Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 2005

By Paul A. Buchanan and Megan A. Lionberger

Prepared in cooperation with the CALFED Bay–Delta Authority and the
U.S. Army Corps of Engineers, San Francisco District

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Conversion Factors, Datum, Abbreviations, and Acronyms

Multiply	By	To obtain
inch (in.)	25.40	millimeter
foot (ft)	.3048	meter
foot per second (ft/s)	.3048	meter per second

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).

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L).

Mean lower low water (MLLW): The average of the lower low water height above the bottom, 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

DWR California Department of Water Resources

mV millivolt

FTS Forest Technology Systems

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

WY water year (October 1–September 30)

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Abstract

Suspended-sediment concentration data were collected by the U.S. Geological Survey in San Francisco Bay during water year 2005 (October 1, 2004–September 30, 2005). Optical 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 output of the optical sensors so that a record of suspended-sediment concentrations could be derived. This report presents the data-collection methods used and summarizes, in graphs, the suspended-sediment concentration data collected from October 2004 through September 2005. Calibration curves and plots of the processed 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 for nutrients that contribute to estuarine productivity (Hammond and others, 1985). Potentially toxic substances, such as metals and pesticides, can adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993; Flegal and others, 1996). Benthic organisms can then ingest these substances and introduce them into the food web (Luoma and others, 1985; Brown and Luoma, 1995; Luoma, 1996). Large tidal-induced current velocities and wind waves in shallow water are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 1996).

The mobilization, resuspension and deposition of suspended sediments are important factors in determining the transport and fate of sediment-associated contaminants. In Suisun Bay, the maximum suspended-sediment concentration (SSC) typically 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 are deposited in ports and shipping channels, which then require dredging in order to remain navigable (U.S. Environmental Protection Agency, 1992). The U.S. Geological Survey (USGS), in cooperation with the CALFED Bay-Delta Authority, 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) 2005 and is the latest in a series of reports that present the 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, 2004, 2005; and Buchanan and Lionberger, 2006). 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. SSC data from WY 1992 through WY 2005 were used to help determine the factors that affect SSC in San Francisco Bay (Schoellhamer and others, 2003; for the current bibliography of reports see U.S. Geological Survey, accessed February 26, 2007). Numerical SSC data for WY 1992 through 2005 are available from the U.S. Geological Survey (accessed February 26, 2007).

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) and have 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 foot per second (ft/s) in shallow water to more than 3 ft/s in deep channels (Cheng and Gartner, 1984; Smith, 1987). The strongest winds typically are sea breezes that blow onshore during summer afternoons. Most precipitation occurs from late autumn to early spring. Freshwater discharge into San Francisco Bay is greatest in the spring as a result of 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 about 60 percent of the fluvial sediments that enter the Bay (McKee and others, 2006), 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 Gregory Brewster, Brad Sullivan and Heather Ramil of the USGS for their assistance with sample collection and maintenance of the data-collection network. The authors also wish to acknowledge the U.S. Coast Guard (USCG), the National Park Service, California Department of Transportation, California Department of Water Resources (DWR), EAI International, and the City of Vallejo for their permission and assistance in establishing the monitoring sites used in this study.

The project was done in cooperation with the CALFED Bay–Delta Authority, and the U.S. Army Corps of Engineers, as part of the San Francisco Estuary Regional Monitoring Program for Trace Substances. Additional funding was supplied by the USGS Priority Ecosystem Science Program.

Methods

Instrument Description and Operation

Three different types of optical sensors were used to monitor SSC during WY 2005. 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. 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 which is converted to a voltage output and recorded on a separate data logger. The second type of sensor, manufactured by Forest Technology Systems (FTS), is self-cleaning and differs from the D & A Instrument Company sensor in that it measures the intensity of light scattered at 90 degrees between a laser diode and a high-sensitivity silicon photodiode detector. The output, in nephelometric turbidity units (NTU), is recorded on a separate data logger. The third type of sensor, versions of which are used by both Hydrolab and YSI instruments, measures the intensity of light scattered at 90 degrees between a light-emitting diode and a high-sensitivity photodiode detector, and the output (NTU) is processed by internal software. The Hydrolab and YSI instruments (sondes) are self-contained, including a power source, data logger, and the capability of supporting additional sensors.

Optical sensors were positioned in the water column by 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 suspension line attached to an anchor weight, which allowed sensors to be easily raised and lowered for servicing (fig. 2). The plane of the optical window maintained a position parallel to the direction of flow as the carriage aligned itself with the changing direction of flow. Optical sensor depths in the water column are listed in table 1.

Biological growth (fouling) interferes with the collection of accurate optical-sensor 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. Self-cleaning optical sensors were used where conditions allowed. Because of the difficulty in servicing some of the monitoring stations, sensors were cleaned manually 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.

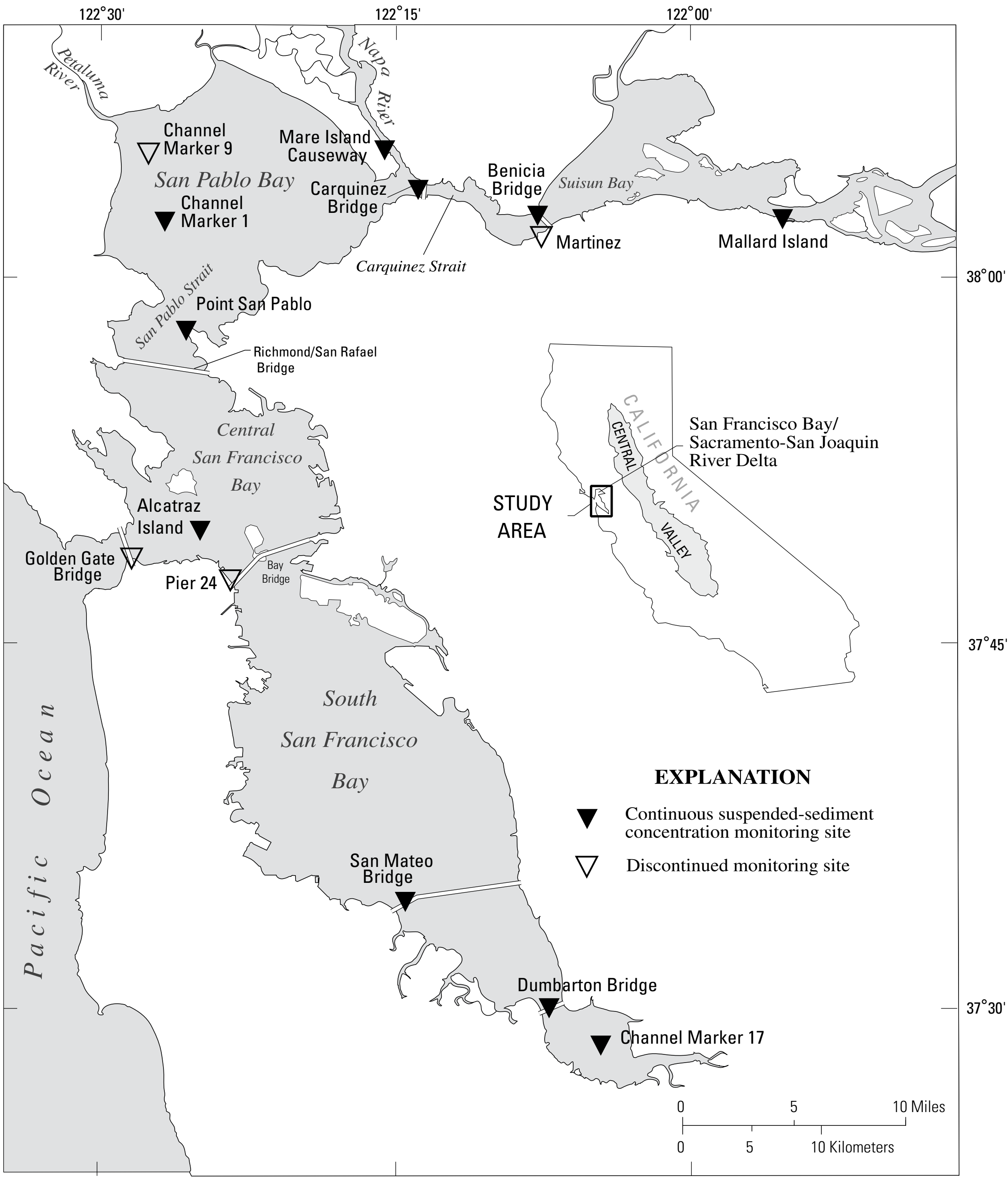

Figure 1. San Francisco Bay study area, California.

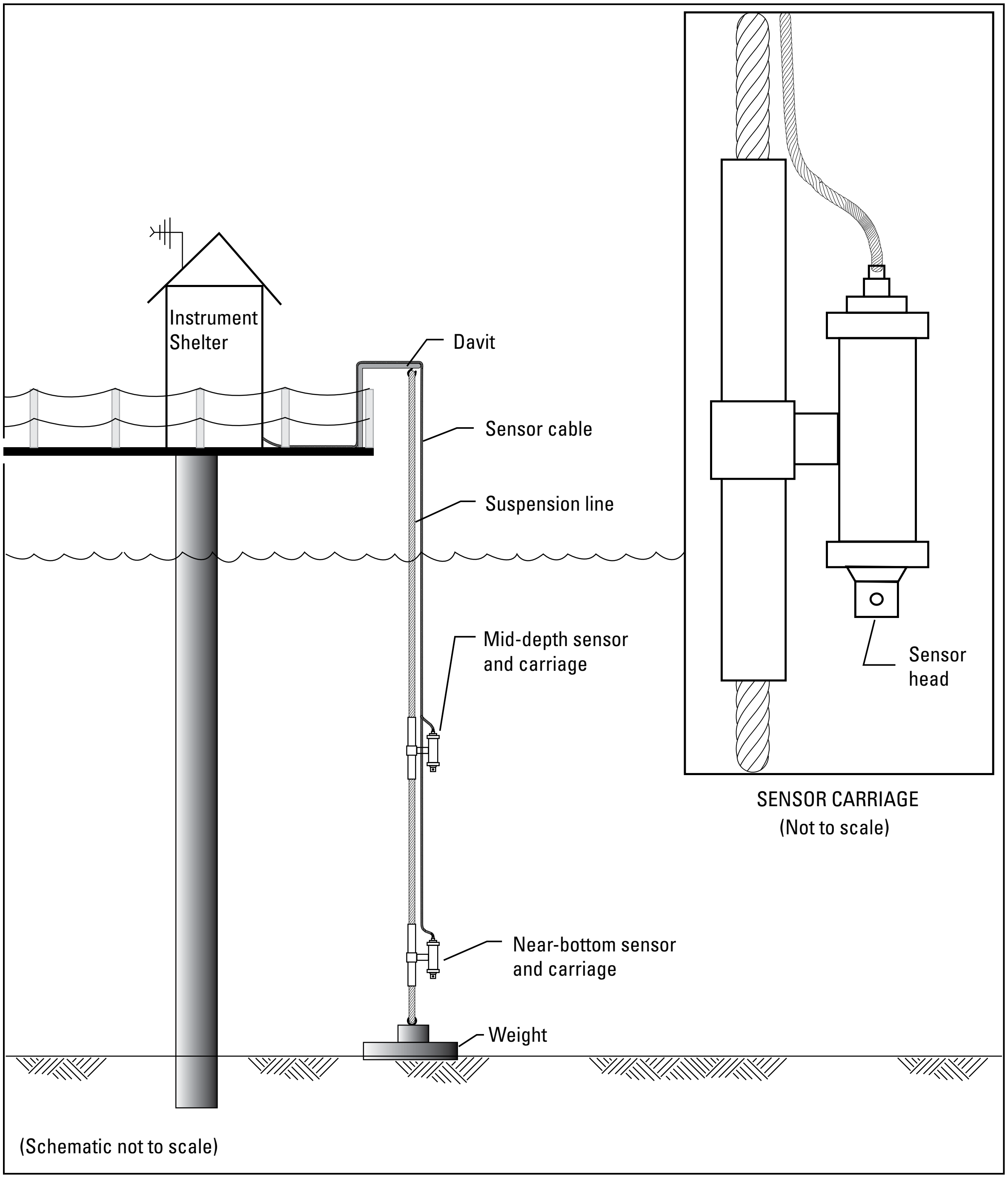

Figure 2. Typical monitoring installation, San Francisco Bay study.

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 2005.

[For definition of MLLW, see Conversion Factors, Datum, Abbreviations, and Acronyms entry at front of this report]

Site	Station No.	Latitude	Longitude	Sensor depth	Depth below MLLW[1]	Water depth at 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	9	80
				Near-bottom	61	
Carquinez Bridge	11455820	38°03´41˝	122°13´53˝	Mid-depth	40	88
				Near-bottom	83	
Mare Island Causeway	11458370	38°06´40˝	122°16´25˝	Mid-depth	3	30
				Near-bottom	25	
Channel Marker 1	380240122255701	38°02´40˝	122°25´57˝	Mid-depth	2	8
Point San Pablo	11181360	37°07´53˝	122°42´42˝	Mid-depth	8	26
				Near-bottom	23	
Alcatraz Island	374938122251801	37°49´38˝	122°25´18˝	Mid-depth	6	16
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	20	45
				Near-bottom	41	
Channel Marker 17	372844122043800	37°28´44˝	122°04´38˝	Mid-depth	11	25
				Near-bottom	21	

[1]Depth below water surface.

On-site checks of sensor accuracy were performed using turbidity solutions prepared from a 4,000-NTU 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-NTU stock standard with de-ionized water in a clean, sealable container. Prepared solutions ranged from 20 to 180 NTU. Prepared solutions were checked with a Hach Drel 2000 Spectrophotometer for accuracy. At the field site, the cleaned sensors were immersed in the solution and the output was recorded on the station log. Monitoring a period of sensor performance in a known standard helps to identify output drift or sensor malfunction.

Data acquisition was controlled by electronic data loggers. The logger used with the D & A Instrument Company sensor 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. The Hydrolab, YSI and FTS data loggers collect instantaneous values every 15 minutes. Power was supplied by 12-volt batteries.

Establishment of Monitoring Sites

Suisun Bay Installations

SSC data were collected in Suisun Bay at Mallard Island and at Benicia Bridge (fig. 1, table 1). Optical sensors were installed at the DWR Mallard Island Compliance Monitoring Station on February 8, 1994. Optical sensors were positioned 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 and draws water from about 3 ft below the surface. The near-surface optical sensor is attached to a separate float and positioned at the same depth as the pump intake.

Optical sensors were installed at Pier 7 on the Benicia Bridge on March 15, 1996. The Benicia Bridge site was shut down August 7, 1998, for seismic retrofitting of the bridge and was reestablished with sondes equiped 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 1 (fig. 1, table 1). Sondes with optical, conductance, and temperature sensors were installed at the center pier structure at Carquinez Bridge on April 21, 1998. Optical sensors were installed off a catwalk beneath Mare Island Causeway on October 1, 1998. A sonde with optical, conductance, and temperature sensors was installed at USCG Channel Marker 1 on October 7, 2003. A monitoring site at USCG Channel Marker 9 was discontinued in WY 2003 because data from the USCG Channel Marker 1 site were considered less affected by the processes that occur at the mouth of the Petaluma River (Ganju and others, 2004).

Central San Francisco Bay Installations

SSC data were collected in San Pablo Strait at Point San Pablo and San Francisco Bay at Alcatraz Island (fig. 1, table 1). Optical sensors were installed in San Pablo Strait at 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, at a pier-adjacent structure approximately 25 ft from the previous deployment site. A sonde with optical, conductance, and temperature sensors was installed on the northeast side of Alcatraz Island on November 6, 2003. A monitoring station at San Francisco Bay at Pier 24 was discontinued on January 3, 2002. The USGS assumed operation of the stations at Point San Pablo and Pier 24 from DWR in October 1989, although the collection of conductivity and temperature data continued to be 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 were installed at Pier 20 on the San Mateo Bridge, on the east side of the ship channel, on December 23, 1991. In addition to SSC, specific conductance and temperature were monitored at near-bottom and near-surface depths at San Mateo Bridge. The USGS assumed operation of this station from DWR in October 1989, although the collection of specific conductance and temperature data continued to be cooperatively funded by DWR and USGS. Specific conductance and temperature data collected at San Mateo Bridge prior to October 1, 1989, can be obtained from DWR. Optical sensors were installed at Pier 23 on the Dumbarton Bridge on the west side of the ship channel on October 21, 1992. Optical sensors were installed at USCG Channel Marker 17 on February 26, 1992.

Water-Sample Collection

Water samples, used to calibrate the output of the optical sensors to SSC, were collected by 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 a clean, 1-liter plastic bottle for transport. 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 that do not pass through a 0.45-micrometer membrane filter. The analytical method used to quantify concentrations of suspended solid-phase material was consistent from 1992 through the present study; however, the nomenclature used to describe sediment data was changed (Gray and others, 2000). Suspended-sediment concentrations were referred to as suspended-solids concentrations in previous reports (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996; Buchanan and Ruhl, 2000, 2001). Water samples collected for this study were analyzed for SSC, in milligrams per liter (mg/L), by filtering samples through a pre-weighed, 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 optical-sensor output at 15-minute intervals (96 data points per day). Recorded data were downloaded from the data loggers onto either a storage module or laptop computer during site visits. Raw data from the storage modules or laptop computer were loaded into the USGS Automated Data-Processing System (ADAPS).

The time-series data were retrieved from ADAPS and processed 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 processed optical sensor data is presented in figure 3. After sensors were cleaned, sensor output immediately decreased (fig. 3A: July 20, August 8, 29, and September 19; dates represented by vertical dashed lines). 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 sensor data is somewhat subjective. Indicators, such as an elevated baseline, increasingly variable signal, and comparisons with the other sensor at the site, are used to help define the point at which fouling begins to take place. 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. 3B). Sometimes, incomplete cleaning of a sensor would cause a small, constant shift in sensor output that could be corrected by using water-sample data that had been collected for calibration of the sensors.

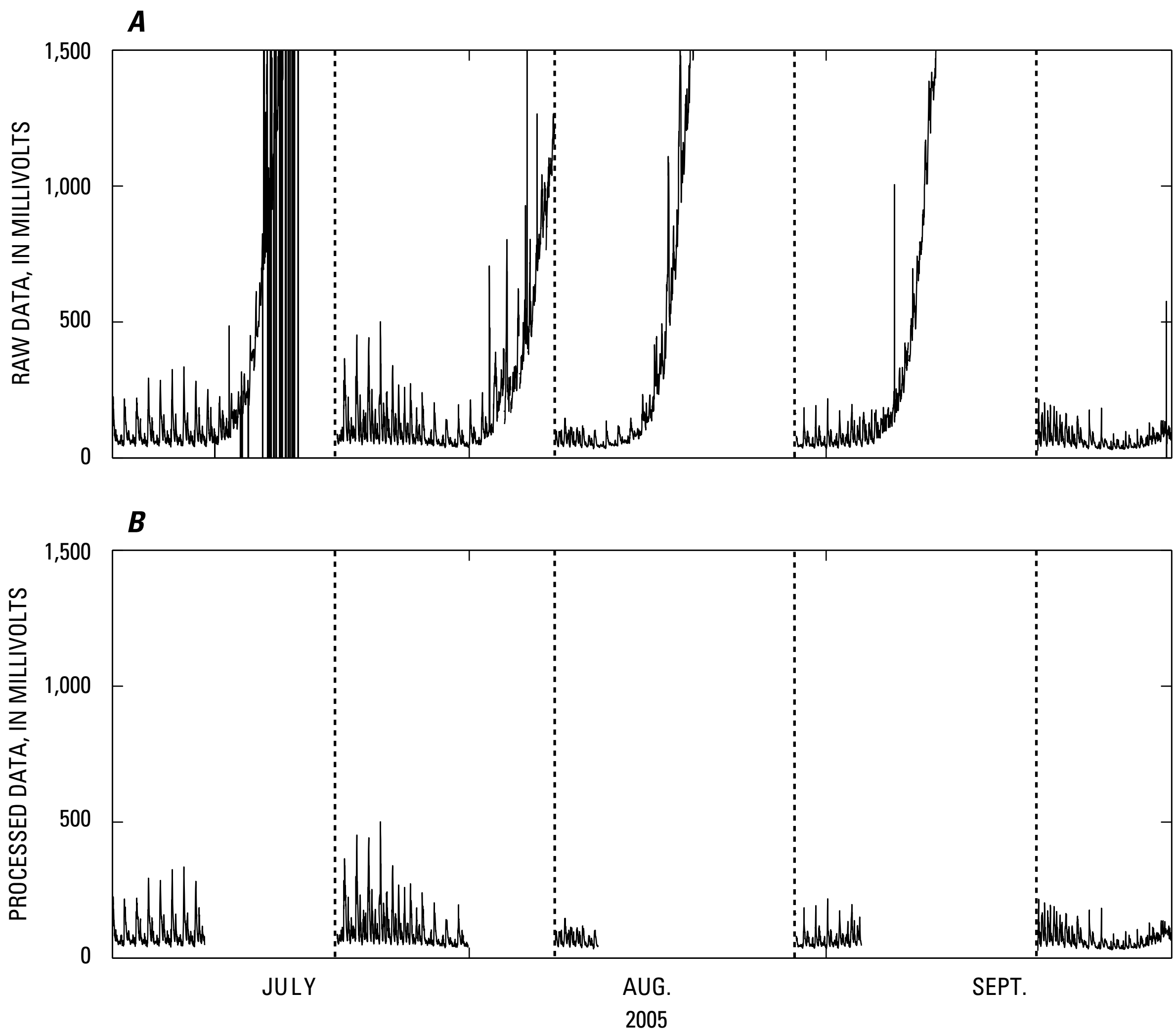

Figure 3. Example of raw and processed optical data, mid-depth sensor, Mare Island Causeway, San Pablo Bay, California, water year 2005.

Sensor Calibration and Suspended-Sediment Concentration Data

The output from each of the three types of sensors used for this study 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 different instrument designs were virtually identical (Buchanan and Schoellhamer, 1998). Calibration of the sensor output to SSC will vary according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated by using suspended material from the field (Levesque and Schoellhamer, 1995).

The output from the optical sensors was used to calculate SSC by linear regression using the robust, nonparametric, repeated median method (Siegel, 1982) rather than ordinary least squares (OLS) regression. Constant variance of residuals is a necessary condition for use of OLS regression to obtain the best linear unbiased estimator of a variable (Helsel and Hirsch, 1992, p.225). The variance of the residuals for some datasets in this study increased with voltage and was not constant; therefore, robust regression was considered to be more appropriate than OLS regression for the development of calibration curves in most cases.

The prediction interval and the 95-percent confidence interval were calculated and presented for each calibration equation. Whenever possible, water-sample data collected in previous water years were included in the calibrations to incorporate the largest range of observed concentrations. Previously collected water-sample data were disgarded if a sensor's calibration had drifted.

The repeated-median method calculates the calibration slope in a two-part process. First, for each point (X,Y) in a set of *n* data points, the median of all possible "point i" to "point j" slopes was calculated

$$\beta_i = median\frac{(Y_j - Y_i)}{(X_j - X_i)} \qquad \text{for j = 1…n, j·I} \tag{1}$$

The calibration slope was calculated as the median of β_ι

$$slope = \hat{\beta}_1 = median(\beta_i) \qquad \text{for i=1…n} \tag{2}$$

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

$$intercept = \hat{\beta}_o = median\left(Y_i - \hat{\beta}_i X_i\right) \qquad \text{for i=1…n} \tag{3}$$

The final linear calibration equation is

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

The nonparametric prediction interval (PInp) (Helsel and Hirsch, 1992, p. 76) is a constant-width error band that contains about 68-percent, or one standard deviation, of the calibration data set. The 68-percent value was selected because essentially it has the same error prediction limits as the root-mean-squared (RMS) error of prediction that was used to describe the error associated with parametric OLS regression methods 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 PInp, unlike the RMS error of prediction, frequently is not symmetrical about the regression line. For example, the PInp may be reported as +10 and -7 mg/L. This asymmetry about the regression line is a result of the distribution of the data set. The PInp is calculated by computing and sorting, from least to greatest, the residuals for each point. Then, based on the sorted list of residuals

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

where

$\hat{\mathrm{Y}}$ is the residual value,
n is the number of data points, and
α is the confidence level of 0.068.

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

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

and

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

where

Ru is the rank of the upper INTERVAL slope,
Rl is the rank of the lower INTERVAL 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. Equations (6) and (7), which represent large-sample approximations for the ranks, were used for each of the confidence intervals presented in this report. However, for those sites that had fewer than 10 samples, an alternative and presumably slightly more accurate method described by Helsel and Hirsch (1992, p. 273-274) could have been used to calculate upper and lower bound ranks.

A statistical summary of the SSC calculated from optical sensor 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 also is presented in table 2

Table 2. Statistical summary of calculated suspended-sediment concentration data and usable percentage of a complete year of valid data (96 data points per day x 365 days) collected using optical sensors, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2005.

[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	27	24	20	30	99
	Near-bottom	28	25	21	31	99
Benicia Bridge	Near-surface	37	31	23	46	65
	Near-bottom	67	61	44	82	74
Carquinez Bridge	Mid-depth	42	30	19	52	87
	Near-bottom	66	50	31	84	73
Mare Island Causeway	Mid-depth	55	42	27	70	74
	Near-bottom	109	82	51	141	59
Channel Marker 1	Mid-depth	38	27	17	47	45
Point San Pablo	Mid-depth	32	25	17	40	62
	Near-bottom	37	28	20	44	86
Alcatraz Island	Mid-depth	18	15	12	21	71
San Mateo Bridge	Mid-depth	47	43	35	57	37
	Near-bottom	45	38	28	53	16
Dumbarton Bridge	Mid-depth	48	43	23	62	45
	Near-bottom	43	32	24	51	30
Channel Marker 17	Mid-depth	51	40	31	57	50
	Near-bottom	56	36	25	65	41

.This section of the report also includes figures showing graphical results of the regression analysis (calibration) relating SSC (in mg/L) to optical sensor output. The calibration figures (for example, fig. 4) include the number of water samples (data points) (all water samples used to develop calibration, including those from previous water years), the linear regression equation, the nonparametric prediction interval (shown on the calibration figures as a grey band), and the 95-percent confidence interval for the regression-line slope. In addition, the time-series plots of calculated SSC data are shown for each site.

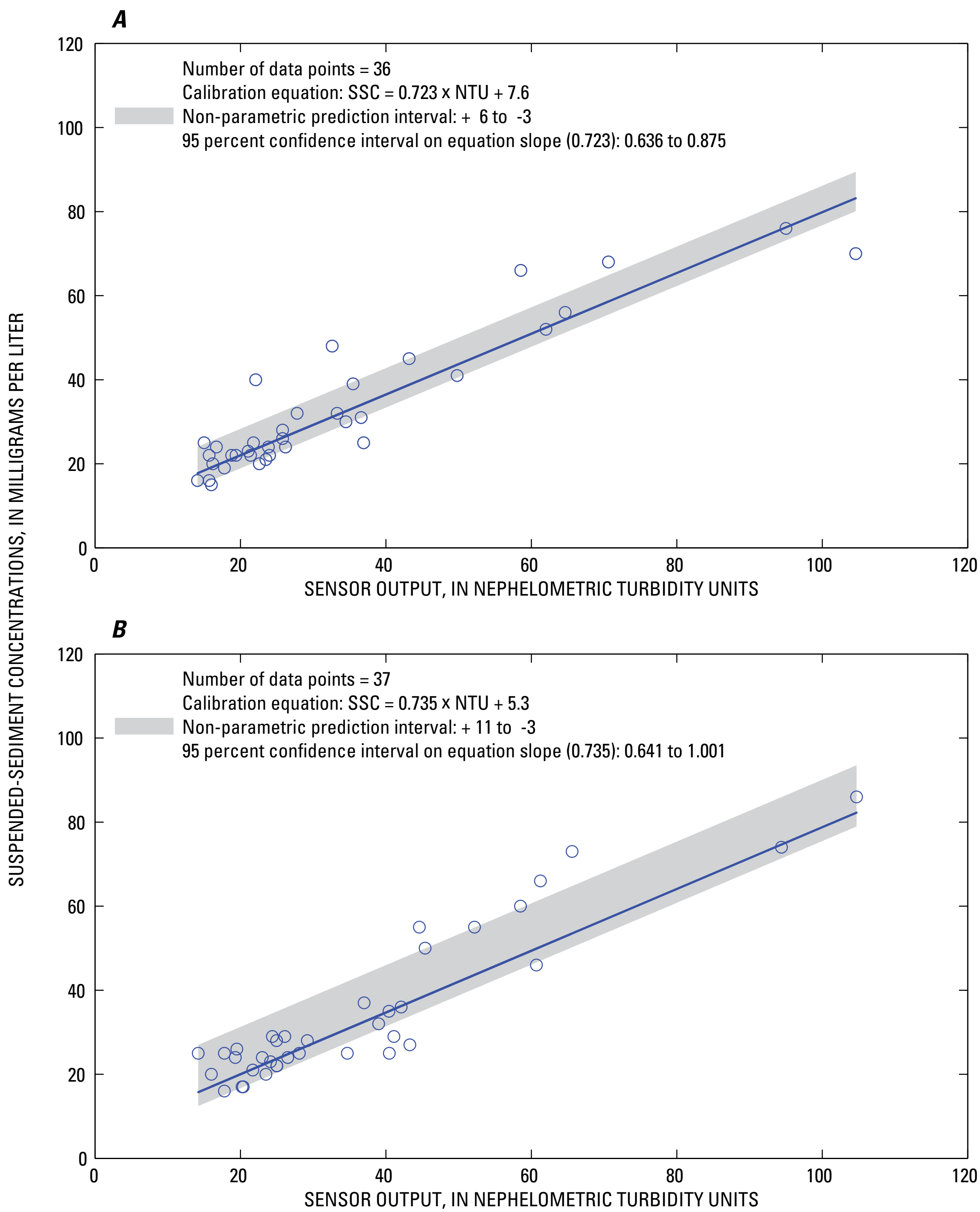

Figure 4. Calibration of near-surface and near-bottom optical sensors at Mallard Island, Suisun Bay, California, water year 2005.

Suisun Bay

Mallard Island

PERIOD OF CALIBRATION.—
NEAR-SURFACE SENSOR: WY 2005 (fig. 4A).
NEAR-BOTTOM SENSOR: WY 2005 (fig. 4B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
NEAR-SURFACE SENSOR: 36 (15 from WY 2005).
NEAR-BOTTOM SENSOR: 37 (16 from WY 2005).
LINEAR REGRESSION EQUATION.—
NEAR-SURFACE SENSOR: SSC = 0.723 × millivolt (mV) + 7.6.
NEAR-BOTTOM SENSOR: SSC = 0.735 × mV + 5.3.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-SURFACE SENSOR: +6 to -3 mg/L.
NEAR-BOTTOM SENSOR: +11 to -3 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
NEAR-SURFACE SENSOR: 0.636 to 0.875.
NEAR-BOTTOM SENSOR: 0.641 to 1.001.

REMARKS.—There were no interruptions in the record. 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 calculated SSC time-series data collected for WY 2005 are presented in figure 5.

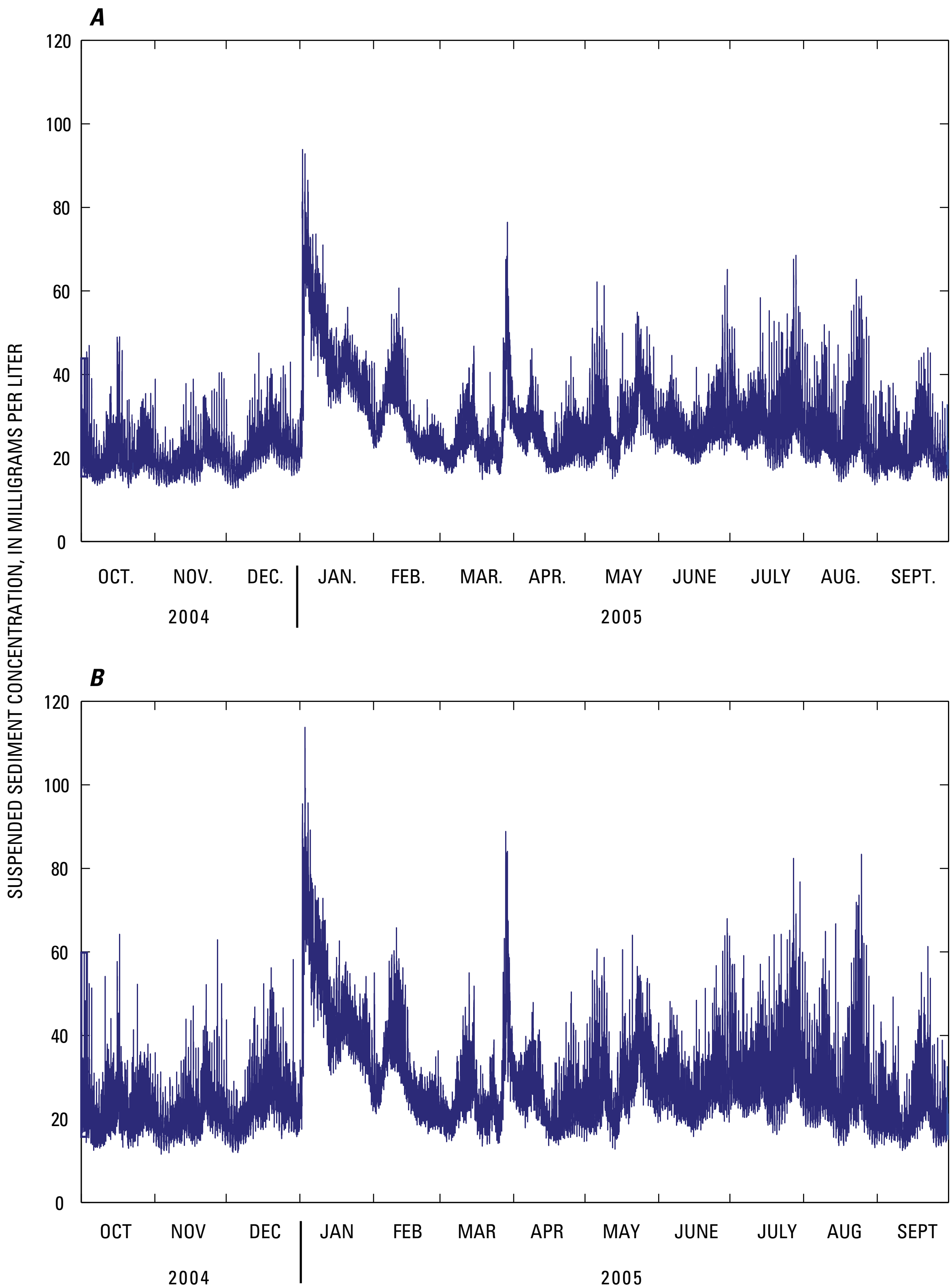

Figure 5. Graphs showing time series of near-surface and near-bottom suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 2005.

Benicia Bridge

PERIOD OF CALIBRATION.—
NEAR-SURFACE SENSOR: WY 2005 (fig. 6).
NEAR-BOTTOM SENSOR (A): October 1, 2004, to November 23, 2004 (fig. 7A).
NEAR-BOTTOM SENSOR (B): November 23, 2004, through September 30, 2005 (fig. 7B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
NEAR-SURFACE SENSOR: 33 (15 from WY 2005, 1 from WY 2006).
NEAR-BOTTOM SENSOR (A): 33 (2 from WY 2005).
NEAR-BOTTOM SENSOR (B): 25 (13 from WY 2005).
LINEAR REGRESSION EQUATION.—
NEAR-SURFACE SENSOR: SSC = 0.916 × NTU + 6.5.
NEAR-BOTTOM SENSOR (A): SSC = 1.138 × NTU + 10.1.
NEAR-BOTTOM SENSOR (B): SSC = 1.125 × NTU + 21.3.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-SURFACE SENSOR: +8 to -6 mg/L.
NEAR-BOTTOM SENSOR (A): +22 to -9 mg/L.
NEAR-BOTTOM SENSOR (B): +11 to -18 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
NEAR-SURFACE SENSOR: 0.824 to 1.100.
NEAR-BOTTOM SENSOR (A): 1.044 to 1.352.
NEAR-BOTTOM SENSOR (B): 0.909 to 1.259.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. 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. The near-surface sonde malfunctioned and was replaced on July 29, 2005. Because the two near-surface optical sensors responded similarly to the uniform sediment characteristics of San Francisco Bay (Schoellhamer and others, 2003), the calibration was developed by combining water samples collected during each sensor deployment (including two samples from WY 2006). The near-bottom sonde was replaced on November 23, 2004, with a sonde from a different manufacturer. On May 18, 2005, the near-bottom sonde was determined to be reading erratically and was replaced. Because the two optical sensors (both YSI's) deployed at the near-bottom position from November 23, 2004, through September 30, 2005, responded similarly to the uniform sediment characteristics of San Francisco Bay (Schoellhamer and others, 2003), the calibration was developed by combining water samples collected during each sensor deployment. The calculated SSC time-series data collected for WY 2005 are presented in figure 8.

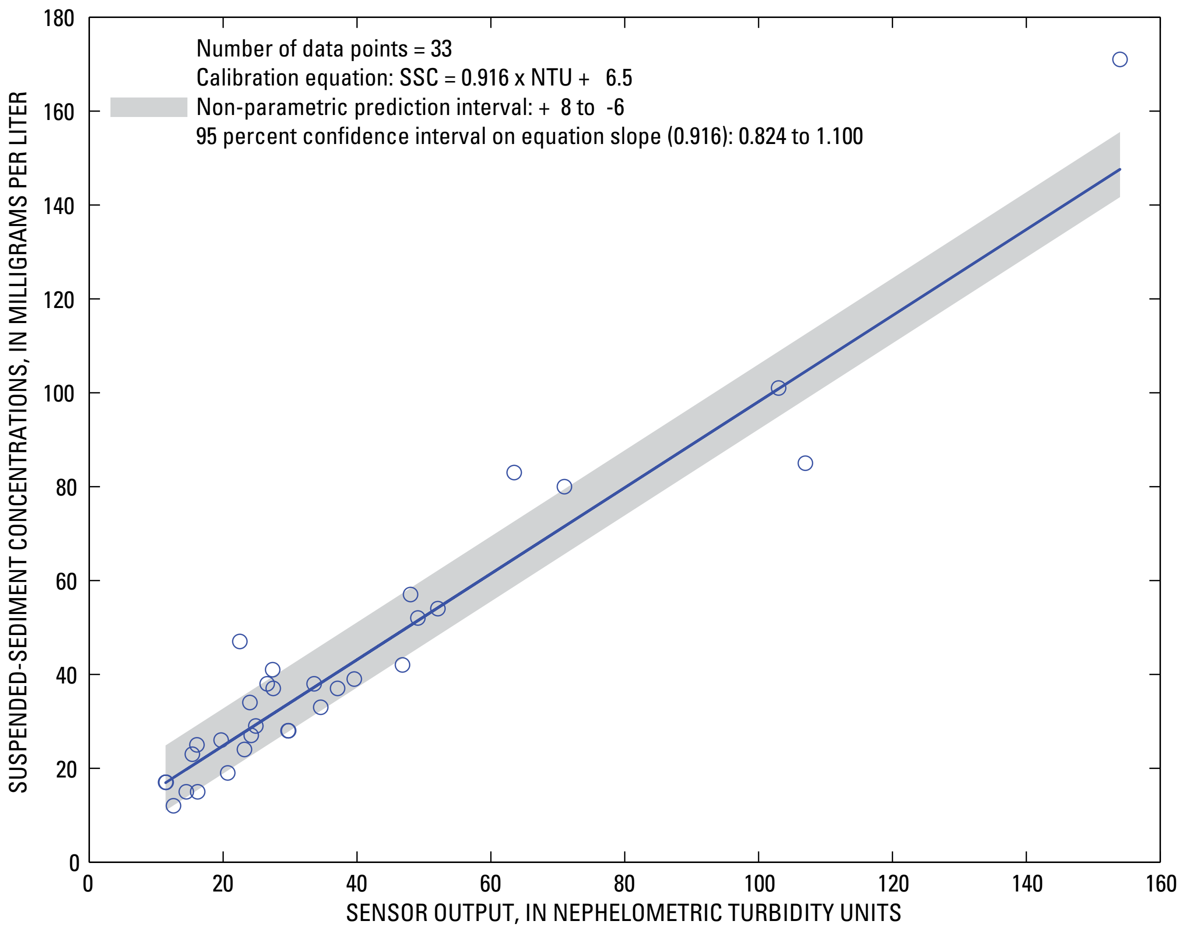

Figure 6. Graph showing calibration of near-surface optical sensor at Benicia Bridge, Suisun Bay, California, water year 2005.

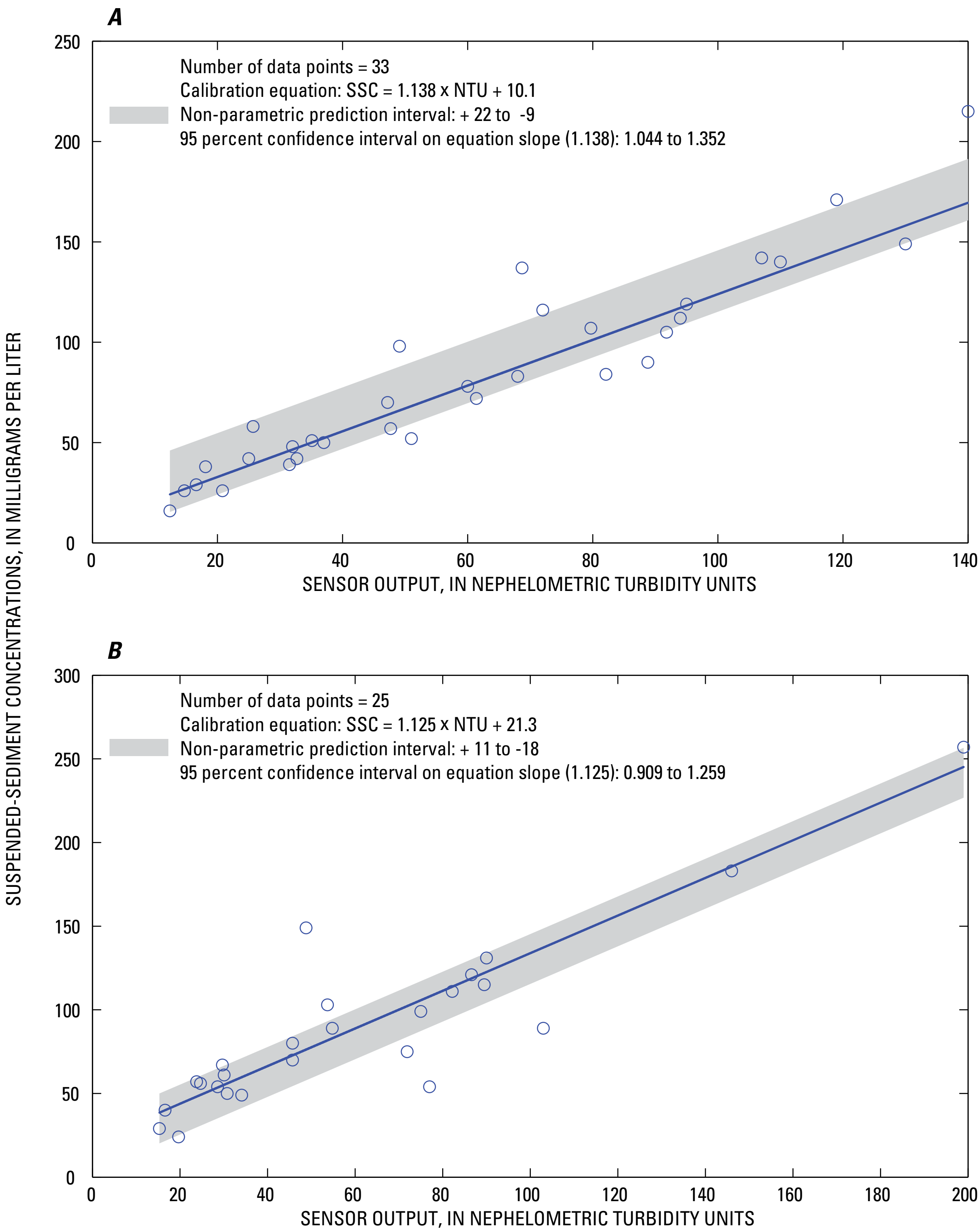

Figure 7. Graphs showing calibration of near-bottom optical sensors, October 1–November 23 and November 23–September 30 at Benicia Bridge, Suisun Bay, California, water year 2005.

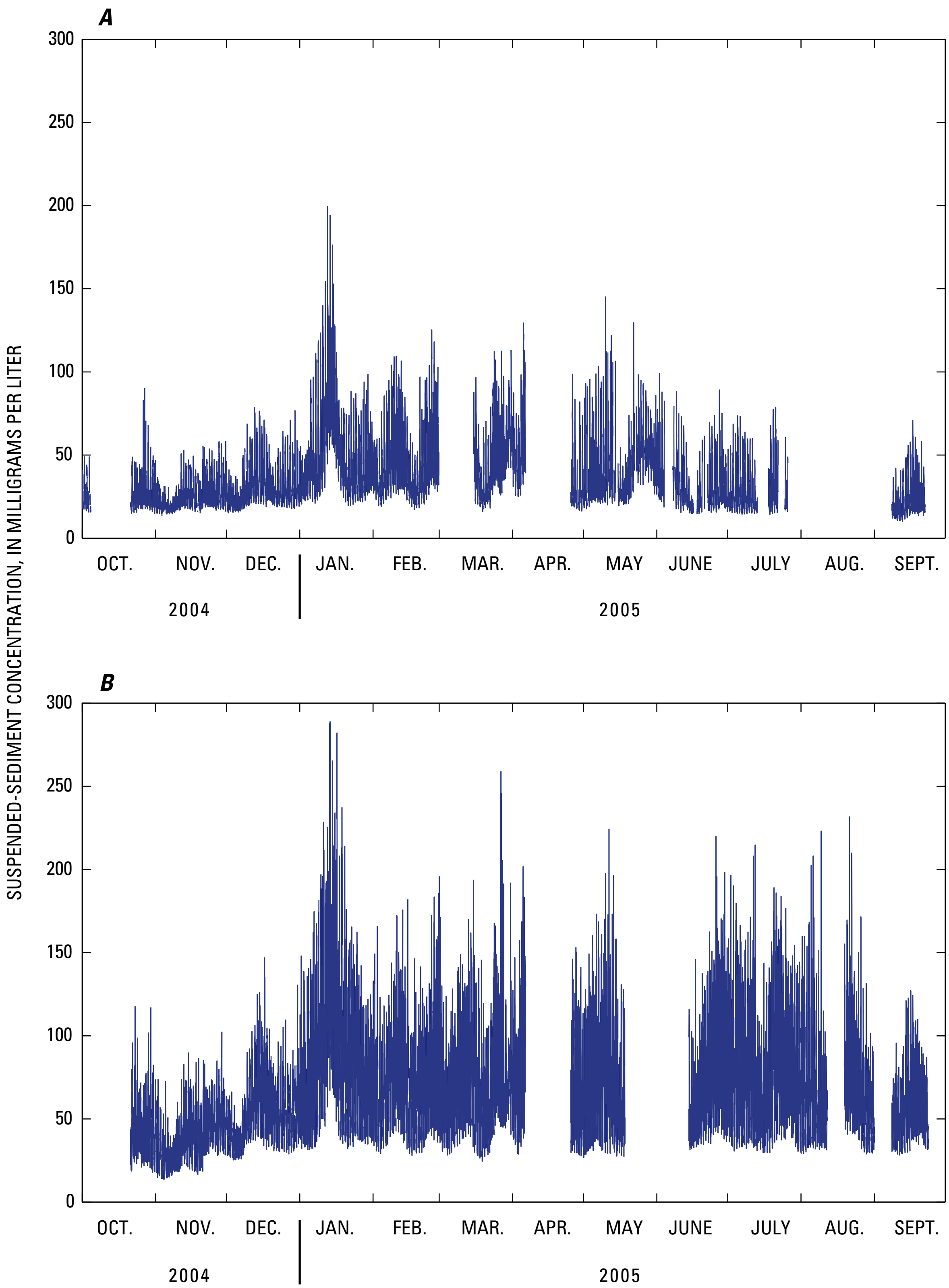

Figure 8. Graphs showing time series of near-surface and near-bottom suspended-sediment concentrations calculated from sensor readings at Benicia Bridge, Suisun Bay, California, water year 2005.

San Pablo Bay

Carquinez Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2005 (fig. 9A).
NEAR-BOTTOM SENSOR: WY 2005 (fig. 9B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 18 (17 from WY 2005).
NEAR-BOTTOM SENSOR: 27 (13 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 1.297 × NTU + 3.6.
NEAR-BOTTOM SENSOR: SSC = 1.173 × NTU + 8.8.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +7 to -6 mg/L.
NEAR-BOTTOM SENSOR: +18 to -13 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 1.111 to 1.481.
NEAR-BOTTOM SENSOR: 1.035 to 1.333.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The suspension cable failed on April 29, 2005, and was replaced on May 20, 2005. The near-bottom sonde malfunctioned during the site visit on August 18, 2005, and was replaced on September 7, 2005, with a sonde without a turbidity sensor. The calculated SSC time-series data collected for water year 2005 are presented in figure 10.

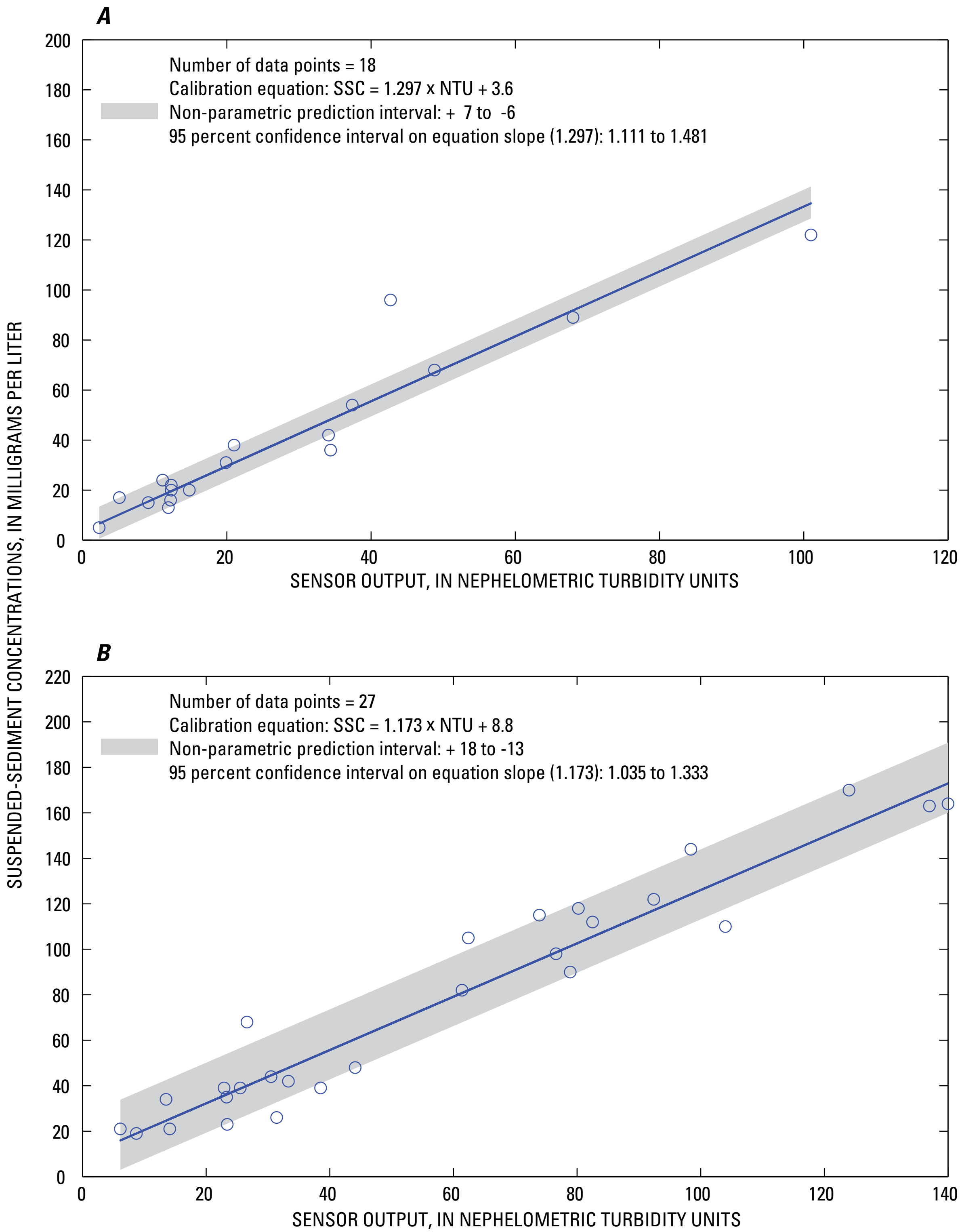

Figure 9. Graphs showing calibration of mid-depth and near-bottom optical sensors at Carquinez Bridge, San Pablo Bay, California, water year 2005.

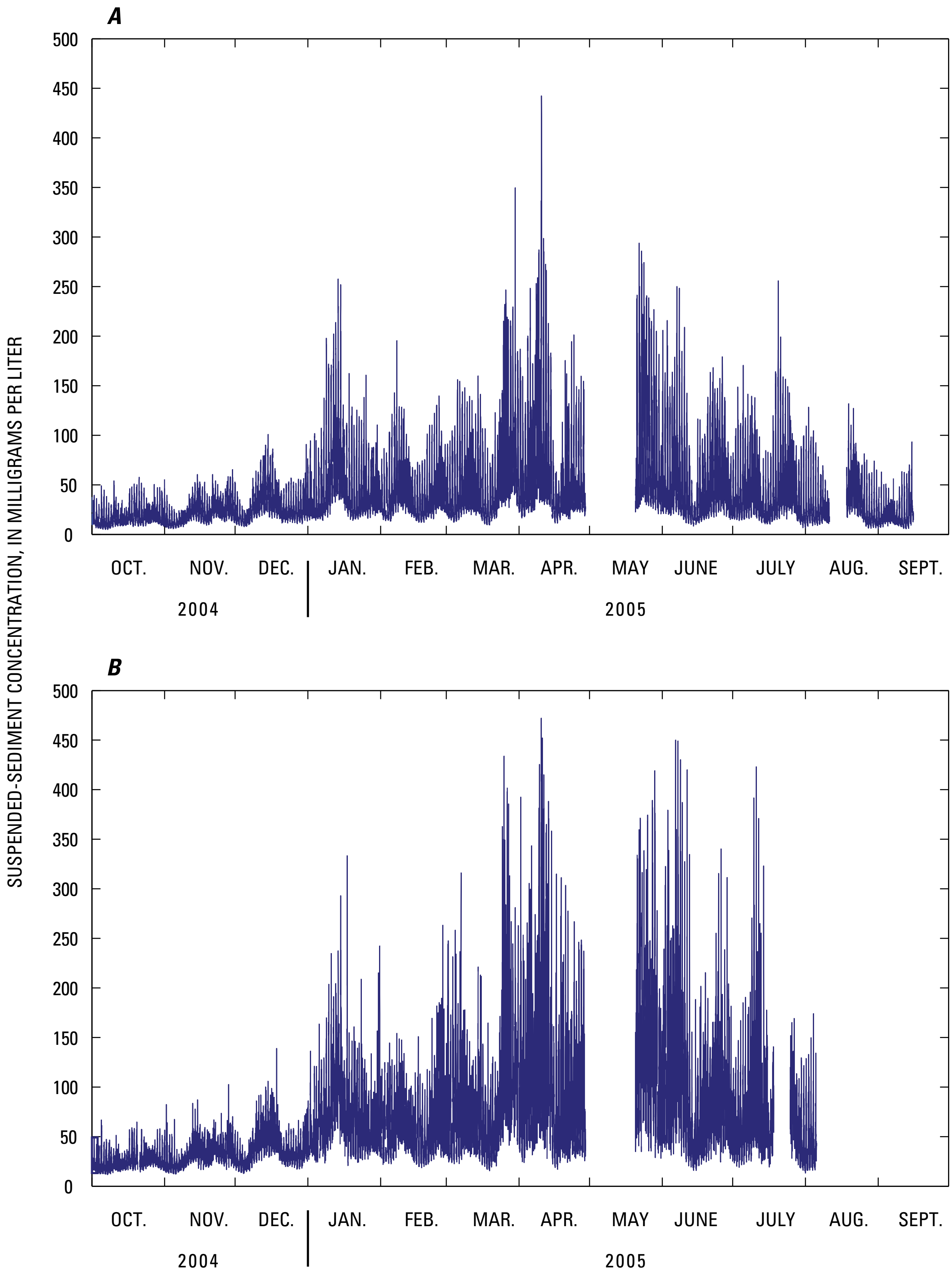

Figure 10. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at Carquinez Bridge, San Pablo Bay, California, water year 2005.

Mare Island Causeway

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2005 (fig. 11).
NEAR-BOTTOM SENSOR (A): October 1, 2004, to March 29, 2005 (fig. 12A).
NEAR-BOTTOM SENSOR (B): March 29, 2005, through September 30, 2005 (fig. 12B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 39 (19 from WY 2005).
NEAR-BOTTOM SENSOR (A): 7 (5 from WY 2005).
NEAR-BOTTOM SENSOR (B): 9 (9 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: $SSC = 0.640 \times mV - 10.8$.
NEAR-BOTTOM SENSOR (A): $SSC = 0.919 \times mV - 39.6$.
NEAR-BOTTOM SENSOR (B): $SSC = 0.633 \times mV - 4.1$.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +13 to -8 mg/L.
NEAR-BOTTOM SENSOR (A): +20 to -24 mg/L.
NEAR-BOTTOM SENSOR (B): +13 to -22 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 0.573 to 0.685.
NEAR-BOTTOM SENSOR (A): 0.811 to 1.657.
NEAR-BOTTOM SENSOR (B): 0.303 to 0.848.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The near-bottom optical sensor output began to drift in late January but the drift was not recognized until March 29, 2005, when the sensor was replaced with another optical sensor. The calculated SSC time-series data collected for WY 2005 are presented in figure 13.

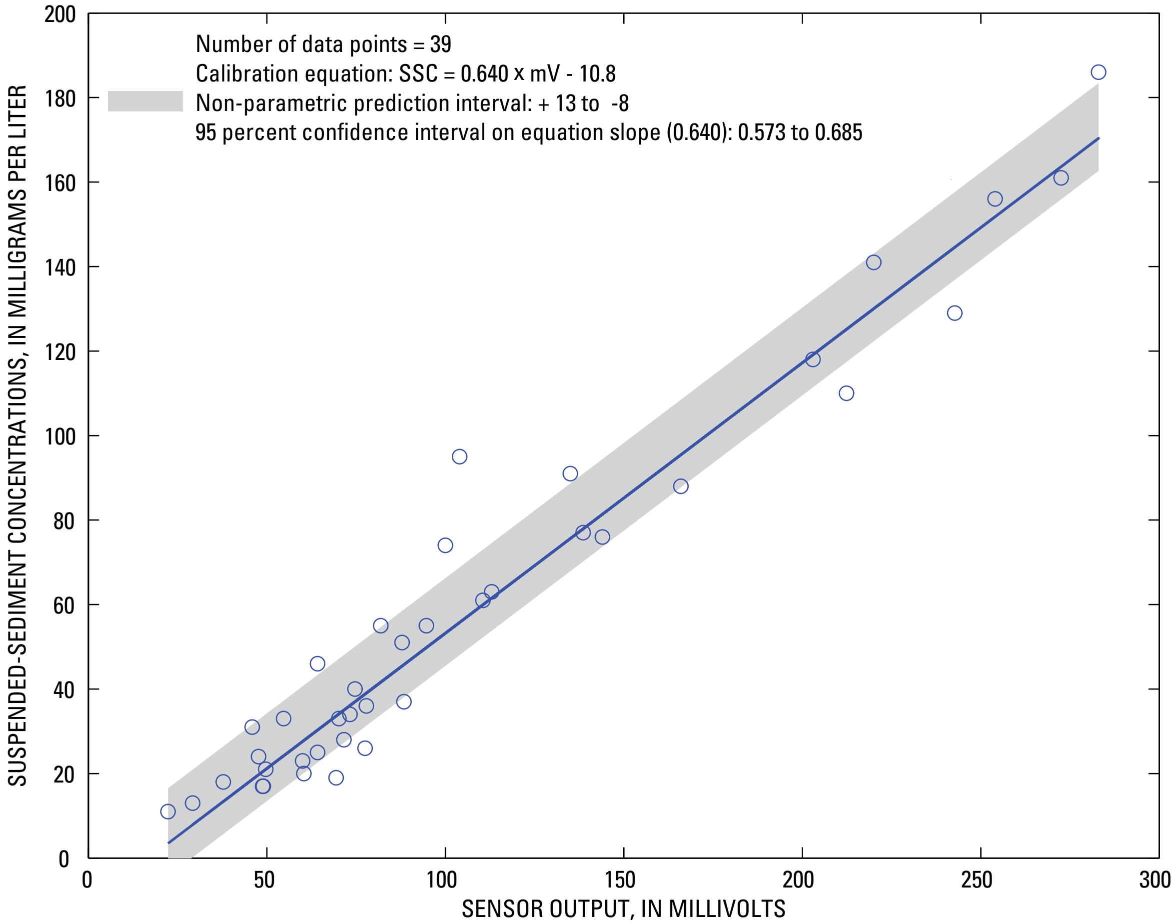

Figure 11. Graph showing calibration of mid-depth optical sensor at Mare Island Causeway, San Pablo Bay, California, water year 2005 .

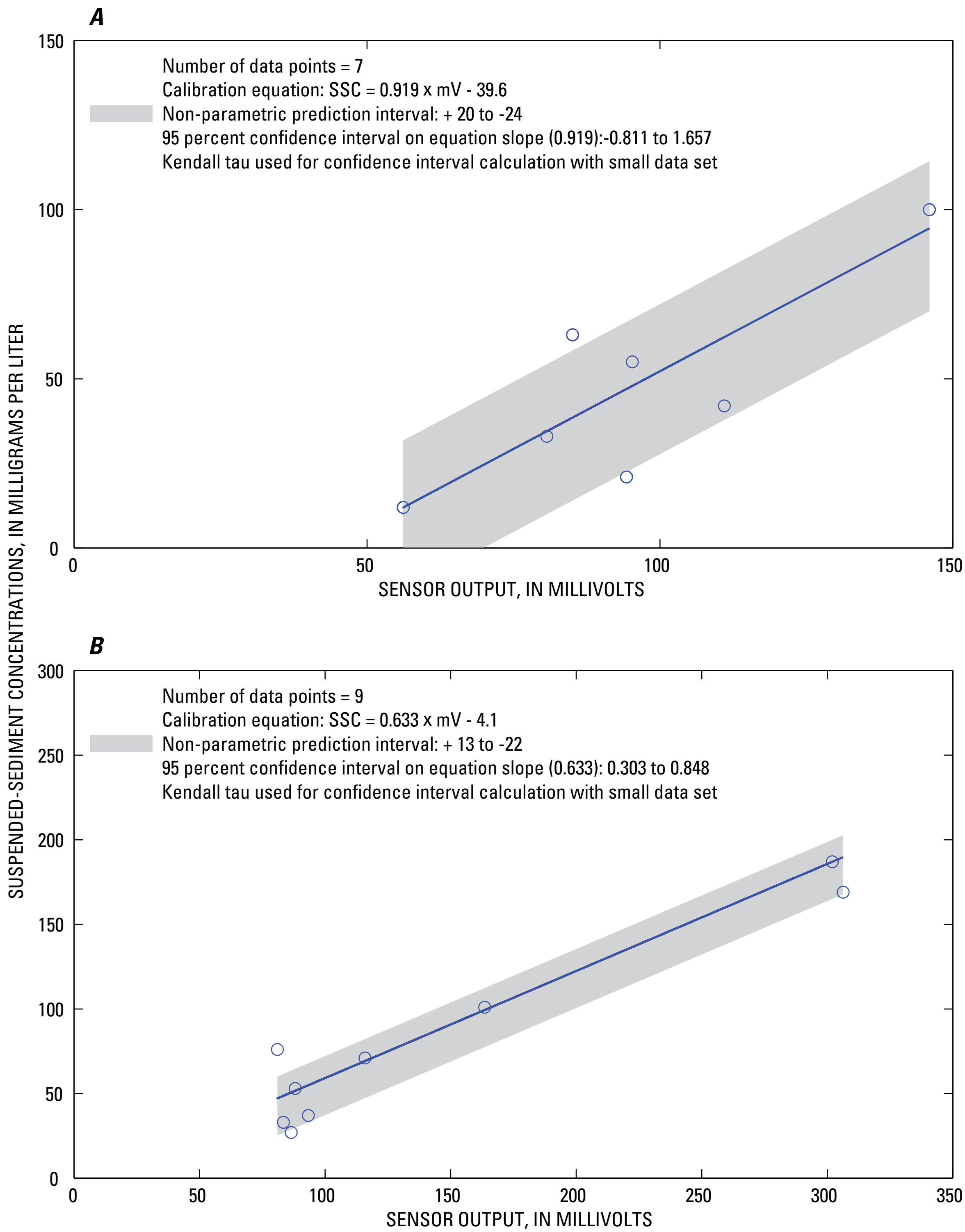

Figure 12. Graphs showing calibrations of near-bottom optical sensors, October 1–March 29 and March 29–September 30 at Mare Island Causeway, San Pablo Bay, California, water year 2005.

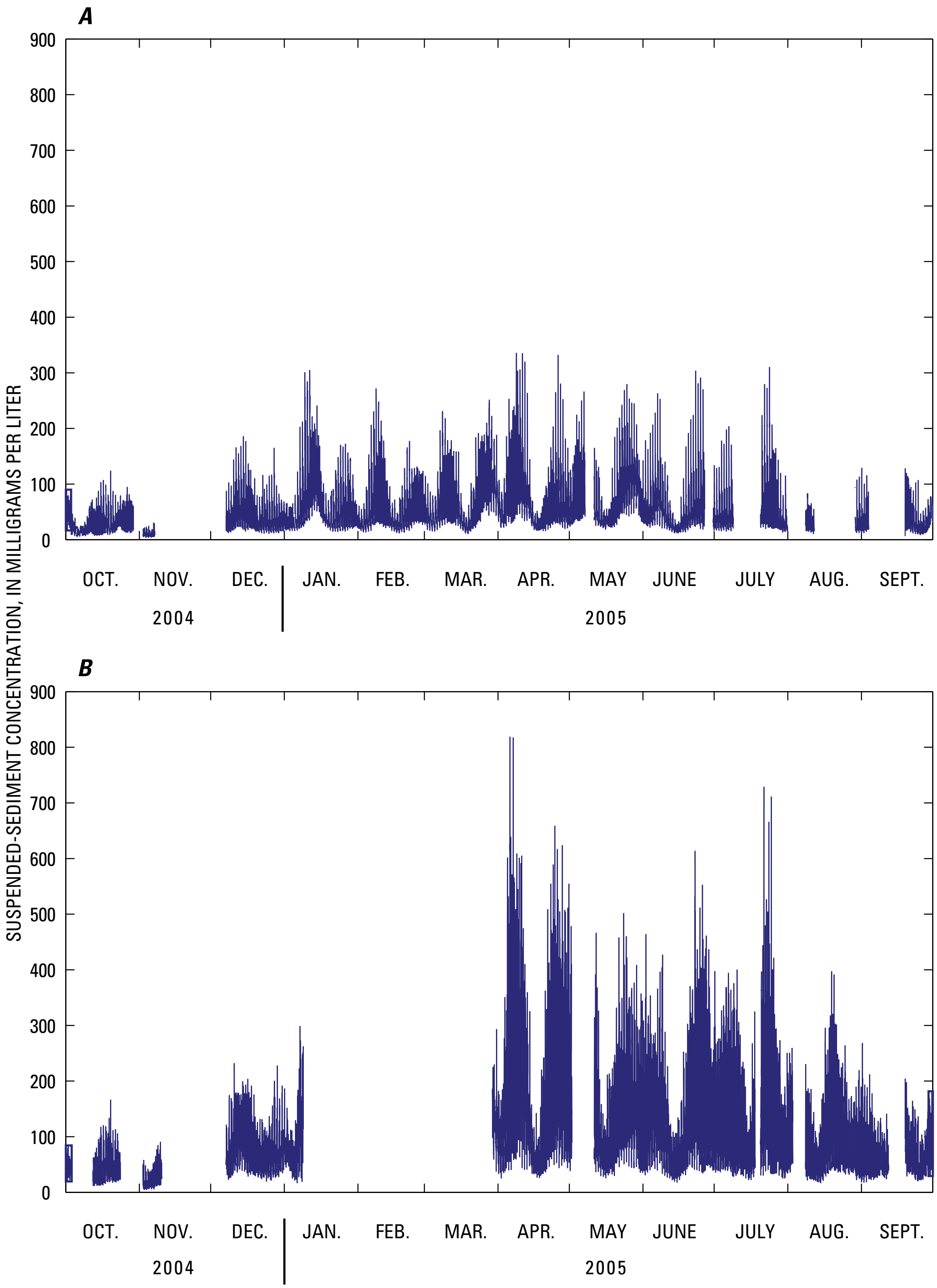

Figure 13. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at Mare Island Causeway, San Pablo Bay, California, water year 2005.

Channel Marker 1

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: October 1, 2004 to September 28, 2005 (fig. 14).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 27 (11 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: $SSC = 1.787 \times NTU + 1.9$
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +19 to -14 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR (A): 1.111 to 2.031.

REMARKS.—Interruptions in record caused by fouling or malfunction of the sensing and(or) recording instruments. During periods of heavy fouling the optical sensor wiper was ineffective in keeping the optical ports clean because of biological growth on the wiper itself obscuring the optical ports. The site was discontinued on September 28, 2005. The calculated SSC time-series data collected for WY 2005 are presented in figure 15.

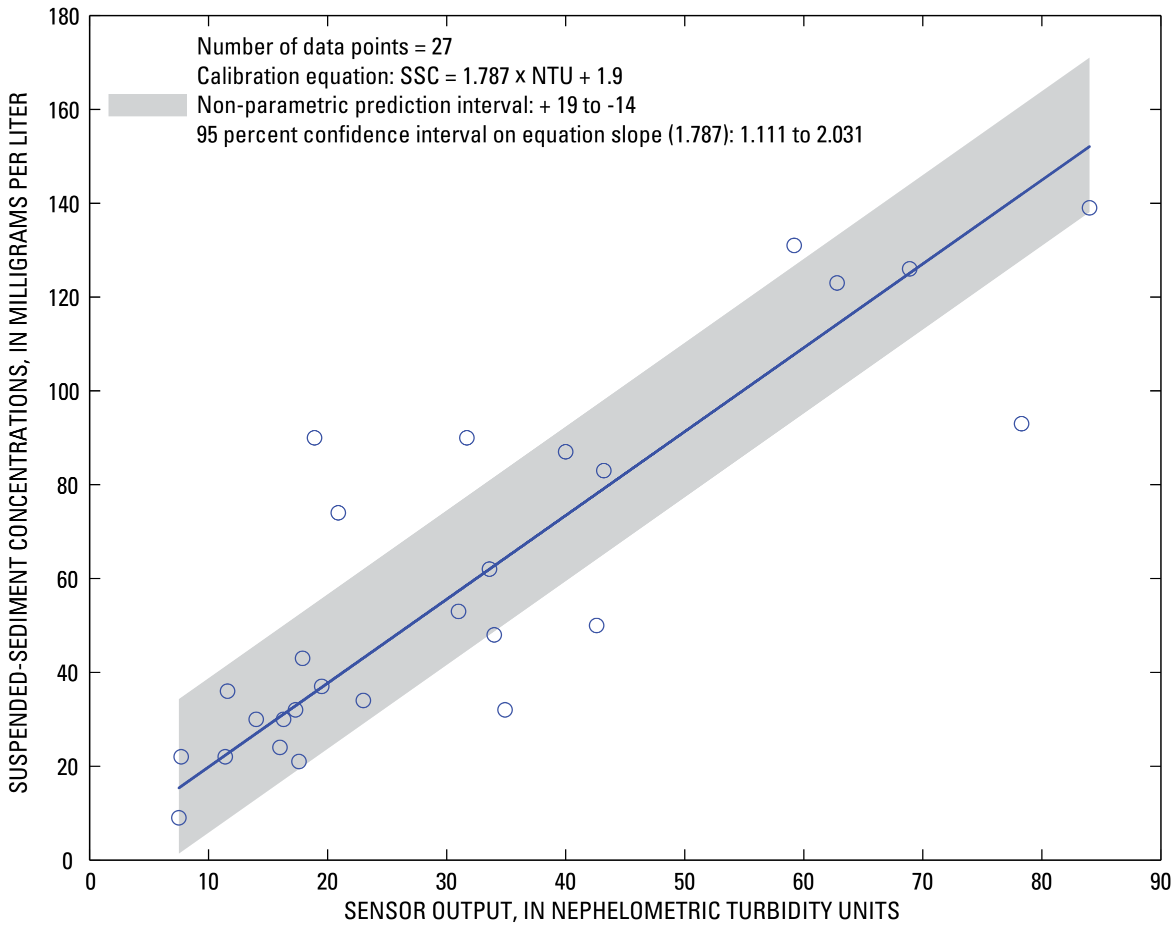

Figure 14. Graph showing calibration of mid-depth optical sensor at Channel Marker 1, San Pablo Bay, California, water year 2005.

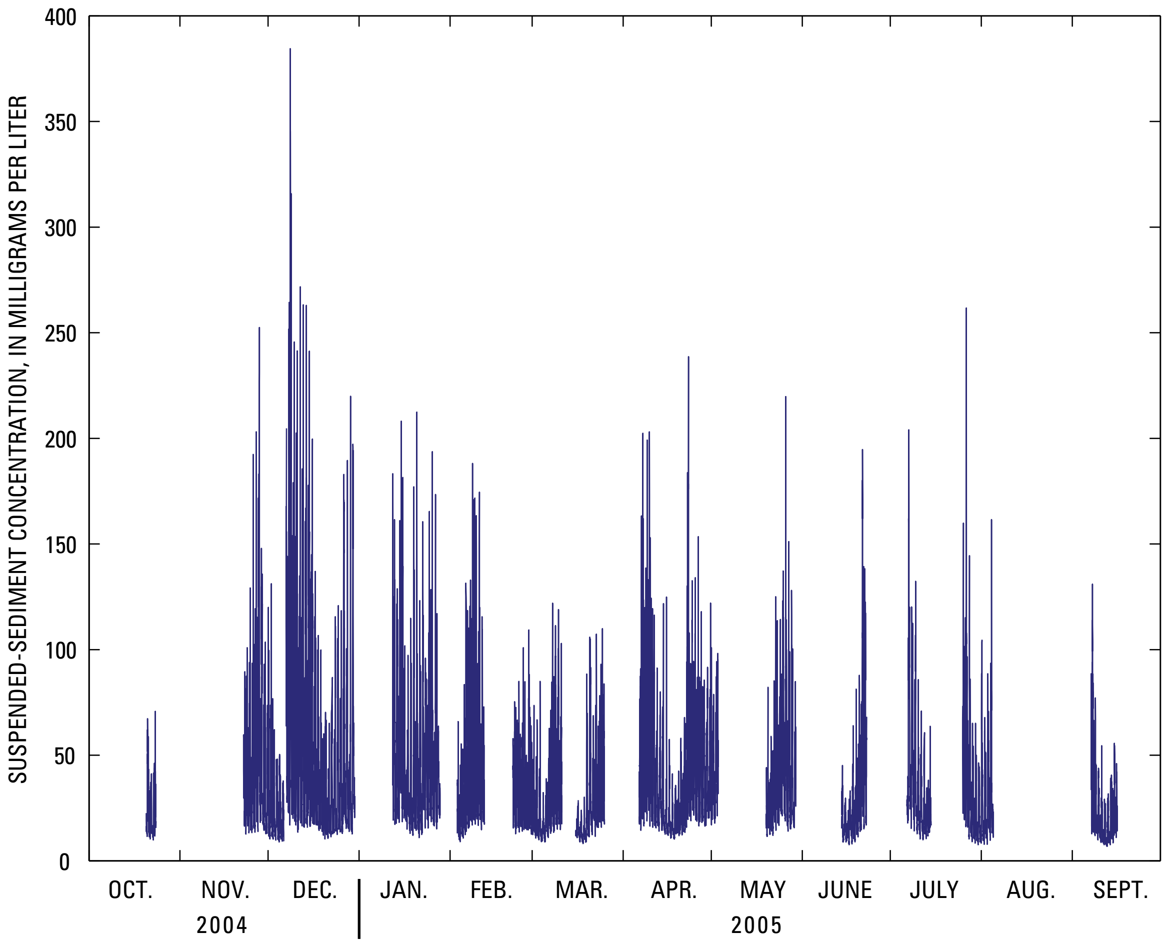

Figure 15. Graph showing time series of mid-depth suspended-sediment concentrations calculated from sensor readings at Channel Marker 1, San Pablo Bay, California, water year 2005.

Central San Francisco Bay

Point San Pablo

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2005 (fig. 16A).
NEAR-BOTTOM SENSOR: WY 2005 (fig. 16B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 29 (13 from WY 2005).
NEAR-BOTTOM SENSOR: 35 (15 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 1.755 × NTU + 0.9.
NEAR-BOTTOM SENSOR: SSC = 1.537 × NTU + 4.4.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +14 to -10 mg/L.
NEAR-BOTTOM SENSOR: +25 to -10 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 1.330 to 2.213.
NEAR-BOTTOM SENSOR: 1.166 to 1.931.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The mid-depth sonde was removed on June 28, 2005, because of a broken communication pin and redeployed on July 21, 2005. The near-bottom sonde was removed on June 7, 2005, because of a flooded battery compartment and a replacement sonde was deployed on June 9, 2005. Because the two optical sensors deployed at the near-bottom position responded similarly to the uniform sediment characteristics of San Francisco Bay (Schoellhamer and others, 2003), the calibration was developed by combining water samples collected during each sensor deployment.The calculated SSC time-series data collected for WY 2005 are presented in figure 17.

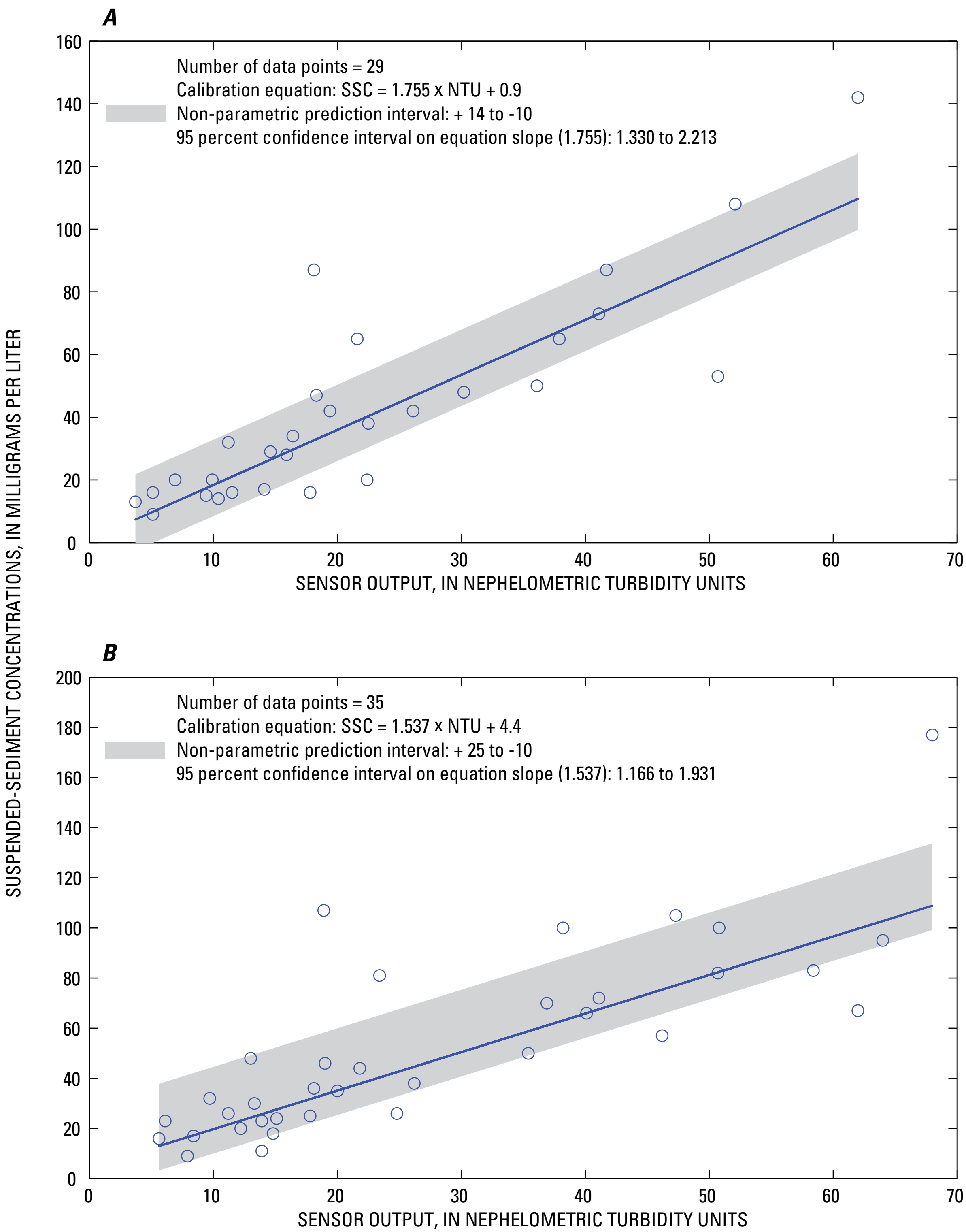

Figure 16. Graphs showing calibration of mid-depth and near-bottom optical sensors at Point San Pablo, Central San Francisco Bay, California, water year 2005.

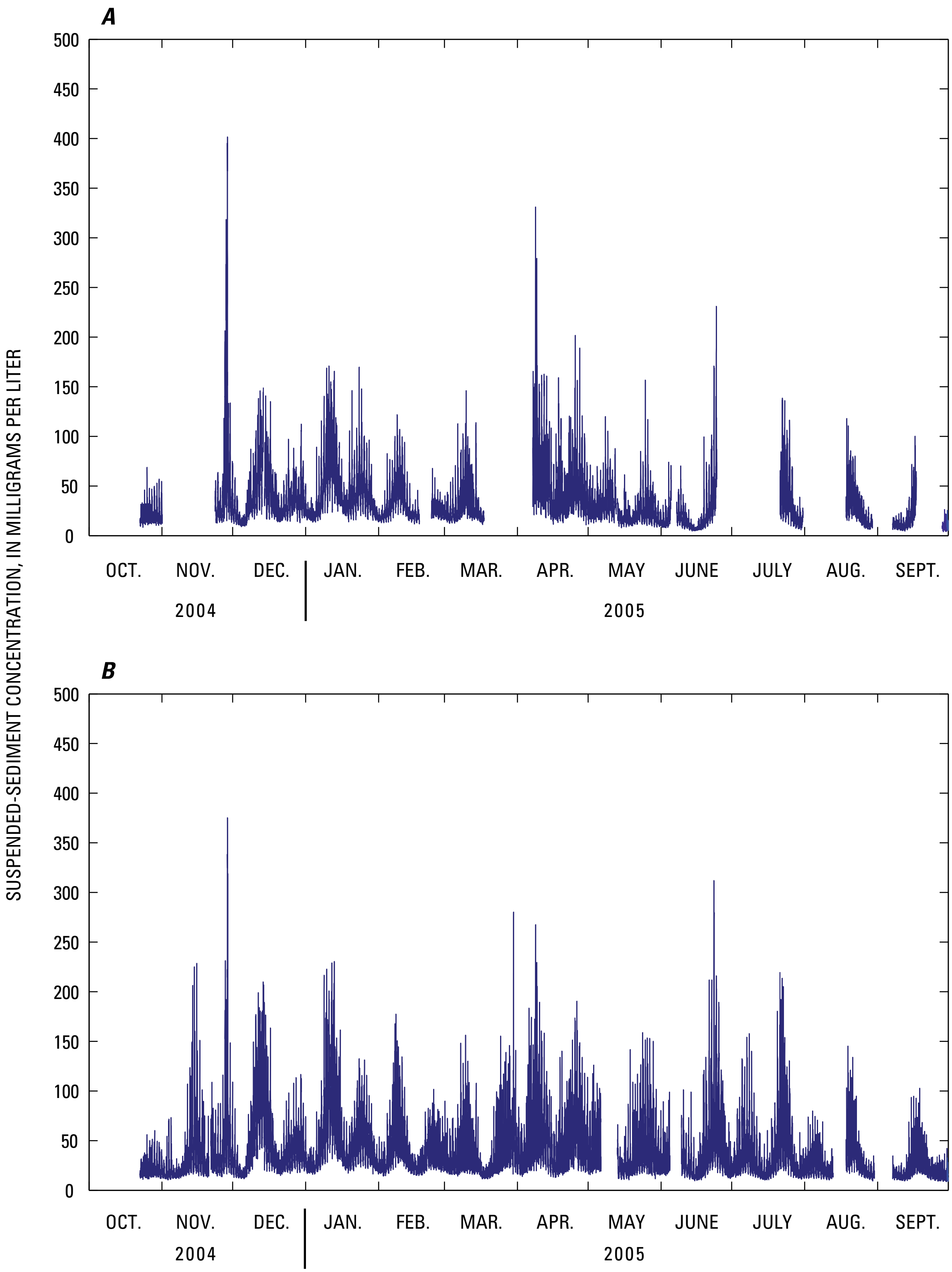

Figure 17. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at Point San Pablo, Central San Francisco Bay, California, water year 2005.

Alcatraz Island

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2005 (fig. 18).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 17 (17 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 2.357 × NTU - 8.4.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +9 to -4 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 1.538 to 4.286.

REMARKS.—Interruptions in record caused by fouling or malfunction of the sensing and(or) recording instruments. The optical sensor wiper was ineffective during periods of heavy fouling because of biological growth on the wiper obscuring the optical ports. The calculated SSC time-series data collected for WY 2005 are presented in figure 19.

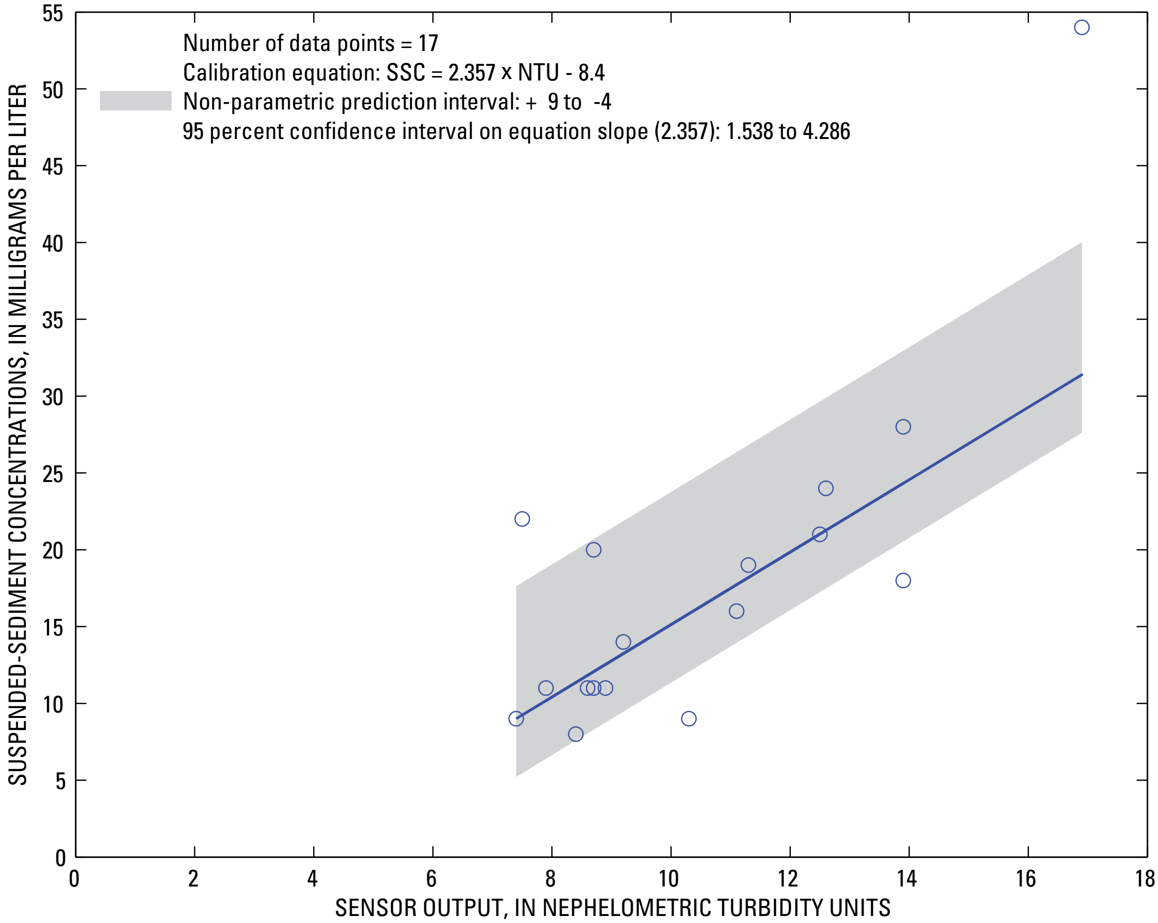

Figure 18. Graph showing calibration of mid-depth optical sensor at Alcatraz Island, Central San Francisco Bay, California, water year 2005.

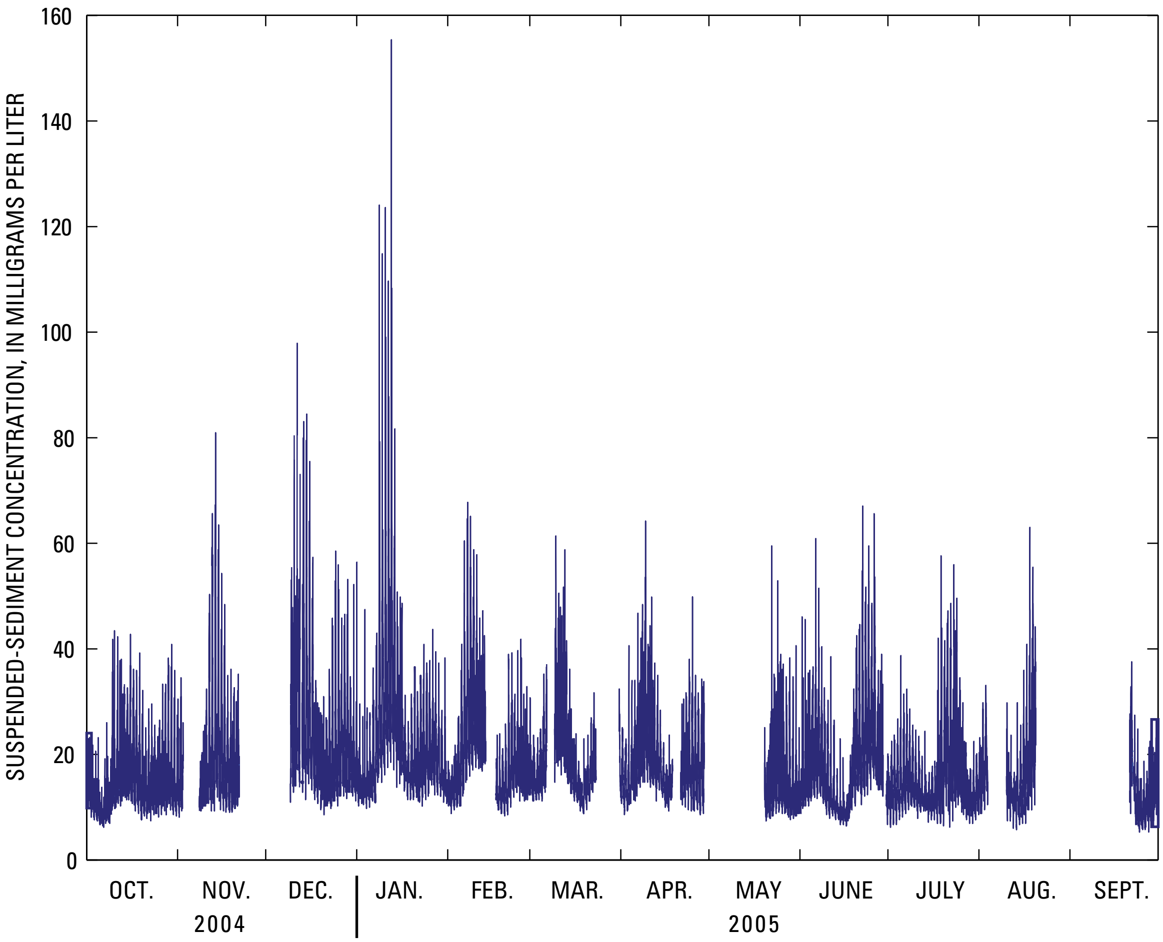

Figure 19. Graph showing time series of mid-depth suspended-sediment concentrations calculated from sensor readings at Alcatraz Island, Central San Francisco Bay, California, water year 2005.

South San Francisco Bay

San Mateo Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2005 (fig. 20A).
NEAR-BOTTOM SENSOR: October 1, 2004 to July 22, 2005 (fig. 20B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 70 (16 from WY 2005).
NEAR-BOTTOM SENSOR: 57 (10 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 0.445 × mV + 5.2.
NEAR-BOTTOM SENSOR: SSC = 0.591 × mV + 1.8.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +10 to -12 mg/L.
NEAR-BOTTOM SENSOR: +9 to -9 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 0.435 to 0.656.
NEAR-BOTTOM SENSOR: 0.509 to 0.720.

REMARKS.— Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. Biological fouling in South San Francisco Bay is extreme, especially during the summer months, resulting in a fragmented data set. The near-bottom sensor malfunctioned on July 22, 2005, and a replacement sensor was deployed on July 27, 2005. The near-bottom sensor deployed from July 27, 2005 through September 30, 2005, did not operate properly and the data were deleted. The calculated SSC time-series data collected for WY 2005 are presented in figure 21.

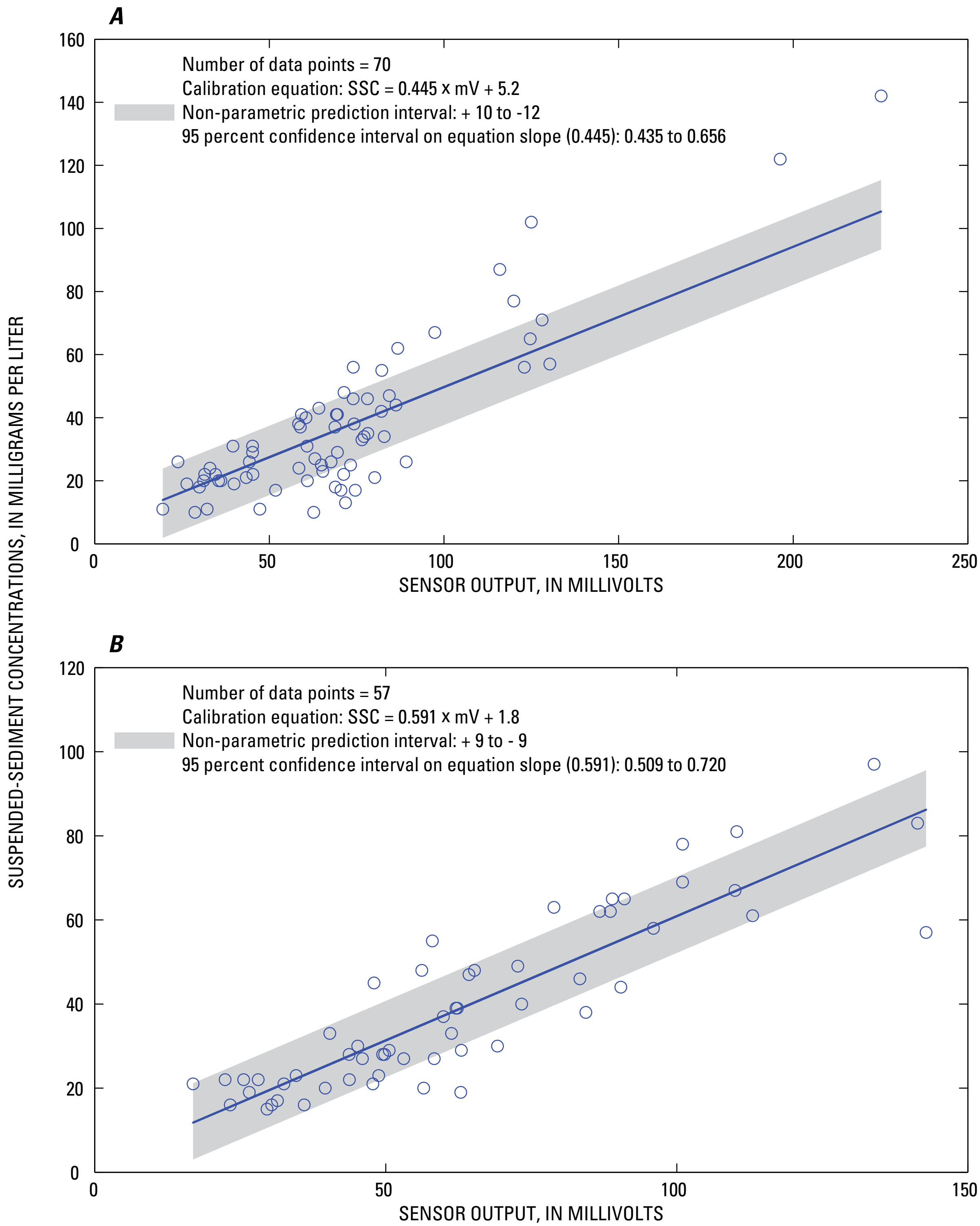

Figure 20. Graphs showing calibration of mid-depth and near-bottom optical sensors at San Mateo Bridge, South San Francisco Bay, California, water year 2005.

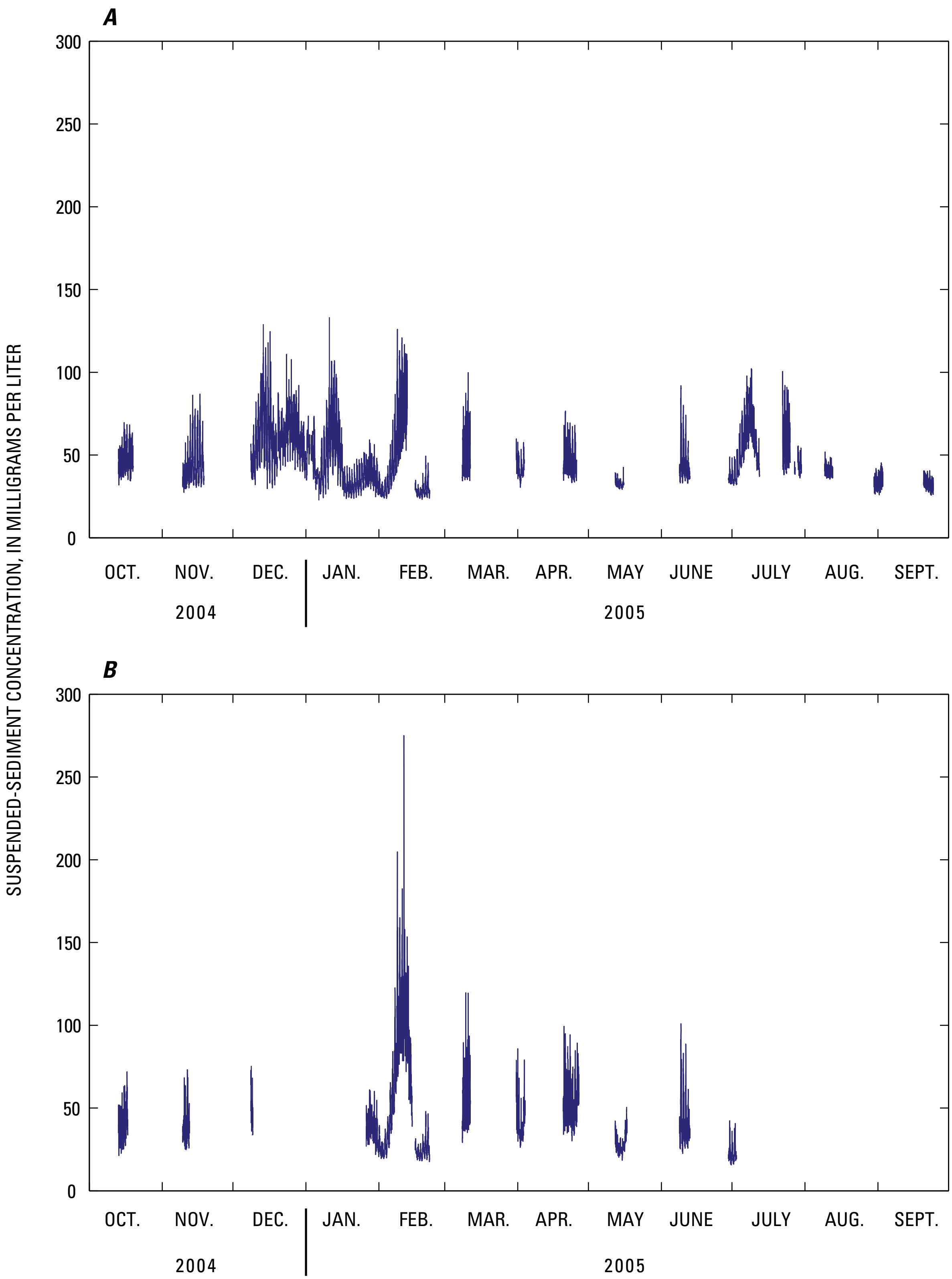

Figure 21. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at San Mateo Bridge, South San Francisco Bay, California, water year 2005.

Dumbarton Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR (A): October 1, 2004, to July 28, 2005 (fig. 22A).
MID-DEPTH SENSOR (B): July 28, 2005, through September 30, 2005 (fig. 22B).
NEAR-BOTTOM SENSOR (A): October 1, 2004, to March 30, 2005 (fig. 23A).
NEAR-BOTTOM SENSOR (B): March 30, 2005, to July 28, 2005 (fig. 23B).
NEAR-BOTTOM SENSOR (C): July 28, 2005, through September 30, 2005 (fig. 23C).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR (A): 49 (9 from WY 2005).
MID-DEPTH SENSOR (B): 12 (4 from WY 2005, 8 from WY 2006).
NEAR-BOTTOM SENSOR (A): 16 (5 from WY 2005).
NEAR-BOTTOM SENSOR (B): 4 (4 from WY 2005).
NEAR-BOTTOM SENSOR (C): 12 (4 from WY 2005, 8 from WY 2006).
LINEAR REGRESSION EQUATION.—`
MID-DEPTH SENSOR (A): SSC = 0.629 × mV - 2.6.
MID-DEPTH SENSOR (B): SSC = 0.386 × NTU +14.5.
NEAR-BOTTOM SENSOR (A): SSC = 0.685 × mV - 13.8.
NEAR-BOTTOM SENSOR (B): SSC = 0.798 × mV - 14.4.
NEAR-BOTTOM SENSOR (C): SSC = 0.803 × NTU - 14.0.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR (A): +9 to -9 mg/L.
MID-DEPTH SENSOR (B): +5 to -3 mg/L.
NEAR-BOTTOM SENSOR (A): +12 to -11 mg/L.
NEAR-BOTTOM SENSOR (B): Undeterminable with four samples.
NEAR-BOTTOM SENSOR (C): +8 to -7 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR (A): 0.562 to 0.742.
MID-DEPTH SENSOR (B): 0.133 to 0.990.
NEAR-BOTTOM SENSOR (A): 0.503 to 0.871.
NEAR-BOTTOM SENSOR (B): 0.094 to 1.667.
NEAR-BOTTOM SENSOR (C): 0.330 to 1.105.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The mid-depth optical sensor was replaced with an optical sensor with wiper on July 28, 2005. The near-bottom optical sensor malfunctioned and was replaced on March 30, 2005. The near-bottom optical sensor was replaced with an optical sensor with wiper on July 28, 2005. The calculated SSC time-series data collected for WY 2005 are presented in figure 24.

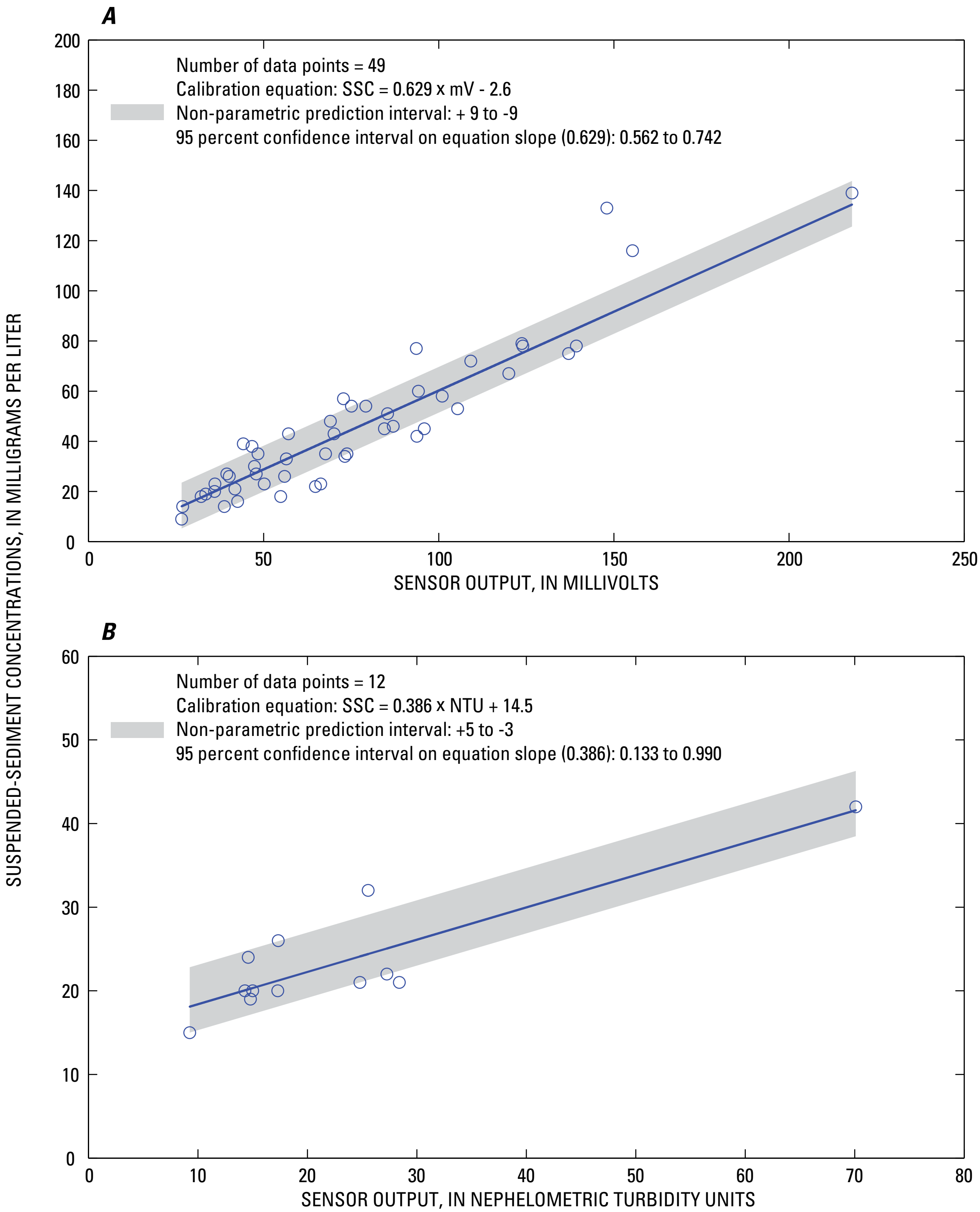

Figure 22. Graphs showing calibration of mid-depth optical sensors, October 1–July 28 and July 28 –September 30 at Dumbarton Bridge, South San Francisco Bay, California, water year 2005.

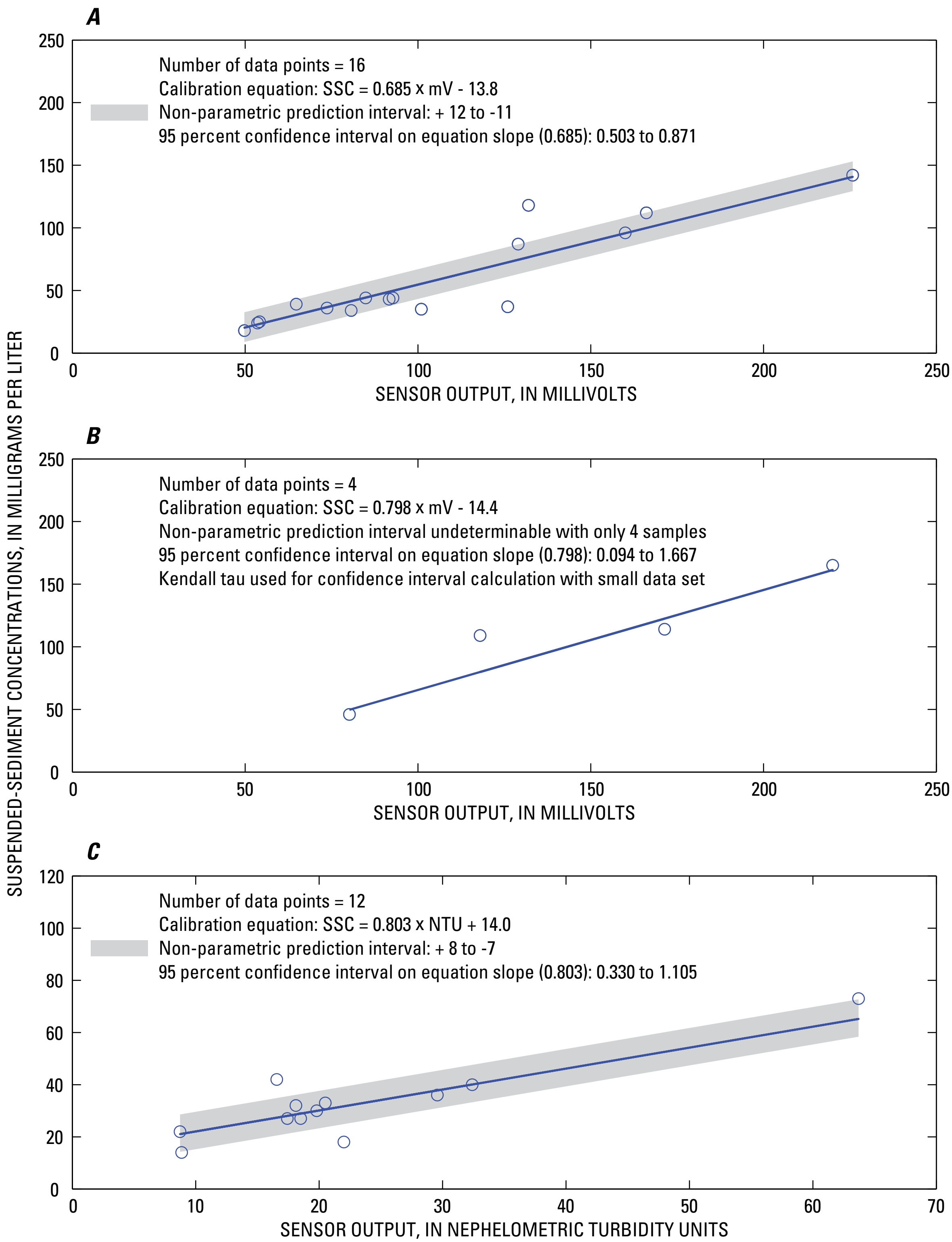

Figure 23. Graphs showing calibration of near-bottom optical sensors, October 1–March 30, March 30–July 28 and July 28 –September 30 at Dumbarton Bridge, South San Francisco Bay, California, water year 2005 .

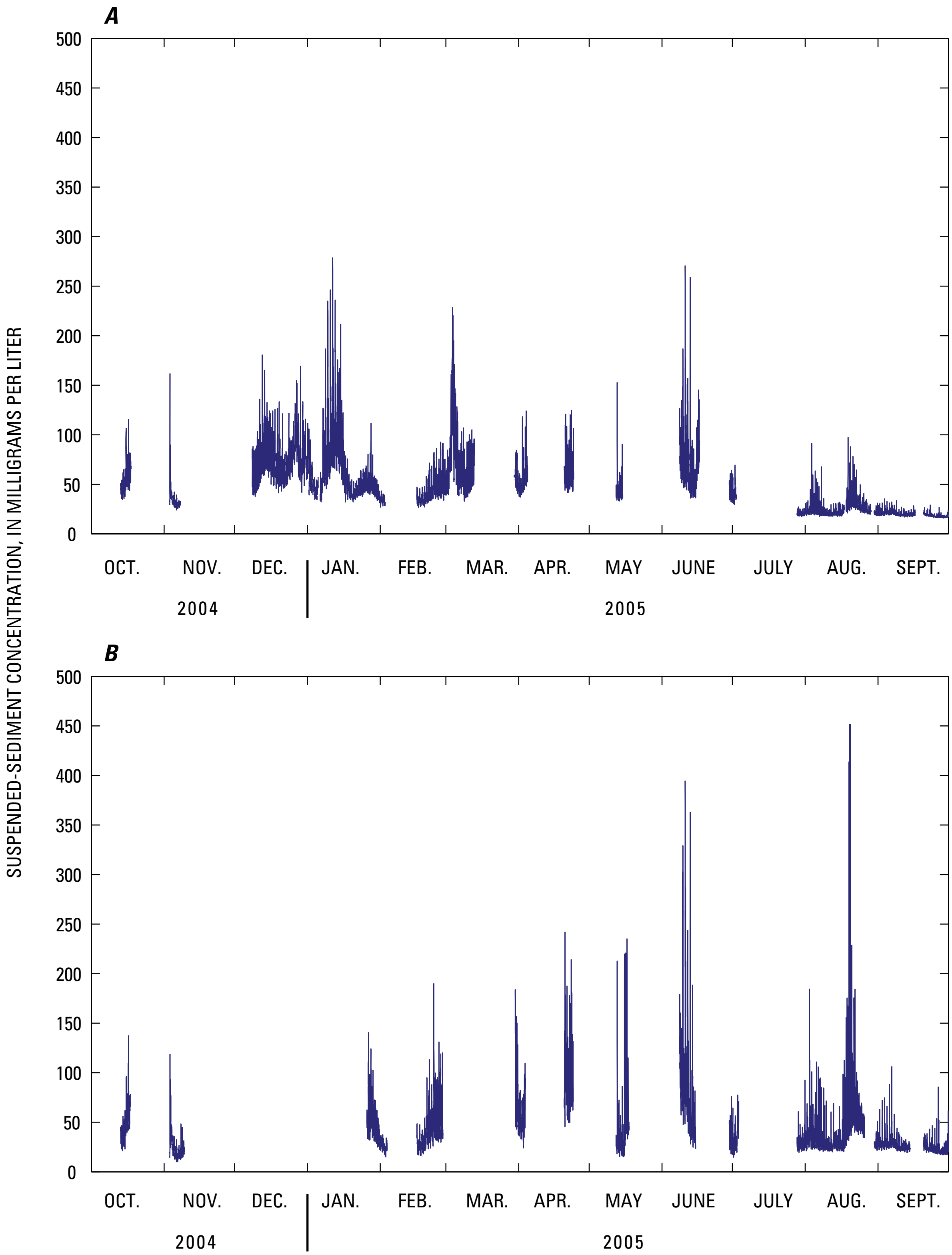

Figure 24. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 2005 .

Channel Marker 17

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR (A): October 13, 2004, to April 20, 2005 (fig. 25A).
MID-DEPTH SENSOR (B): April 20, 2005, through September 30, 2005 (fig. 25B).
NEAR-BOTTOM SENSOR (A): October 1, 2004, to March 30, 2005 (fig. 26A).
NEAR-BOTTOM SENSOR (B): April 20, 2005, through September 30, 2005 (fig. 26B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR (A): 8 (7 from WY 2005).
MID-DEPTH SENSOR (B): 7 (7 from WY 2005).
NEAR-BOTTOM SENSOR (A): 23 (7 from WY 2005).
NEAR-BOTTOM SENSOR (B): 16 (7 from WY 2005).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR (A): SSC = 0.768 × NTU + 15.5.
MID-DEPTH SENSOR (B): SSC = 0.486 × mV + 4.3.
NEAR-BOTTOM SENSOR (A): SSC = 1.193 × NTU + 4.5.
NEAR-BOTTOM SENSOR (B): SSC = 0.620 × mV - 17.6.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR (A): +3 to -12 mg/L.
MID-DEPTH SENSOR (B): +20 to -9 mg/L.
NEAR-BOTTOM SENSOR (A): +16 to -7 mg/L.
NEAR-BOTTOM SENSOR (B): +15 to -16 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR (A): -0.208 to 1.243.
MID-DEPTH SENSOR (B): 0.100 to 0.650.
NEAR-BOTTOM SENSOR (A): 0.889 to 1.491.
NEAR-BOTTOM SENSOR (B): 0.499 to 0.700.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The mid-depth sonde was replaced with an optical sensor on April 20, 2005. The near-bottom sonde malfunctioned and was replaced on January 6, 2005. The near-bottom sonde malfunctioned on March 30, 2005 and was replaced with an optical sensor on April 20, 2005. Because the sondes optical sensors responded similarly to the uniform sediment characteristics of San Francisco Bay (Schoellhamer and others, 2003), the near-bottom calibration used from October 1, 2004, to March 30, 2005 was developed by combining water samples collected during each optical sensor deployment. The calculated SSC time-series data collected for WY 2005 are presented in figure 27.

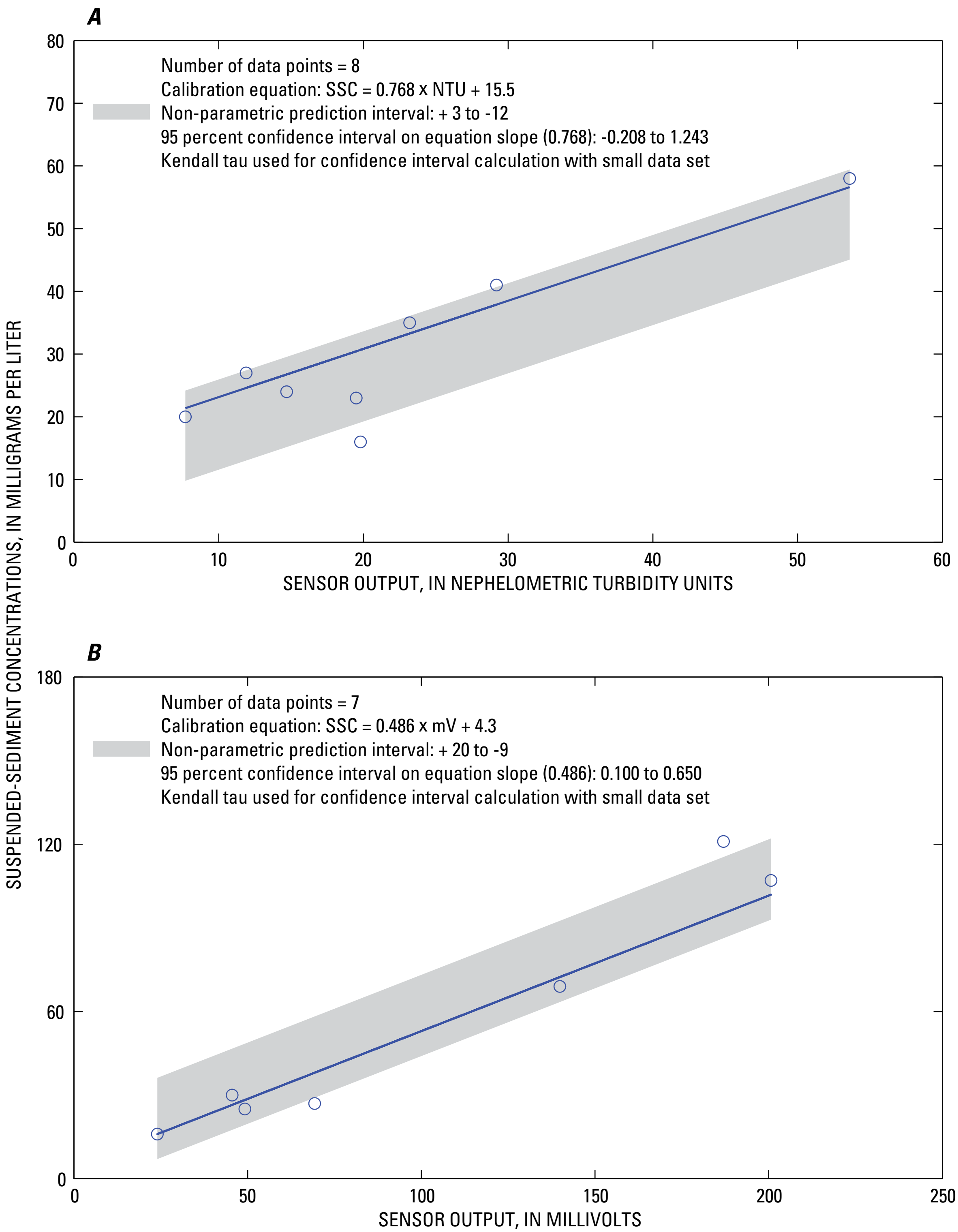

Figure 25. Graphs showing calibration of mid-depth optical sensors, October 13–April 20 and April 20–September 30 at Channel Marker 17, South San Francisco Bay, California, water year 2005.

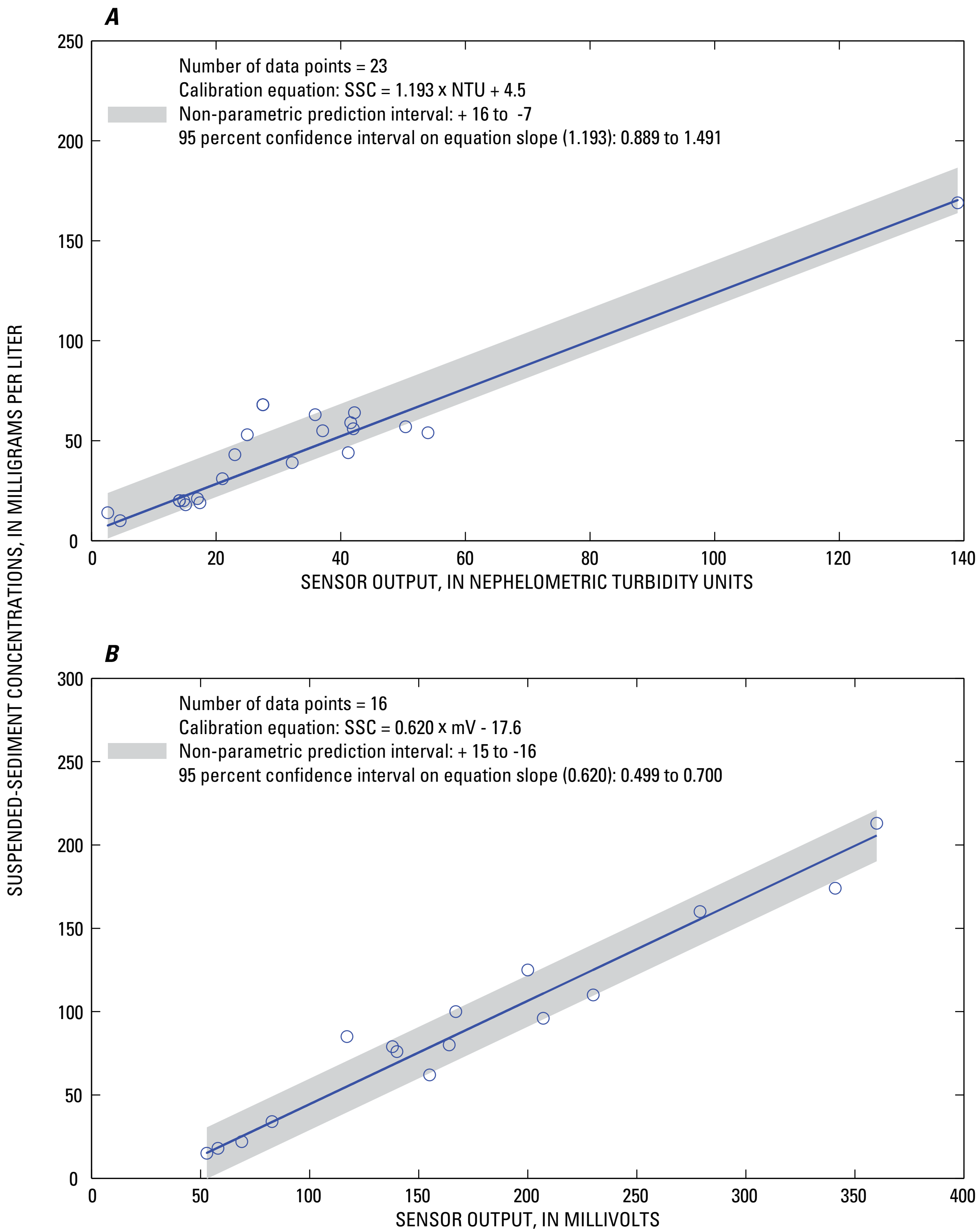

Figure 26. Graphs showing calibration of near-bottom optical sensors, October 1–March 30 and April 20 –September 30 at Channel Marker 17, South San Francisco Bay, California, water year 2005.

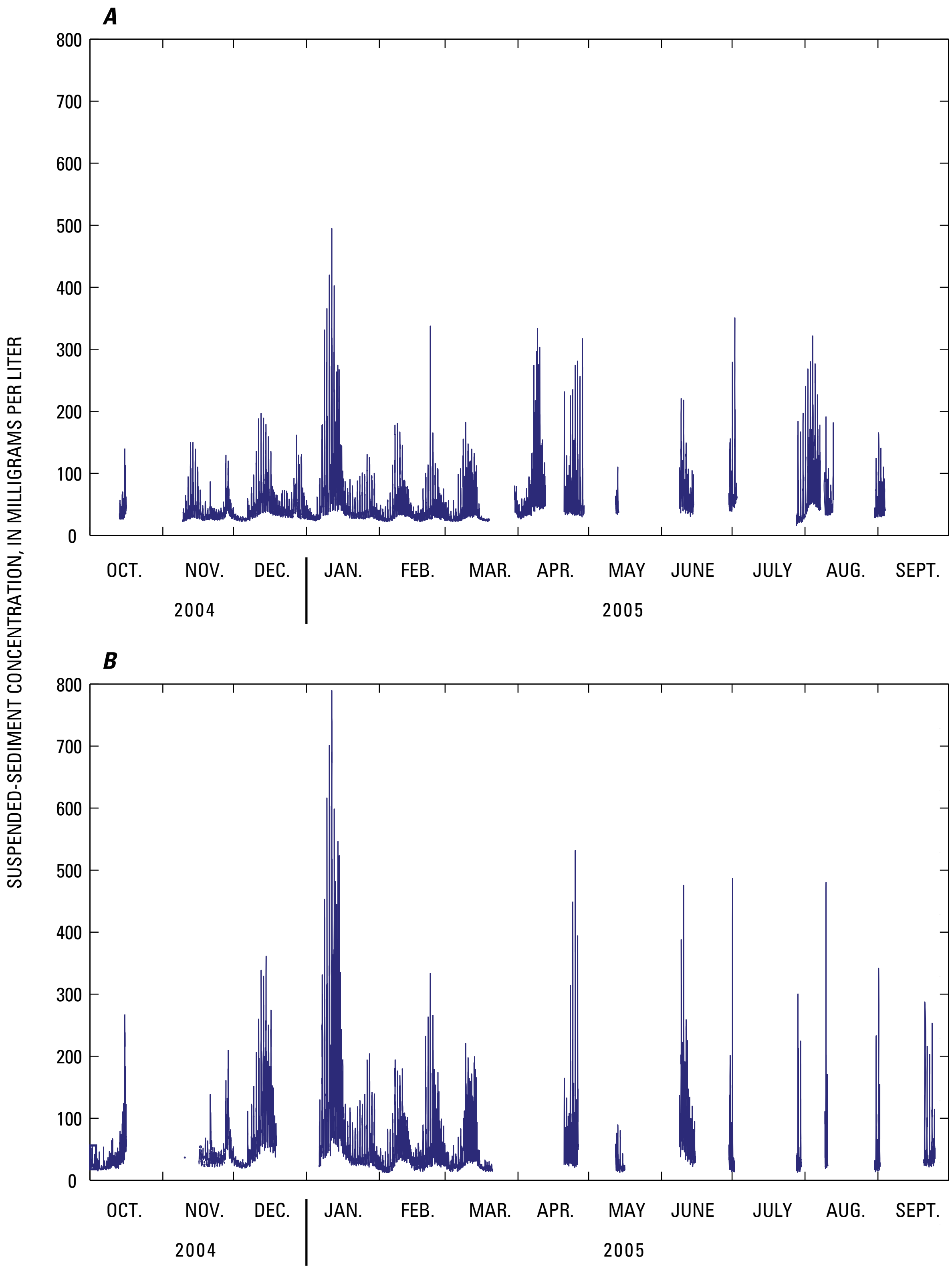

Figure 27. Graphs showing time series of mid-depth and near-bottom suspended-sediment concentrations calculated from sensor readings at Channel Marker 17, South San Francisco Bay, California, water year 2005.

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 2005. Three types of optical sensors, each controlled by electronic data loggers, were used to monitor suspended sediment. Water samples were collected to calibrate the output of the optical sensors to SSC by using robust, nonparametric regression. Water-sample sediment-concentration data are available in the USGS Sediment Laboratory Environmental Database. Time-series data are available in the USGS sediment database and the USGS automated data-processing system database. The calculated SSC data are available from the USGS (accessed February 26, 2007).

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