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Summary of Suspended–Sediment Concentration Data, San Francisco Bay, California, Water Year 2002

Open-File Report 2004–1219

U.S. Department of the Interior
U.S. Geological Survey

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By Paul A. Buchanan and Neil K. Ganju

3009-52

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Conversion Factors, Datum, and Abbreviations and Acronyms

Multiply	By	To obtain
foot (ft)	0.3048	meter
foot per second (ft/s)	.3048	meter
inch (in.)	25.4	millimeter

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88); horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27).

Mean lower low water (MLLW): The average of the lower low water height, in feet, of each tidal day observed during 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 during which tide observations are taken and reduced to obtain mean values.

Abbreviations and Acronyms

ADAPS	automated data-processing system
Ah	ampere hour
DC	direct current
DWR	California Department of Water Resources
mg/L	milligram per liter
mV	millivolt
NTU	nephelometric turbidity units
PI_{np}	nonparametric prediction interval
PVC	polyvinyl chloride
RMS	root-mean-squared (error)
SSC	suspended-sediment concentration
USCG	U.S. Coast Guard
USGS	U.S. Geological Survey
V	volt
WY	water year (October 1-September 30)

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Abstract

Suspended-sediment concentration data were collected in San Francisco Bay during water year 2002 (October 1, 2001–September 30, 2002). Optical backscatterance sensors and water samples were used to monitor suspended-sediment concentration at two sites in Suisun Bay, three sites in San Pablo Bay, two 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 analyzed for concentrations of suspended sediment. The results of the analyses were used to calibrate the electrical output of the optical backscatterance sensors so that a record of suspended-sediment concentrations could be derived. This report presents the data-collection methods used and summarizes the suspended-sediment concentration data collected from October 2001 through September 2002. Calibration curves 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 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). Large tidal velocities, spring tides, and wind waves in shallow water all are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 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 suspended-sediment concentration (SSC) usually marks the position of the turbidity maximum—a crucial ecological zone where 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; Schoellhamer, 2001).

Suspended sediments limit the penetration of light into San Francisco Bay, which affects photosynthesis and primary phytosynthetic carbon production (Cole and Cloern, 1987; Cloern, 1987, 1996). Sediments also deposit in ports and shipping channels, which then require dredging to maintain navigation (U.S. Environmental Protection Agency, 1992). The U.S. Geological Survey (USGS), in cooperation with the CALFED Bay-Delta Program, and the U.S. Army Corps of Engineers, is studying the factors that affect SSC in San Francisco Bay.

Purpose and Scope

This report summarizes SSC data collected by the USGS in San Francisco Bay during water year (WY) 2002 and is the latest in a series based on data collected beginning in WY 1992 (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others; 1996; Buchanan and Ruhl, 2000, 2001; Buchanan and Ganju, 2002, 2003). Collection of SSC data in San Francisco Bay required development of monitoring methods and calibration techniques that are presented in this report. SSC were monitored at two sites in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay. These data were used to determine the factors that affect SSC in San Francisco Bay (U.S. Geological Survey, accessed April 19, 2004). SSC data for WY 1992 through 2002 also are available online from the U.S. Geological Survey (accessed May 31, 2004).

Study Area

San Francisco Bay (*fig. 1*) comprises 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 of about 5.5 feet (ft) in Suisun Bay, 6.5 ft at the Golden Gate and Central Bay, and about 10 ft in South Bay. The tides also follow 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 (Cheng and Gartner, 1984; Smith, 1987). Winds typically are strongest in summer during afternoon, onshore sea breezes. Most precipitation occurs from late autumn to early spring, and freshwater discharge into San Francisco Bay is greatest in the spring due to runoff from snowmelt. About 90 percent of the discharge into the Bay is from the Sacramento-San Joaquin River Delta, which drains the Central Valley of California (Smith, 1987).

Typically, discharge from the Delta contains over 60 percent of the fluvial sediments that enter the Bay (McKee and others, 2002), though this percentage varies from year to year. 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 areas (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).

Acknowledgments

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

The CALFED Bay/Delta Program, USGS Place-based Program, and the U.S. Army Corps of Engineers, as part of the San Francisco Estuary Regional Monitoring Program for Trace Substances, supported collection of these data.

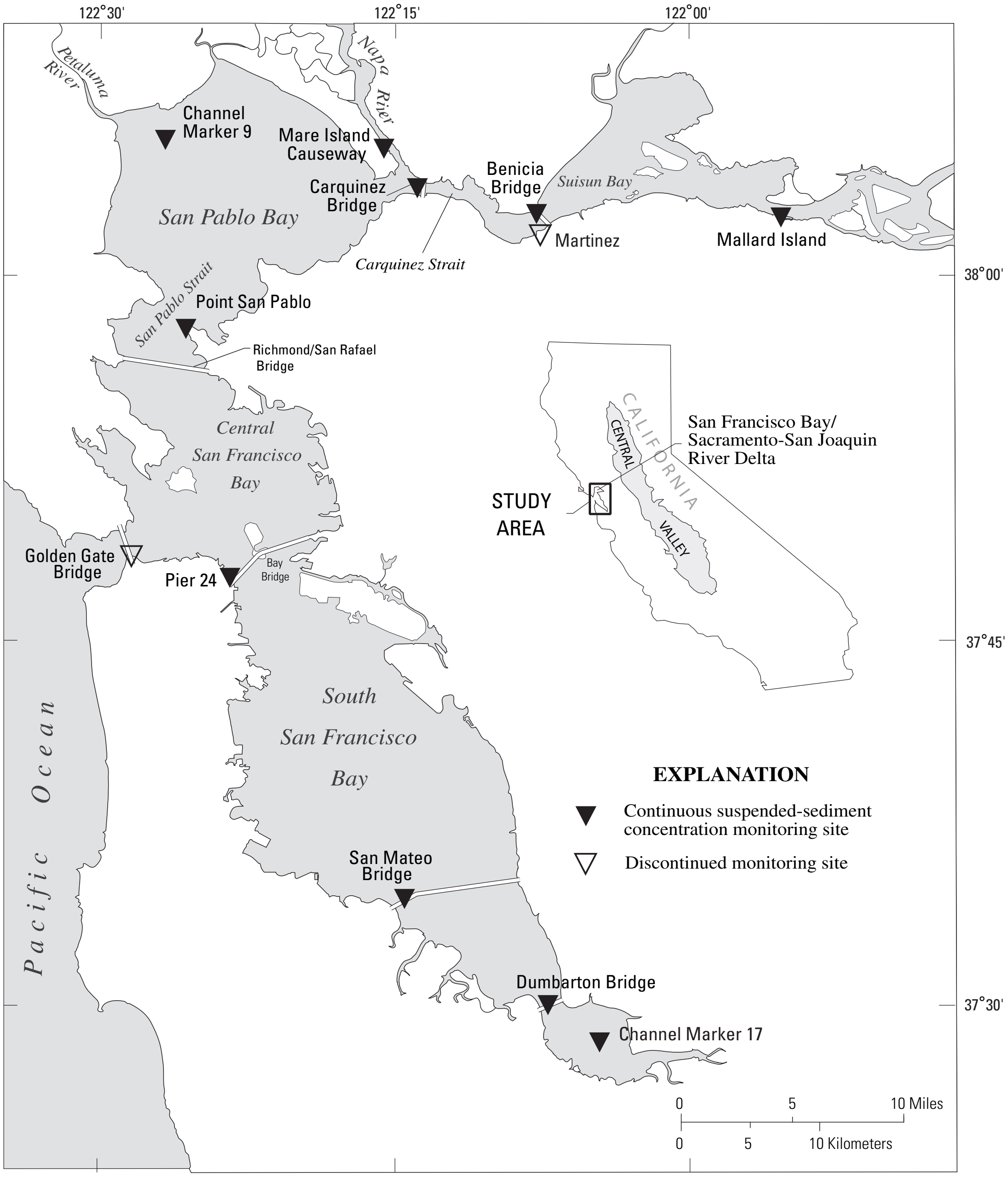

Figure 1. San Francisco Bay study area, California.

Methods

Instrument Description and Operation

Three different types of optical backscatterance sensors were used to monitor SSC during WY 2002. The first type of sensor is manufactured by D & A Instrument Company and is a cylinder approximately 7 inches (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 that 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 a field of 140–165 degrees (D & A Instrument Company, 1991), which is converted to a voltage output and recorded on a separate data logger. The second type of sensor, manufactured by BTG, is self-cleaning and differs from the D & A sensor in that it measures the intensity of light scattered at 90 degrees from two light-emitting diodes and each sensor has a separate electronic unit that sets the resolution and maximum reading, expressed in nephelometric turbidity units (NTU). The voltage output from the electronic unit is recorded on a separate data logger. The third type of sensor, manufactured by Hydrolab, is part of a multiprobe that also measures specific conductance, temperature, and depth. The Hydrolab optical sensor measures the intensity of light scattered at 90 degrees from two light-emitting diodes and is expressed in NTU. The multiprobe (sonde) is self-contained, including a power source and data logger.

The output for all three types of sensors is proportional to the SSC in the water column at the depth of the sensor. SSC calculated from the output of side-by-side sensors with and without the self-cleaning function (BTG and D & A Instrument Company) are virtually identical (Buchanan and Schoellhamer, 1998). Calibration of the sensor voltage output to SSC will vary according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated using suspended material from the field (Levesque and Schoellhamer, 1995).

Optical sensors were positioned in the water column using polyvinyl chloride (PVC) pipe carriages coated with an antifoulant paint to impede biological growth. 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 sensors to be easily raised and lowered for servicing (*fig. 2*). Optical sensor depths in the water column are listed in *table 1*. The plane of the optical window maintained a position parallel to the direction of flow as the carriage and sensor aligned itself with the changing direction of flow.

Data acquisition was controlled by an electronic data logger. The logger was programmed to power the optical sensor every 15 minutes, collect data each second for 1 minute, 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, except for the sonde, which used eight size-C alkaline batteries.

Biological growth (fouling) interferes with the collection of accurate optical backscatterance data. 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 similar on both sensors. Optical sensors required frequent cleaning but, due to the difficulty in servicing some of the monitoring stations, they were cleaned every 1–5 (usually 3) weeks. 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 spring and summer.

Self-cleaning optical sensors with wipers were deployed at two sites in Suisun Bay and at two sites in South Bay during WY 1994 to reduce biological fouling. The self-cleaning sensors were effective in keeping optical ports clean at the Suisun Bay sites, but were ineffective at the two sites in South Bay due to extreme biological growth on the carriage and wiper mechanism. During WY 1995, all self-cleaning sensors deployed in South Bay failed due to salt crystals forming on an O-ring, which resulted in water leakage. In WY 1996, an updated version of the self-cleaning sensor was deployed at the Dumbarton Bridge site in South Bay, but it failed within the first month of operation. Thereafter, the self-cleaning sensors were used only at the less saline Mallard Island site in Suisun Bay.

On-site checks of sensor accuracy were performed using turbidity solutions prepared from a 4,000-nephelometric turbidity unit formazin standard. Formazin is an aqueous suspension of an insoluble polymer and is the primary turbidity standard (Greenberg and others, 1992). The turbidity solutions were prepared by diluting a 4,000-nephelometric turbidity unit stock standard with de-ionized water in a clean, sealable bucket. Prepared solutions ranged from 50 to 200 NTU. At the field site, the cleaned sensors are immersed in the solution and the voltage output is recorded on the station log. Monitoring a period of sensor performance in a known standard helps to identify output drift or sensor malfunction.

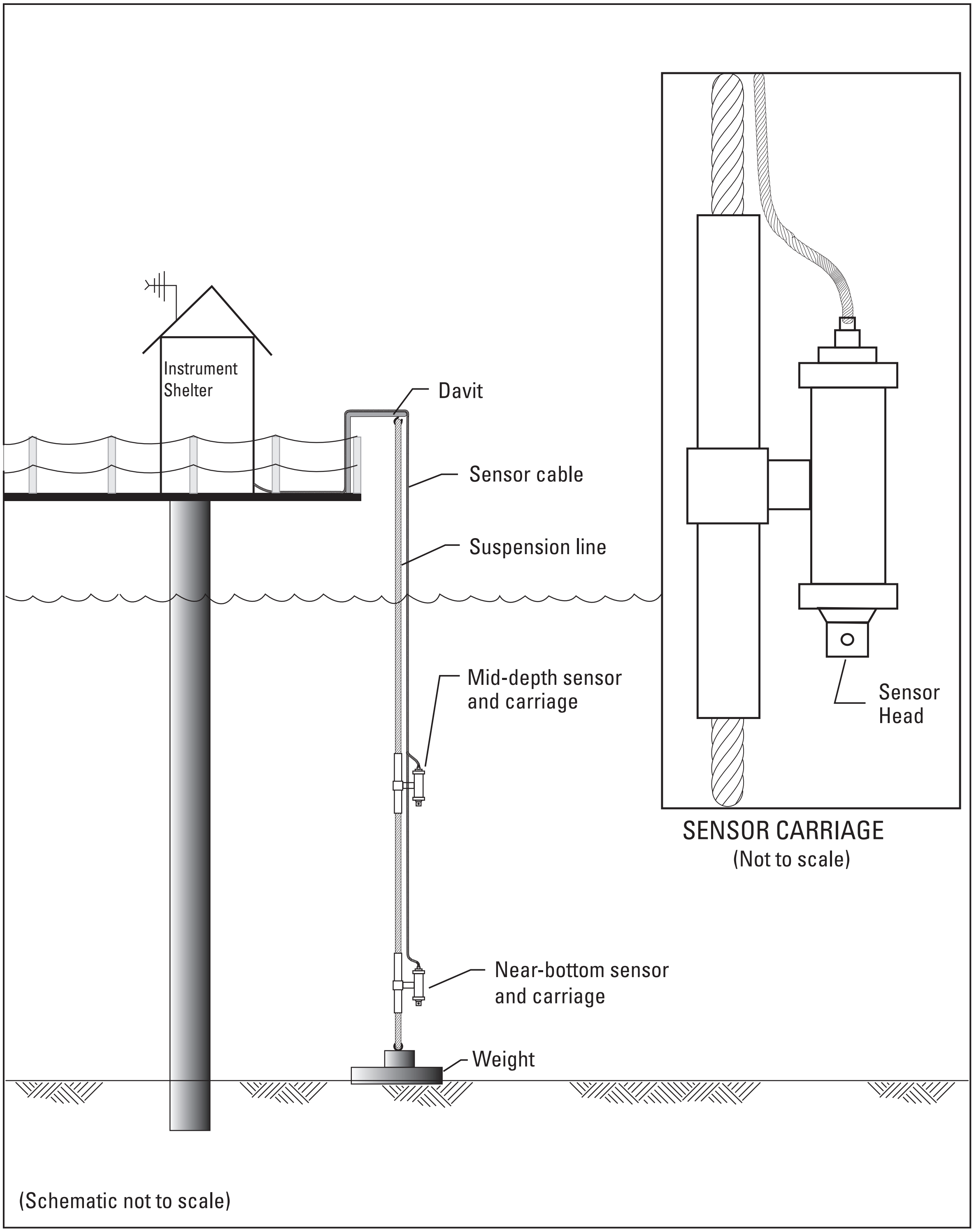

Figure 2. Typical monitoring installation, San Francisco Bay study.

Table 1. Optical sensor depths (in feet) below mean lower low water (MLLW), Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2002.

[For definition of MLLW, see Vertical Datum entry at front of this report]

Site	Station No.	Latitude	Longitude	Sensor depth	Depth below MLLW	MLLW
Mallard Island	11185185	38°02′34″	121°55′09″	Near-surface	3.3	25
				Near-bottom	20	
Benicia Bridge	11455780	38°02′42″	122°07′32″	Near-surface	6	80
				Near-bottom	55	
Carquinez Bridge	11455820	38°03′41″	122°13′23″	Mid-depth	40	88
				Near-bottom	83	
Mare Island Causeway	11458370	38°06′40″	122°16′25″	Mid-depth	15	30
				Near-bottom	25	
Channel Marker 9	380519122262901	38°05′19″	122°26′29″	Near-bottom	4	6
Point San Pablo	11181360	37°57′53″	122°25′42″	Mid-depth	13	26
				Near-bottom	23	
Pier 24	11162700	37°47′27″	122°23′05″	Mid-depth	18	41
				Near-bottom	38	
San Mateo Bridge	11162765	37°35′04″	122°14′59″	Mid-depth	19	48
				Near-bottom	40	
Dumbarton Bridge	373015122071000	37°30′15″	122°07′10″	Mid-depth	22	45
				Near-bottom	41	
Channel Marker 17	372844122043800	37°28′44″	122°04′38″	Mid-depth	12	25
				Near-bottom	22	

Monitoring Sites

Suisun Bay Installations

SSC data were collected in Suisun Bay at Mallard Island and Benicia Bridge (*fig. 1*, *table 1*). Optical sensors with wipers were installed at the DWR Mallard Island Compliance Monitoring Station on February 8, 1994. Optical sensors without wipers were deployed off of Pier 7 on the Benicia Bridge on March 15, 1996. This Benicia Bridge site was shut down in WY 1998 for seismic retrofitting of the bridge and was reestablished with sondes equipped with optical, conductance, and temperature sensors on May 1, 2001. A monitoring site at the Martinez Marina fishing pier was discontinued in WY 1996 because data from the Benicia Bridge site were considered more representative of SSC in the Carquinez Strait area of Suisun Bay (Buchanan and Schoellhamer, 1998).

San Pablo Bay Installations

SSC data were collected in Carquinez Strait at Carquinez Bridge, Napa River at Mare Island Causeway, and San Pablo Bay at Channel Marker 9 (*fig. 1*, *table 1*). Sondes with optical, conductance, and temperature sensors were deployed off the center pier structure at Carquinez Bridge on April 21, 1998. Optical sensors without wipers were deployed off a catwalk beneath Mare Island Causeway on October 1, 1998. A sonde with optical, conductance, and temperature sensors was deployed off of USCG Channel Marker 9 on November 12, 1998.

Central San Francisco Bay Installations

SSC data were collected in San Pablo Strait at Point San Pablo and San Francisco Bay at Pier 24 (*fig. 1*, *table 1*). Optical sensors without wipers were deployed at San Pablo Strait on the northern end of the Richmond Terminal no. 4 pier on the western side of Point San Pablo on December 1, 1992. The station at Point San Pablo was shut down on January 2, 2001, and reestablished on December 11, 2001, off a pier-adjacent structure approximately 25 ft from the previous deployment site. Optical sensors without wipers were installed at Pier 24 on the western end of the San Francisco-Oakland Bay Bridge on May 25, 1993. The Pier 24 station was discontinued on January 3, 2002. The USGS assumed operation of these stations from DWR in October 1989 (collection of conductivity and temperature data were cooperatively funded by DWR and the USGS). A monitoring station at the south tower of the Golden Gate Bridge was operational during water years 1996 and 1997. Conductivity and temperature data collected at Point San Pablo and Pier 24 prior to October 1, 1989, can be obtained from DWR.

South San Francisco Bay Installations

SSC data were collected in South San Francisco Bay at San Mateo Bridge, Dumbarton Bridge, and USCG Channel Marker 17 (*fig. 1*, *table 1*). Optical sensors without wipers were deployed off of Pier 20 on the San Mateo Bridge, on the east side of the ship channel, on December 23, 1991. The USGS assumed operation of this station from DWR in October 1989 (collection of conductivity and temperature data were cooperatively funded by DWR and the USGS). Conductivity and temperature data collected at San Mateo Bridge prior to October 1, 1989, can be obtained from DWR. Optical sensors without wipers were deployed off of Pier 23 on the Dumbarton Bridge on the west side of the ship channel on October 21, 1992. Optical sensors without wipers were deployed at USCG Channel Marker 17 on February 26, 1992.

Water-Sample Collection

Water samples, used to calibrate the voltage output of the optical sensors to SSC, 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. After collection, the water sample was marked for identification and placed in an ice chest to limit biological growth. The SSC of water samples collected with a Van Dorn sampler and a P-72 point sampler, used until WY 1994, were virtually identical (Buchanan and others, 1996).

Samples were sent to the USGS Sediment Laboratory in Marina, California, for analysis of SSC. Suspended sediment includes all particles in the sample; the suspended particles that settle to the bottom of the sample bottle and buoyant particles that do not settle. Suspended-sediment concentrations were referred to as suspended-solids concentration in previous reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996; Buchanan and Ruhl, 2000, 2001). The analytical method used to quantify concentrations of suspended solid-phase material defines the nomenclature used to describe sediment data (Gray and others, 2000). Water samples collected for this study were analyzed for suspended-sediment concentration by filtering samples through a pre-tared 0.45-micrometer membrane filter. The filtrate was rinsed with de-ionized water to remove salts, and the insoluble material and filter were dried at 103°C and weighed (Fishman and Friedman, 1989).

Data Processing

Data loggers stored the voltage outputs from the optical sensors at 15-minute intervals (96 data points per day). 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 (except for the Hydrolab's optical sensor output, which decreased). An example time series of raw and edited optical backscatterance data is presented in *figure 3*. After sensors were cleaned, sensor output immediately decreased (*fig. 3A*: January 3, 29, and February 20). Efforts to correct for biofouling proved to be unsuccessful because the signal often was highly variable. Thus, data affected by biofouling often were unusable and were removed from the record (*fig. 3B*). Identifying the point at which fouling begins to affect optical backscatterance data is somewhat subjective. Indicators are used to help define the point at which fouling begins to take place such as an elevated baseline, increasingly variable signal, and comparisons with the other sensor at the site. 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. Sometimes, incomplete cleaning of a sensor would cause a small, constant shift in sensor output that could be corrected using water-sample data.

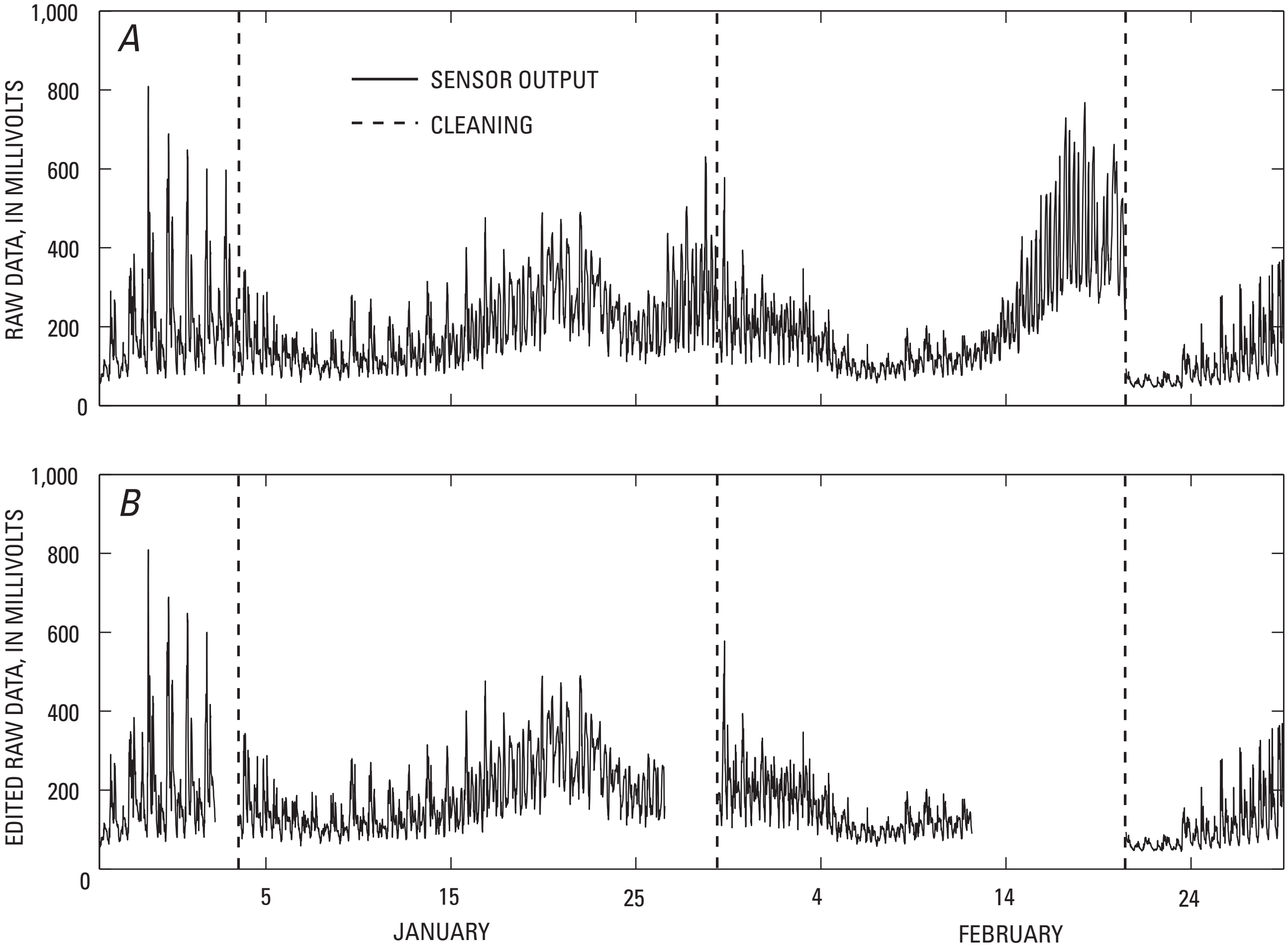

Figure 3. Example of (***A***) raw and (***B***) edited optical backscatterance data, mid-depth sensor, Channel Marker 17, South San Francisco Bay, California, water year 2002.

Sensor Calibration and Suspended-Sediment Concentration Data

The output from the optical sensors was converted to SSC by linear regression using the robust, nonparametric, repeated median method (Siegel, 1982). In addition, the prediction interval and the 95-percent confidence interval were calculated and presented for each calibration equation.

The repeated median method calculates the slope in a two-part process. First, for each point (X,Y), the median of all possible “point i” to “point j” slopes was calculated

$$\beta_i = median\frac{(Y_j - Y_i)}{(X_j - X_i)} \qquad \text{for all } j \neq i. \tag{1}$$

The calibration slope was calculated as the median of β_i

$$\text{slope} = \hat{\beta}_1 = median(\beta_i). \tag{2}$$

Finally, the calibration intercept was calculated as the median of all possible intercepts using the slope calculated above

$$\text{intercept} = \hat{\beta}_0 = median(Y_i - \hat{\beta}_1 X_i). \tag{3}$$

The final linear calibration equation is

$$Y = \hat{\beta}_1 X + \hat{\beta}_0. \tag{4}$$

The nonparametric prediction interval (PI_{np}) (Helsel and Hirsch, 1992, p. 76) is a constant-width error band that contains 68.26 percent, or one standard deviation, of the calibration data set. The 68.26 percent value was selected because essentially it has the same error prediction limits as the root-mean-squared (RMS) error of prediction in ordinary least–squared regression; the latter was used in previous data reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996) to analyze random sets of normally distributed data. The prediction interval describes the likelihood that a new observation comes from the same distribution as the previously collected data set.

The PI_{np}, unlike the RMS error of prediction, frequently is not symmetrical about the regression line. For example, the PI_{np} may be reported as +10 milligrams per liter (mg/L) and –7 mg/L. This asymmetry about the regression line is a result of the distribution of the data set. The PI_{np} is calculated by computing and sorting, from least to greatest, the residuals for each point. Then, based on the sorted list of residuals:

$$\text{nonparametric prediction interval} = PI_{np} = \hat{Y}_{\left(\frac{\alpha}{2}\right)(n+1)} \text{ to } \hat{Y}_{\left(1-\frac{\alpha}{2}\right)(n+1)}, \tag{5}$$

where

$\hat{Y}$ is the residual value,

n is the number of data points, and

α is the confidence level of 0.6826.

To calculate the confidence interval, all possible point-to-point slopes must be sorted in ascending order. Based on the confidence interval desired, 95-percent for the purposes of this report, the ranks of the upper and lower bounds are calculated as follows:

$$Ru = \left(\frac{\frac{n(n-1)}{2} + 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2} + 1 \right), \text{ and} \tag{6}$$

$$Rl = \frac{\frac{n(n-1)}{2} - 1.96\left(\sqrt{\frac{n(n-1)(2n+5)}{18}}\right)}{2} \quad , \tag{7}$$

where

Ru is the rank of the upper bound slope,

Rl is the rank of the lower bound slope, and

n is the number of samples.

To establish the 95-percent confidence interval, the ranks calculated above are rounded to the nearest integer and the slope associated with each rank in the sorted list is identified. This is a large-sample approximation and was used for each of the confidence intervals presented in this report. However, in the event that fewer than 10 samples had been collected, a direct calculation could be performed based on the methodology presented in Helsel and Hirsch (1992, p. 273–274).

A statistical summary of the SSC, calculated from optical backscatterance data, is presented in *table 2*. The usable percentage of a complete year of valid data (96 data points per day × 365 days) for each site is presented in *table 2*.

This section of the report also includes the robust regression (calibration) plots for optical sensor output versus SSC (in milligrams per liter). The repeated median regression plots include the number of water samples (all water samples used to develop calibration, including those from previous water years), the calculated linear correlation equation, the nonparametric prediction interval (shown on the plots as a grey band), and the 95-percent confidence interval (shown on the plots as a dash-dot line). In addition, the time-series plots of calculated SSC data are shown for each site.

Table 2. Statistical summary of calculated suspended-sediment concentration data and percent valid data for the water year (96 data points per day × 365 days) collected using optical backscatterance sensors, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2002.

[All values are in milligrams per liter except percent valid data. Lower quartile is 25th percentile; upper quartile is 75th percentile]

Site	Depth	Mean	Median	Lower quartile	Upper quartile	Percent valid data
Mallard Island	Near-surface	36	34	29	41	66
	Near-bottom	58	55	43	70	78
Benicia Bridge	Near-surface	29	21	13	37	41
	Near-bottom	70	54	33	93	67
Carquinez Bridge	Mid-depth	39	27	19	48	64
	Near-bottom	54	39	25	69	88
Mare Island Causeway	Mid-depth	53	42	27	67	66
	Near-bottom	126	94	53	169	59
Channel Marker 9	Near-bottom	110	69	39	132	48
Point San Pablo	Mid-depth	32	27	21	37	57
	Near-bottom	46	39	29	55	56
Pier 24	Mid-depth	20	18	15	22	59
	Near-bottom	32	27	20	39	54
San Mateo Bridge	Mid-depth	54	47	34	65	39
	Near-bottom	75	67	43	96	42
Dumbarton Bridge	Mid-depth	70	57	41	85	49
	Near-bottom	98	76	53	120	50
Channel Marker 17	Mid-depth	80	61	35	103	41
	Near-bottom	88	64	35	112	38

Suisun Bay

Mallard Island

PERIOD OF CALIBRATION.—
NEAR-SURFACE SENSOR (*A*): October 1, 2001, to July 31, 2002 (*fig. 4A*).
NEAR-SURFACE SENSOR (*B*): September 23, 2002, through WY 2002 (*fig. 4B*).
NEAR-BOTTOM SENSOR: WY 2001 (*fig. 5*).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
NEAR-SURFACE SENSOR (*A*): 40 (23 from WY 2002).
NEAR-SURFACE SENSOR (*B*): 14 (2 from WY 2002).
NEAR-BOTTOM SENSOR: 176 (26 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
NEAR-SURFACE SENSOR (*A*): SSC = 0.216 *mV + 10.6.
NEAR-SURFACE SENSOR (*B*): SSC = 0.274 *mV + 9.2.
NEAR-BOTTOM SENSOR: SSC = 0.510 *mV − 9.6.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-SURFACE SENSOR (*A*): + 12 to − 6 mg/L.
NEAR-SURFACE SENSOR (*B*): + 8 to − 3 mg/L.
NEAR-BOTTOM SENSOR: + 9 to − 8 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. Sensors were positioned at near-surface (attached to float assembly) and near-bottom depths to coincide with DWR near-surface pump intake and the near-bottom electrical conductance and temperature sensors. The near-surface sensor malfunctioned on July 31, 2002. A replacement sensor deployed on August 7 was found damaged on August 30, 2002, and an insufficient number of water samples were collected to develop a calibration. A second replacement sensor was deployed on September 23, 2002, and was calibrated using water samples collected mostly in WY 2003 to help define the calibration. The calculated SSC time-series data collected during WY 2002 are presented in *figure 6*.

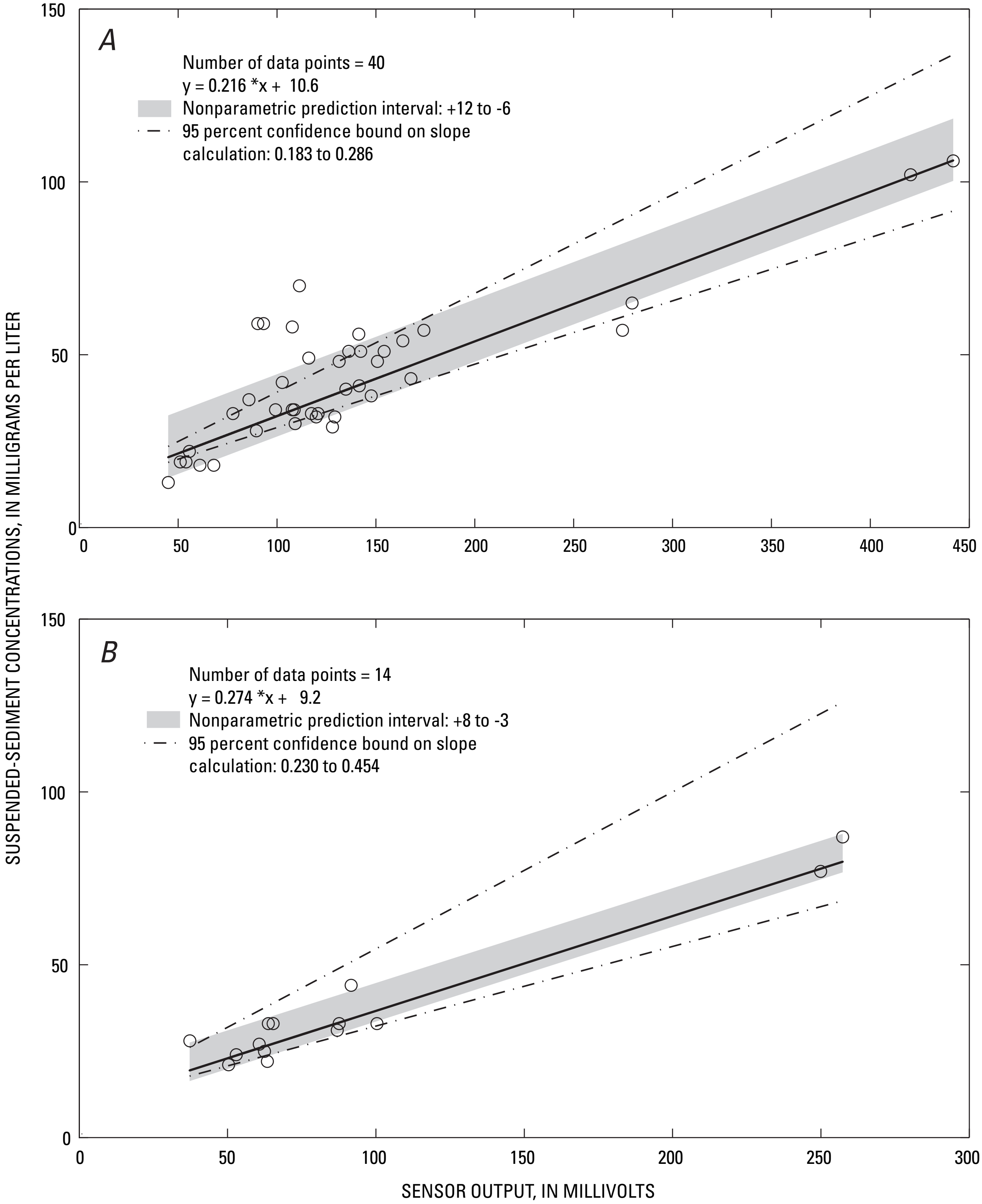

Figure 4. Calibration of near-surface optical backscatterance sensor, (***A***) October 1–July 31 and (***B***) September 23–September 30 at Mallard Island, Suisun Bay, California, water year 2002.

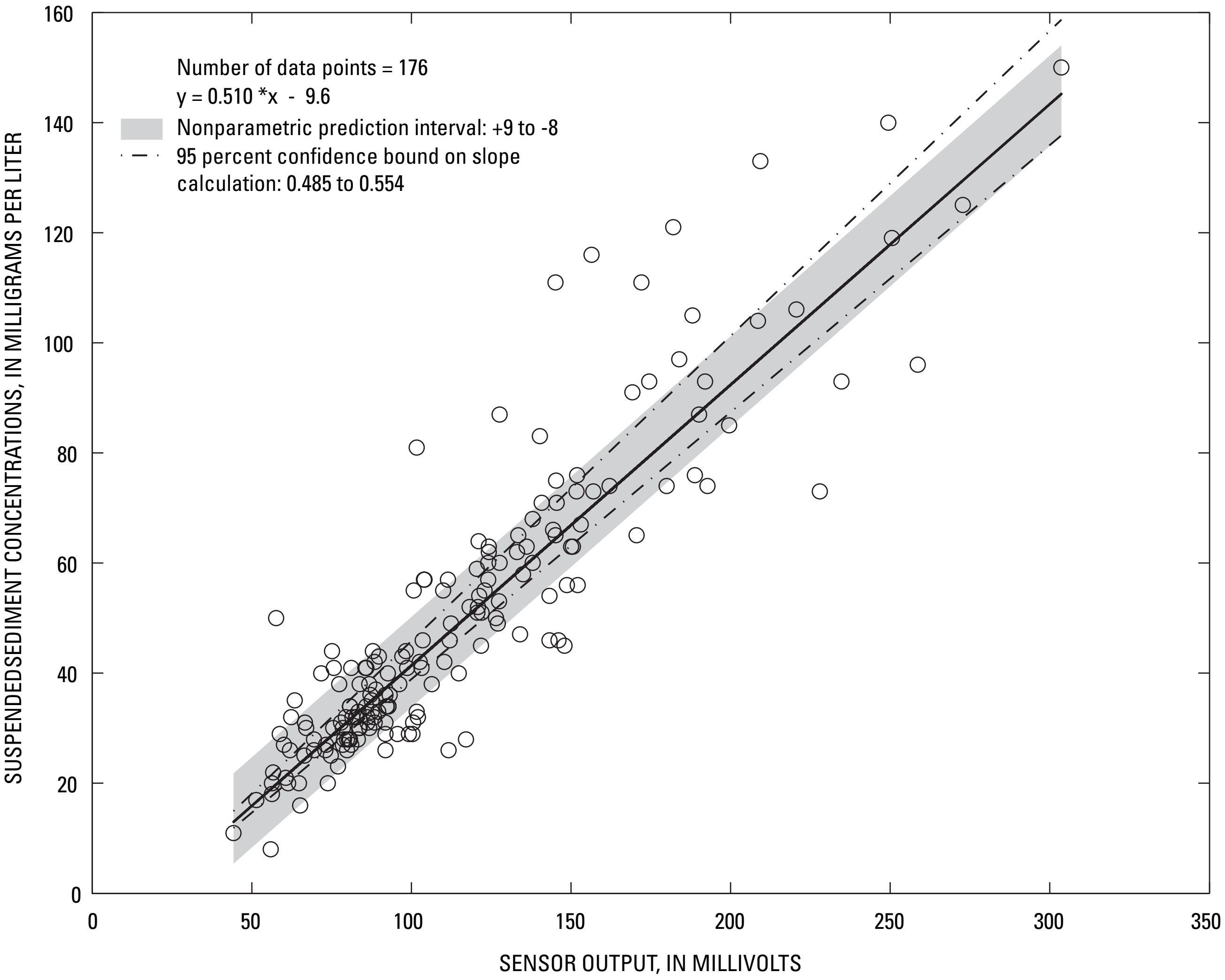

Figure 5. Calibration of near-bottom optical backscatterance sensor at Mallard Island, Suisun Bay, California, water year 2002.

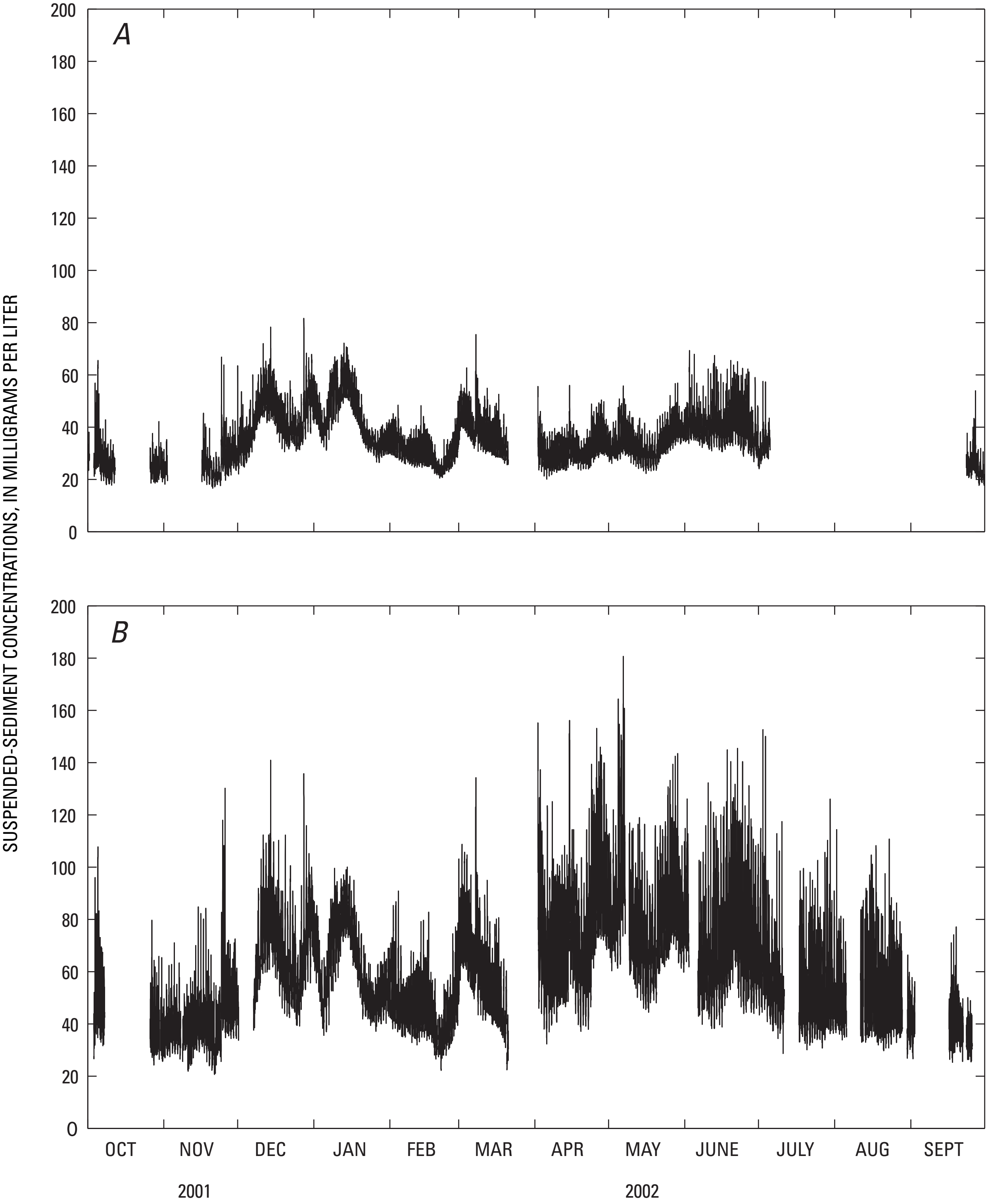

Figure 6. Time series of (***A***) near-surface and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 2002.

Benicia Bridge

PERIOD OF CALIBRATION.—

NEAR-SURFACE SENSOR: May 1, 2001, through WY 2002 (*fig. 7A*).

NEAR-BOTTOM SENSOR: May 1, 2001, through WY 2002 (*fig. 7B*).

NUMBER OF DATA POINTS.—

NEAR-SURFACE SENSOR: 22 (17 from WY 2002).

NEAR-BOTTOM SENSOR: 29 (23 from WY 2002).

CALCULATED LINEAR CORRELATION EQUATION.—

NEAR-SURFACE SENSOR: SSC = 1.030 *NTU + 1.0.

NEAR-BOTTOM SENSOR: SSC = 1.221 *NTU + 0.7.

NONPARAMETRIC PREDICTION INTERVAL.—

NEAR-SURFACE SENSOR: + 10 to − 10 mg/L.

NEAR-BOTTOM SENSOR: + 9 to − 24 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments and seismic work on the bridge. MLLW was approximately 80 ft at the site but approximately 60 ft immediately adjacent, therefore, the near-bottom sonde was set approximately 25 ft above the bottom so that the data are representative of the surrounding area. Several different sensors were used in both the near-surface and near-bottom locations. Because the different sensors (all Hydrolab DS-4's) responded similarly to the uniform sediment characteristics found in San Francisco Bay (Schoellhamer and others, 2003), calibrations were developed by combining water samples collected during each sensor deployment for both the near-surface and near-bottom locations. The calculated SSC time-series data collected during WY 2002 are presented in *figure 8*.

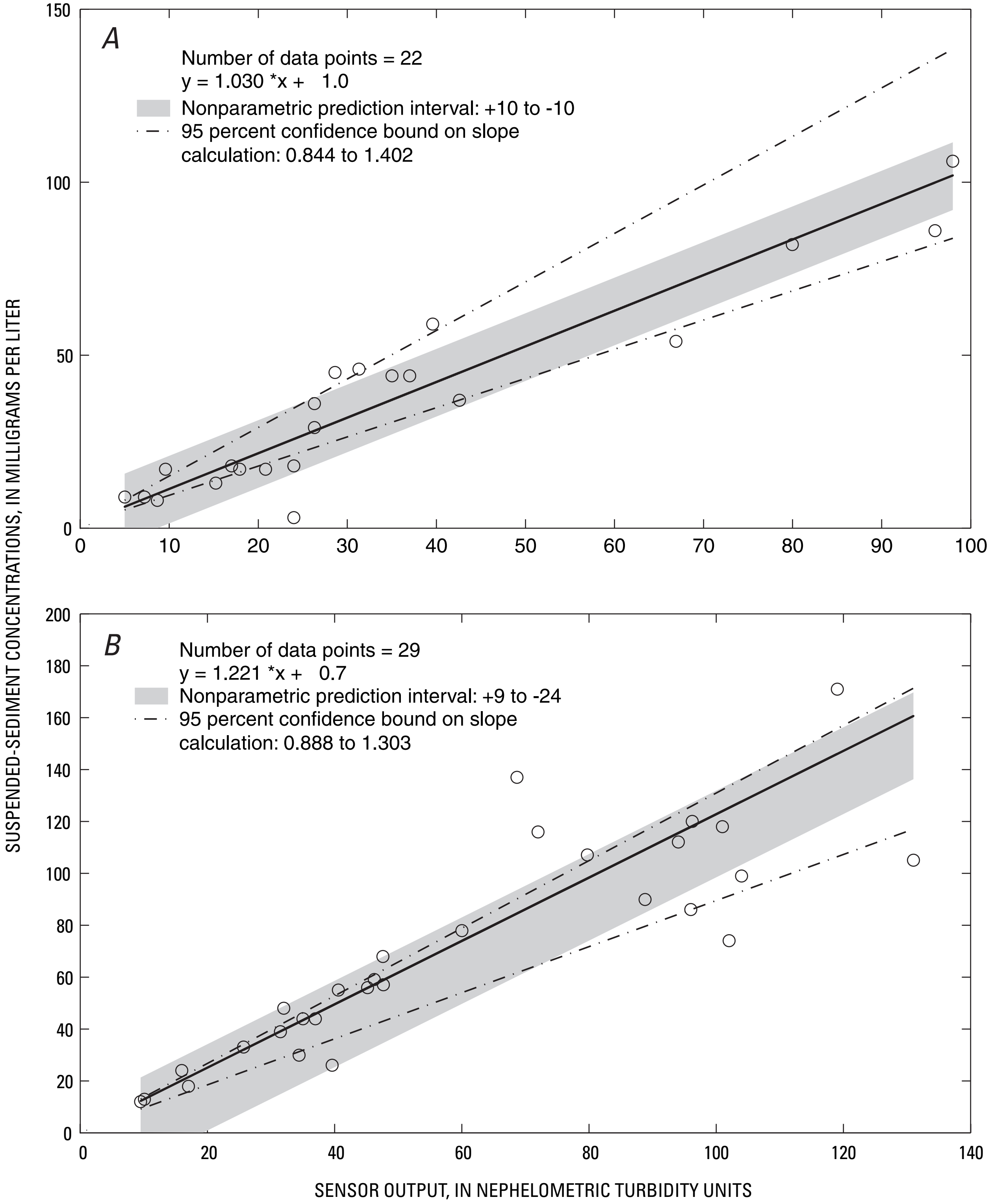

Figure 7. Calibration of (***A***) near-surface and (***B***) near-bottom optical backscatterance sensors at Benicia Bridge, Suisun Bay, California, water year 2002.

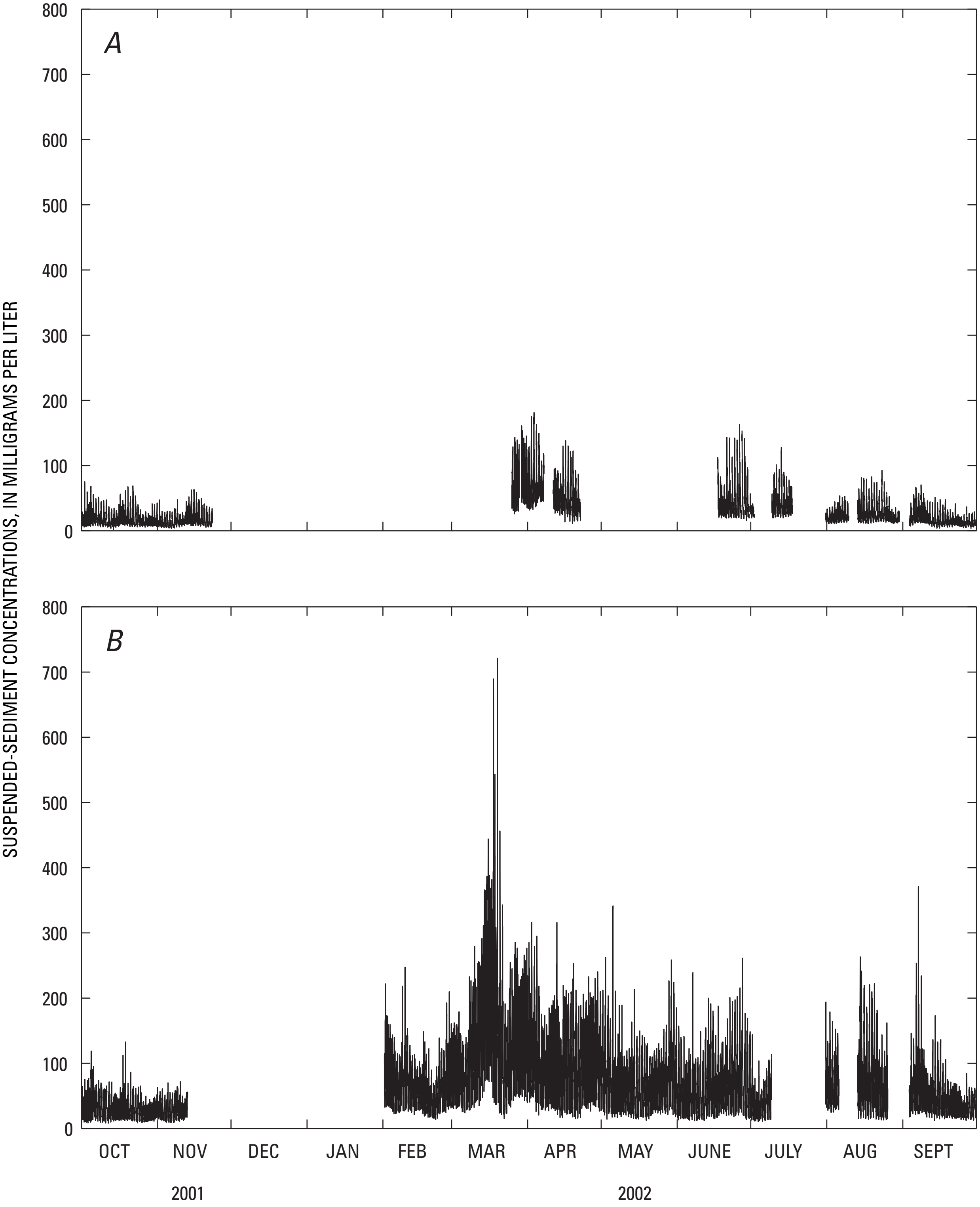

Figure 8. Time series of (***A***) near-surface and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Benicia Bridge, Suisun Bay, California, water year 2002.

San Pablo Bay

Carquinez Bridge

PERIOD OF CALIBRATION.—
  MID-DEPTH SENSOR: WY 2002 (*fig. 9A*).
  NEAR-BOTTOM SENSOR: WY 2002 (*fig. 9B*).
NUMBER OF DATA POINTS.—
  MID-DEPTH SENSOR: 34 (19 from WY 2002).
  NEAR-BOTTOM SENSOR: 58 (22 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
  MID-DEPTH SENSOR: SSC = 0.964 *NTU + 3.4.
  NEAR-BOTTOM SENSOR: SSC = 0.977 *NTU + 5.4.
NONPARAMETRIC PREDICTION INTERVAL.—
  MID-DEPTH SENSOR: + 10 to – 6 mg/L.
  NEAR-BOTTOM SENSOR: + 19 to – 14 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The calculated SSC time-series data collected during water year 2002 are presented in *figure 10*.

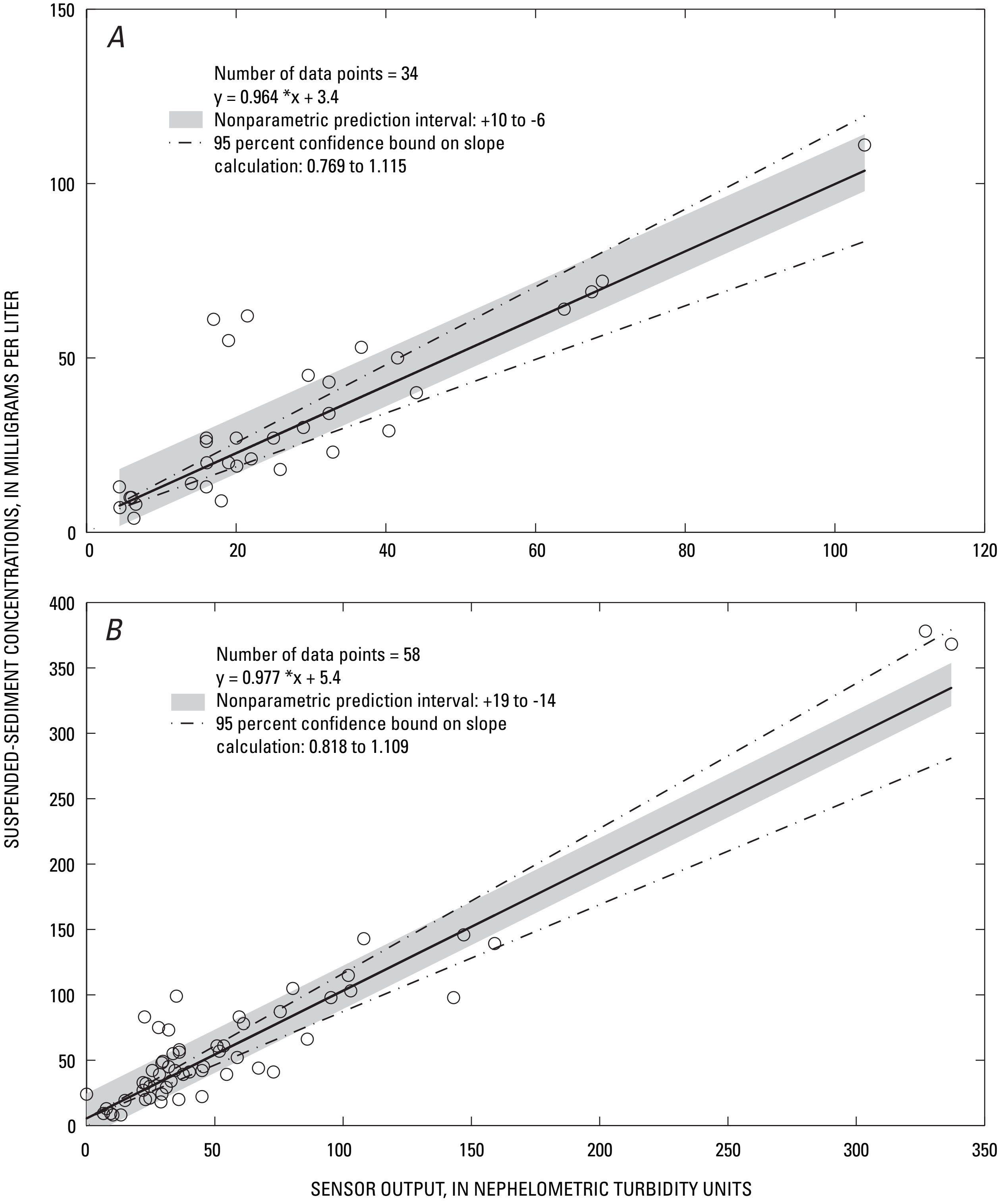

Figure 9. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at Carquinez Bridge, San Pablo Bay, California, water year 2002.

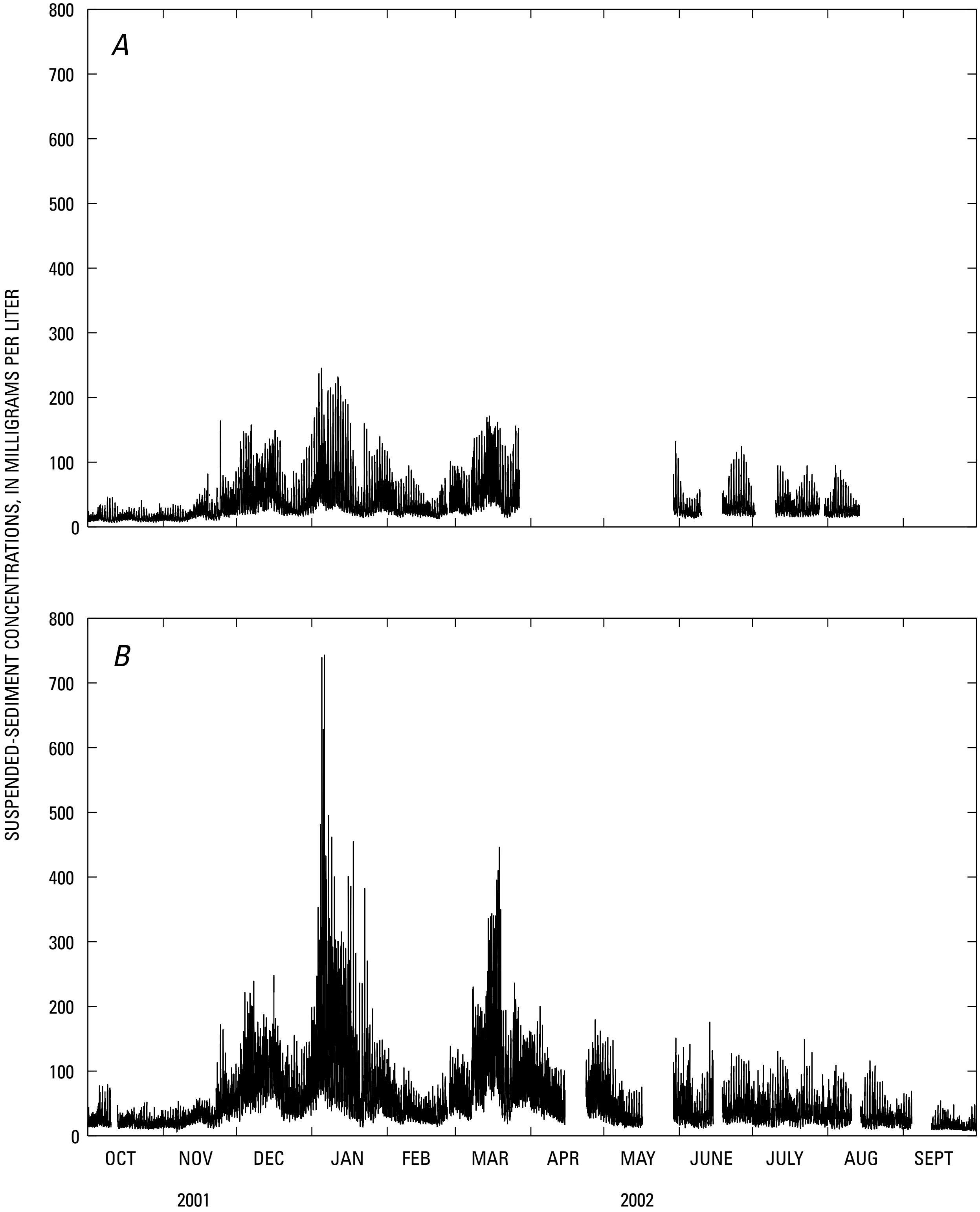

Figure 10. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Carquinez Bridge, San Pablo Bay, California, water year 2002.

Mare Island Causeway

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2002 (*fig. 11A*).
NEAR-BOTTOM SENSOR: WY 2002 (*fig. 11B*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR: 43 (25 from WY 2002).
NEAR-BOTTOM SENSOR: 92 (24 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.520 millivolt *(mV) – 13.6.
NEAR-BOTTOM SENSOR: SSC = 0.680 *mV – 11.0.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: + 10 to – 12 mg/L.
NEAR-BOTTOM SENSOR: + 32 to – 26 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The calculated SSC time-series data collected during WY 2002 are presented in *figure 12*.

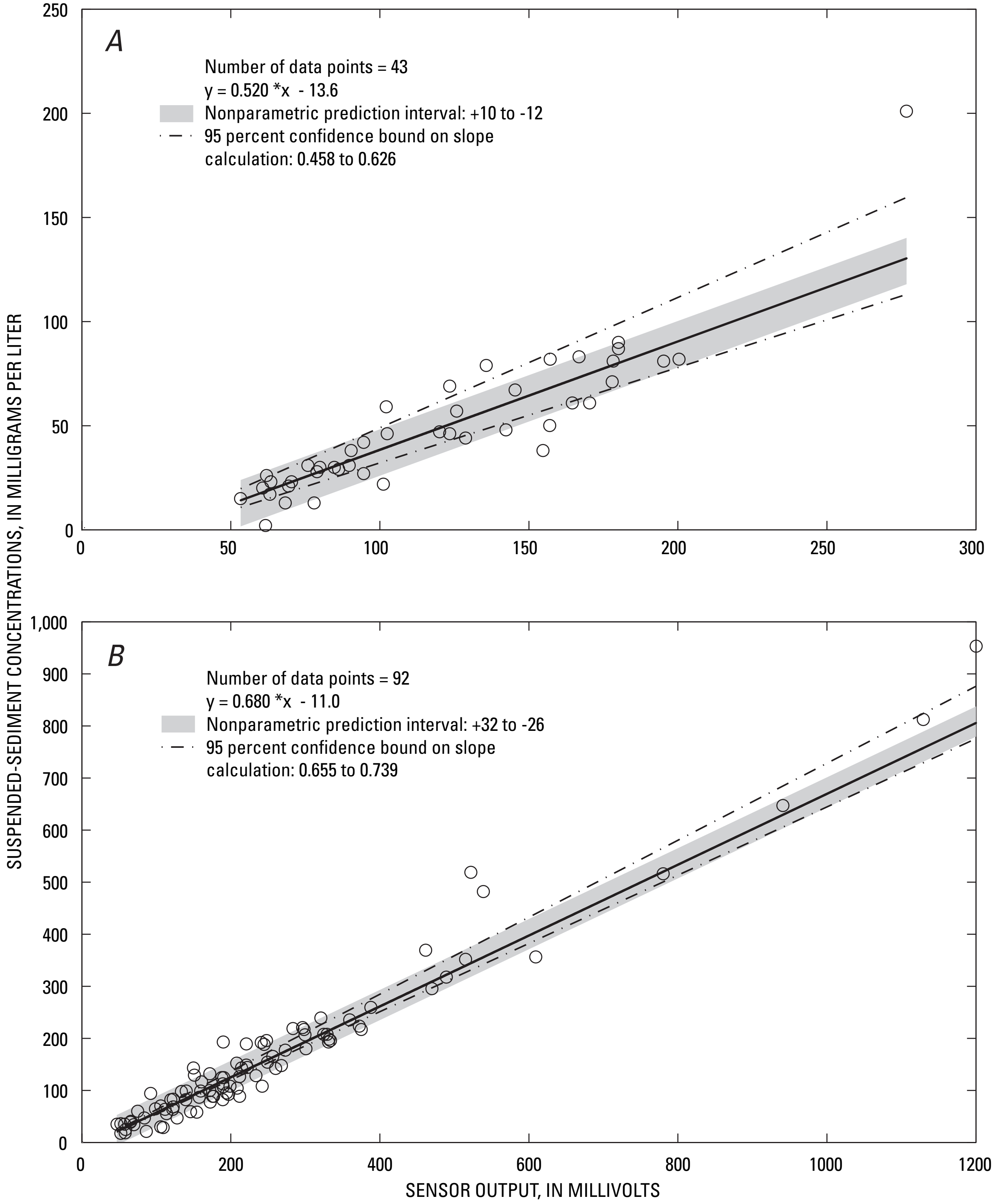

Figure 11. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at Mare Island Causeway, San Pablo Bay, California, water year 2002.

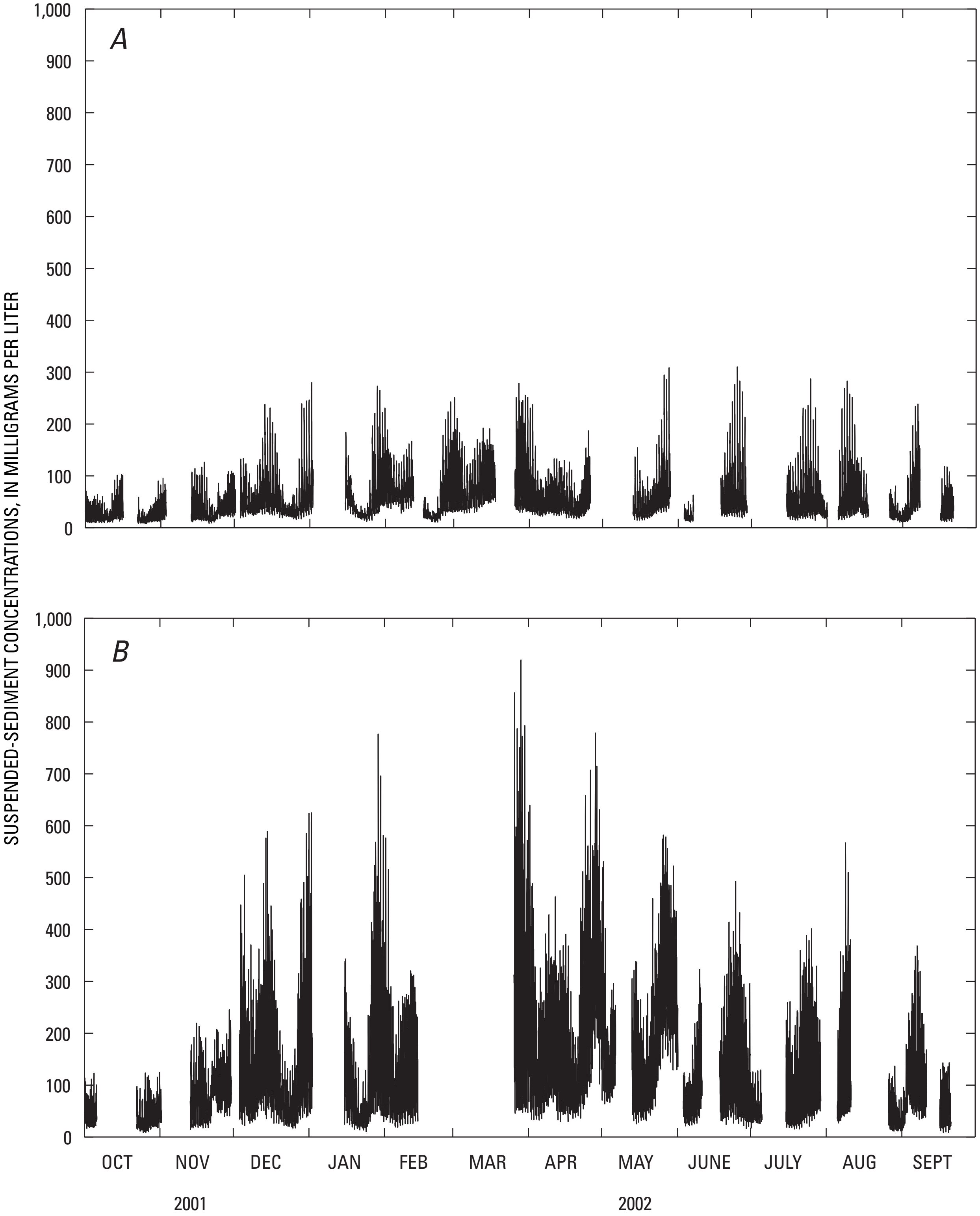

Figure 12. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Mare Island Causeway, San Pablo Bay, California, water year 2002.

Channel Marker 9

PERIOD OF CALIBRATION.—
NEAR-BOTTOM SENSOR: WY 2002 (*fig. 13*).
NUMBER OF DATA POINTS.—
NEAR-BOTTOM SENSOR: 73 (14 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
NEAR-BOTTOM SENSOR: SSC = 1.221 *NTU + 15.6.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-BOTTOM SENSOR: + 35 to – 32 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The calculated SSC time-series data collected during WY 2002 are presented in *figure 14*.

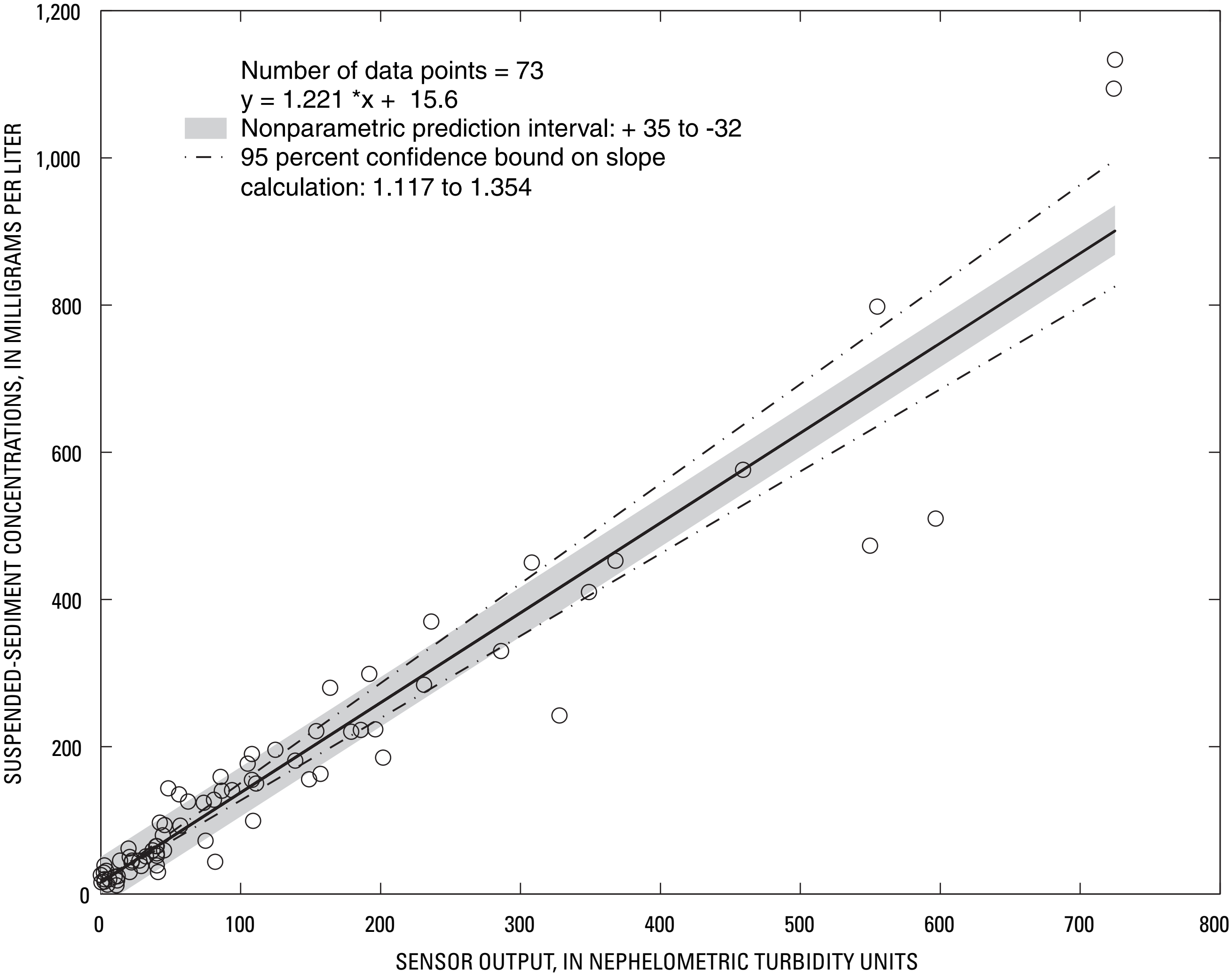

Figure 13. Calibration of near-bottom optical backscatterance sensor at Channel Marker 9, San Pablo Bay, California, water year 2002.

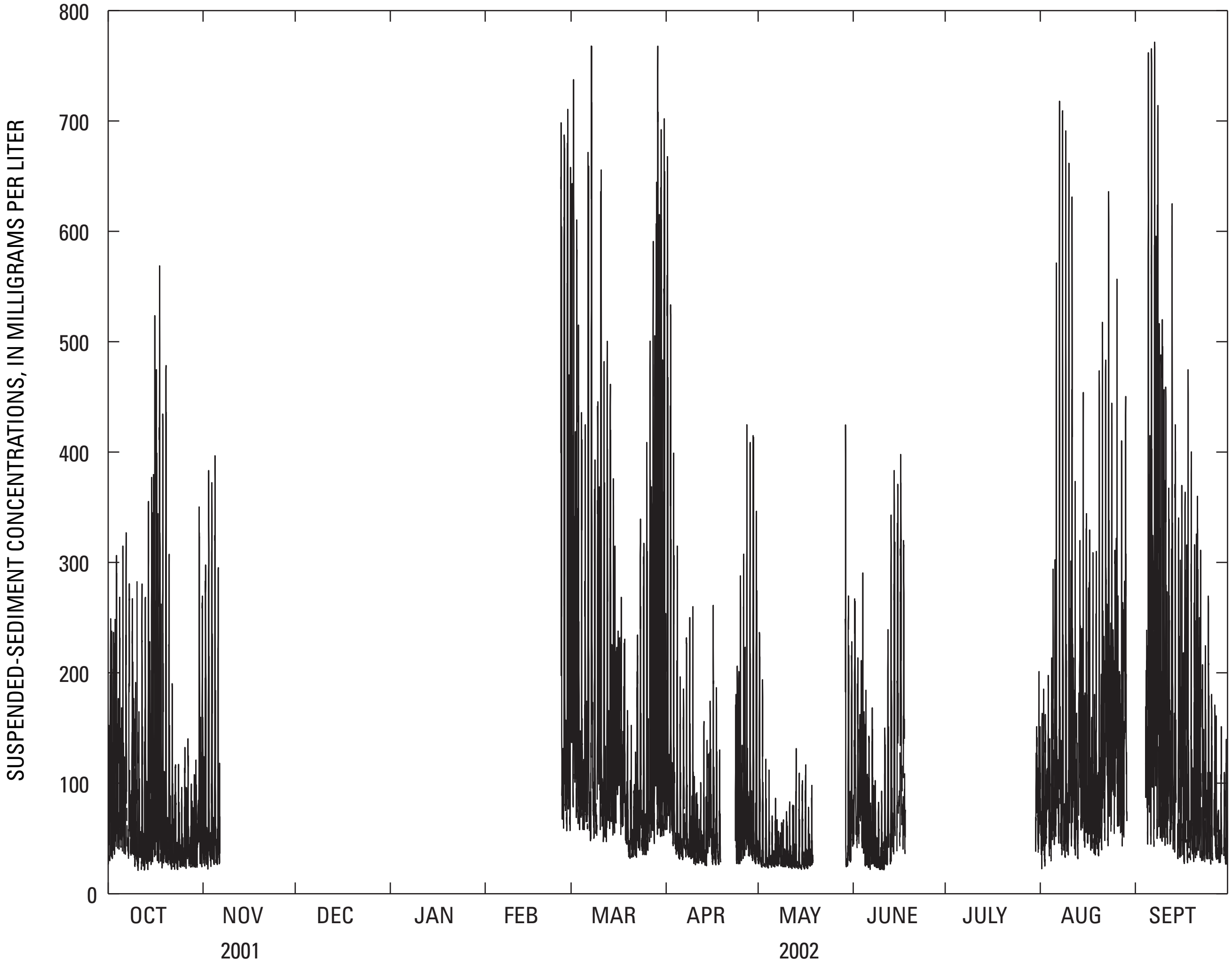

Figure 14. Time series of near-bottom suspended-sediment concentrations calculated from sensor readings at Channel Marker 9, San Pablo Bay, California, water year 2002.

Central San Francisco Bay

Point San Pablo

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: December 11, 2001, through WY 2002 (*fig. 15A*).
NEAR-BOTTOM SENSOR: December 11, 2001, through WY 2002 (*fig. 15B*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR: 17 (all from WY 2002).
NEAR-BOTTOM SENSOR: 10 (all from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.981 *NTU + 9.5.
NEAR-BOTTOM SENSOR: SSC = 1.026 *NTU + 6.4.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: + 7 to – 9 mg/L.
NEAR-BOTTOM SENSOR: + 54 to – 10 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The calculated SSC time-series data collected during WY 2002 are presented in *figure 16*.

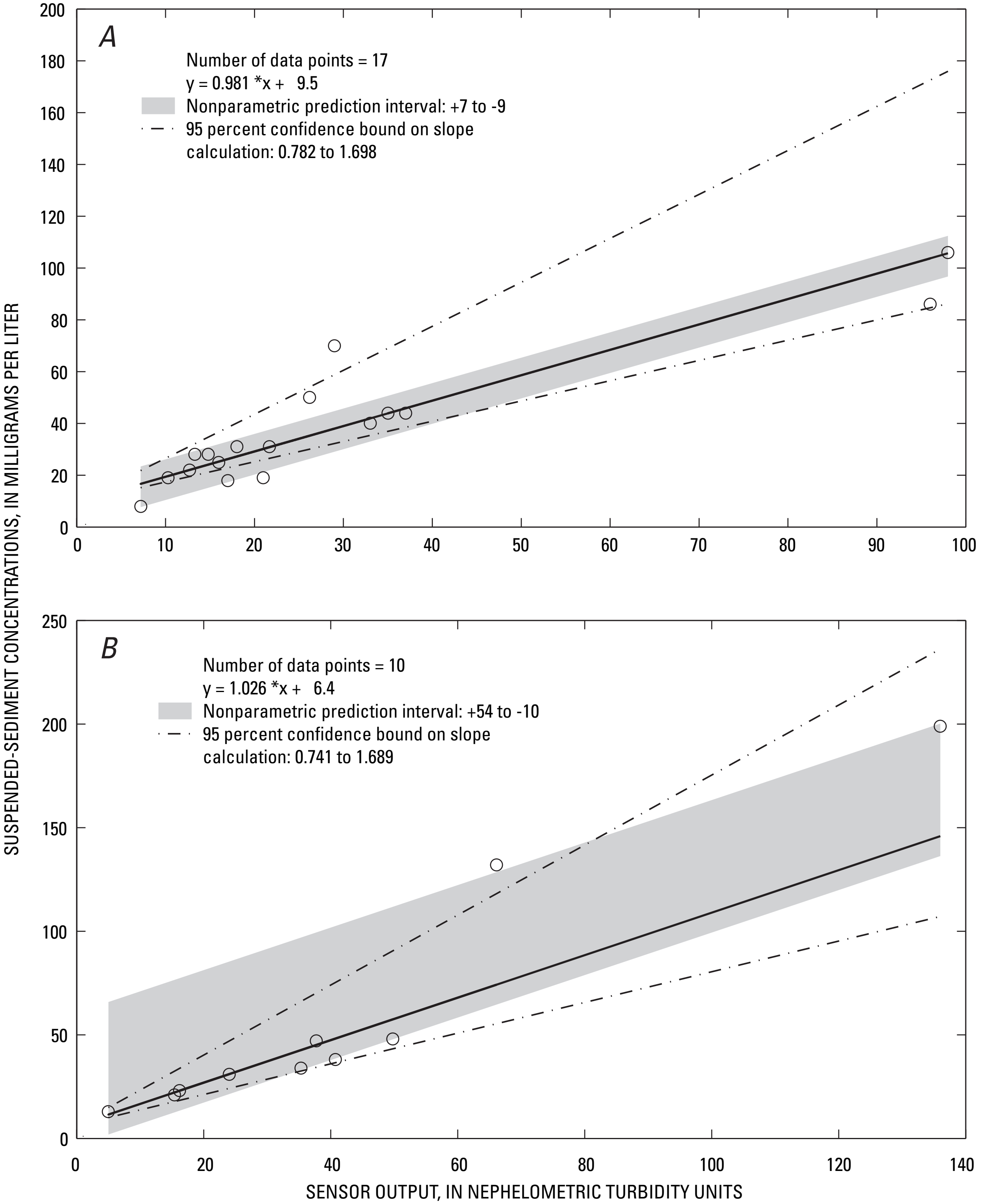

Figure 15. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at Point San Pablo, Central San Francisco Bay, California, water year 2002.

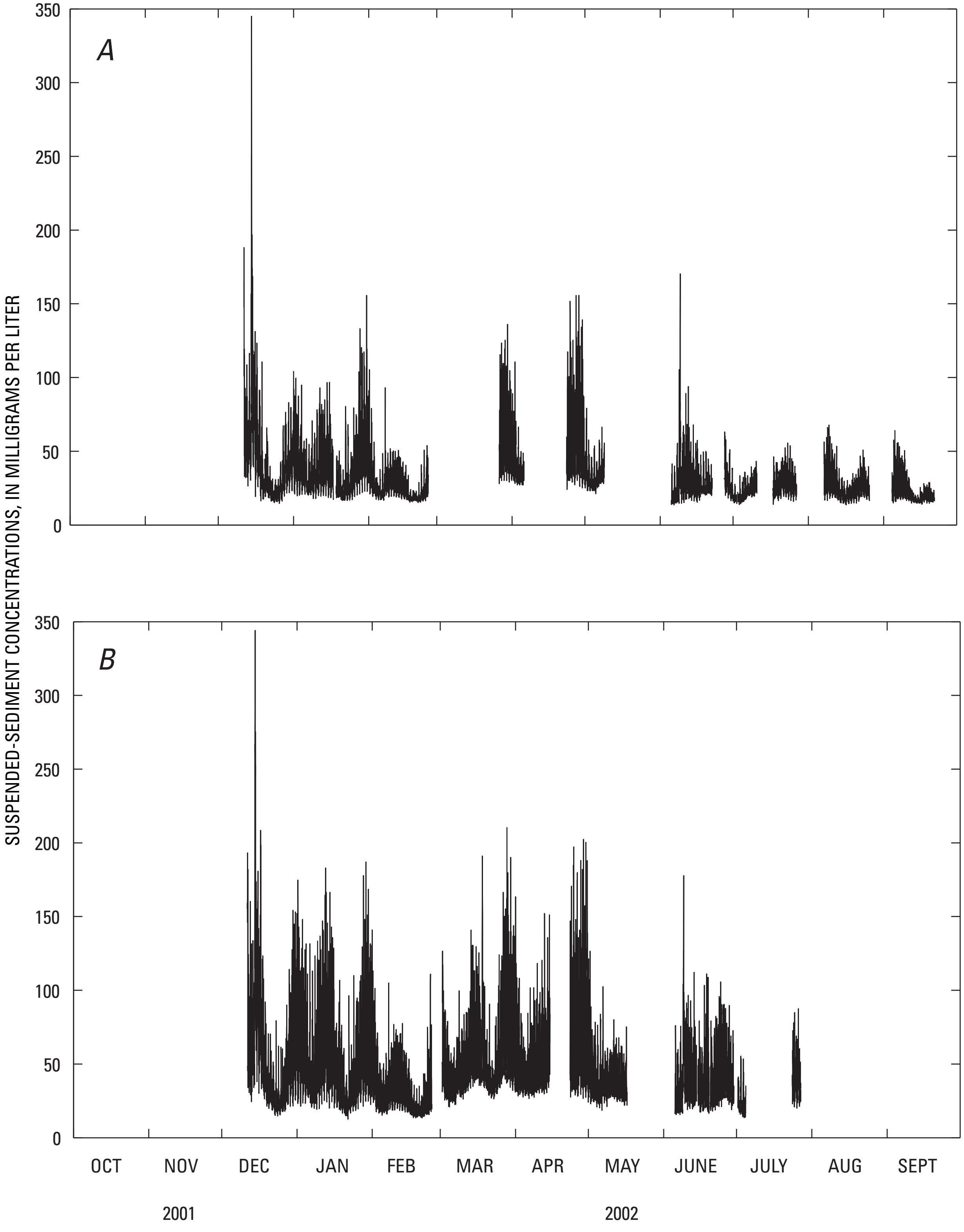

Figure 16. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 2002.

Pier 24

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: October 23, 2001, to January 3, 2002 (*fig. 17A*).
NEAR-BOTTOM SENSOR: October 1, 2001, to January 3, 2002 (*fig. 17B*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR: 4 (4 from WY 2002).
NEAR-BOTTOM SENSOR: 7 (7 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.323 *mV + 5.4.
NEAR-BOTTOM SENSOR: SSC = 0.640 *mV − 8.2.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: undetermined.
NEAR-BOTTOM SENSOR: + 3 to − 3 mg/L.

REMARKS.—Interruptions in the existing record were due to fouling or malfunction of the sensing and(or) recording instruments. The mid-depth sensor malfunctioned and was replaced on October 23, 2001. The calibrations developed for the mid-depth and the near-bottom sensors are poor due to the few water samples collected. The four water samples collected for the mid-depth sensor were insufficient for determining a nonparametric prediction interval. The calculated SSC time-series data collected during WY 2002 are presented in *figure 18*. The station was discontinued on January 3, 2002.

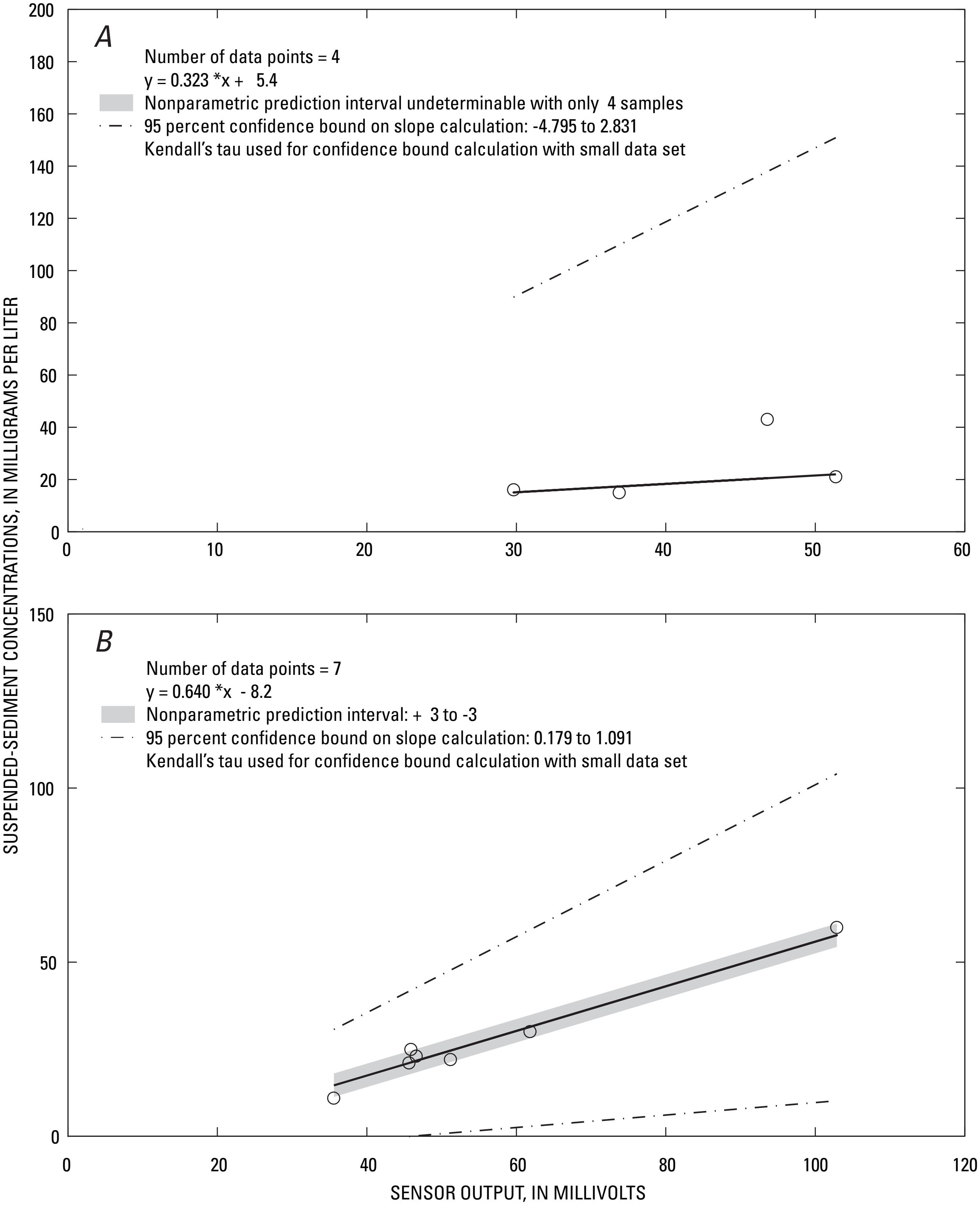

Figure 17. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at Pier 24, Central San Francisco Bay, California, water year 2002.

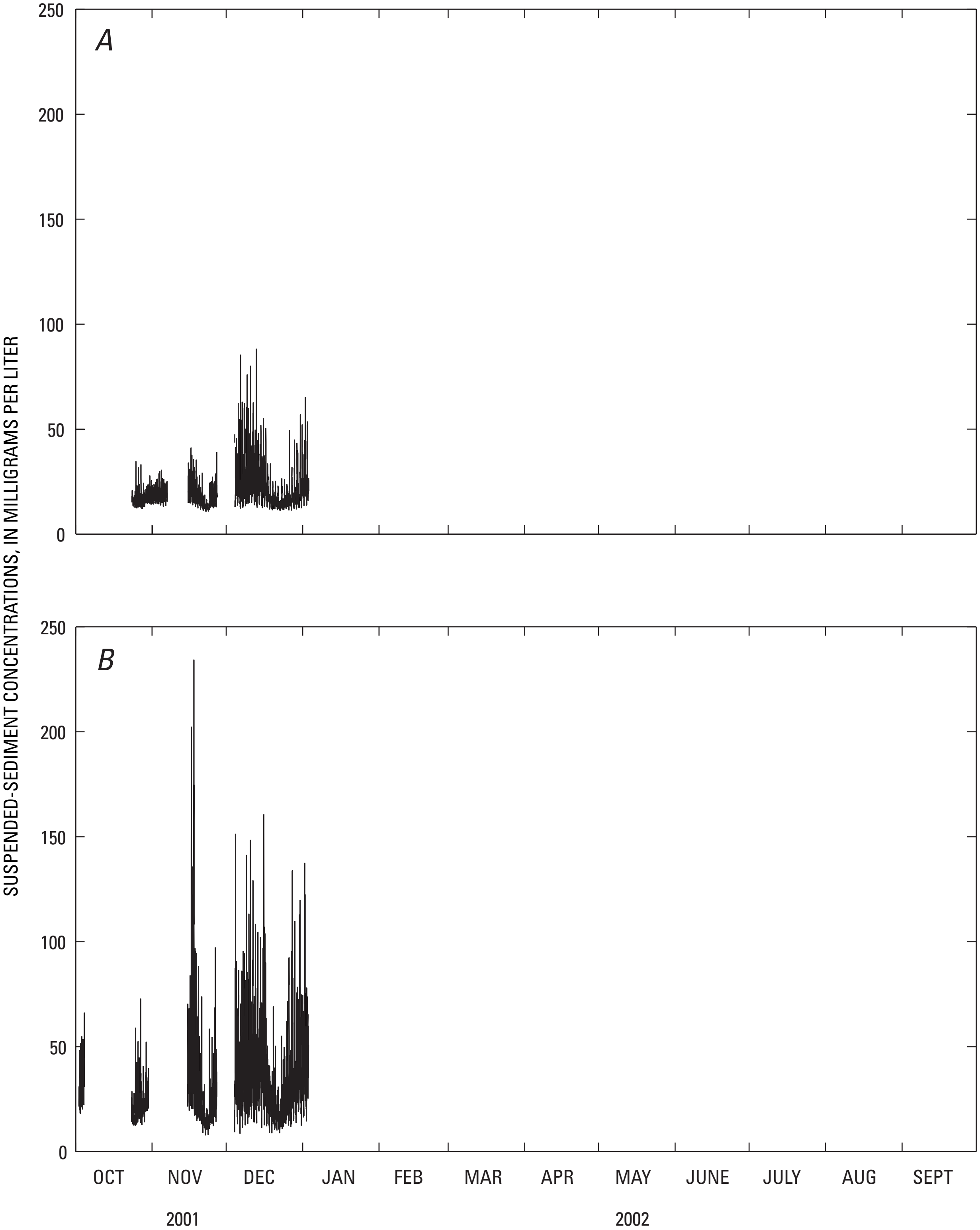

Figure 18. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Pier 24, Central San Francisco Bay, California, water year 2002.

South San Francisco Bay

San Mateo Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2002 (*fig. 19A*).
NEAR-BOTTOM SENSOR: WY 2002 (*fig. 19B*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR: 23 (18 from WY 2002).
NEAR-BOTTOM SENSOR: 15 (all from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.512 *mV + 5.5.
NEAR-BOTTOM SENSOR: SSC = 0.565 *mV + 3.2.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: + 9 to − 11 mg/L.
NEAR-BOTTOM SENSOR: + 11 to − 14 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The calculated SSC time-series data collected during WY 2002 are presented in *figure 20*.

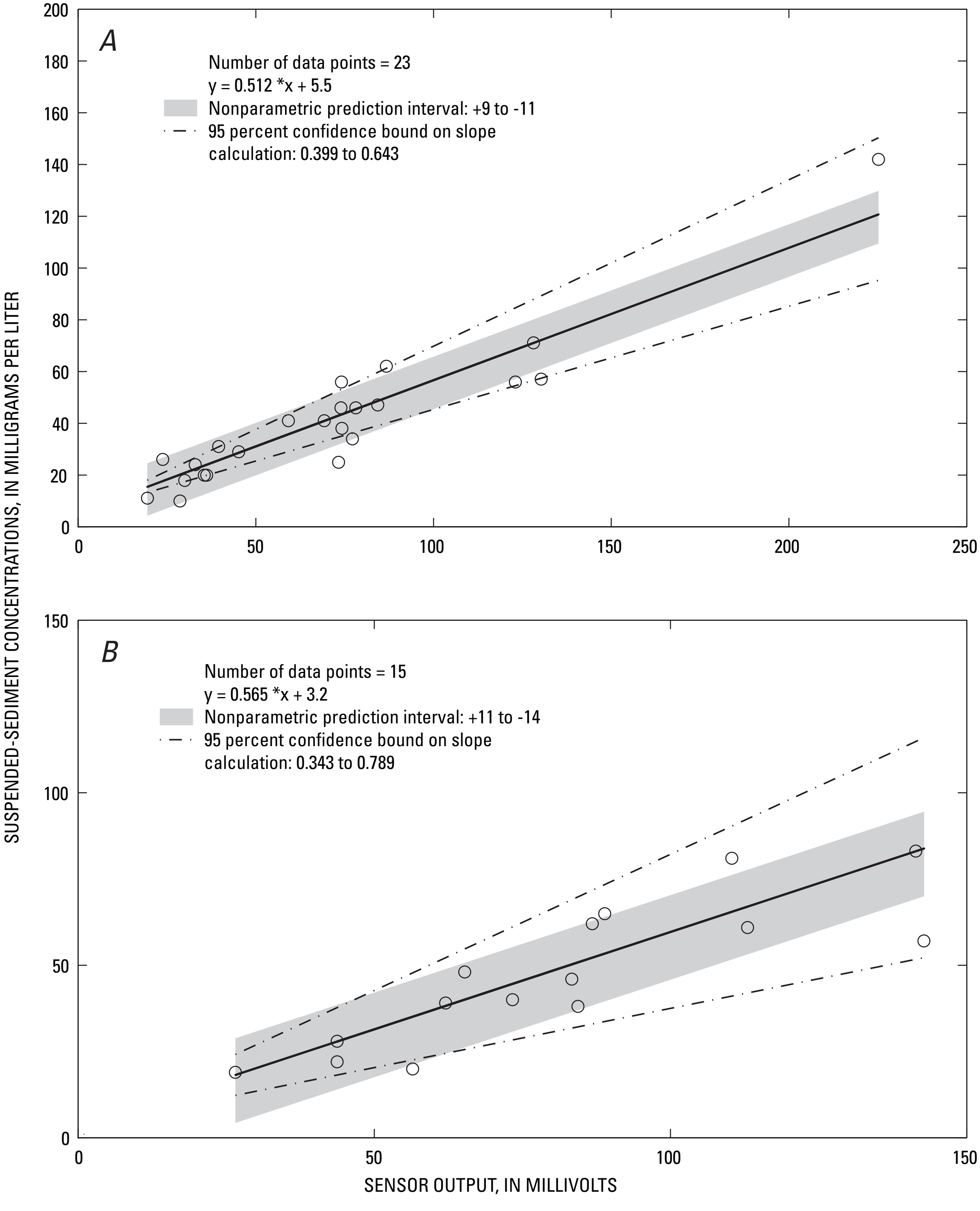

Figure 19. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at San Mateo Bridge, South San Francisco Bay, California, water year 2002.

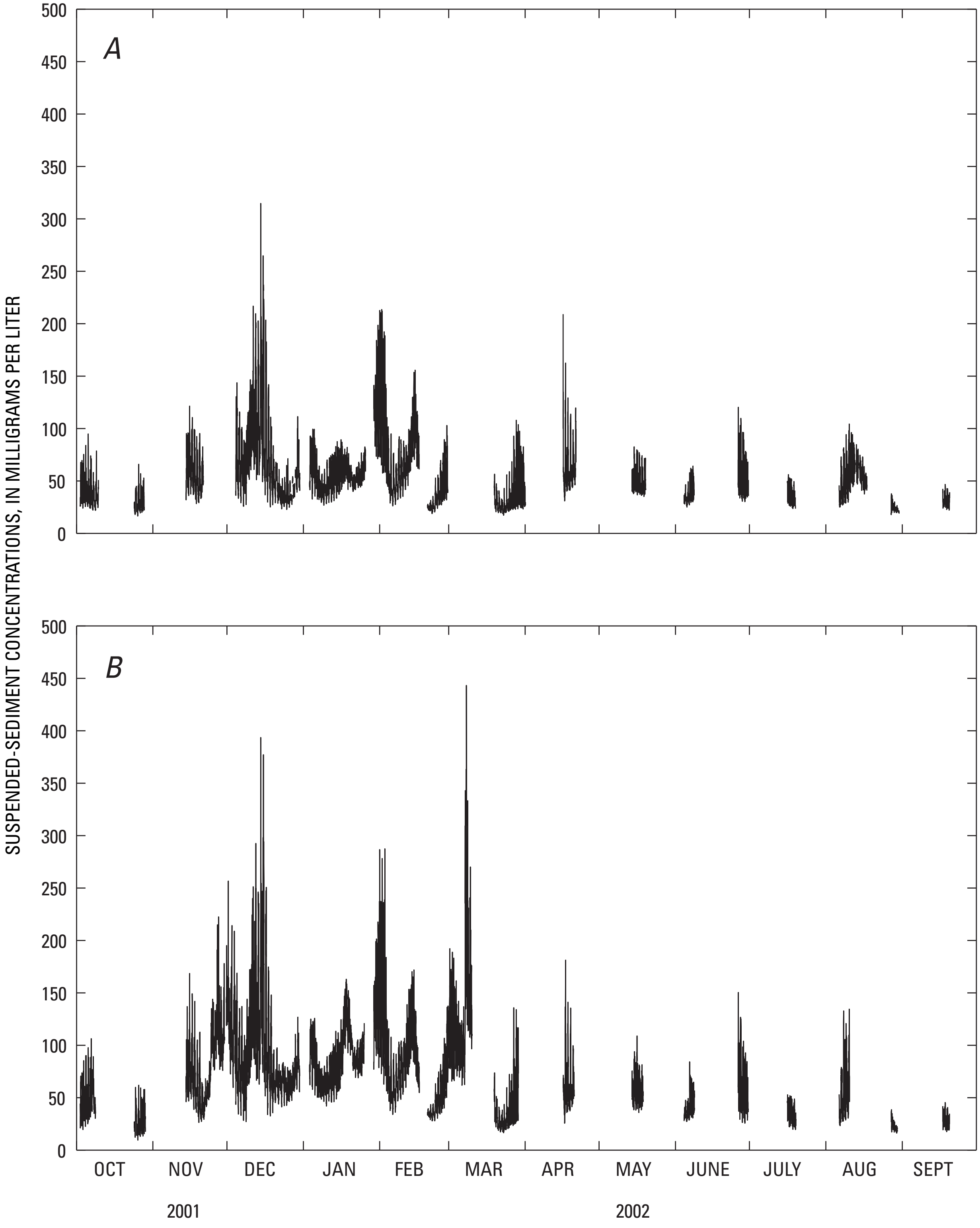

Figure 20. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 2002.

Dumbarton Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR (*A*): October 1, 2001, to November 15, 2001 (*fig. 21A*).
MID-DEPTH SENSOR (*B*): November 15, 2001, through WY 2002 (*fig. 21B*).
NEAR-BOTTOM SENSOR: WY 2002 (*fig. 22*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR (*A*): 32 (2 from WY 2002).
MID-DEPTH SENSOR (*B*): 10 (10 from WY 2002).
NEAR-BOTTOM SENSOR: 63 (14 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR (*A*): SSC = 0.242 *mV + 4.9.
MID-DEPTH SENSOR (*B*): SSC = 0.576 *mV − 1.4.
NEAR-BOTTOM SENSOR: SSC = 0.623 *mV − 14.3.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR (*A*): + 18 to − 14 mg/L.
MID-DEPTH SENSOR (*B*): + 19 to − 4 mg/L.
NEAR-BOTTOM SENSOR: + 11 to − 14 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. The station was shut down from March 19 to July 16, 2002, for retrofitting of the bridge pier. The mid-depth sensor malfunctioned and was replaced on November 15, 2001. The calculated SSC time-series data collected during WY 2002 are presented in *figure 23*.

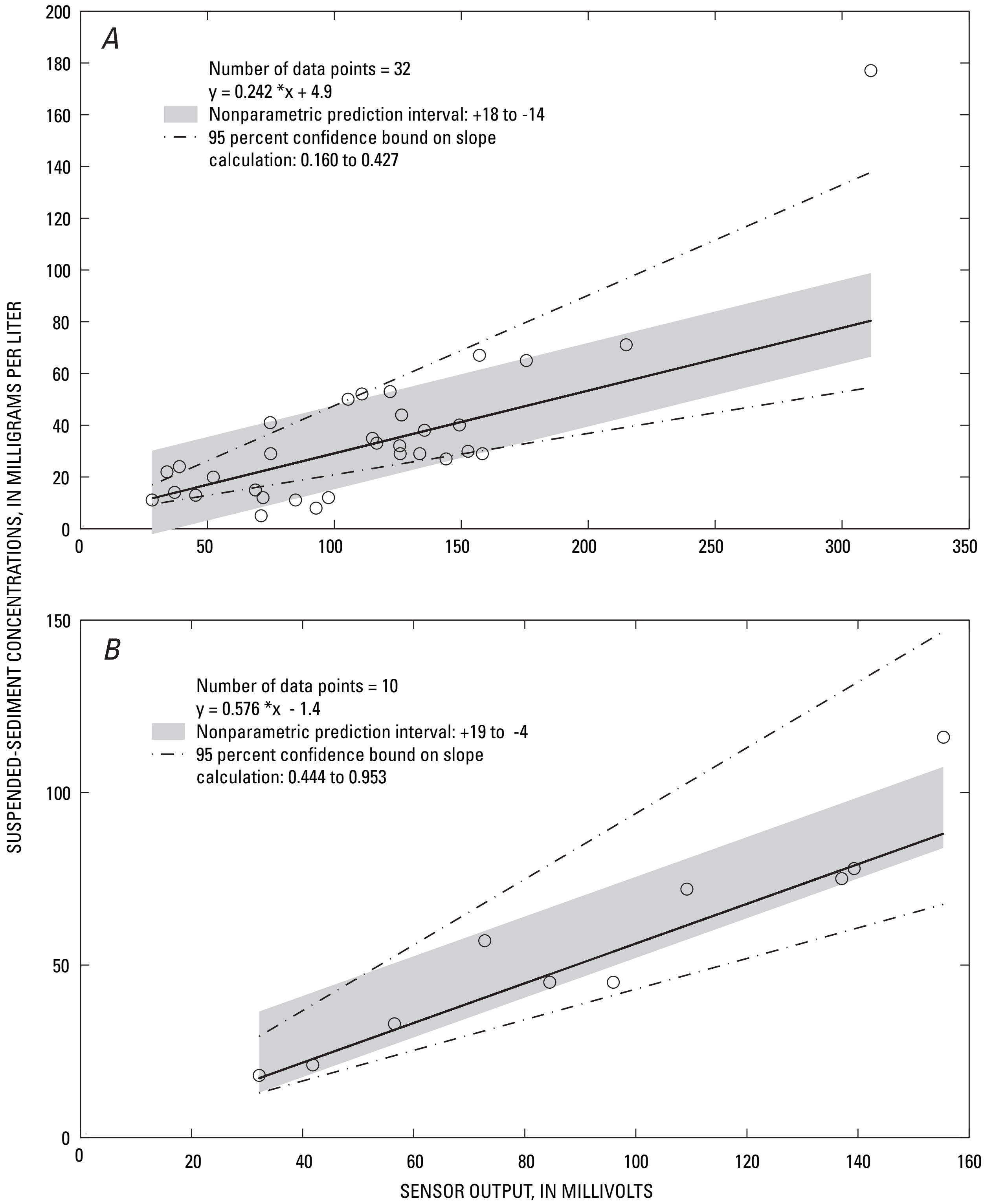

Figure 21. Calibration of mid-depth optical backscatterance sensors, (***A***) October 1–November 15 and (***B***) November 15–September 30 at Dumbarton Bridge, South San Francisco Bay, California, water year 2002.

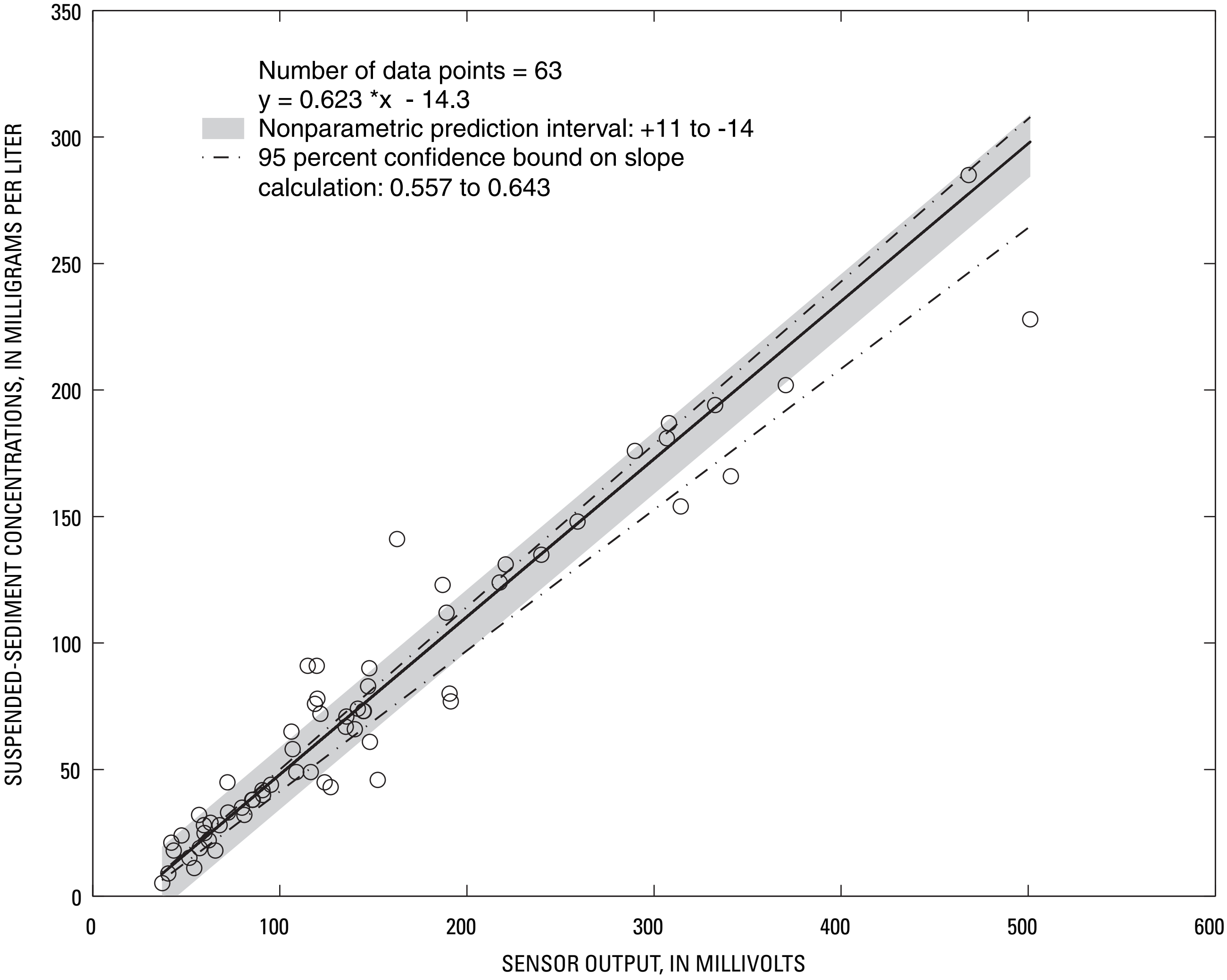

Figure 22. Calibration of near-bottom optical backscatterance sensor at Dumbarton Bridge, South San Francisco Bay, California, water year 2002.

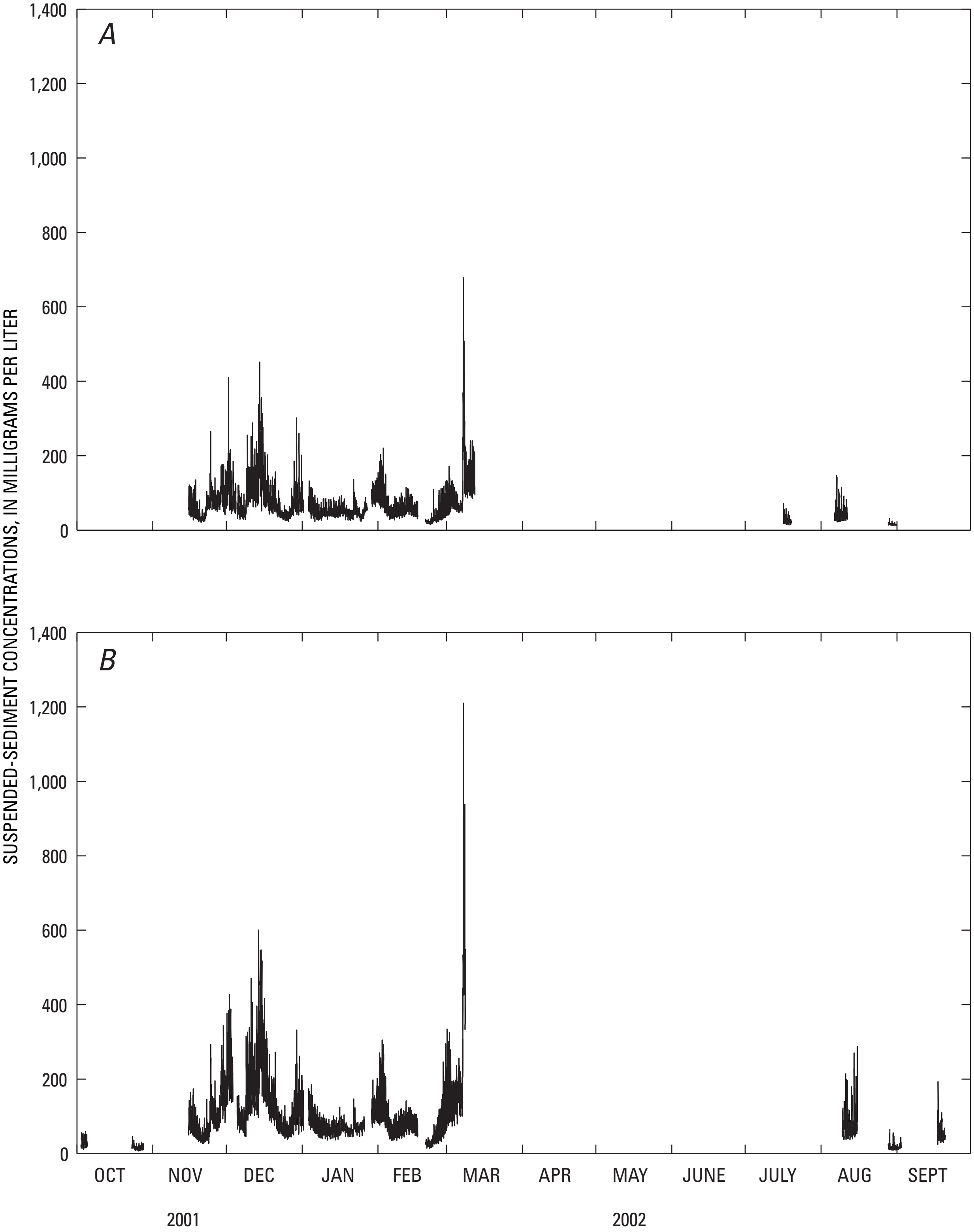

Figure 23. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 2002.

Channel Marker 17

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2002 (*fig. 24A*).
NEAR-BOTTOM SENSOR: WY 2002 (*fig. 24B*).
NUMBER OF DATA POINTS.—
MID-DEPTH SENSOR: 100 (17 from WY 2002).
NEAR-BOTTOM SENSOR: 74 (15 from WY 2002).
CALCULATED LINEAR CORRELATION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.638 *mV – 17.2.
NEAR-BOTTOM SENSOR: SSC = 0.593 *mV – 5.7.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: + 15 to – 13 mg/L.
NEAR-BOTTOM SENSOR: + 22 to – 12 mg/L.

REMARKS.—Interruptions in record were due to fouling or malfunction of the sensing and(or) recording instruments. A +7.4-millivolt shift to the near-bottom sensor, calculated from water samples not shown on *fig. 24B* (not used to develop calibration), was applied from October 2 through October 31, 2001. The calculated SSC time-series data collected during WY 2002 are presented in *figure 25*.

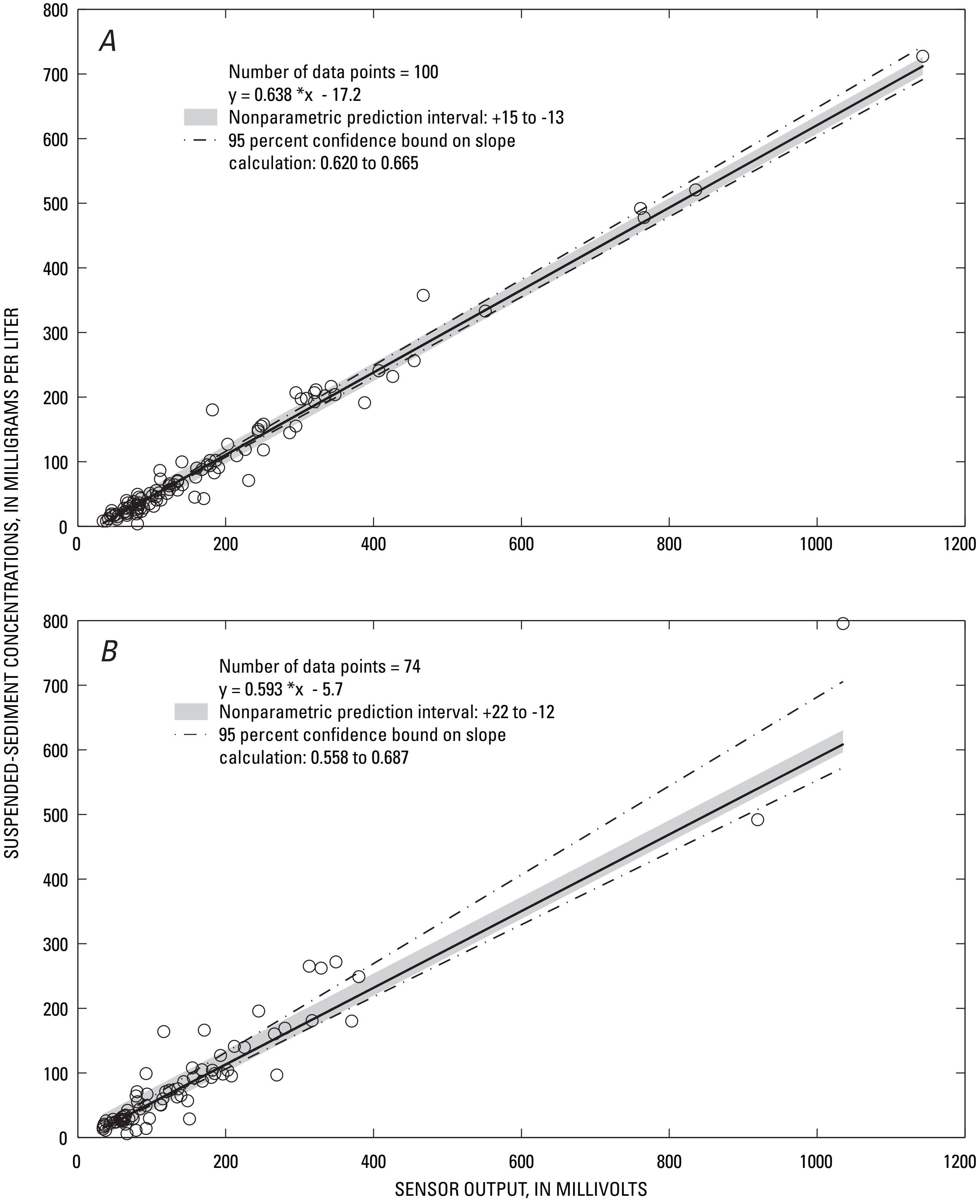

Figure 24. Calibration of (***A***) mid-depth and (***B***) near-bottom optical backscatterance sensors at Channel Marker 17, South San Francisco Bay, California, water year 2002.

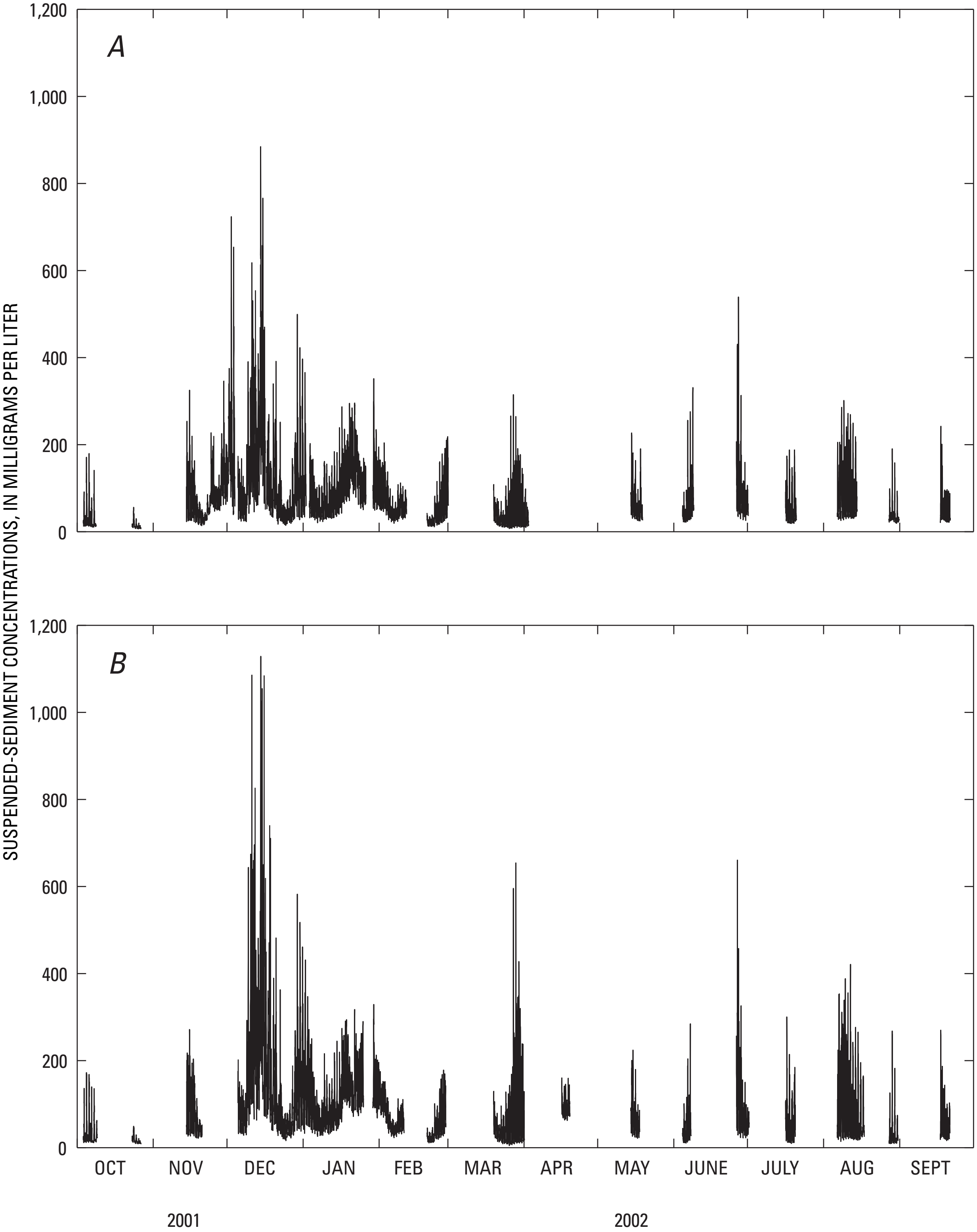

Figure 25. Time series of (***A***) mid-depth and (***B***) near-bottom suspended-sediment concentrations calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 2002.

Summary

Suspended-sediment concentration (SSC) data were collected by the U.S. Geological Survey (USGS) at two sites in Suisun Bay, three sites in San Pablo Bay, two sites in Central San Francisco Bay, and three sites in South San Francisco Bay during water year 2002. Three types of optical backscatterance sensors, each controlled by electronic data loggers, were used to monitor suspended sediment. Water samples were collected to calibrate the electrical output of the optical sensors to SSC, and the recorded data were recovered and edited. The calculated SSC data are available from the USGS (accessed August 13, 2003).

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