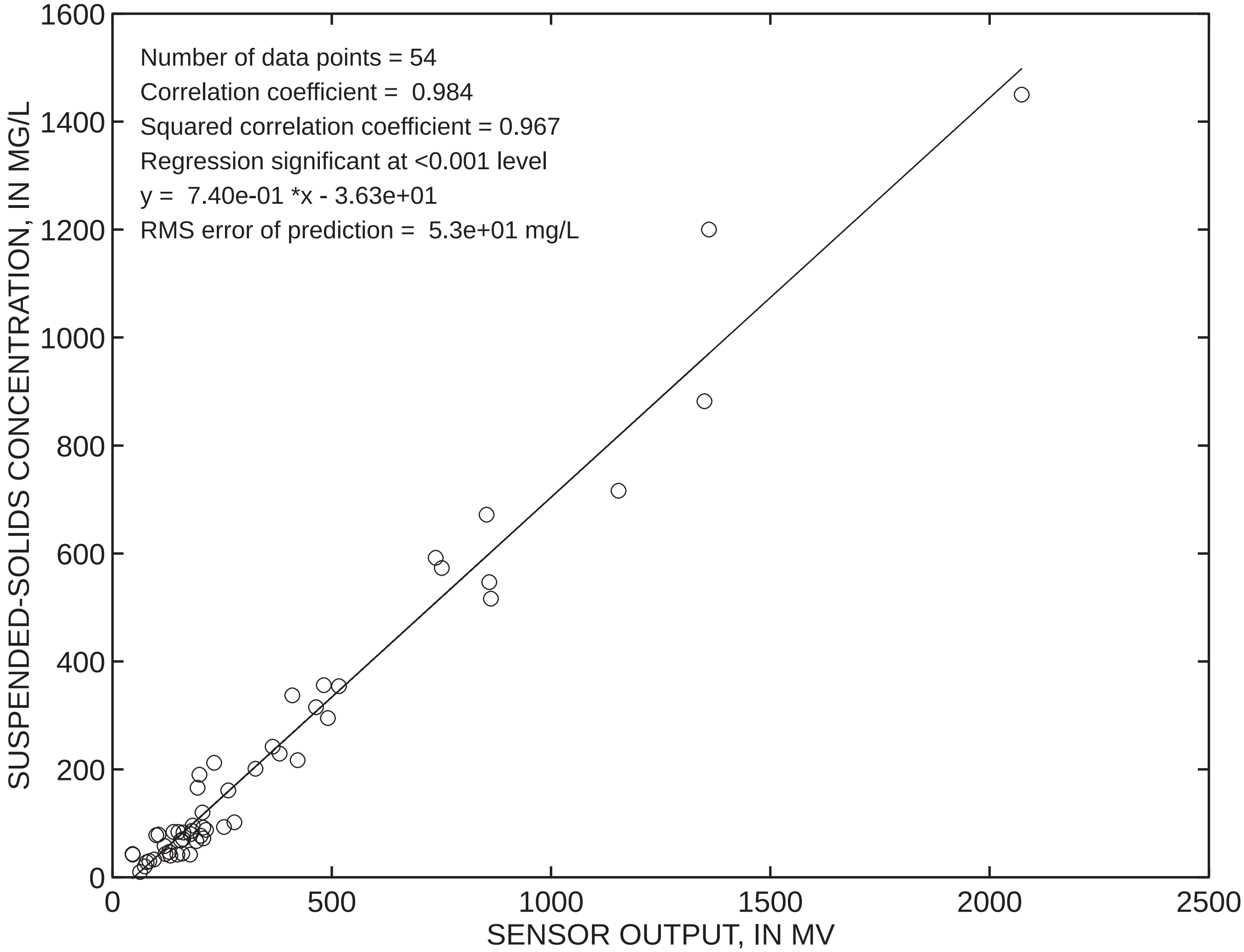

Figure 28. Calibration of near-bottom optical backscatterance sensor at Channel Marker 17, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

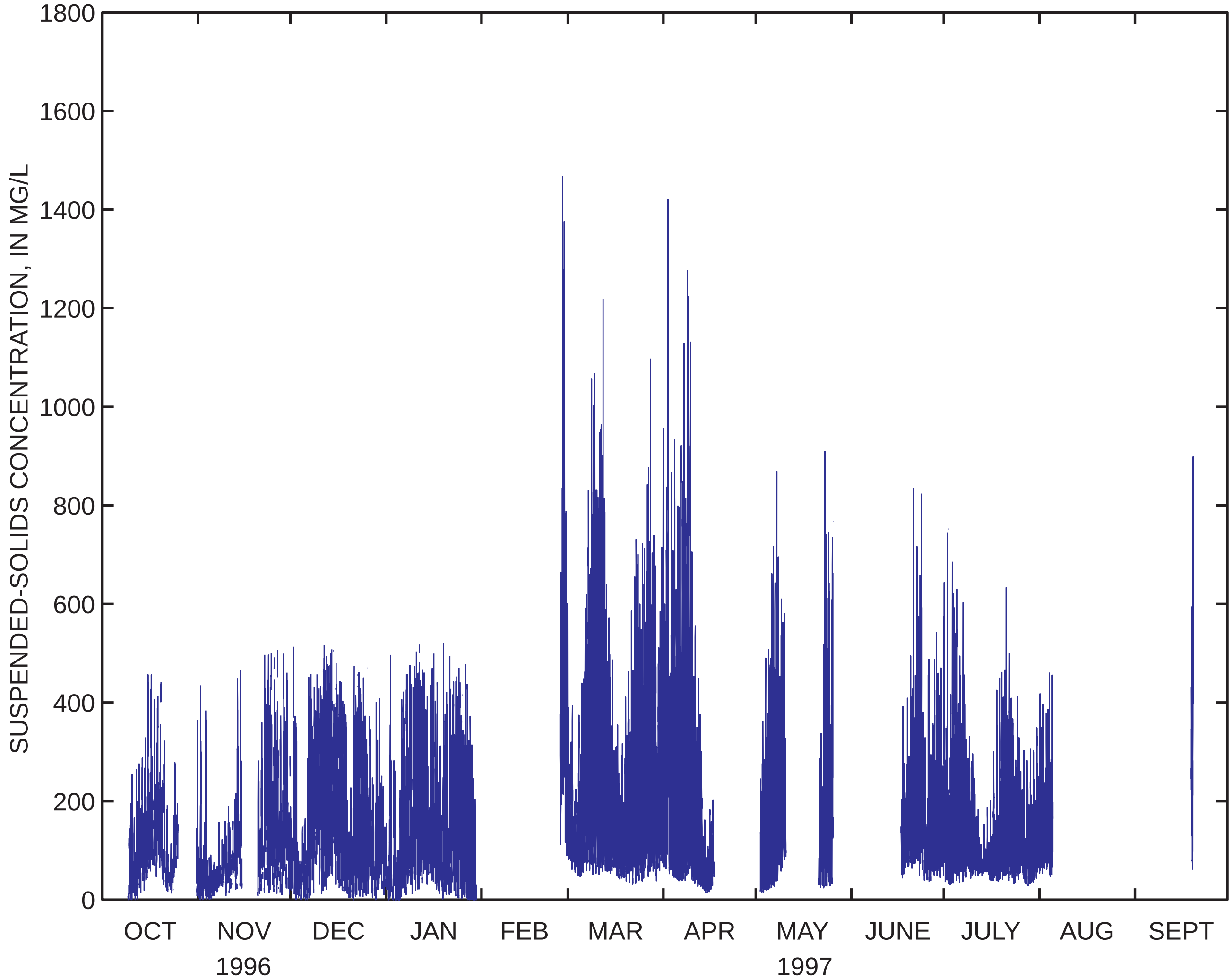

Figure 29. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

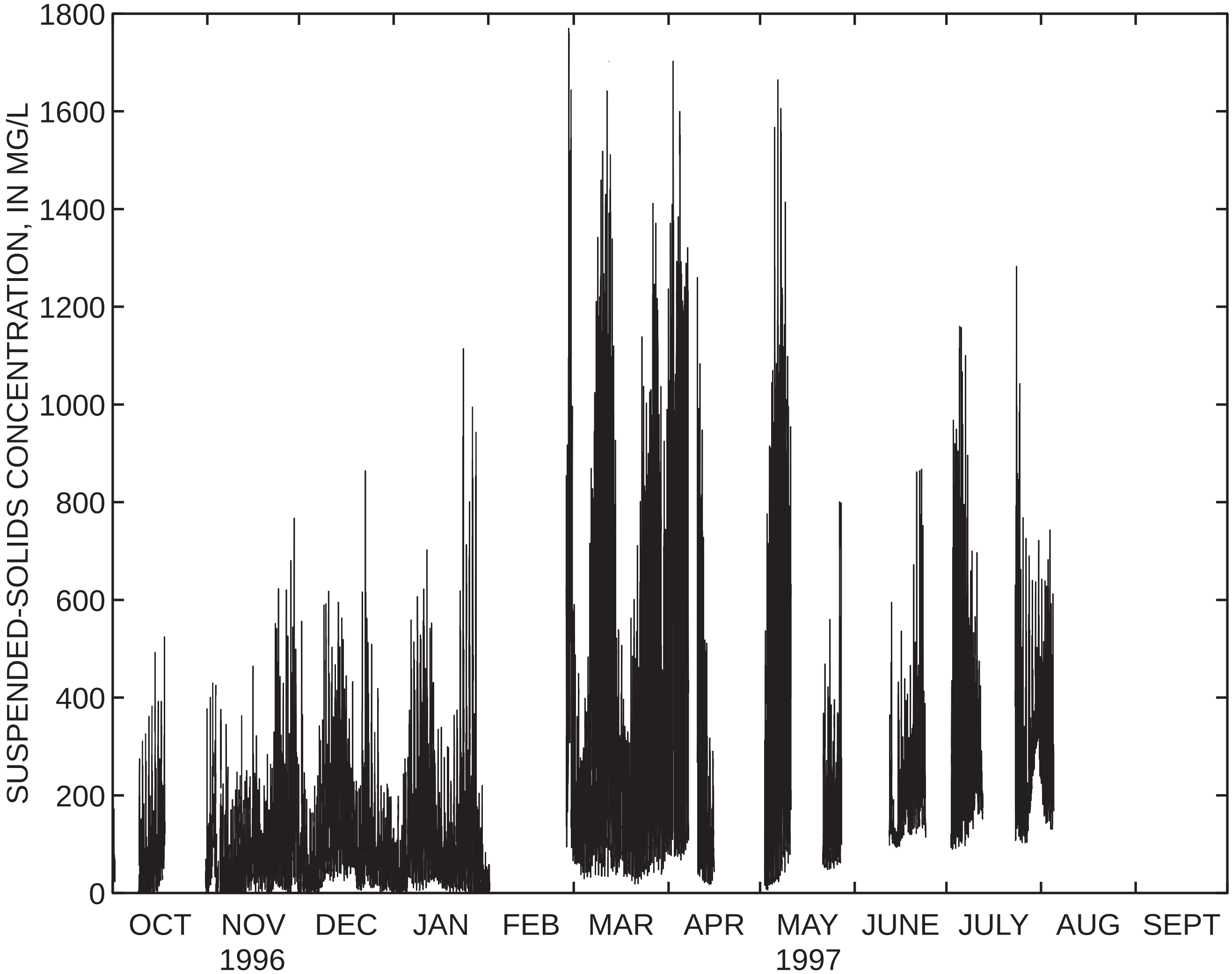

Figure 30. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

Dumbarton Bridge

The calibration of the mid-depth sensor was based on water samples collected from June 18, 1996, through September 30, 1997, and had a standard error of 20 mg/L (RMS; fig. 31). The calibration of the near-bottom sensor was based on water samples collected from October 12, 1995, through July 23, 1997, and had a standard error of 23 mg/L (RMS; fig. 32). The near-bottom sensor failed sometime in late July and was replaced on August 14, 1997. The calibration of the near-bottom replacement sensor was based on 27 samples, all but three that were collected using an autosampler that was deployed September 18–19, 1997, and had a standard error of 18 mg/L (RMS; fig. 33). Suspended-solids concentration data collected during water year 1997 are presented in figures 34 and 35.

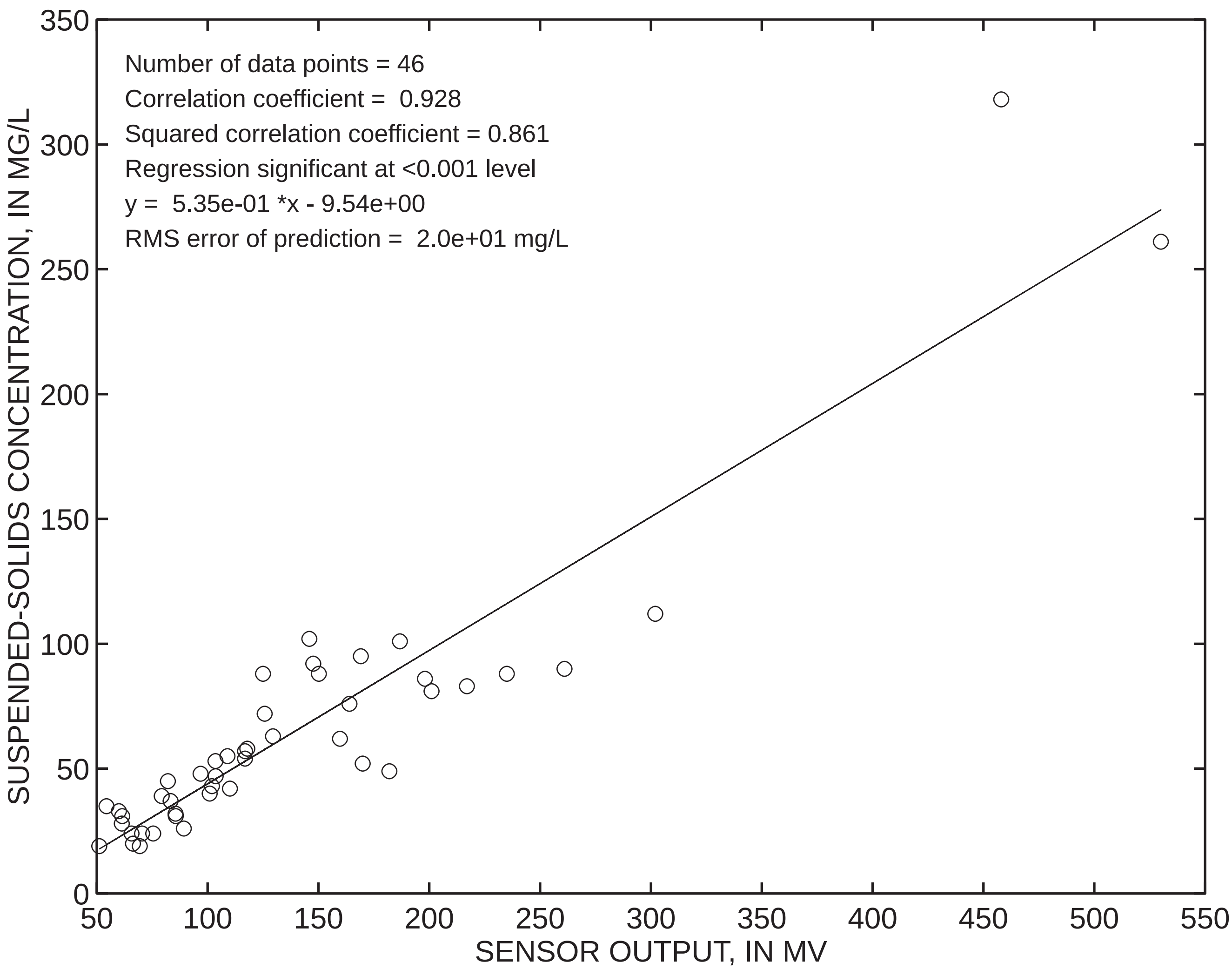

Figure 31. Calibration of mid-depth optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

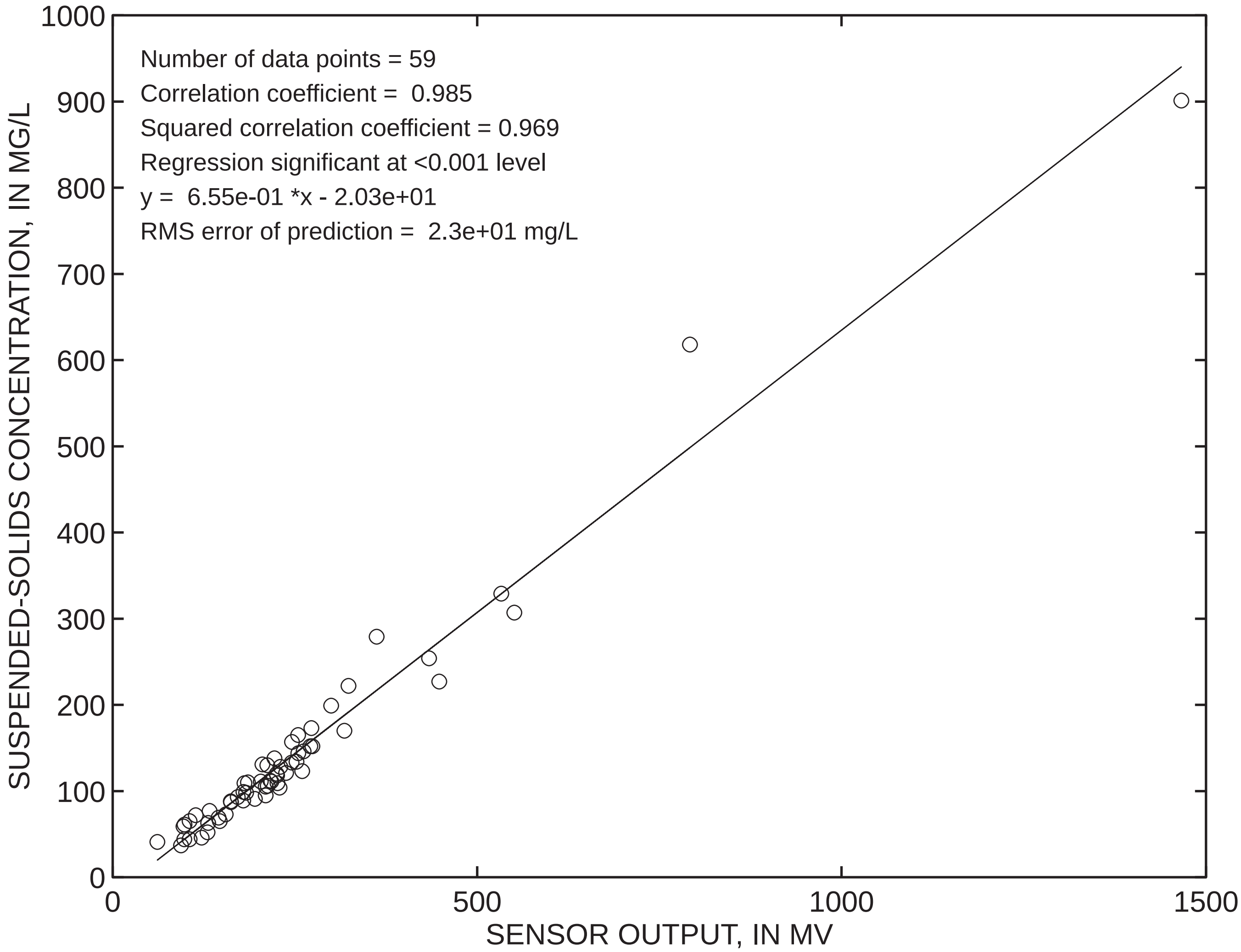

Figure 32. Calibration of near-bottom optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, October 1–August 13, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

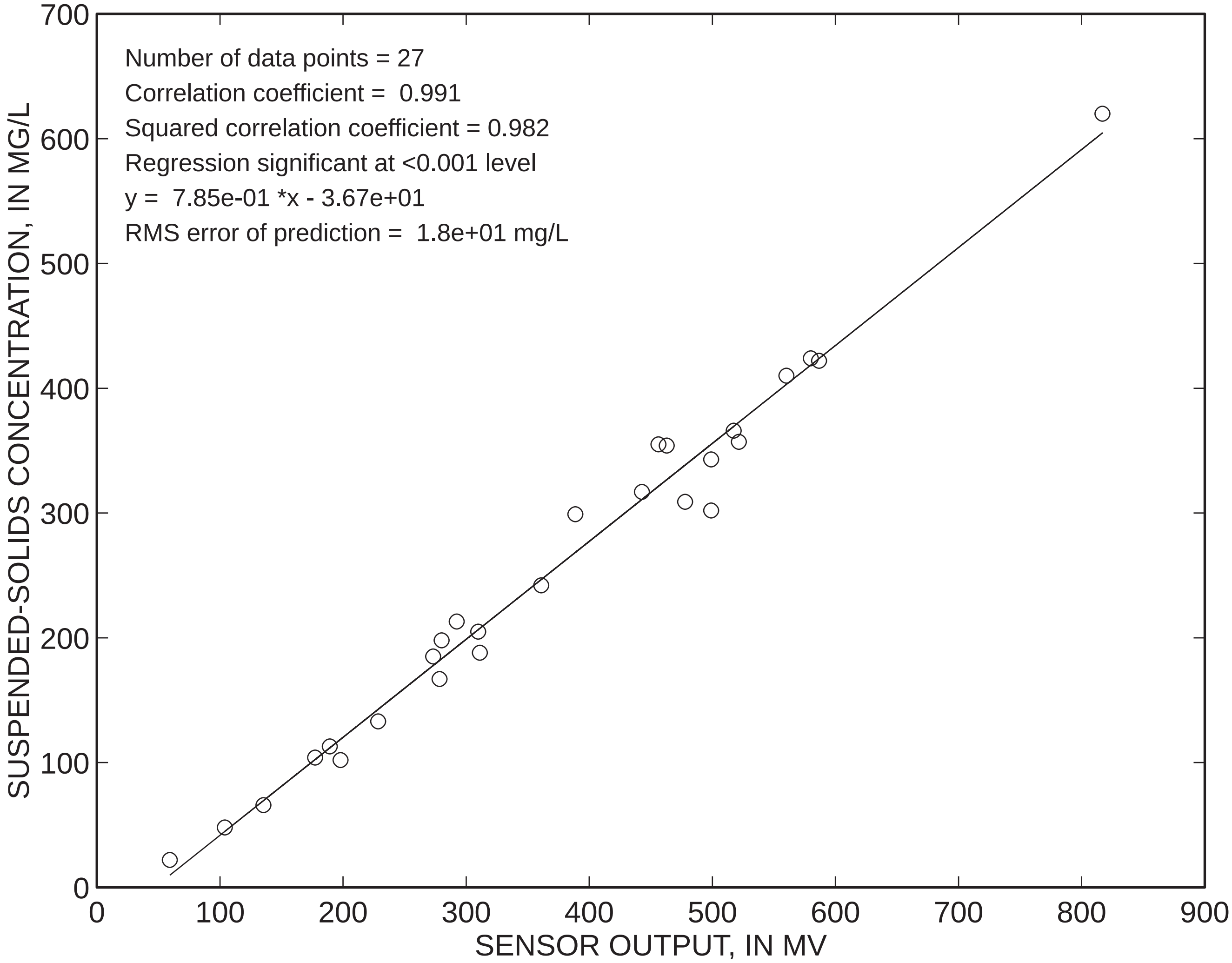

Figure 33. Calibration of near-bottom optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, August 14–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

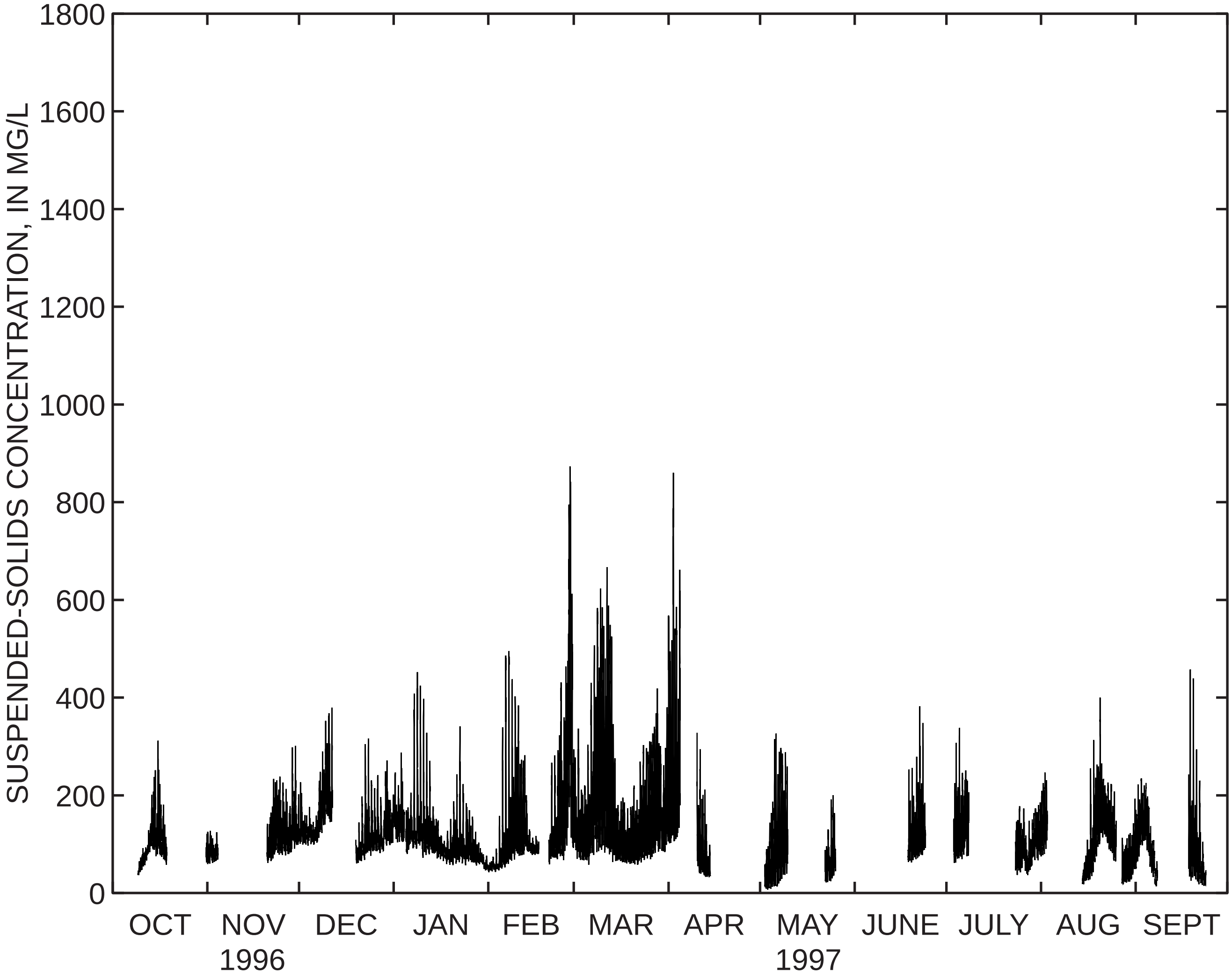

Figure 34. Time series of mid-depth suspended-solids concentration calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

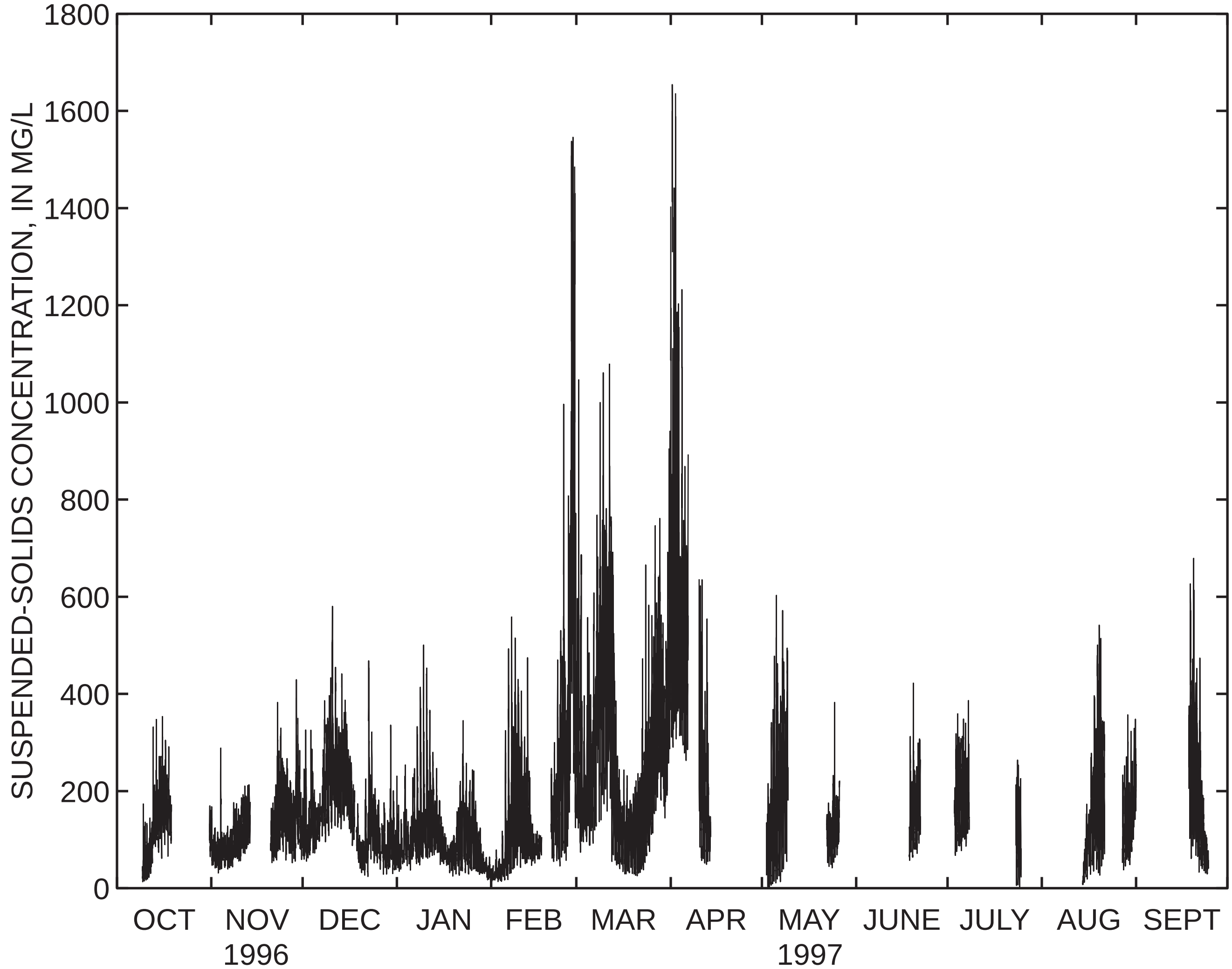

Figure 35. Time series of near-bottom suspended-solids concentration calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

San Mateo Bridge

The calibration of the mid-depth sensor was based on water samples collected from April 24, 1996, through January 10, 1997, and had a standard error of 7.4 mg/L (RMS; fig. 36). The record prior to March 13, 1997, is considered poor due to the few calibration samples over a small range of concentrations. On March 13, 1997, the gain was changed on the mid-depth sensor. A second calibration of the mid-depth sensor was based on water samples collected from March 13 through September 30, 1997, and had a standard error of 9.6 mg/L (RMS; fig. 37). The calibration of the near-bottom sensor was based on water samples collected from January 11, 1996, through water year 1997 and had a standard error of 13 mg/L (RMS; fig. 38). A shift of -117 mV, based on one water sample not shown on figure 38, was applied to the record for August 14–27, 1997, to correct for a shift in sensor output. Suspended-solids concentration data collected during water year 1997 are presented in figures 39 and 40.

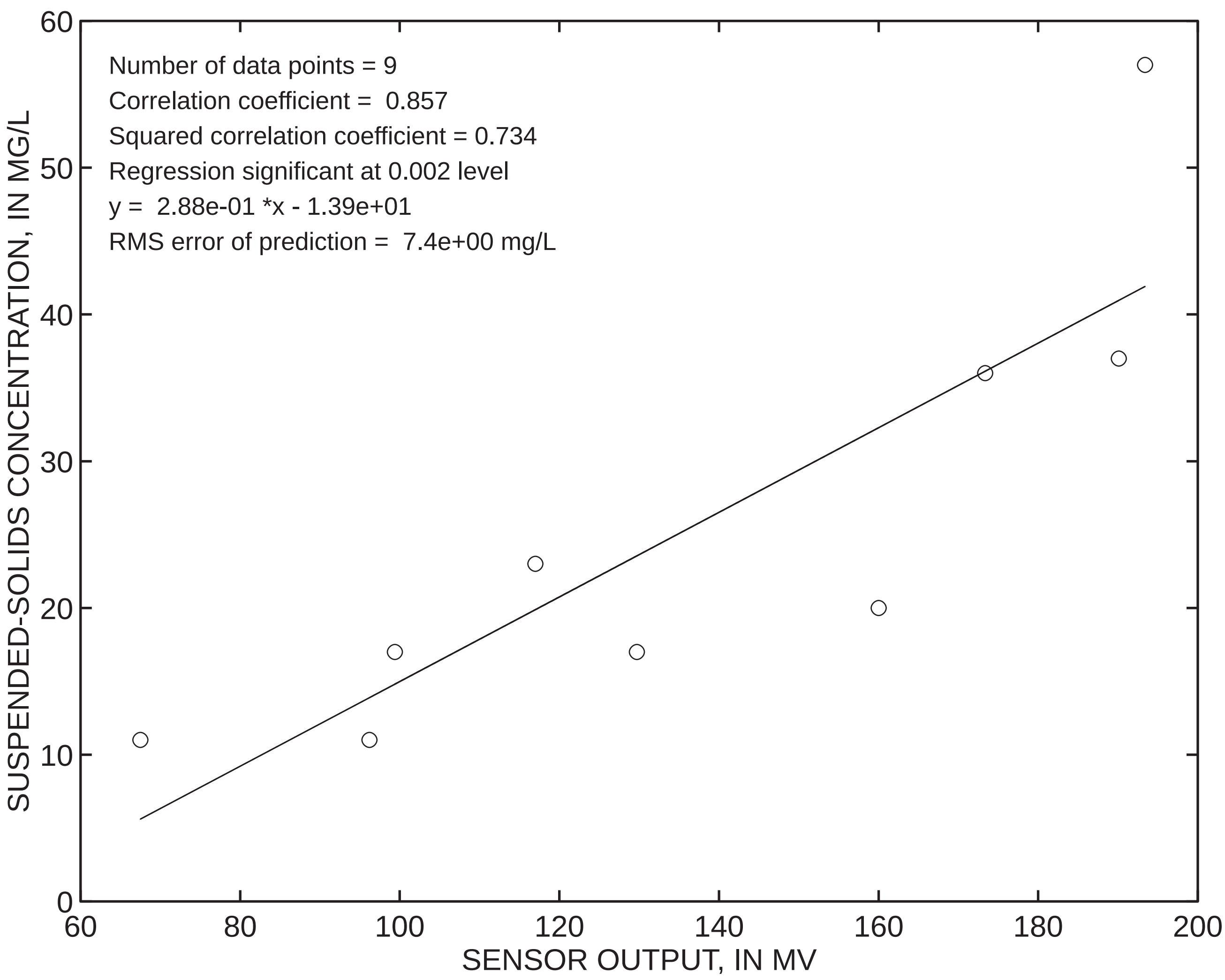

Figure 36. Calibration of mid-depth optical backscatterance sensor at San Mateo Bridge, South San Francisco Bay, California, October 1–March 12, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

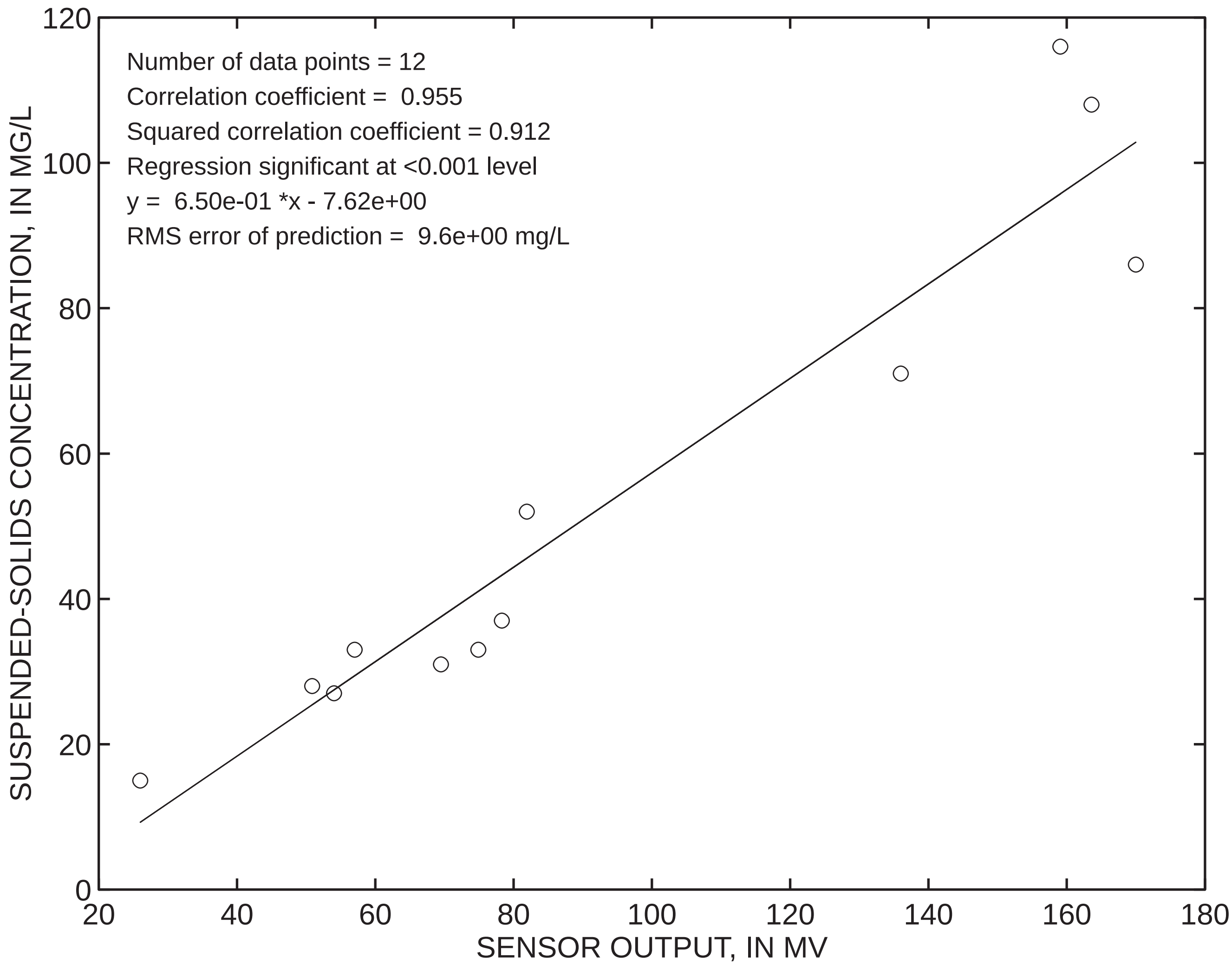

Figure 37. Calibration of mid-depth optical backscatterance sensor at San Mateo Bridge, South San Francisco Bay, California, March 13–September 30, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

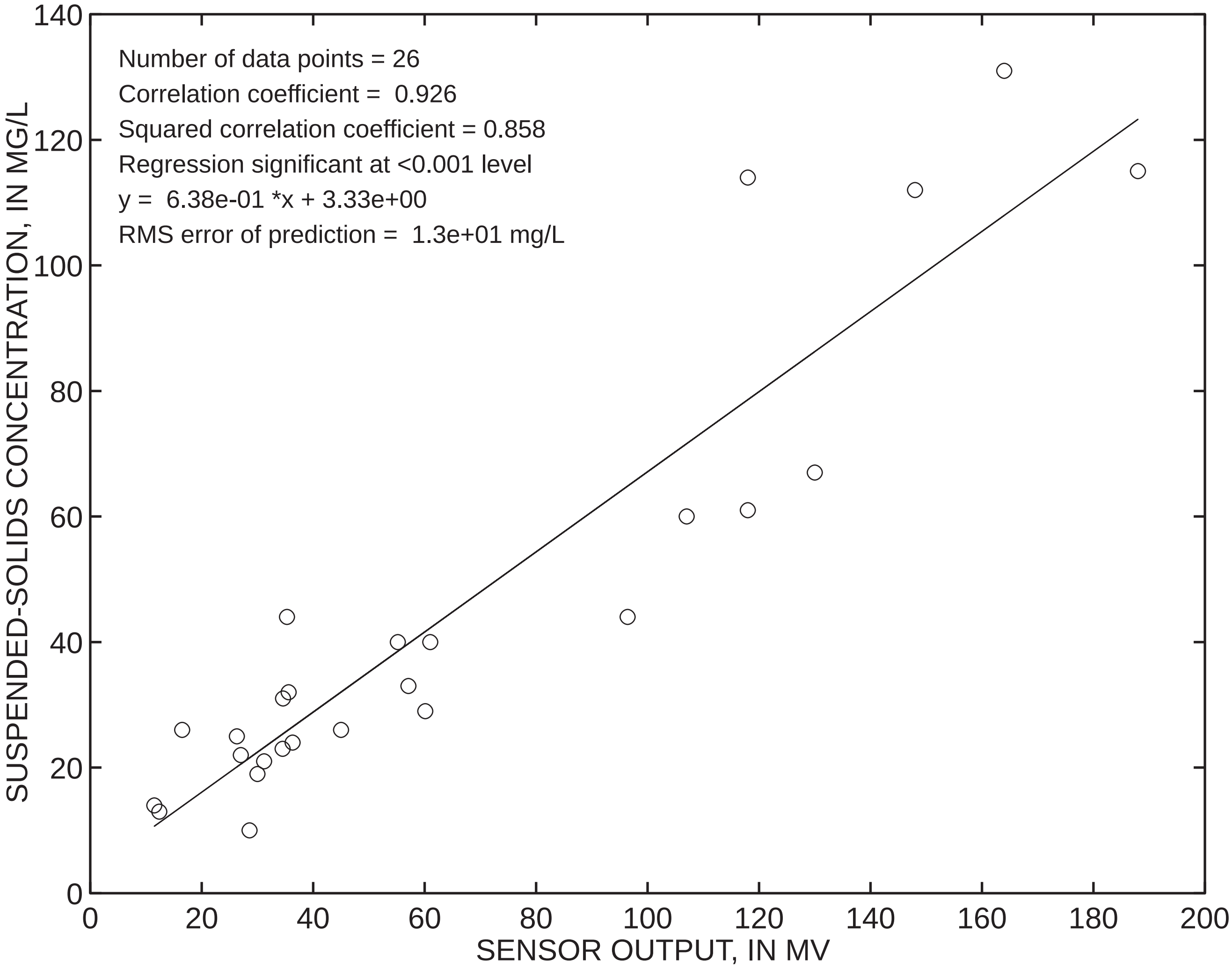

Figure 38. Calibration of near-bottom optical backscatterance sensor at San Mateo Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter; mV, millivolt.

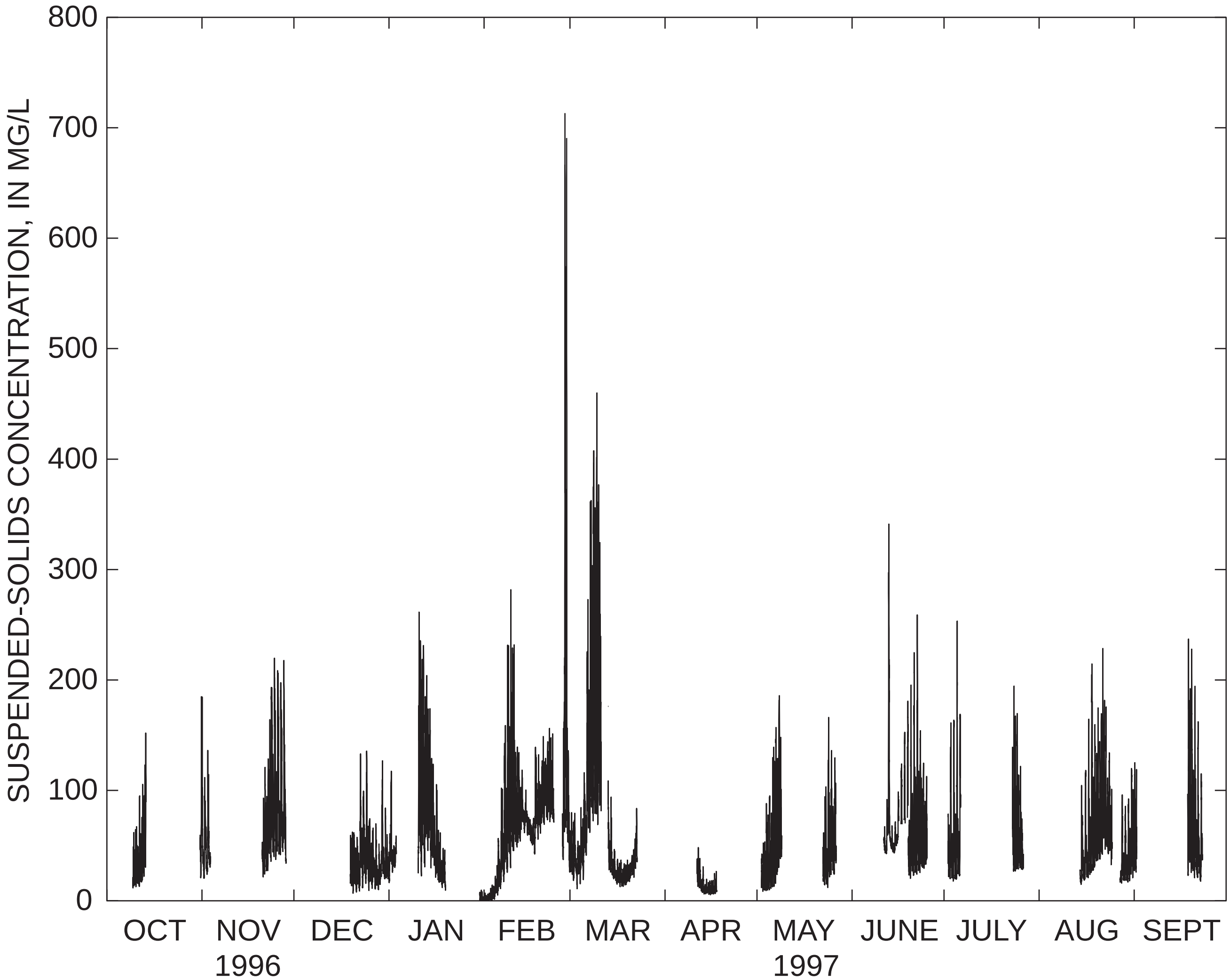

Figure 39. Time series of mid-depth suspended-solids concentration calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

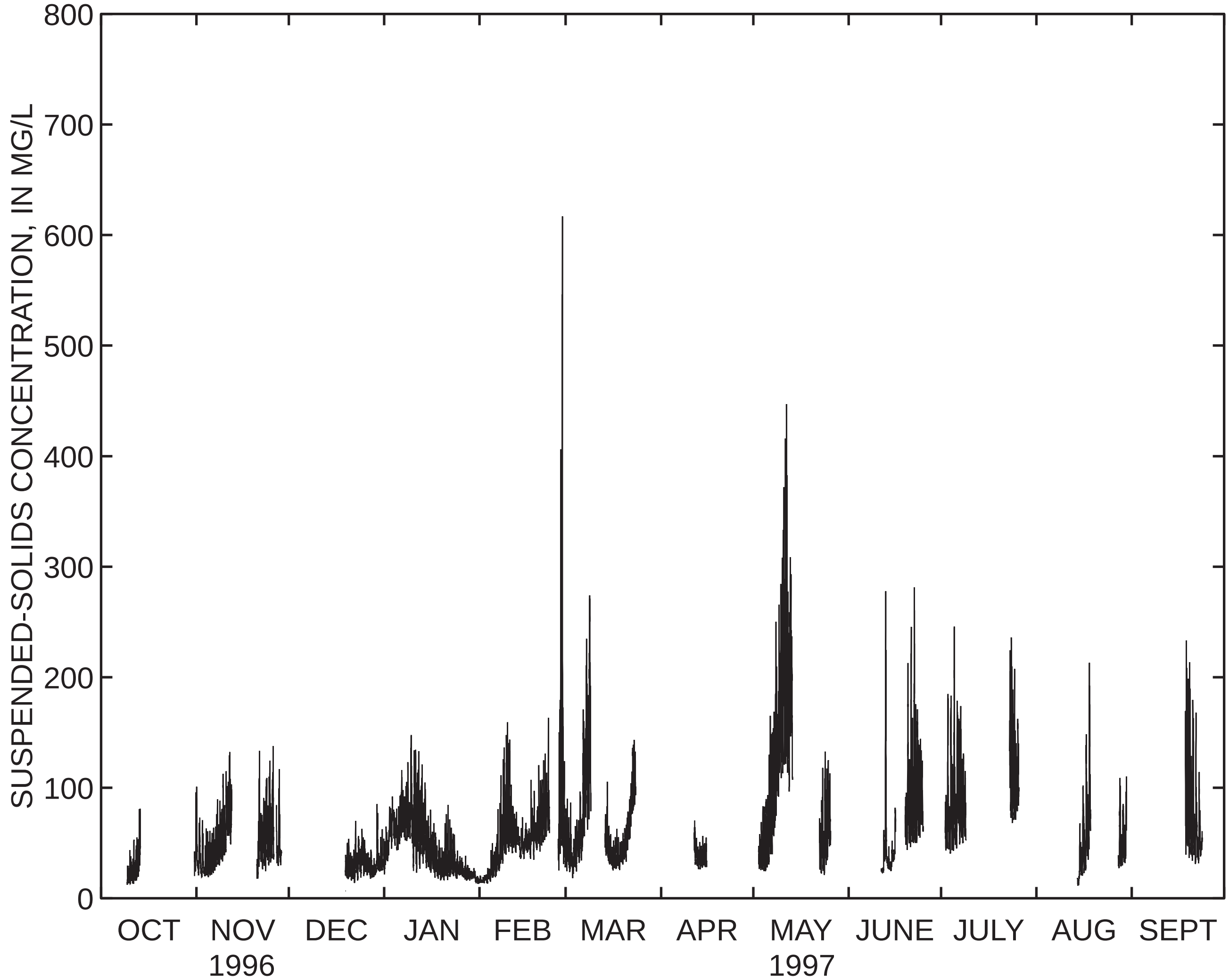

Figure 40. Time series of near-bottom suspended-solids concentration calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 1997. Mg/L, milligrams per liter.

SUMMARY

Suspended-solids concentration data were collected by the U.S. Geological Survey (USGS) at two sites in Suisun Bay, three sites in Central San Francisco Bay, and three sites in South San Francisco Bay during water year 1997. Two types of optical backscatterance sensors that were 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 40 percent of the data were invalidated by fouling. Suspended-solids concentration data are available from the files of the USGS in Sacramento, California.

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