Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 2007

By Paul A. Buchanan and Tara L. Morgan

Prepared in cooperation with the CALFED Bay–Delta Authority and the

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Conversion Factors, Datums, Abbreviations, and Acronyms

Inch/Pound to SI

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second

SI to Inch/Pound

Multiply	By	To obtain
micrometer (µm)	3.937 × 10-5	inch (in.)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

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 either in milligrams per liter (mg/L) or micrograms per liter (µg/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
FTS	Forest Technology Systems
mg/L	milligram per liter
mV	millivolt
NTU	nephelometric turbidity unit
OLS	ordinary least squares (regression)
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)
YSI	Yellow Springs Instruments

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Abstract

Suspended-sediment concentration data were collected by the U.S. Geological Survey in San Francisco Bay during water year 2007 (October 1, 2006–September 30, 2007). Optical sensors and water samples were used to monitor suspended-sediment concentration at two sites in Suisun Bay, two sites in Central San Francisco Bay, and one site in South San Francisco Bay. Sensors were positioned at two depths at most sites to help define the vertical variability of suspended sediments. 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 2006 through September 2007. 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 then can 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, and thus affect photosynthesis and primary phytosynthetic carbon production (Cloern, 1987, 1996; Cole and Cloern, 1987). 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 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) 2007 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, 2007, 2009). Collection of SSC data in San Francisco Bay required development of monitoring methods and calibration techniques which are presented in this report. SSC were monitored at two sites in Suisun Bay, two sites in Central San Francisco Bay, and one site in South San Francisco Bay. SSC data from WY 1992 through WY 2007 were used to help determine the factors that affect SSC in San Francisco Bay (Schoellhamer and others, 2003b, accessed December 2, 2008, at http://ca.water.usgs.gov/user_projects/sfbay/publications_group.htm). Numerical SSC data are available from the U.S. Geological Survey (accessed December 2, 2008, at http://sfbay.wr.usgs.gov/sediment/cont_monitoring/index.html).

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 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 14¾-day spring-neap cycle. Typical tidal currents range from 0.6 ft/s in shallow water to more than 3 ft/s in deep channels (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).

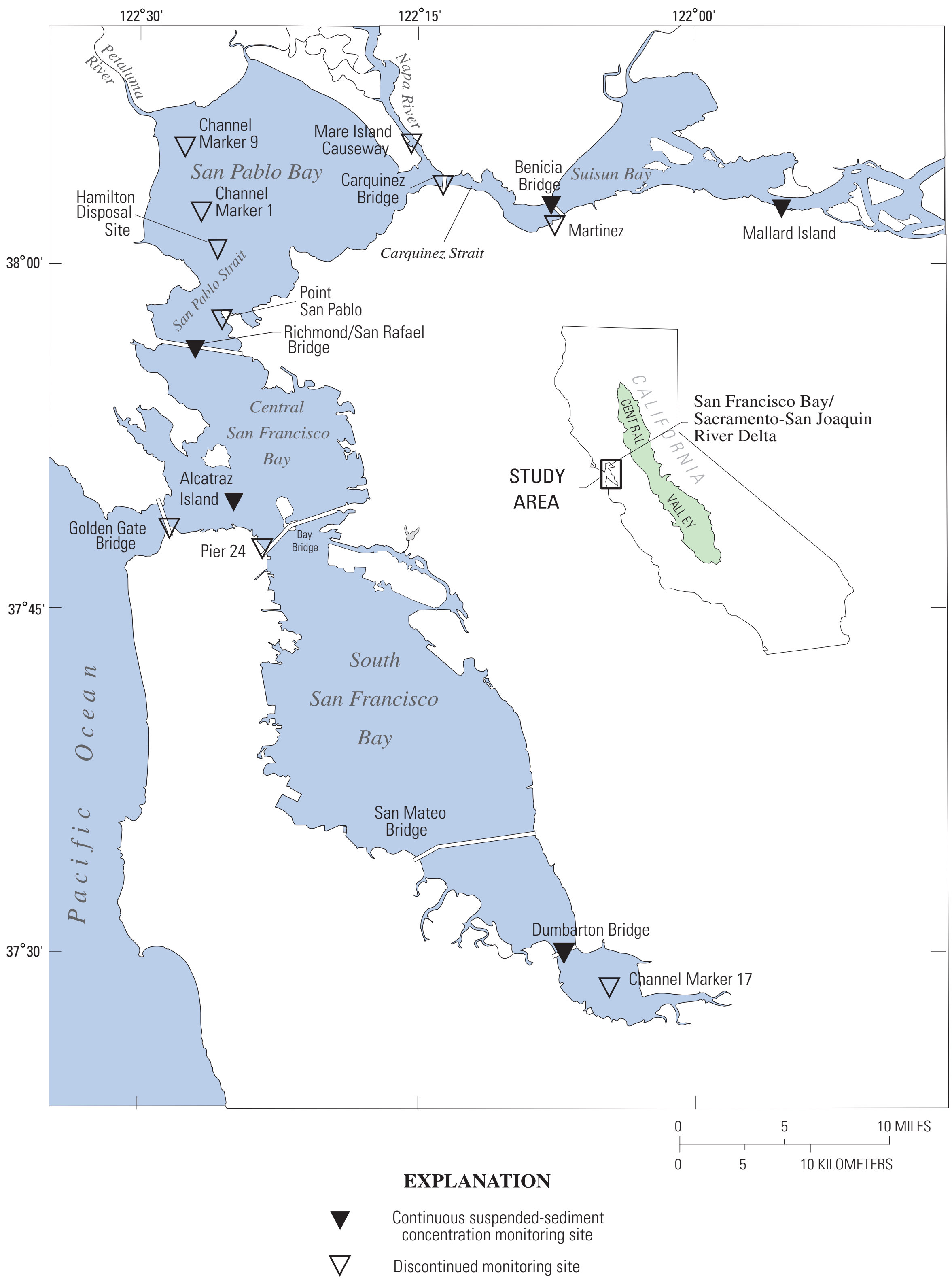

Figure 1. San Francisco Bay study area, California.

Methods

Instrument Description and Operation

Two types of optical sensors were used to monitor SSC during WY 2007. The first type of sensor, manufactured by Forest Technology Systems (FTS), is self-cleaning and 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 converted to millivolts (mV) when recorded on a separate data logger. The second type of sensor manufactured by Yellow Springs Instruments (YSI), also 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 YSI instruments (sondes) are self-contained and include a power source, data logger, and the capability of supporting additional sensors. The YSI and FTS data loggers collect instantaneous values every 15 minutes. Power was supplied by 12-volt batteries.

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. Self-cleaning optical sensors were used at all sites. Because of the difficulty in servicing some of the monitoring stations, sensors were cleaned manually every 2–5 (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.

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 220 NTU, which defined the expected range of turbidity values in WY 2007. 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.

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 California Department of Water Resources (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 that moves water through the DWR flow-through water-quality monitor. 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 station was shut down August 7, 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 station 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

No SSC data were collected in San Pablo Bay in WY 2007 (fig. 1). A monitoring station at U.S. Coast Guard (USCG) Channel Marker 9 was discontinued October 7, 2003. A monitoring station at USCG Channel Marker 1 was discontinued September 28, 2005. A monitoring station at Napa River at Mare Island Causeway was discontinued October 11, 2005. SSC monitoring was discontinued at Carquinez Bridge October 19, 2005 (specific conductance and water temperature were monitored at this site in WY 2007). A monitoring station at Point San Pablo was discontinued on August 1, 2006. A monitoring station at the Hamilton Disposal Site was discontinued November 16, 2006.

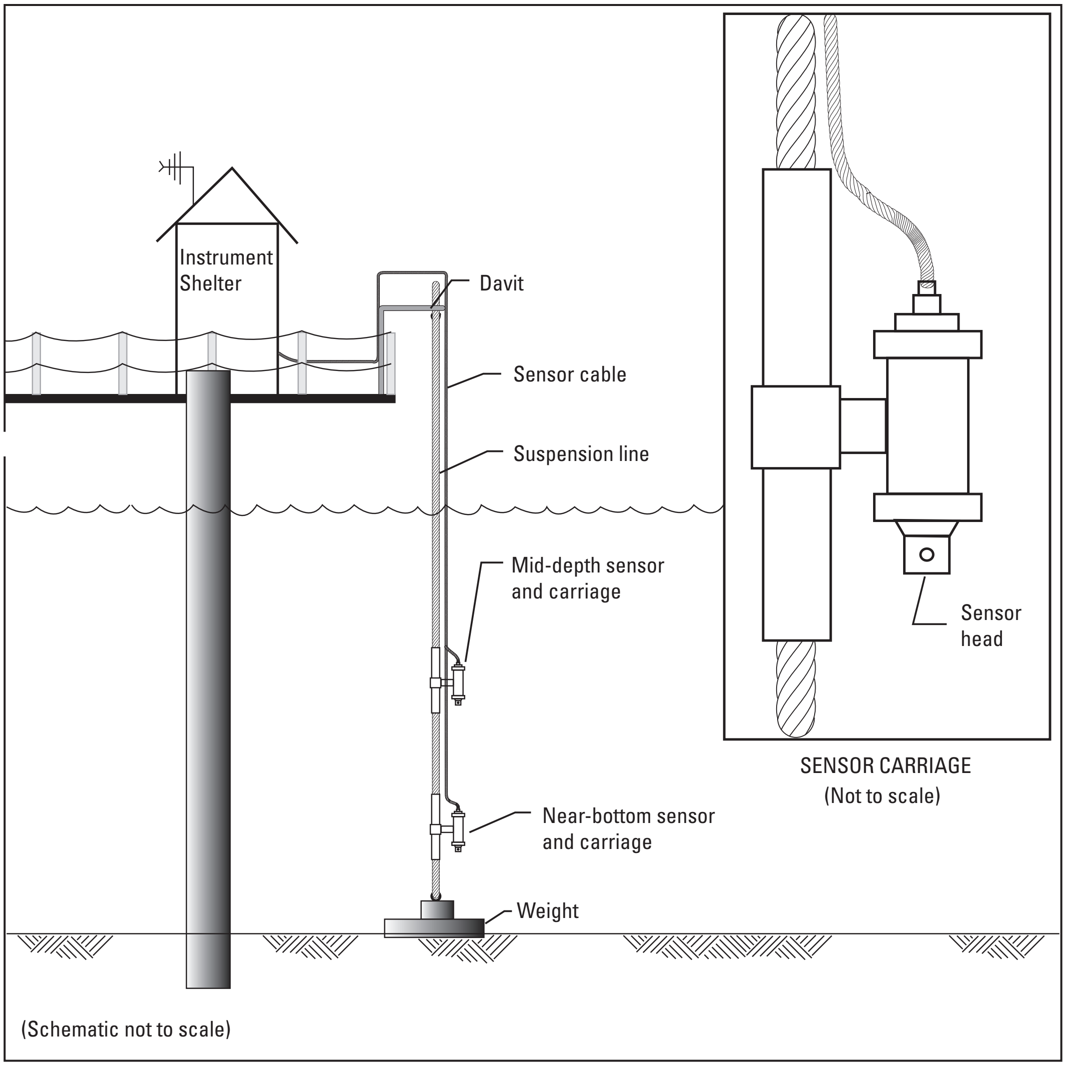

Figure 2. Schematic showing typical monitoring installation, San Francisco Bay study.

Table 1. Optical sensor depths (in feet) below mean lower low water (MLLW), Suisun Bay, Central and South San Francisco Bays, California, water year 2007

[**Abbreviations:** MLLW, mean lower low water; depth below, depth below water surface]

Site	Station No.	Latitude	Longitude	Sensor depth	MMLW	
					Depth below	Water depth at
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	
Richmond/San Rafael Bridge	375607122264701	37°56’07”	122°26’47”	Mid-depth	15	45
				Near-bottom	40	
Alcatraz Island	374938122251801	37°49’38”	122°25’18”	Mid-depth	6	16
Dumbarton Bridge	373015122071000	37°30’15”	122°07’10”	Mid-depth	20	45
				Near-bottom	41	

Central San Francisco Bay Installations

SSC data were collected in San Francisco Bay at Alcatraz Island and at Richmond/San Rafael Bridge (fig. 1; table 1). A sonde with optical, conductance, and temperature sensors was installed on the northeast side of Alcatraz Island on November 6, 2003. Sondes with optical, conductance, and temperature sensors were installed on the Richmond/San Rafael Bridge pier west of the main channel on October 18, 2006. A monitoring station at the south tower of the Golden Gate Bridge was operational during water years 1996 and 1997. A monitoring station at San Francisco Bay at Pier 24 was discontinued on January 3, 2002.

South San Francisco Bay Installations

SSC data were collected in South San Francisco Bay at Dumbarton Bridge (fig. 1; table 1). Optical sensors were installed at Pier 23 on the Dumbarton Bridge on the west side of the ship channel on October 21, 1992. SSC monitoring was discontinued at San Mateo Bridge on October 19, 2005 (specific conductance and water temperature were monitored at this site in WY 2007). A monitoring station at USCG Channel Marker 17 was discontinued on October 26, 2005.

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-style sampler usually after the sensors were cleaned. In previous WYs, samples were collected before the sensors were cleaned; however, the time-series data collected before cleaning was often unusable due to fouling and the calibration points from the water samples were discarded. The Van Dorn-style 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-style 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-style sampler and a P-72 point sampler, used until WY 1994, were virtually identical (Buchanan and others, 1996).

SSC samples were analyzed at the USGS Sediment Laboratory in Marina, California. Suspended sediment includes all particles in the sample that do not pass through a 0.45-µm 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 by filtering samples through a pre-weighed, tared, 0.45-µm 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 record the optical-sensor output at 15-minute intervals (96 data points per day). Recorded data were downloaded from the data loggers onto a storage module or a 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. 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: November 29; 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 readings 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.

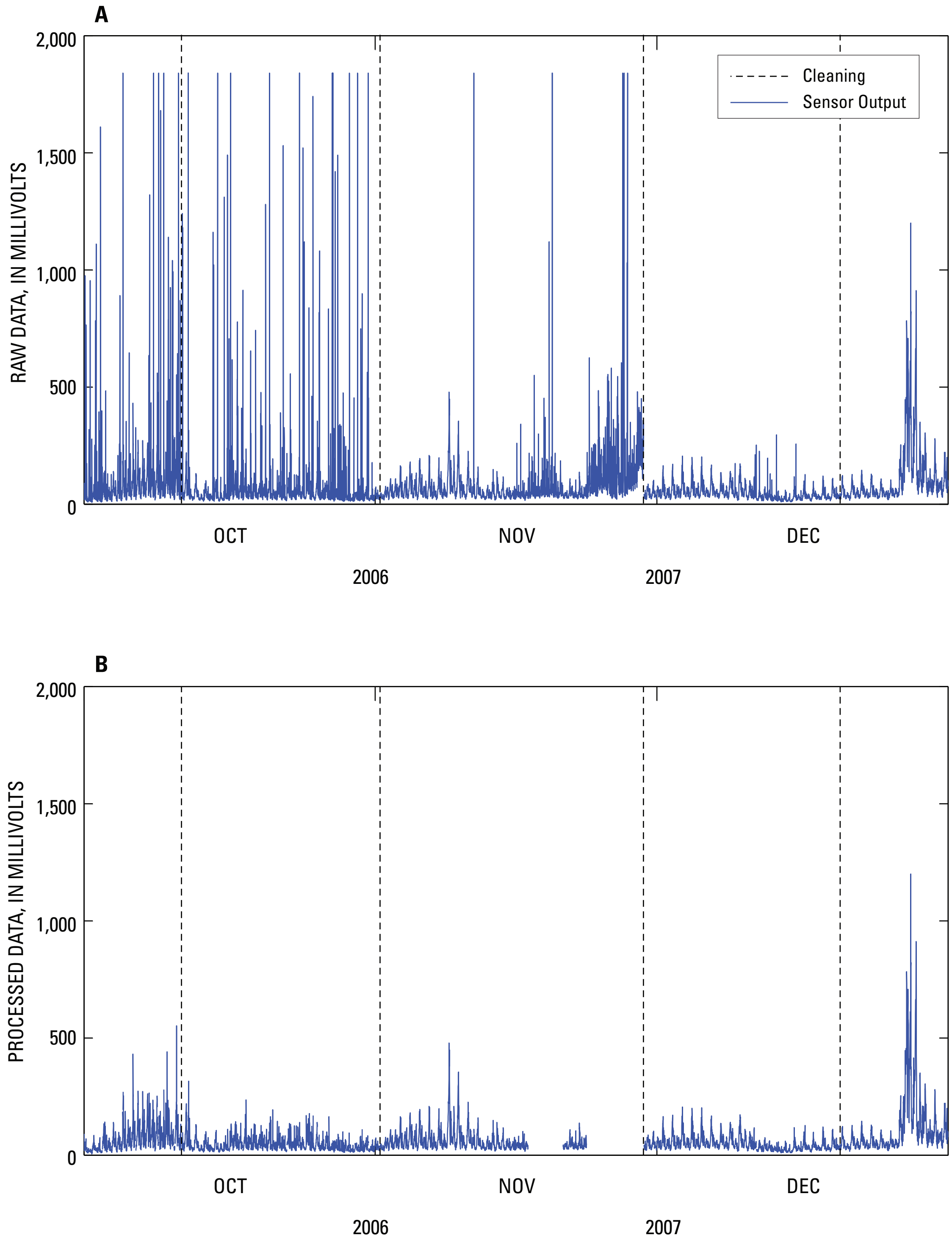

Figure 3. Example of (*A*) raw, and (*B*) processed optical-sensor data, near-bottom sensor, Dumbarton Bridge, South San Francisco Bay, California, water year 2007.

Sensor Calibration and Suspended-Sediment Concentration Data

The output from each of the two 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:

$$\beta_i = \text{median} \frac{(Y_j - Y_i)}{\left(X_j - X_i\right)} \text{ for } j = 1 \ldots n, j \neq I \tag{1}$$

The calibration slope was calculated as the median of β_i:

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

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

$$\text{intercept} = \hat{\beta}_0 = \text{median}\,(Y_i - \hat{\beta}_i\, X_i) \quad \text{for } i = 1 \ldots n \tag{3}$$

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 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). 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 and –7 mg/L. This asymmetry about the regression line is a result of the non-normal 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 0.068.

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:

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

and

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

where

Ru is the rank of the upper interval slope,

RI is the rank of the lower interval slope,

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 10 or fewer samples, an alternative and presumably slightly more accurate method described by Helsel and Hirsch (1992, p. 273–274) was 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.

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 (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.

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, Central and South San Francisco Bays, California, water year 2007.

[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	Quartile		Percent valid data
				Lower	Upper	
Mallard Island	Near-surface	24	22	16	30	86
	Near-bottom	27	26	21	32	97
Benicia Bridge	Near-surface	43	32	23	53	85
	Near-bottom	83	72	53	102	85
Richmond/San Rafael Bridge	Mid-depth	37	27	20	39	73
	Near-bottom	41	30	24	43	70
Alcatraz Island	Mid-depth	20	18	14	23	73
Dumbarton Bridge	Mid-depth	86	66	44	101	73
	Near-bottom	139	107	66	171	79

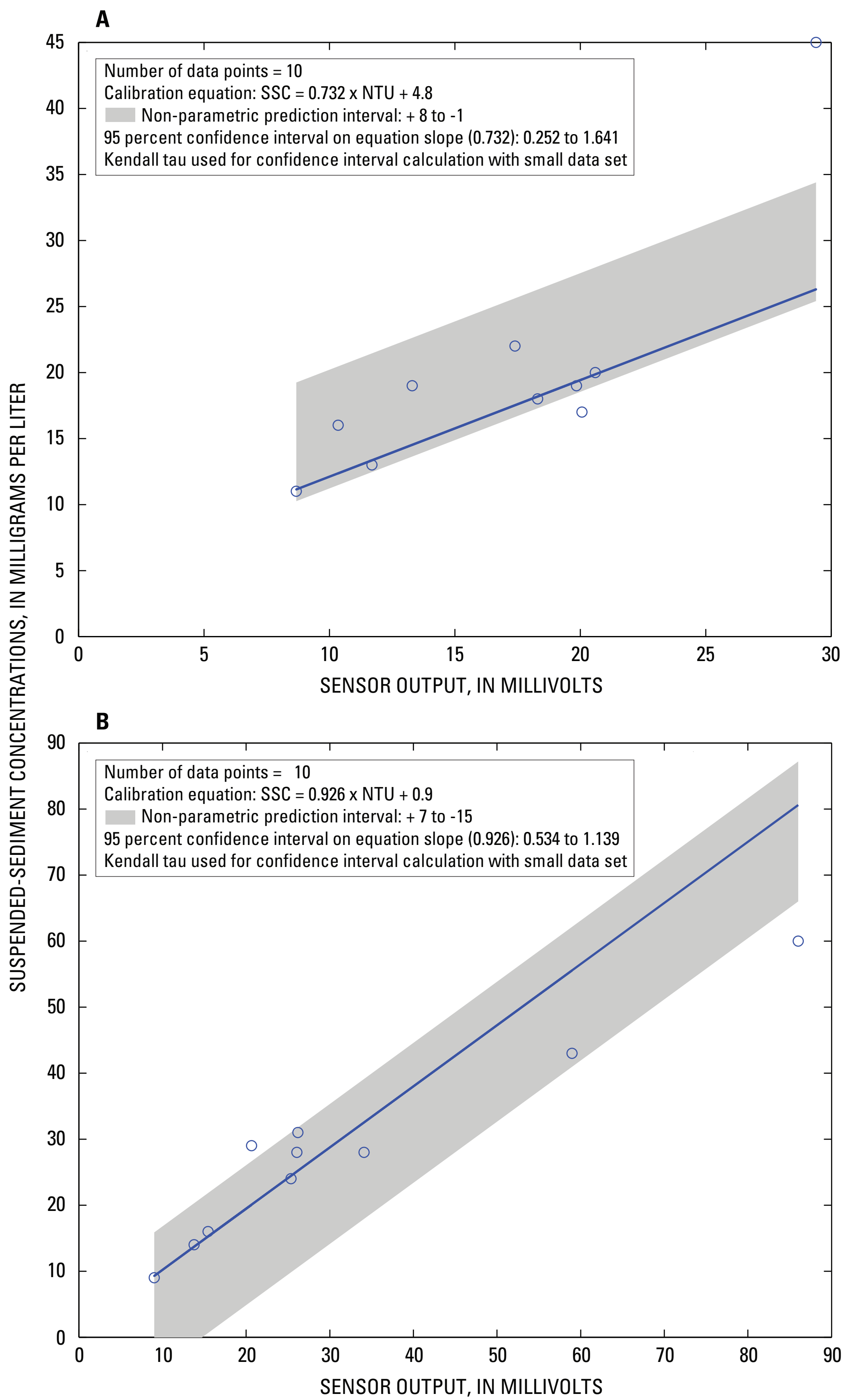

Figure 4. Calibration of near-surface optical sensors, October 1–April 20 and April 20–September 30, at Mallard Island, Suisun Bay, California, water year 2007.

Suisun Bay

Mallard Island

PERIOD OF CALIBRATION.—
NEAR-SURFACE SENSOR (*A*): October 1, 2006, to April 20, 2007 (fig. 4A).
NEAR-SURFACE SENSOR (*B*): April 20, 2007, through September 30, 2007 (fig. 4B).
NEAR-BOTTOM SENSOR: WY 2007 (fig. 5).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
NEAR-SURFACE SENSOR (*A*) : 10 (5 from WY 2007).
NEAR-SURFACE SENSOR (*B*): 10 (6 from WY 2007).
NEAR-BOTTOM SENSOR: 60 (8 from WY 2007).
LINEAR REGRESSION EQUATION.—
NEAR-SURFACE SENSOR (*A*): SSC = 0.732 × millivolt (mV) + 4.8.
NEAR-SURFACE SENSOR (*B*): SSC = 0.926 × millivolt (mV) + 0.9.
NEAR-BOTTOM SENSOR: SSC = 0.607 × mV + 10.1.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-SURFACE SENSOR (*A*): +8 to –1 mg/L.
NEAR-SURFACE SENSOR (*B*): +7 to –15 mg/L.
NEAR-BOTTOM SENSOR: +8 to –5 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
NEAR-SURFACE SENSOR (*A*): 0.252 to 1.641.
NEAR-SURFACE SENSOR (*B*): 0.534 to 1.139.
NEAR-BOTTOM SENSOR: 0.579 to 0.833.

REMARKS.— Interruptions in record were caused by 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 senor was replaced on April 20, 2007, because of a faulty wiper. Water samples from WY 2008 were included in the second near-surface sensor calibration to supplement the small number of water samples collected in WY 2007. The calculated SSC time-series data collected for WY 2007 are presented in figure 6.

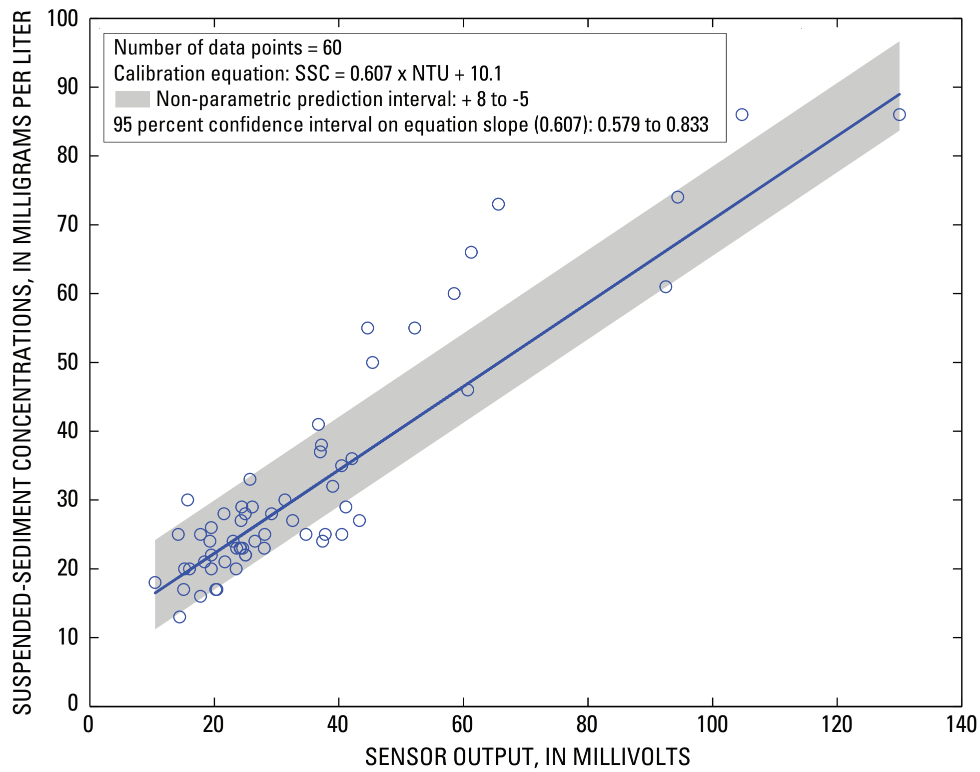

Figure 5. Calibration of near-bottom optical sensor at Mallard Island, Suisun Bay, California, water year 2007.

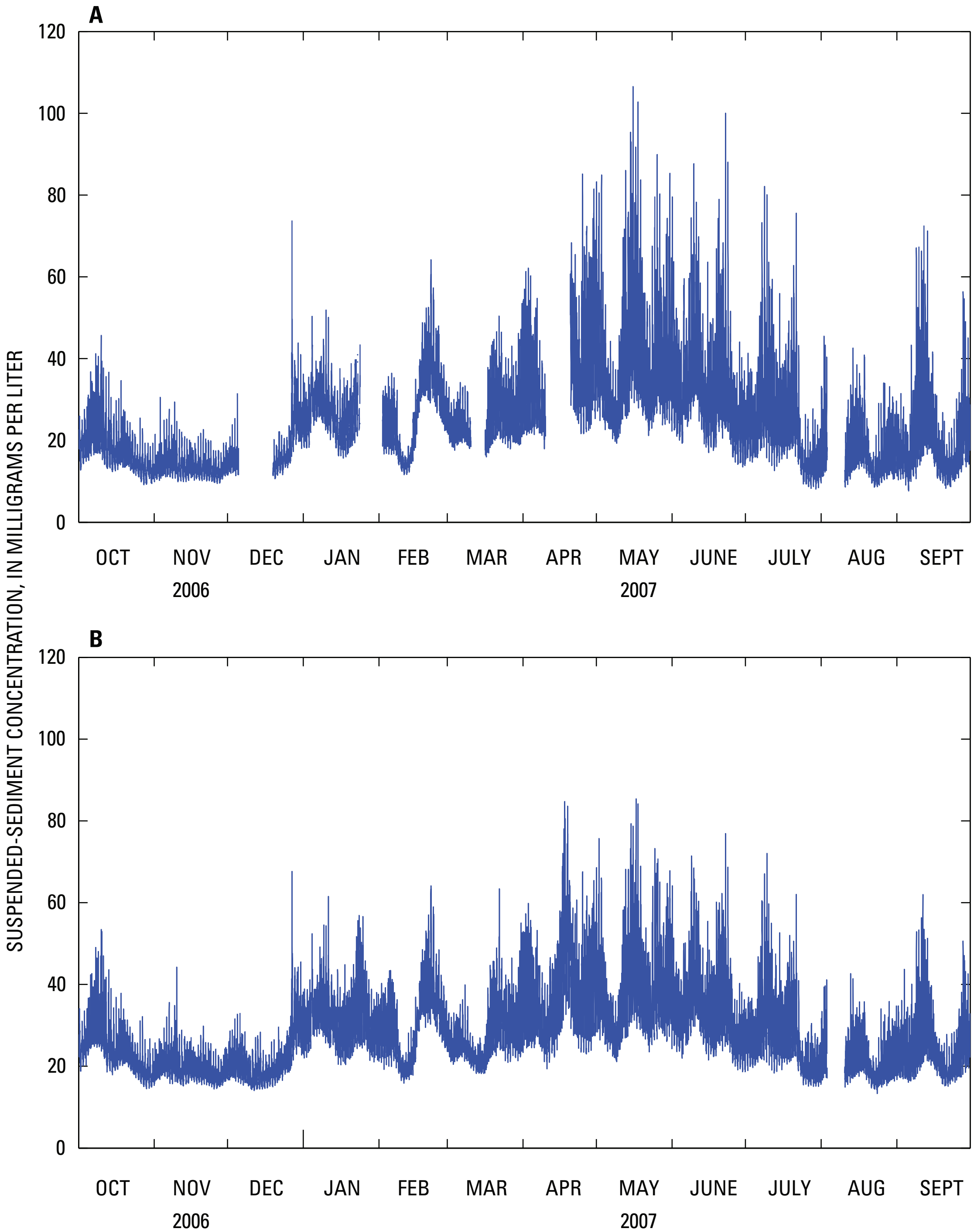

Figure 6. Time series of (*A*) near-surface and (*B*) near-bottom suspended-sediment concentrations calculated from sensor readings at Mallard Island, Suisun Bay, California, water year 2007.

Benicia Bridge

PERIOD OF CALIBRATION.—
NEAR-SURFACE SENSOR: WY 2007 (fig. 7A).
NEAR-BOTTOM SENSOR: WY 2007 (fig. 7B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
NEAR-SURFACE SENSOR: 17 (15 from WY 2007).
NEAR-BOTTOM SENSOR: 20 (13 from WY 2007).
LINEAR REGRESSION EQUATION.—
NEAR-SURFACE SENSOR: SSC = 1.151 × NTU + 7.1.
NEAR-BOTTOM SENSOR: SSC = 1.081 × NTU – 22.0.
NONPARAMETRIC PREDICTION INTERVAL.—
NEAR-SURFACE SENSOR: +16 to –17 mg/L.
NEAR-BOTTOM SENSOR: +14 to –24 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
NEAR-SURFACE SENSOR: 0.737 to 1.404.
NEAR-BOTTOM SENSOR: 0.845 to 1.242.

REMARKS.—Interruptions in record were caused by fouling, malfunction of the sensing and(or) recording instruments. MLLW was about 80 ft at the site, but about 60 ft immediately adjacent. Therefore, the near-bottom sonde was set about 20 ft above the bottom so that the data are representative of the surrounding area. The conductivity sensor on the near-surface sonde malfunctioned, and the sonde was removed November 7, 2006, but the unit was not replaced until December 07, 2006. The near-surface replacement sonde's conductivity sensor malfunctioned, and was replaced June 20, 2007, with the sonde that was pulled November 7, 2006. Because the two optical sensors (both YSIs) deployed at the near-surface position during WY 2007 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Schoellhamer and others, 2003a), the calibration was developed by combining water samples collected during each sensor deployment. The near-bottom optical sensor began to malfunction in September 2006, and the sonde was removed on October 5, 2006, but not replaced until November 7, 2006. The near-bottom optical sensor wiper malfunctioned and the sonde was replaced August 8, 2007. Water samples from WY 2008 were included in the near-surface sensor calibration to supplement the number of water samples collected in WY 2007. Because the two optical sensors (both YSIs) deployed at the near-bottom position during WY 2007 responded similarly to the uniform sediment characteristics found in San Francisco Bay, the calibration was developed by combining water samples collected during each sensor deployment. The calculated SSC time-series data collected for WY 2007 are presented in figure 8.

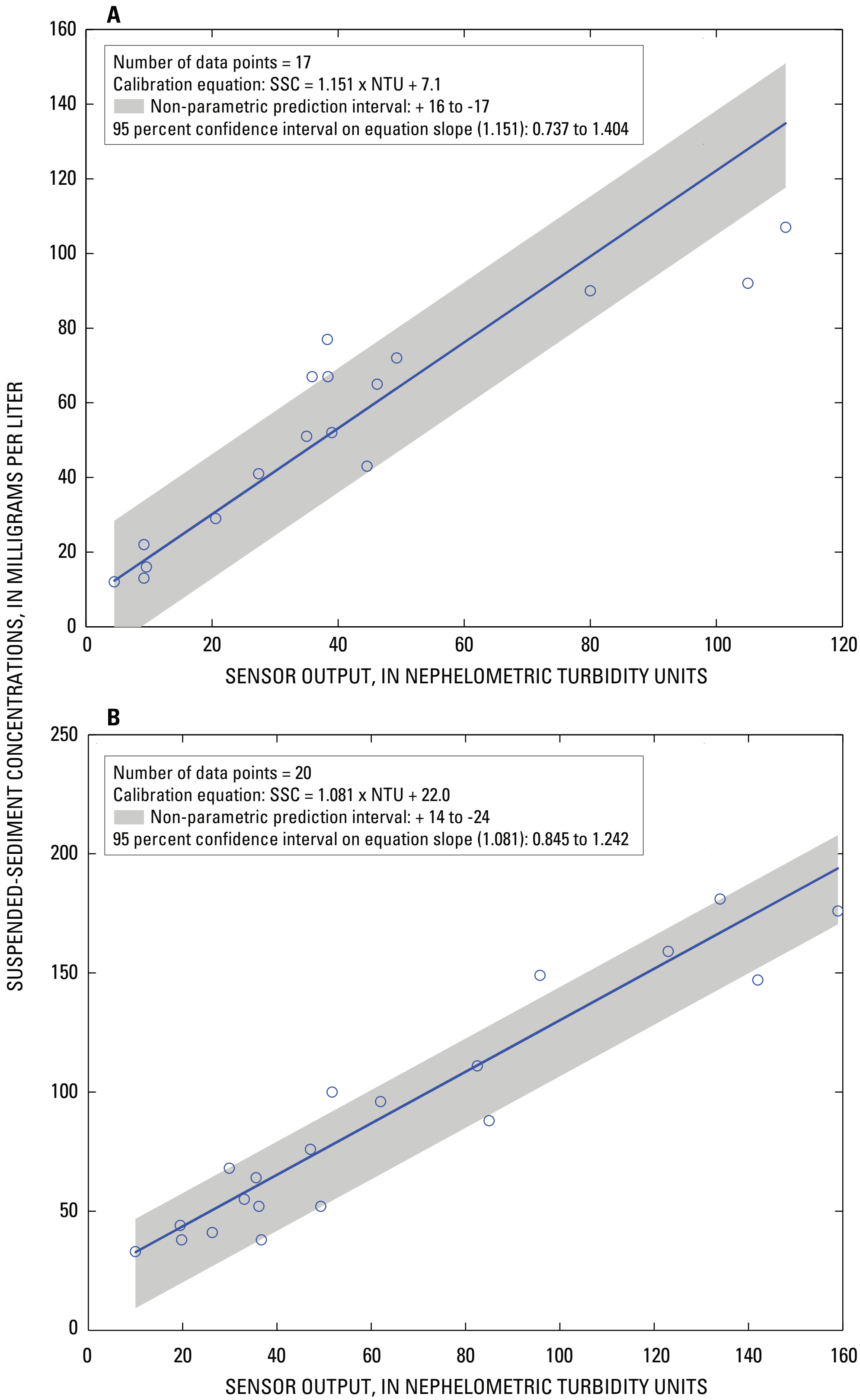

Figure 7. Calibration of (*A*) near-surface and *(B)* near-bottom optical sensors at Benicia Bridge, Suisun Bay, California, water year 2007.

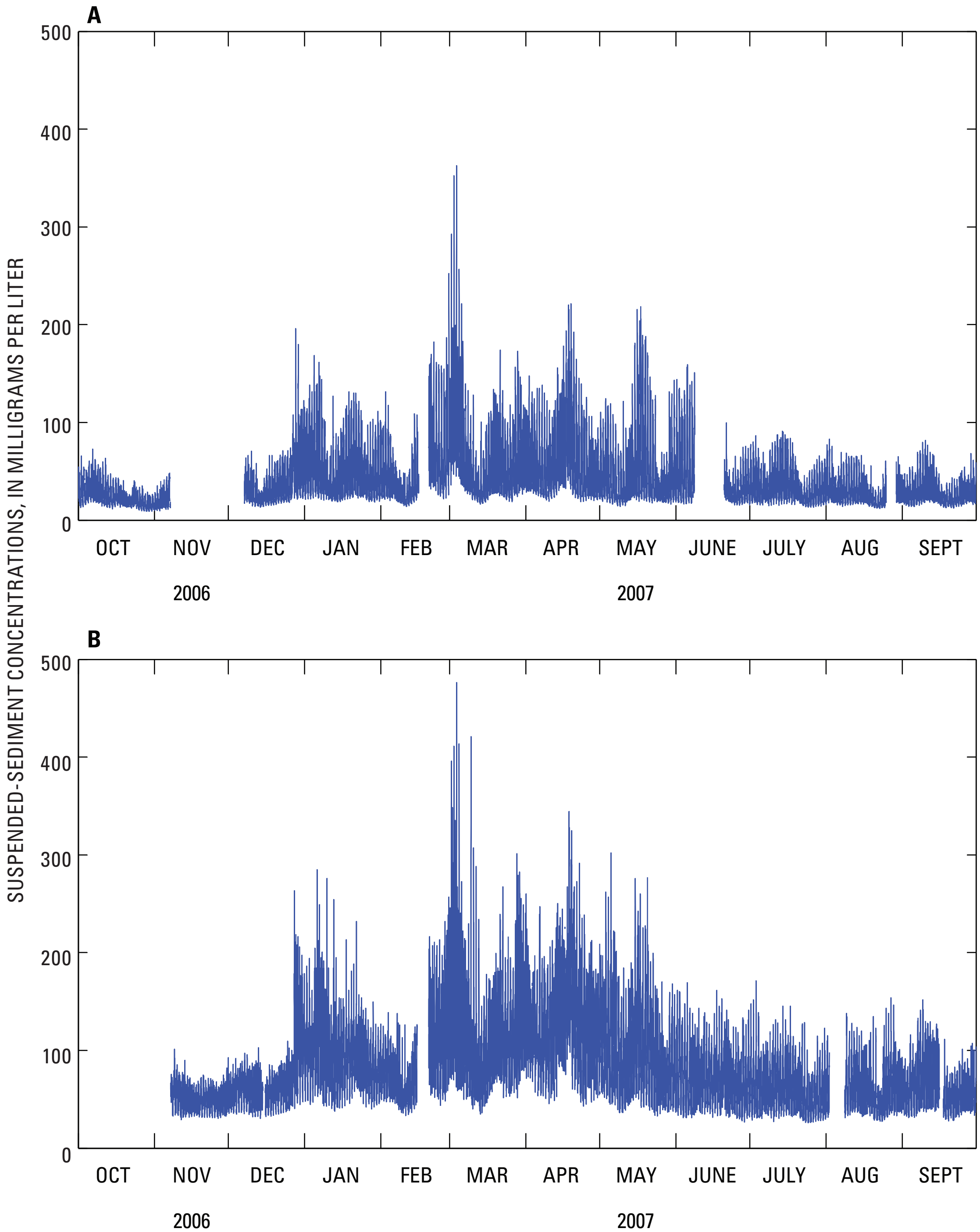

Figure 8. Time series of (*A*) near-surface and (*B*) near-bottom suspended-sediment concentrations calculated from sensor readings at Benicia Bridge, Suisun Bay, California, water year 2007.

Central San Francisco Bay

Richmond/San Rafael Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: October 18, 2006, to September 30, 2007 (fig. 9A).
NEAR-BOTTOM SENSOR: October 18, 2006, to September 30, 2007 (fig. 9B).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 22 (14 from WY 2007).
NEAR-BOTTOM SENSOR: 20 (15 from WY 2007).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 1.495 × NTU + 8.0.
NEAR-BOTTOM SENSOR: SSC = 1.038 × NTU + 10.8.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +15 to –8 mg/L.
NEAR-BOTTOM SENSOR: +30 to –8 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 0.880 to 2.260.
NEAR-BOTTOM SENSOR: 0.645 to 2.393.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The mid-depth conductivity sensor malfunctioned and the sonde was replaced December 29, 2006. The mid-depth conductivity sensor again malfunctioned, and the sonde was replaced May 11, 2007. Because the two optical sensors (both YSIs) deployed at the near-bottom position during WY 2007 responded similarly to the uniform sediment characteristics found in San Francisco Bay, the calibration was developed by combining water samples collected during each sensor deployment. Water samples from WY 2008 were included in the mid-depth and near-bottom sensor calibrations to supplement the number of water samples collected in WY 2007. The calculated SSC time-series data collected for WY 2007 are presented in figure 10.

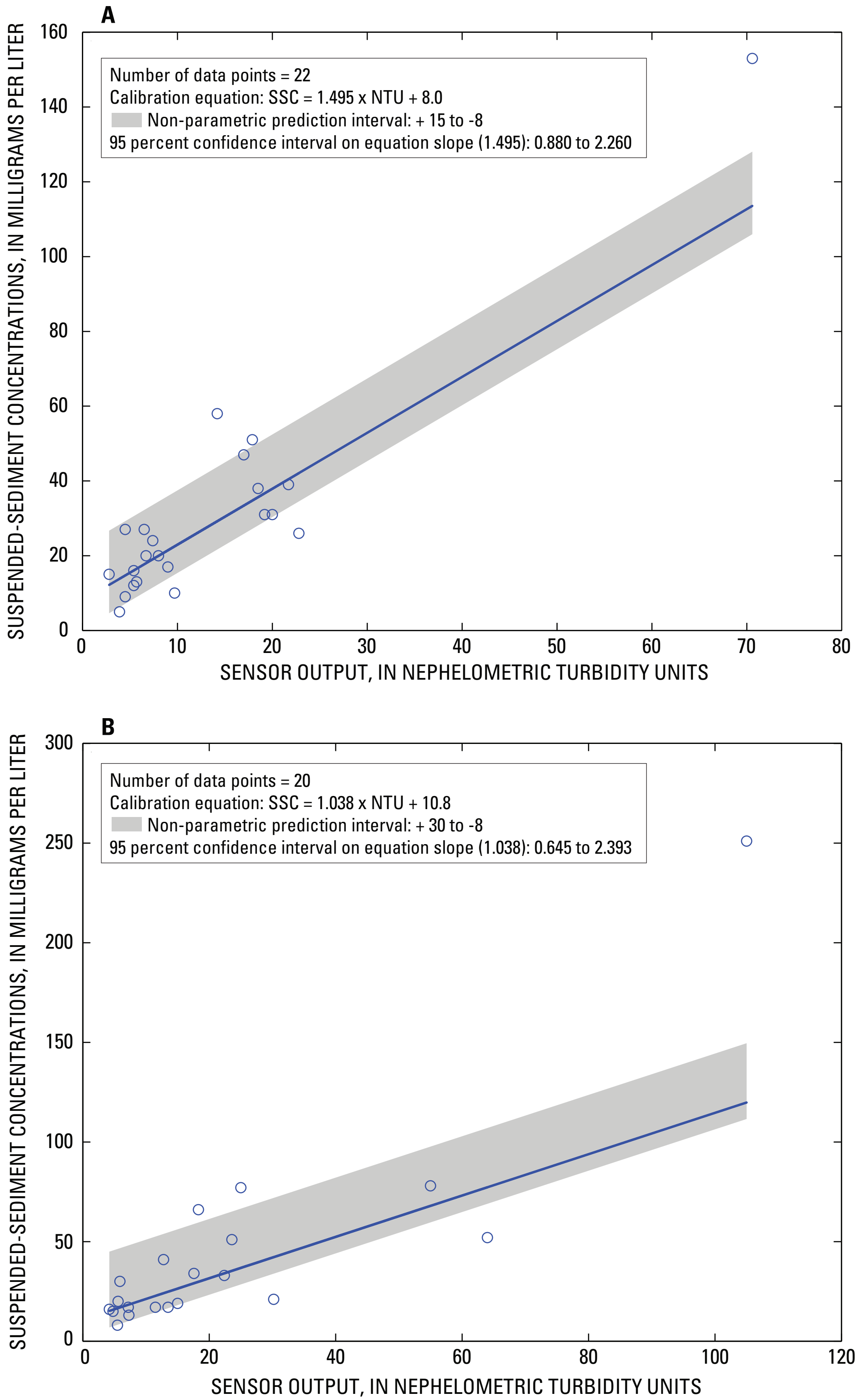

Figure 9. Calibration of (A) mid-depth and (B) near-bottom sensors, October 18–September 30 at Richmond/San Rafael Bridge, Central San Francisco Bay, California, water year 2007.

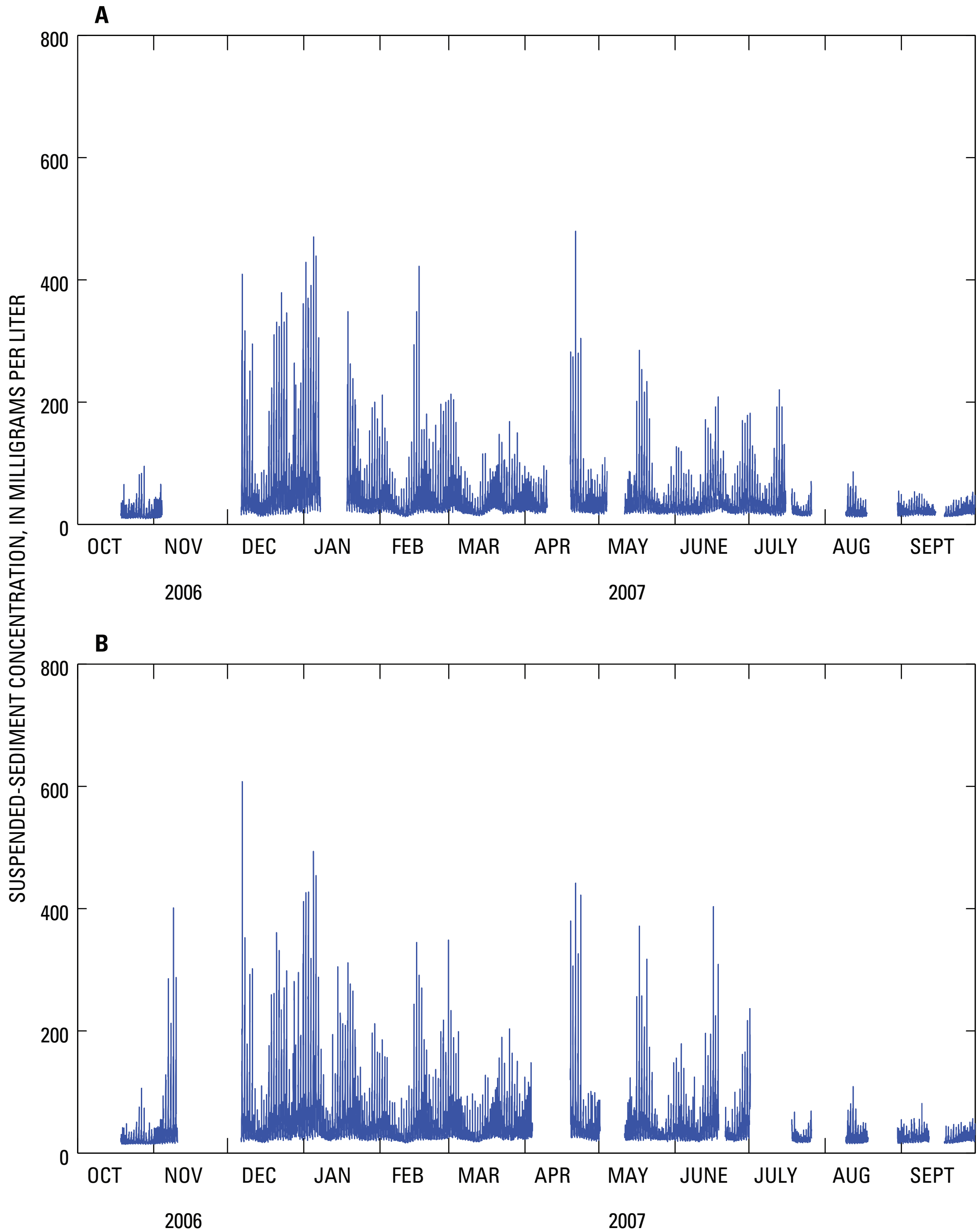

Figure 10. Time series of (A) mid-depth and (B) near-bottom suspended-sediment concentrations calculated from sensor readings at Richmond/San Rafael Bridge, Central San Francisco Bay, California, water year 2007.

Alcatraz Island

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR: WY 2007 (fig. 11).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR: 31 (15 from WY 2007).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR: SSC = 1.245 × NTU + 9.7.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR: +9 to –3 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR: 0.984 to 1.795.

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 conductivity sensor malfunctioned and the sonde was replaced on February 27, 2007. The calibration of the optical sensor deployed from February 27 to June 12, 2007, drifted with time and a correction was developed using interpolated equations derived from sensor readings taken in NTU standards during site visits. The slope and y-intercept values from the correction equations were interpolated between site visits enabling a continuous corrected time series. The optical sensor eventually malfunctioned and was replaced on June 12, 2007. Water samples from WY 2008 were included in the calibration to supplement the number of water samples collected in WY 2007. The calculated SSC time-series data collected for WY 2007 are presented in figure 12.

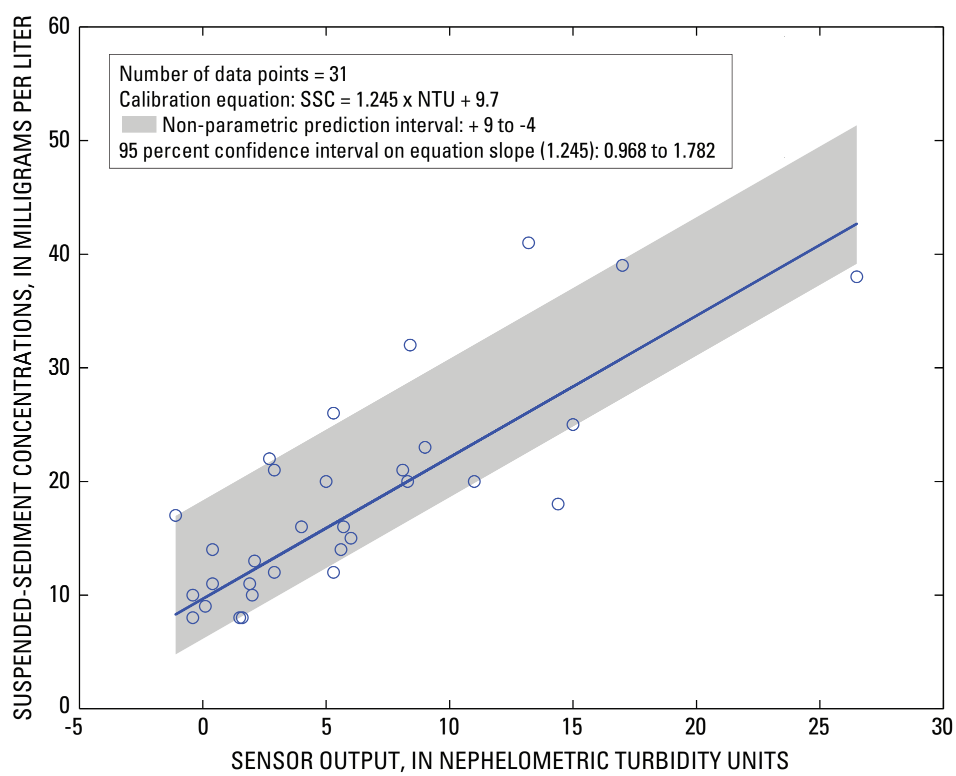

Figure 11. Calibration of mid-depth optical sensors at Alcatraz Island, Central San Francisco Bay, California, water year 2007.

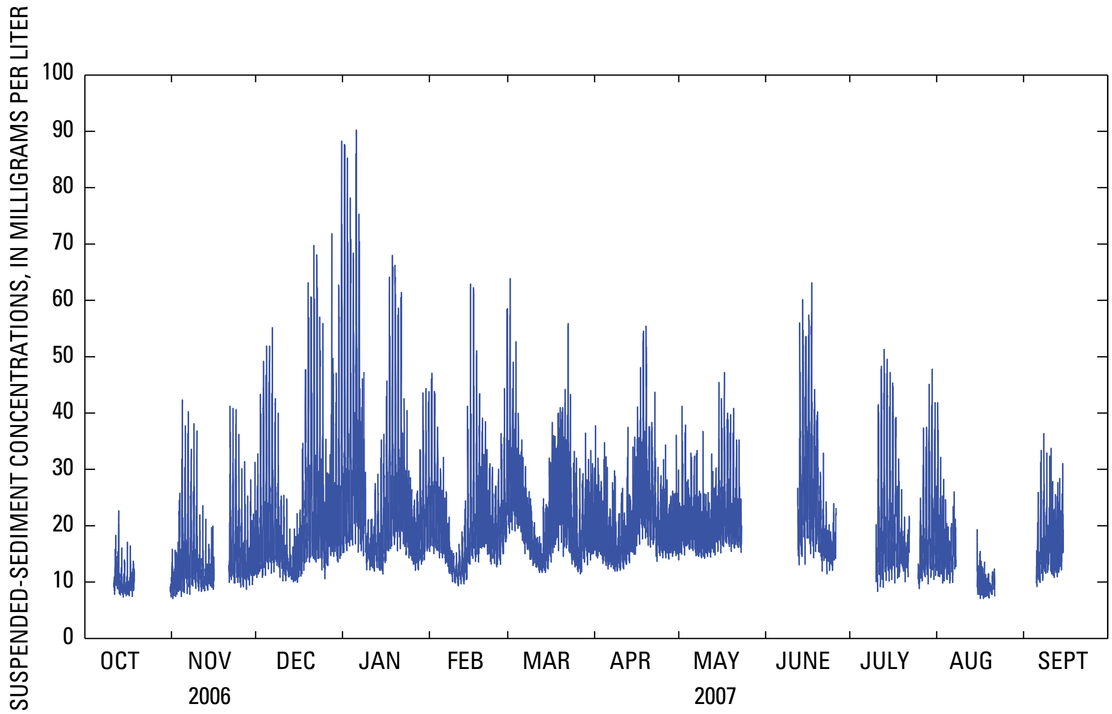

Figure 12. Time series of mid-depth suspended-sediment concentrations calculated from sensor readings at Alcatraz Island, Central San Francisco Bay, California, water year 2007.

South San Francisco Bay

Dumbarton Bridge

PERIOD OF CALIBRATION.—
MID-DEPTH SENSOR (*A*): October 1, 2006, to July 26, 2007 (fig. 13A).
MID-DEPTH SENSOR (*B*): July 26, 2007, to September 30, 2007 (fig. 13B).
NEAR-BOTTOM SENSOR: WY 2007 (fig. 14).
NUMBER OF DATA POINTS (WATER SAMPLES) USED FOR CALIBRATION.—
MID-DEPTH SENSOR(*A*): 25 (12 from WY 2007).
MID-DEPTH SENSOR (*B*): 8 (3 from WY 2007, 5 from WY 2008).
NEAR-BOTTOM SENSOR: 26 (13 from WY 2007).
LINEAR REGRESSION EQUATION.—
MID-DEPTH SENSOR(*A*): SSC = 1.037 × mV + 5.4.
MID-DEPTH SENSOR (*B*): SSC = 0.973 × mV + 4.2.
NEAR-BOTTOM SENSOR: SSC = 1.335 × mV + 3.9.
NONPARAMETRIC PREDICTION INTERVAL.—
MID-DEPTH SENSOR(*A*): +6 to –11 mg/L.
MID-DEPTH SENSOR (*B*): +15 to –2 mg/L.
NEAR-BOTTOM SENSOR: +23 to –13 mg/L.
95-PERCENT CONFIDENCE INTERVAL ON SLOPE CALCULATION.—
MID-DEPTH SENSOR(*A*): 0.756 to 1.199.
MID-DEPTH SENSOR (*B*): 0.894 to 1.121.
NEAR-BOTTOM SENSOR: 1.028 to 1.589.

REMARKS.—Interruptions in record were caused by fouling or malfunction of the sensing and(or) recording instruments. The wiper on the mid-depth optical sensor malfunctioned and the sensor was replaced on July 26, 2007. Water samples from WY 2008 were included in the second mid-depth sensor calibration to supplement the small number of water samples collected in WY 2007. The calculated SSC time-series data collected for WY 2007 are presented in figure 15.

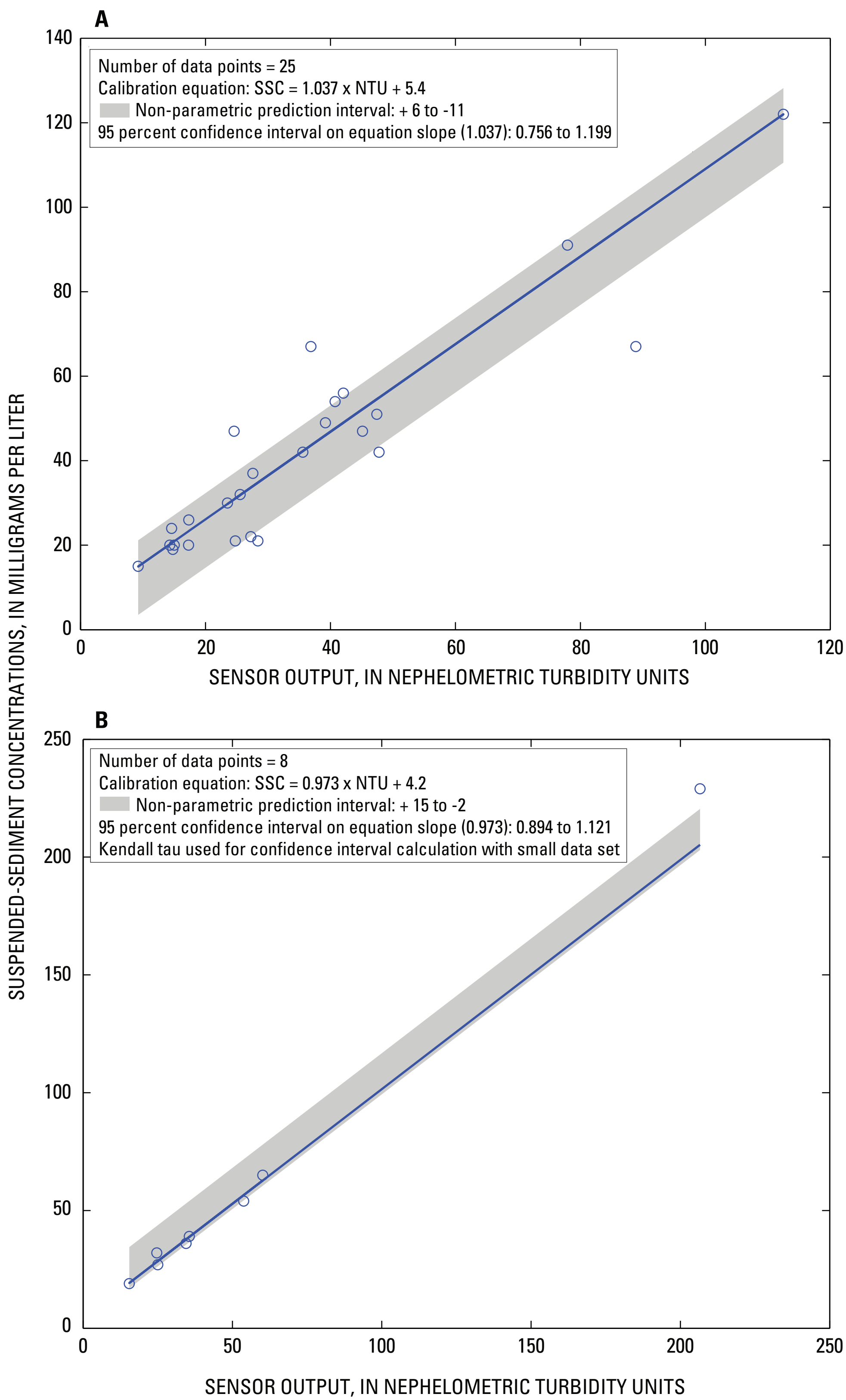

Figure 13. Calibration of mid-depth optical sensors, (A) October 1–July 26 and (B) July 26–September 30 at Dumbarton Bridge, South San Francisco Bay, California, water year 2007.

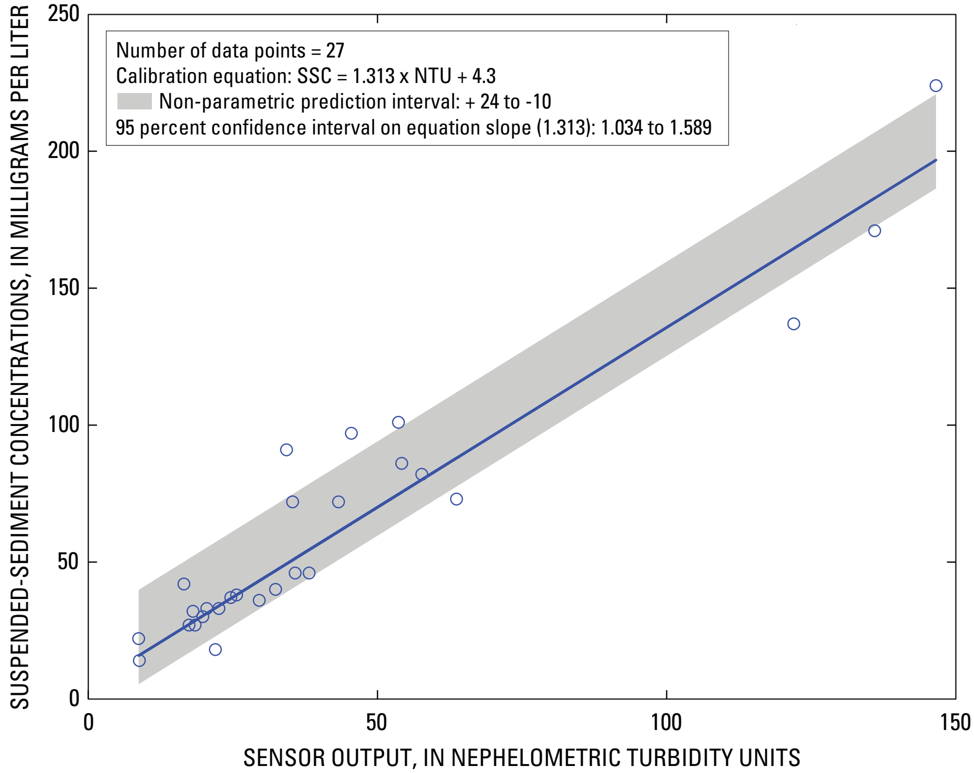

Figure 14. Calibration of near-bottom optical sensor at Dumbarton Bridge, South San Francisco Bay, California, water year 2007.

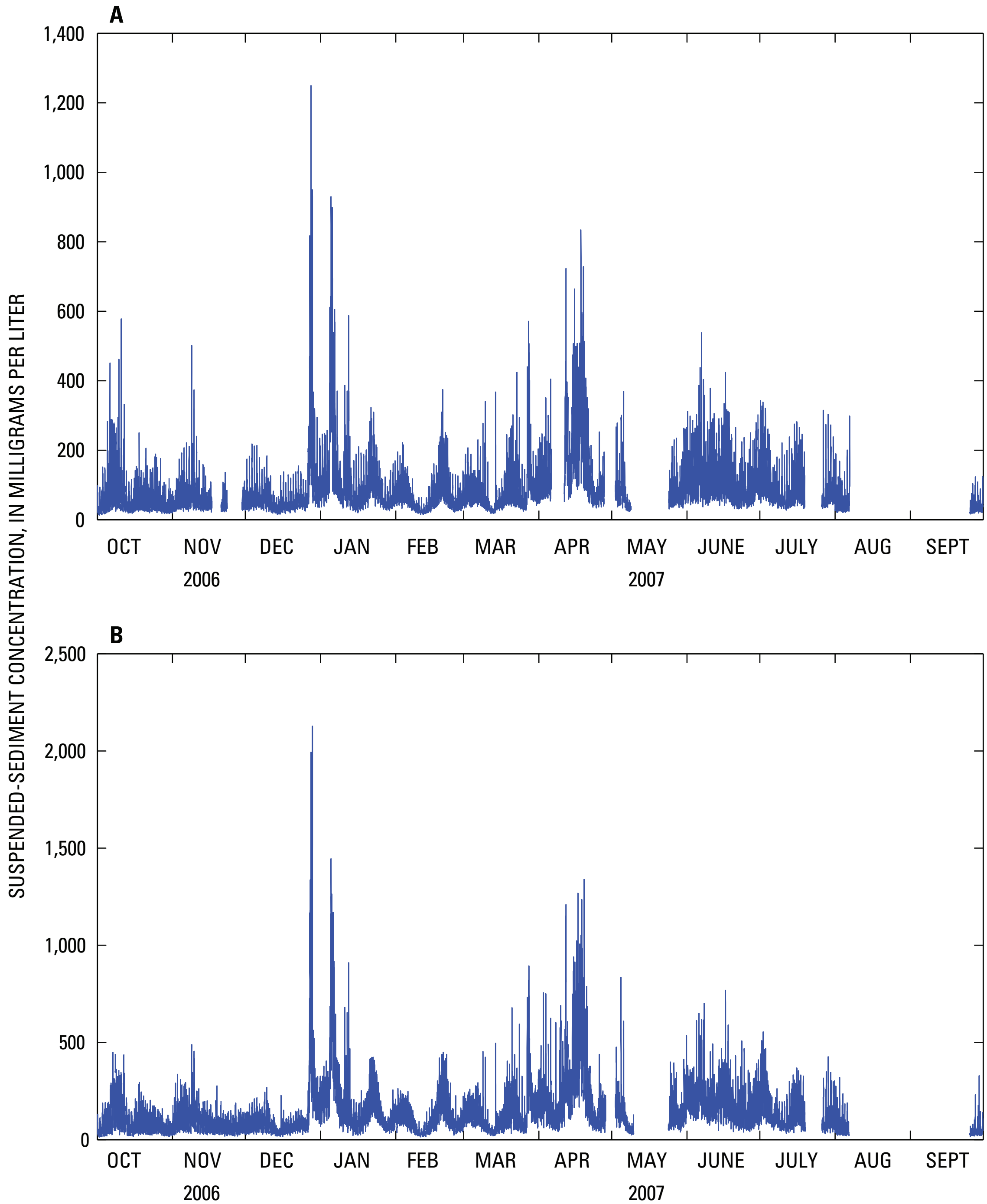

Figure 15. Time series of (A) mid-depth and (B) near-bottom suspended-sediment concentrations calculated from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 2007.

Summary

Suspended-sediment concentration (SSC) data were collected by the U.S. Geological Survey (USGS) at two sites in Suisun Bay, two sites in Central San Francisco Bay, and one site in South San Francisco Bay during water year 2007. Two 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 (SLEDS) and the USGS automated data-processing system database (ADAPS). The calculated SSC data are available from the USGS (accessed December 2, 2008).

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References Cited

Arthur, J.F., and Ball, M.D., 1979, Factors influencing the entrapment of suspended material in the San Francisco Bay–Delta Estuary, *in* Conomos, T.J., ed., San Francisco Bay—The urbanized estuary: San Francisco, Pacific Division of the American Association for the Advancement of Science, p. 143–174.

Brown, C.L., and Luoma, S.N., 1995, Use of the euryhaline bivalve *Potamocorbula amurensis* as a biosentinal species to assess trace metal contamination in San Francisco Bay: Marine Ecology Progress Series, v. 124, p. 129–142.

Buchanan, P.A., and Ganju, N.K., 2002, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2000: U.S. Geological Survey Open- File Report 02–146, 42 p.

Buchanan, P.A., and Ganju, N.K., 2003, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2001: U.S. Geological Survey Open-File Report 03–312, 47 p.

Buchanan, P.A., and Ganju, N.K., 2004, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2002: U.S. Geological Survey Open-File Report 04–1219, 45 p.

Buchanan, P.A., and Ganju, N.K., 2005, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2003: U.S. Geological Survey Data Series 113, 46 p.

Buchanan, P.A., and Lionberger, M.A., 2006, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2004: U.S. Geological Survey Data Series 226, 49 p.

Buchanan, P.A., and Lionberger, M.A., 2007, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2005: U.S. Geological Survey Data Series 282, 46 p.

Buchanan, P.A., and Lionberger, M.A., 2009, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 2006: U.S. Geological Survey Data Series 362, 35 p.

Buchanan, P.A., and Ruhl, C.A., 2000, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1998: U.S. Geological Survey Open-File Report 00-88, 41 p.

Buchanan, P.A., and Ruhl, C.A., 2001, Summary of suspended-sediment concentration data, San Francisco Bay, California, water year 1999: U.S. Geological Survey Open-File Report 01-100, 41 p.

Buchanan, P.A., and Schoellhamer, D.H., 1995, Summary of suspended-solids concentration data, Central and South San Francisco Bay, California, water years 1992 and 1993: U.S. Geological Survey Open-File Report 94-543, 15 p.

Buchanan, P.A., and Schoellhamer, D.H., 1996, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1995: U.S. Geological Survey Open-File Report 96-591, 40 p.

Buchanan, P.A., and Schoellhamer, D.H., 1998, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1996: U.S. Geological Survey Open-File Report 98-175, 59 p.

Buchanan, P.A., and Schoellhamer, D.H., 1999, Summary of suspended-solids concentration data, San Francisco Bay, California, water year 1997: U.S. Geological Survey Open-File Report 99-189, 52 p.

Buchanan, P.A., Schoellhamer, D.H., and Sheipline, R.C., 1996, Summary of suspended- solids concentration data, San Francisco Bay, California, water year 1994: U.S. Geological Survey Open-File Report 95-776, 48 p.

Carlson, P.R., and McCulloch, D.S., 1974, Aerial observations of suspended-sediment plumes in San Francisco Bay and adjacent Pacific Ocean: U.S. Geological Survey Water-Resources Research, v. 2, no. 5, p. 519–526.

Cheng, R.T., and Gartner, J.W., 1984, Tides, tidal and residual currents in San Francisco Bay, California—Results of measurements, 1979–1980: U.S. Geological Survey Water-Resources Investigations Report 84-4339, 72 p.

Cloern, J.E., 1987, Turbidity as a control on phytoplankton biomass and productivity in estuaries: Continental Shelf Research, v. 7, no. 11/12, p. 1367–1381.

Cloern, J.E., 1996, Phytoplankton bloom dynamics in coastal ecosystems—a review with some general lessons from sustained investigation of San Francisco Bay, California: Reviews of Geophysics, v. 34, no. 2, p. 127–168.

Cole, B.E., and Cloern, J.E., 1987, An empirical model for estimating phytoplankton productivity in estuaries: Marine Ecology Progress Series, v. 36, p. 299–305.

Conomos, T.J., and Peterson, D.H., 1977, Suspended-particle transport and circulation in San Francisco Bay, an overview: New York, Academic Press, Estuarine Processes, v. 2, p. 82–97.

Domagalski, J.L., and Kuivila, K.M., 1993, Distributions of pesticides and organic contaminants between water and suspended sediment, San Francisco Bay, California: Estuaries, v. 16, no. 3A, p. 416–426.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Flegal, A.R., Rivera-Duarte, I., Ritson, P.I., Scelfo, G.M., Smith, G.J., Gordon, M.R., and Sanudo-Wilhelmy, S.A., 1996, Metal contamination in San Francisco Bay waters: Historic perturbations, contemporary concentrations, and future considerations: San Francisco Bay *in* The Ecosystem, Hollibaugh, J.T., ed., Pacific Division of the American Association for the Advancement of Science, San Francisco, p. 173–188.

Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwarz, G.E., 2000, Comparability of suspended-sediment concentration and total suspended-solids data: U.S. Geological Survey Water-Resources Investigations Report 00-4191, p. 14.

Greenberg, A.E., Clesceri, L.S., and Eaton, A.D., 1992, Standard methods for the examination of water and wastewater (18th ed.): American Public Health Association, variously paged.

Hammond, D.E., Fuller, C., Harmon, D., Hartman, B., Korosec, M., Miller, L.G., Rea, R., Warren, S., Berelson, W., and Hager, S.W., 1985, Benthic fluxes in San Francisco Bay: Hydrobiologia, v. 129, p. 69–90.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Studies in Environmental Science, v. 49, Elsevier, 522 p.

Jassby, A.D., and Powell, T.M., 1994, Hydrodynamic influences on interannual chlorophyll variability in an estuary: Upper San Francisco Bay–Delta (California, U.S.A.): Estuarine, Coastal and Shelf Science, v. 39, p. 595–618.

Kimmerer, Wim, 1992, An evaluation of existing data in the entrapment zone of the San Francisco Bay Estuary: Tiburon, California, Biosystems Analysis, Inc., Technical Report 33, 49 p.

Kuwabara, J.S., Chang, C.C.Y., Cloern, J.E., Fries, T.L., Davis, J.A., and Luoma, S.N., 1989, Trace metal associations in the water column of South San Francisco Bay, California: Estuarine, Coastal and Shelf Science, v. 28, p. 307–325.

Levesque, V.A., and Schoellhamer, D.H., 1995, Summary of sediment resuspension monitoring, Old Tampa Bay and Hillsborough Bay, Florida, 1988–91: U.S. Geological Survey Water-Resources Investigations Report 94-4081, 31 p.

Luoma, S.N., 1996, The developing framework of marine ecotoxicology: Pollutants as a variable in marine ecosystems?: Journal of experimental marine biology and ecology, v. 200, p. 29–55.

Luoma, S.N., Cain, D., and Johansson, C., 1985, Temporal fluctuations of silver, copper, and zinc in the bivalve *Macoma balthica* at five stations in South San Francisco Bay: Hydrobiologia, v. 129, p. 109–120.

McKee, L., Ganju, N.K., and Schoellhamer, D.H., 2006, Estimates of suspended sediment entering San Francisco Bay from the Sacramento and San Joaquin Delta, San Francisco Bay, California: Journal of Hydrology, v. 323, p. 335–352.

Peterson, D.H., Conomos, T.J., Broenkow, W.W., and Doherty, P.C., 1975, Location of the non-tidal current null zone in northern San Francisco Bay: Estuarine and Coastal Marine Science, v. 3, p. 1–11.

Powell, T.M., Cloern, J.E., and Huzzey, L.M., 1989, Spatial and temporal variability in South San Francisco Bay (U.S.A.). I. Horizontal distributions of salinity, suspended sediments, and phytoplankton biomass and productivity: Estuarine, Coastal and Shelf Science, v. 28, p. 583–597.

Schoellhamer, D.H., 1996, Factors affecting suspended-sediment concentrations in South San Francisco Bay, California: Journal of Geophysical Research, v. 101, no. C5, p. 12087–12095.

Schoellhamer, D.H., 2001, Influence of salinity, bottom topography, and tides on locations of estuarine turbidity maxima in northern San Francisco Bay, *in* McAnally, W.H. and Mehta, A.J., ed., Coastal and Estuarine Fine Sediment Transport Processes: Elsevier Science B.V., p. 343–357, accessed June 26, 2009, at http://ca.water.usgs.gov/abstract/sfbay/elsevier0102.pdf

Schoellhamer, D.H., and Burau, J.R., 1998, Summary of findings about circulation and the estuarine turbidity maximum in Suisun Bay, California: U.S. Geological Survey Fact Sheet FS-047-98, 6 p.

Schoellhamer, D.H., Ganju, N.K.,Gartner, J.W., Murrell, M.C., and Wright, S.A., 2003a, Seasonal and longitudinal homogeneity of suspended sediment in San Francisco Bay, California: Proceedings of the 17th Biennial Conference of the Estuarine Research Federation, Seattle, Washington, September 14–18, 2003, p. 119.

Schoellhamer, D.H., Shellenbarger, G.G., Ganju, N.K., Davis, J.A., and McKee, L.J., 2003b, Sediment dynamics drive contaminant dynamics: Pulse of the Estuary: Monitoring and Managing Contamination in the San Francisco Estuary: San Francisco Estuary Institute, Oakland, California, p. 21–26, accessed June 26, 2009, at http://www.sfei.org/rmp/pulse/pulse2003.pdf

Siegel, A.R., 1982, Robust regression using repeated medians: Biometrika, v. 69, p. 242–244.

Smith, L.H., 1987, A review of circulation and mixing studies of San Francisco Bay, California: U.S. Geological Survey Circular 1015, 38 p.

U.S. Environmental Protection Agency, 1992, State of the estuary: Dredging and waterway modification: U.S. Environmental Protection Agency San Francisco Estuary Project, chap. 8, p. 191–215.

U.S. Geological Survey, Publications of the San Francisco Bay Sediment Group, accessed December 2, 2008, at http://ca.water.usgs.gov/user_projects/sfbay/publications_group.htm

U.S. Geological Survey, Continuous Monitoring in the San Francisco Bay and Delta: accessed December 2, 2008, at http://sfbay.wr.usgs.gov/sediment/cont_monitoring/index.html

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