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Summary of Suspended-Sediment Concentration Data, San Francisco Bay, California, Water Year 2010

Data Series 808

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

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By Paul A. Buchanan and Tara L. Morgan

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SALLY JEWELL, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia: 2014

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)

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

°F=(1.8×°C)+32

Concentrations of 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 (1960–78 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

ADAPS	automated data-processing system
DWR	California Department of Water Resources
FNU	formazin nephelometric units
FTS	Forest Technology Systems
nm	nanometer
NTU	nephelometric turbidity units
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)

Acknowledgments

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Abstract

Suspended-sediment concentration data were collected by the U.S. Geological Survey in San Francisco Bay during water year 2010 (October 1, 2009–September 30, 2010). Turbidity sensors and water samples were used to monitor suspended-sediment concentration at two sites in Suisun Bay, one site in San Pablo Bay, three 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 turbidity sensors so that a record of suspended-sediment concentrations could be computed. This report presents the data-collection methods used and summarizes, in graphs, the suspended-sediment concentration data collected from October 2009 through September 2010. 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 onto 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). The mobilization, resuspension, and deposition of suspended sediments are important factors in determining the transport and fate of sediment-associated contaminants. Large tidal-induced current velocities and wind waves in shallow water are capable of resuspending bottom sediments (Powell and others, 1989; Schoellhamer, 1996). 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 require dredging to remain navigable (U.S. Environmental Protection Agency, 1992).

In Suisun Bay, the maximum suspended-sediment concentration (SSC) typically occurs at the estuarine 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).

Purpose and Scope

The U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers, has been studying the factors that affect SSC in San Francisco Bay since water year (WY) 1992. This report summarizes SSC data collected by the USGS in San Francisco Bay during water year (WY) 2010 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; Buchanan and Lionberger, 2006, 2007, 2009; and Buchanan and Morgan, 2010, 2011, 2012). Collection of SSC data in San Francisco Bay required development of monitoring methods and calibration techniques, which are presented in this report. SSC was monitored at two sites in Suisun Bay, one site in San Pablo Bay, three sites in Central San Francisco Bay, and one site in South San Francisco Bay. SSC data from WY 1992 through WY 2010 were used to help determine the factors that affect SSC in San Francisco Bay (U.S. Geological Survey, variously dated, at URL *http://ca.water.usgs.gov/user_projects/sfbay/publications_group.htm*). Numerical SSC data are available from the U.S. Geological Survey (variously dated, at URL *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 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 and ¾-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). Typically, the strongest winds 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 flowing into the Sacramento-San Joaquin River Delta. 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 44 percent of the fluvial sediments that enter the bay (Lewicki and McKee, 2009), though this percentage varies from year to year. Local tributaries (defined as tributaries that enter the bay seaward of Mallard Island) supply 56 percent of fluvial sediments that enter the bay. 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).

Instrument Description and Operation

Two types of turbidity sensors were used to monitor SSC during WY 2010. The first type of sensor, the DTS-12 manufactured by Forest Technology Systems (FTS), is self-cleaning and measures the intensity of light scattered at 90 degrees between a laser diode (780 nanometer wavelength) and a high-sensitivity silicon photodiode detector. The output, in formazin nephelometric units (FNU), is recorded on a separate data logger. The second type of sensor, model 6136 manufactured by YSI, Inc., also measures the intensity of light scattered at 90 degrees between a light-emitting diode (860 ± 30 nanometer wavelength) and a high-sensitivity photodiode detector, and the output (FNU) is processed by internal software. In previous reports, the output of the DTS-12 and the YSI, Inc., sensors was reported as nephelometric turbidity units (NTU). The USGS has developed new reporting units for turbidity that are based on the instrument design (U.S. Geological Survey, 2004). The design of both the DTS-12 and the YSI, Inc., instruments specifies the use of FNU as the reporting unit. The YSI, Inc., instruments (sondes) are self-contained and include a power source (AA-sized batteries), data logger, and the capability of supporting additional sensors. The YSI, Inc., and FTS data loggers collect instantaneous values every 15 minutes. Power to the data logger used with the DTS-12 sensor was supplied by 12-volt batteries.

Turbidity 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. Turbidity-sensor depths in the water column are listed in table 1.

Biological growth (fouling) interferes with the collection of accurate optical-sensor data. Self-cleaning turbidity sensors were used at all sites (cleaning cycle performed hourly). Fouling generally was greatest on the sensor closest to the water surface. Fouling on the cleaning mechanism or the sensor body would begin to obscur the sensor optics and affect sensor output 5 days to several weeks after servicing a monitoring station, depending on the level of biological activity in the bay. Because of the difficulty in servicing some of the monitoring stations, sensors were cleaned manually every 3–5 (usually 3) weeks. Generally, fouling was greatest during spring and summer.

Sensor performance was monitored by using known standards to identify output drift or sensor malfunction. 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 of about 0 and 100 NTU were used in WY 2010. Prepared solutions were checked with a Hach Drel 2000 spectrophotometer for accuracy (acceptable within 5 percent of measured value, as specified by Wagner and others, 2006). At the field site, the cleaned sensors were immersed in the solution and the output was recorded on the station log.

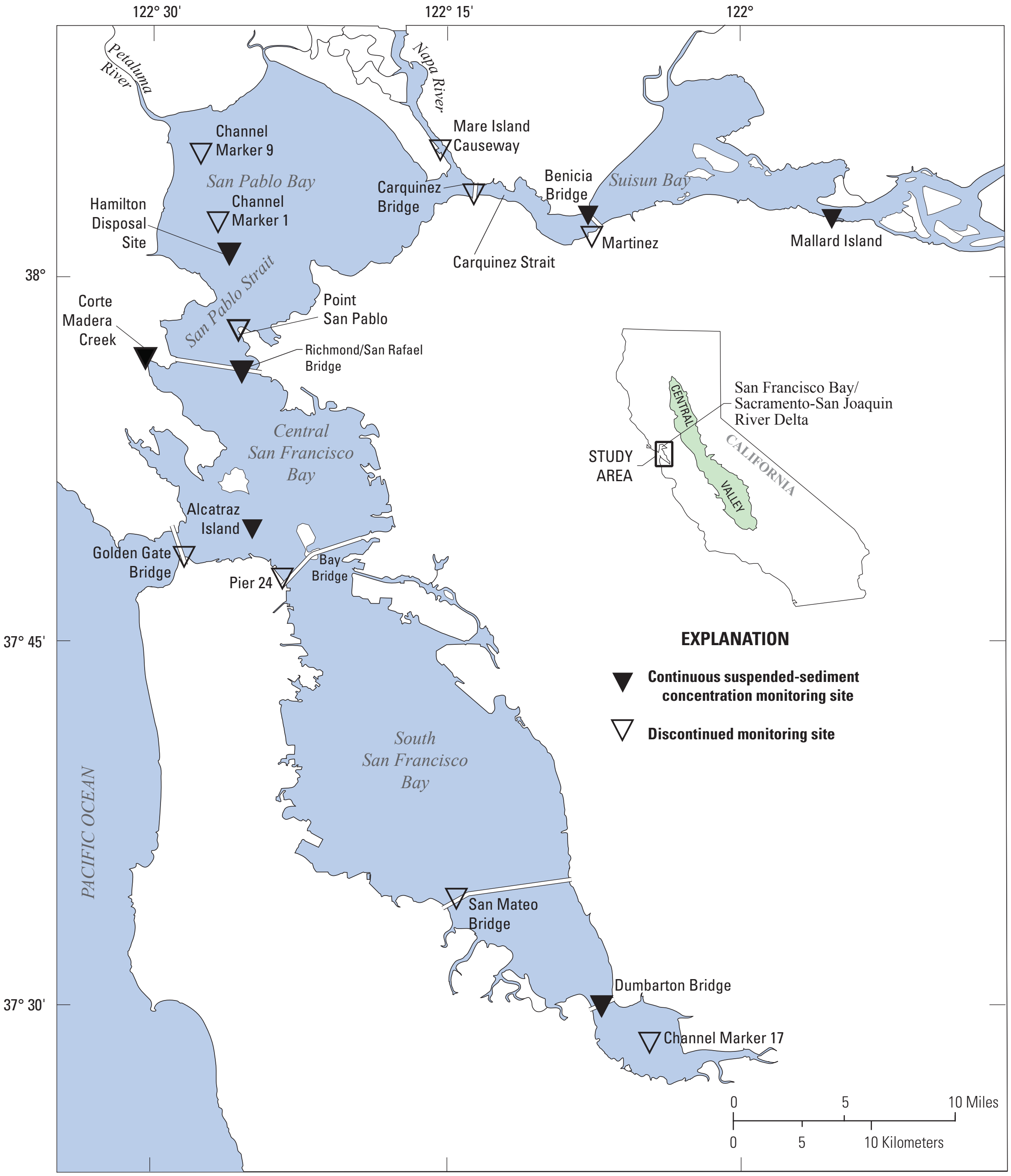

Figure 1. San Francisco Bay study area, California.

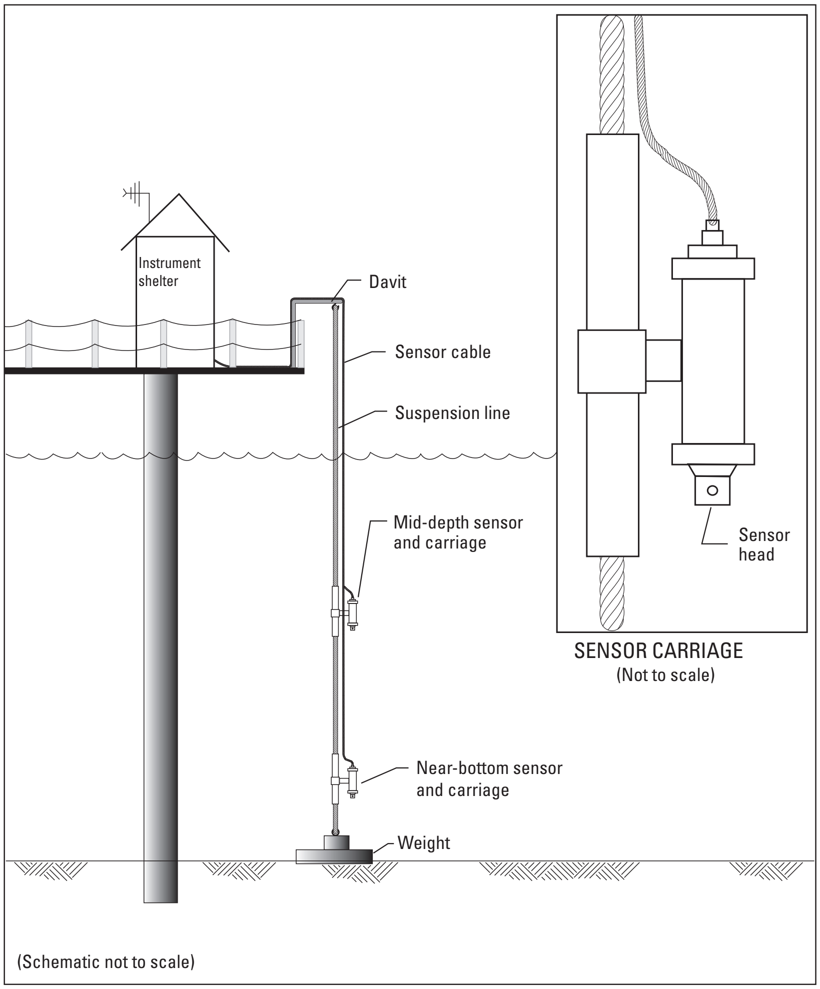

Figure 2. Typical monitoring installation, San Francisco Bay study.

Table 1. Turbidity-sensor depths (in feet) below mean lower low water (MLLW), San Francisco Bay, California, water year 2010.

[MLLW is 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 (1960–78 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**: °, degree; ′, minute; ″, second; —, not applicable]

Site	Station number	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
Mallard Island	11185185	38°02′34″	121°55′09″	Near-bottom	20	—
Benicia Bridge	11455780	38°02′42″	122°07′32″	Near-surface	9	80
Benicia Bridge	11455780	38°02′42″	122°07′32″	Near-bottom	61	—
Hamilton Disposal Site	380109122250401	38°01′09″	122°25′04″	Mid-depth	10	16
Richmond/San Rafael Bridge	375607122264701	37°56′07″	122°26′47″	Mid-depth	15	45
Richmond/San Rafael Bridge	375607122264701	37°56′07″	122°26′47″	Near-bottom	40	—
Corte Madera Creek	11450090	37°56′36″	122°30′53″	Mid-depth	0	4
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
Dumbarton Bridge	373015122071000	37°30′15″	122°07′10″	Near-bottom	41	—

[1]Depth below water surface.

Monitoring Sites

Suisun Bay Installations

SSC data were collected in Suisun Bay at Mallard Island and at Benicia Bridge (fig. 1, table 1). Turbidity sensors were installed at the California Departmennt of Water Resources (DWR) Mallard Island Compliance Monitoring Station on February 8, 1994, and were positioned to coincide with DWR near-surface and near-bottom electrical-conductance and temperature sensors. DWR replaced the near-bottom sensors, near-surface pump intake, and associated flow-through water-quality monitor with YSI, Inc., monitors on April 16, 2008. The DWR near-surface YSI, Inc., monitor was attached to a float that positioned the monitor about 3 ft below the surface. The near-surface turbidity sensor was attached to a separate float and positioned at the same depth as the DWR near-surface monitor.

Turbidity 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 May 1, 2001, using sondes equipped with optical, conductance, and temperature sensors. 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

SSC data were collected in San Pablo Bay at Hamilton Disposal Site (fig. 1, table 1). A sonde with optical, conductance, and temperature sensors was deployed by attaching to a stainless-steel cable moored using a subsurface buoy and lead weight (fig. 3) on November 9, 2005. The Hamilton site was discontinued November 16, 2006, but reestablished July 24, 2008. The sonde was co-located with an upward-looking acoustic Doppler current profiler used to collect velocity and wave data (fig. 3). A monitoring station at the 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, although specific conductance and water temperature were monitored at this site in WY 2010. A monitoring station at Point San Pablo was discontinued on August 1, 2006.

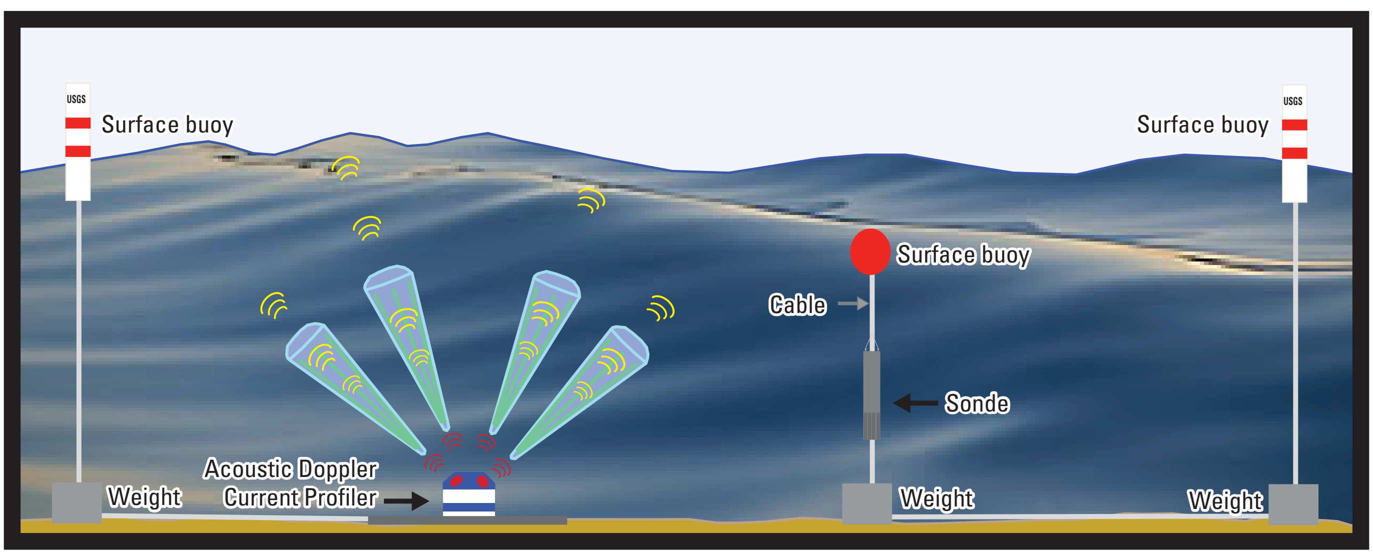

Figure 3. Atypical monitoring installation, Hamilton Disposal site, San Pablo Bay.

Central San Francisco Bay Installations

SSC data were collected in Central San Francisco Bay at Alcatraz Island, Corte Madera Creek, and at the 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. A sonde with optical, conductance, and temperature sensors was installed on the north side of an abandoned railroad bridge pier about 2,600 ft upstream of the mouth of Corte Madera Creek. The Corte Madera Creek sonde was co-located with a sideward-looking acoustic Doppler current profiler used to collect velocity data. 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 WY 1996 and WY 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 the Dumbarton Bridge (fig. 1, table 1). Turbidity 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, although specific conductance and water temperature were monitored at this site in WY 2010. 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 turbidity sensors to SSC were collected by using a horizontally positioned Van Dorn-style sampler, usually after the sensors were cleaned (fig.4). In previous WYs, samples were collected before the sensors were cleaned; however, the time-series data collected before cleaning was often unusable as a result of fouling, and the calibration data 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, then 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-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. 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), but because the total water-sediment mass and all sediment were measured in the analysis, these data are more appropriately referred to as SSC (Gray and others, 2000). 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 degrees Celsius, then weighed (Fishman and Friedman, 1989).

Figure 4. Scientist collecting a water sample by using a horizontally positioned Van Dorn-style sampler with bridge board.

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 either a storage module or laptop computer during site visits. Raw data from the storage modules or laptop computer were loaded into the USGS National Water Inventory System (NWIS) database and stored with appropriate data descriptors for electrical output and turbidity (depending on the instrument used).

The turbidity time-series data were retrieved from NWIS and processed to remove invalid data. Invalid data included rapidly increasing sensor outputs and unusually high sensor outputs of short duration (spikes). As biological growth accumulated on the turbidity sensors, the sensor outputs increased. An example time-series of raw and processed turbidity sensor data is presented in figure 5. After sensors were cleaned, sensor outputs immediately decreased (see fig. 5*A*). Efforts to correct for biofouling proved to be unsuccessful because the signal often was highly variable. Thus, data affected by biofouling were often unusable and were removed from the record (fig. 5*B*). Identifying the point at which fouling begins to affect turbidity sensor data is somewhat subjective. Indicators, such as an elevated baseline, an increasingly variable sensor output, comparisons with the output from other nearby sensors, and neap/spring tidal patterns, were used to help define the point at which fouling began. Spikes in the data, which are anomalously high sensor outputs probably caused by debris temporarily wrapped around the sensor or by large marine organisms (fish, crabs) on or near the sensor, were also removed from the computed record (fig. 5*B*). Sometimes, incomplete cleaning of a sensor (usually caused by a worn-out wiper pad) would cause a small, constant change in sensor output that could be corrected by applying a shift to the record based on water-sample data that had been collected for calibration of the sensors.

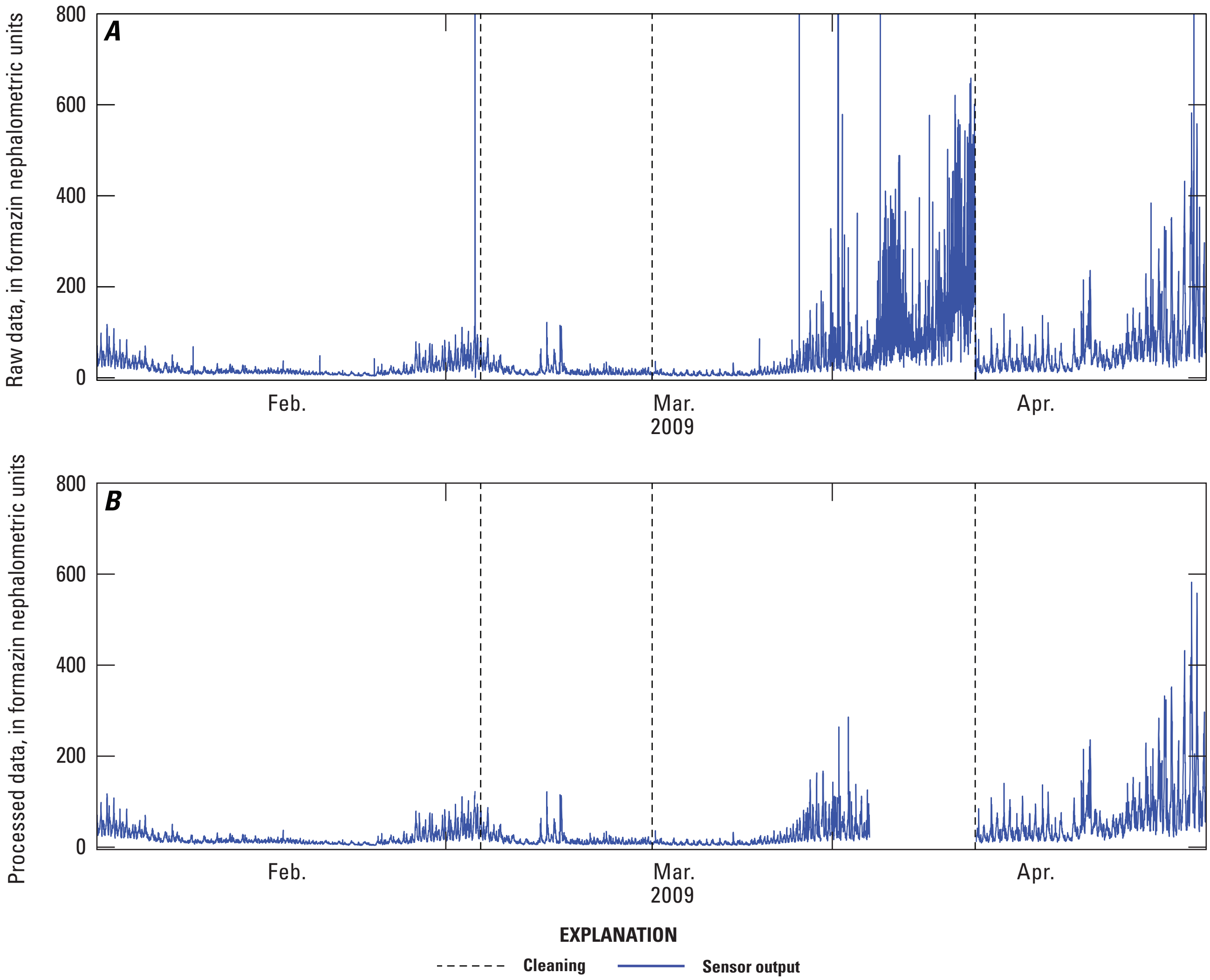

Figure 5. Example of raw and processed turbidity sensor data, mid-depth sensor, Dumbarton Bridge, South San Francisco Bay, California, water year 2010: *A*, raw and *B*, processed.

Calibration Data, Regression Model Development, and Computation of Suspended-Sediment Concentration Data

The turbidity 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 and location of the sensor. SSC computed from the output of side-by-side sensors with different instrument designs were virtually identical (Buchanan and Schoellhamer, 1998). The turbidity-to-SSC relationship will vary according to the size and optical properties of the suspended sediment at the site; therefore, regression-model calibrations were unique to each turbidity sensor's location (Levesque and Schoellhamer, 1995).

The output from the turbidity sensors was used to calculate SSC by linear regression using the robust, nonparametric, repeated median method (Siegel, 1982). Because the variance of the residuals for some datasets in this study increased with voltage and was not constant, the non-parametric method was considered to be more appropriate than other methods. However, ordinary least squares (OLS) regression was used to develop the model in cases where the nonparametric method was insufficient because of a poor distribution of data points (Helsel and Hirsch, 2002). 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, 2002, p. 225).

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

Robust statistics were used to estimate the slope of the equation for the nonparametric fit. The slope estimate was calculated from the comparison of all X, Y pairs (in this report X refers to sensor output in FNU, and Y refers to sampled SSC in mg/L). The repeated-median method calculated the calibration slope in a two-part process (refer to Helsel and Hirsh, 2002 for more detail). First, for each pairwise combination in a set of *n* data points, the median of all possible slopes is calculated:

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

The calibration slope is calculated as the median of β_i:

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

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

$$intercept = \hat{\beta}_o = median\left(Y_i - \hat{\beta}_1 X_i\right) \quad \text{for } i = 1 \ldots n \tag{3}$$

The final linear calibration equation is as follows:

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

The nonparametric prediction interval (PI_{np}) (Helsel and Hirsch, 2002, p. 76–78 and 243) used for data analysis in this study is an interval with a certain probability that will contain future observations. The prediction interval describes the likelihood that a new observation comes from the same distribution as the previously collected data set. PI_{np} 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 it has about the same error prediction limits as the root-mean-squared error (RMSE) of prediction that was used to describe the error associated with parametric OLS regression methods as were used in previous USGS summary data reports of SSC in San Francisco Bay (Buchanan and Schoellhamer, 1995, 1996, 1998, 1999; Buchanan and others, 1996).

The PI_{np}, unlike the RMSE of prediction, is not frequently symmetrical about the regression line. For example, PI_{np} could be reported as +10 and −7 mg/L. This asymmetry about the regression line is a result of the non-normal distribution of the dataset. 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:

$$PI_{np} = Y + e(L),\ \hat{Y} + e(U) \tag{5}$$

where

$\hat{Y}$ is the value of the predicted observation,

e(L) and e(U) are the L[th] and U[th] ranked residuals, and

$$L = (n+1) \times \frac{\alpha}{2} \quad \text{and} \quad U = (n+1) \times \left(1 - \frac{\alpha}{2}\right)$$

n is the number of data points, and

α is 0.32 for a 68 percent confidence.

To calculate the confidence interval for the regression line slope, all possible point-to-point slopes must be sorted in ascending order. The confidence interval (Helsel and Hirsh, 2002 p. 239) on the slope indicates the quality of the estimated slope. On the basis of the confidence interval desired, 95 percent for the purposes of this report, the ranks of the upper and lower bounds are calculated as follows:

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

and

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

where

R_u is the rank of the upper interval slope,

R_l is the rank of the lower interval slope, and

n is the number of samples.

To establish the 95-percent confidence interval on the slope of the equation, the calculated ranks 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. For those sites that had 10 or fewer samples, however, an alternative and presumably slightly more accurate method, Kendall tau, described by Helsel and Hirsch (2002, p. 273–274), was used to calculate upper and lower bound ranks.

A statistical summary of the computed SSC is presented in table 2. The usable percentage of a complete year of valid data (96 data points per day x 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 analyses (calibration) relating SSC (in mg/L) to turbidity sensor output. The model-calibration figures (for example, fig. 6) include the number of water samples (or points, which are all water samples used in the model 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 (table 3). In addition, the time-series plots of computed SSC data are shown for each site.

Table 2. Statistical summary of computed suspended-sediment concentration data and usable percentage of a complete year of valid data (96 data points per day by 365 days) collected by using turbidity sensors, San Francisco Bay, California, water year 2010.

[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	Valid data (percent)
Mallard Island	Near-surface	27	24	19	30	83
Mallard Island	Near-bottom	29	26	21	32	94
Benicia Bridge	Near-surface	44	36	26	54	75
Benicia Bridge	Near-bottom	78	62	42	101	78
Hamilton Disposal Site	Mid-depth	149	120	92	174	41
Richmond/San Rafael Bridge	Mid-depth	32	23	16	38	76
Richmond/San Rafael Bridge	Near-bottom	35	27	19	40	68
Corte Madera Creek	Mid-depth	38	31	24	44	83
Alcatraz Island	Mid-depth	19	17	14	22	54
Dumbarton Bridge	Mid-depth	52	37	25	60	81
Dumbarton Bridge	Near-bottom	97	67	41	120	64

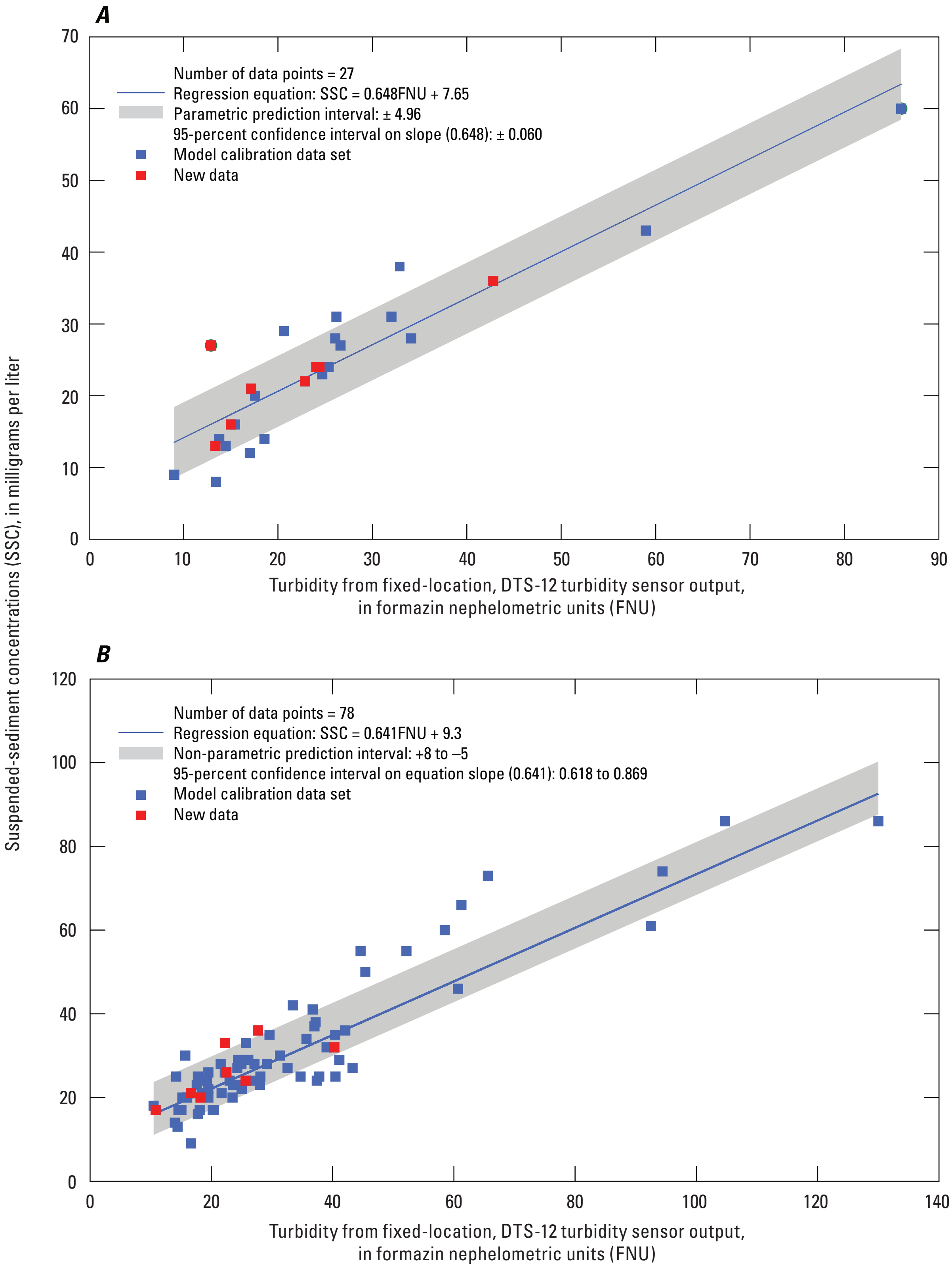

Figure 6. Calibration of turbidity sensors at Mallard Island, Suisun Bay, California, water year 2010: *A*, near surface and *B*, near bottom.

Table 3. Summary of suspended-sediment concentration calibration statistics, Suisun Bay, San Pablo Bay, and Central and South San Francisco Bays, California, water year 2010.

[**Abbreviations**: FNU, formazin nephelometric units; mg/L, milligram per liter; mm/dd/yyyy, month/day/year; SSC, suspended-sediment concentration; —, not applicable]

Site	Sensor location	Period of calibration (mm/dd/yyyy)	Number of data points (water samples)	Linear regression equation	Parametric prediction interval (mg/L)	Non-parametric prediction interval (mg/L)	95-percent confidence interval on slope calculation
Mallard Island	Near-surface	10/01/2009 to 09/30/2010	27	SSC=0.648FNU+7.65	+5.0 to –5.0	—	0.588 to 0.708
Mallard Island	Near-bottom	10/01/2009 to 09/30/2010	78	SSC=0.641FNU+9.3	—	+8.0 to –5.0	0.618 to 0.869
Benicia Bridge	Near-surface	10/01/2009 to 09/30/2010	20	SSC=1.354FNU+8.5	—	+7.0 to –16.0	0.899 to 1.50
Benicia Bridge	Near-bottom	10/01/2009 to 09/30/2010	30	SSC=1.41FNU+8.0	—	+17.0 to –16.0	1.21 to 1.56
Hamilton Disposal Site	Near-bottom	02/17/2010 to 07/21/2010	8	SSC=1.97FNU+6.0	—	+13.0 to –16.0	1.09 to 2.57
Richmond/ San Rafael Bridge	Mid-depth	10/01/2009 to 09/30/2010	53	SSC=2.09FNU+6.0	—	+7.0 to –8.0	1.82 to 2.27
Richmond/ San Rafael Bridge	Near-bottom	10/01/2009 to 09/30/2010	55	SSC=1.64FNU+8.2	—	+20.0 to –10.0	1.37 to 2.24
Corte Madera Creek	Mid-depth	10/01/2009 to 09/30/2010	8	SSC=1.81FNU+7.5	—	+48.0 to –23.0	0.565 to 2.73
Alcatraz Island	Mid-depth	10/01/2009 to 09/30/2010	59	SSC=1.53FNU+9.0	—	+9.0 to –4.0	1.15 to 1.94
Dumbarton Bridge	Mid-depth	10/01/2009 to 09/30/2010	32	SSC=1.22FNU+6.4	—	+20.0 to –12.0	0.941 to 1.70
Dumbarton Bridge	Near-bottom	10/01/2009 to 09/30/2010	30	SSC=1.64FNU+3.1	—	+13.0 to –20.0	1.40 to 1.84

Calibration Remarks

Mallard Island

Interruptions in the record were caused by fouling or malfunction of the sensing or recording instruments, or both. Sensors were positioned at near-surface (attached to float assembly) and near-bottom depths to coincide with DWR near-surface and near-bottom sensors. The near-surface sensor malfunctioned and was replaced on November 20, 2009. Because the turbidity sensors (DTS-12s) deployed at the near-surface position from WY 2007 through WY 2010 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Ganju and others, 2007), the calibration was developed by combining water samples collected during each sensor deployment. The near-surface sensor calibration was developed by using OLS regression because of the poor distribution of data points (fig. 6*A*). The near-bottom sensor was replaced on November 20, 2009. Because the turbidity sensors (DTS-12s) deployed at the near-bottom position from WY 2008 through WY 2010 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Ganju and others, 2007), the calibration was developed by combining water samples collected during each sensor deployment (fig. 6*B*). The computed SSC time-series data for WY 2010 are presented in figure 7.

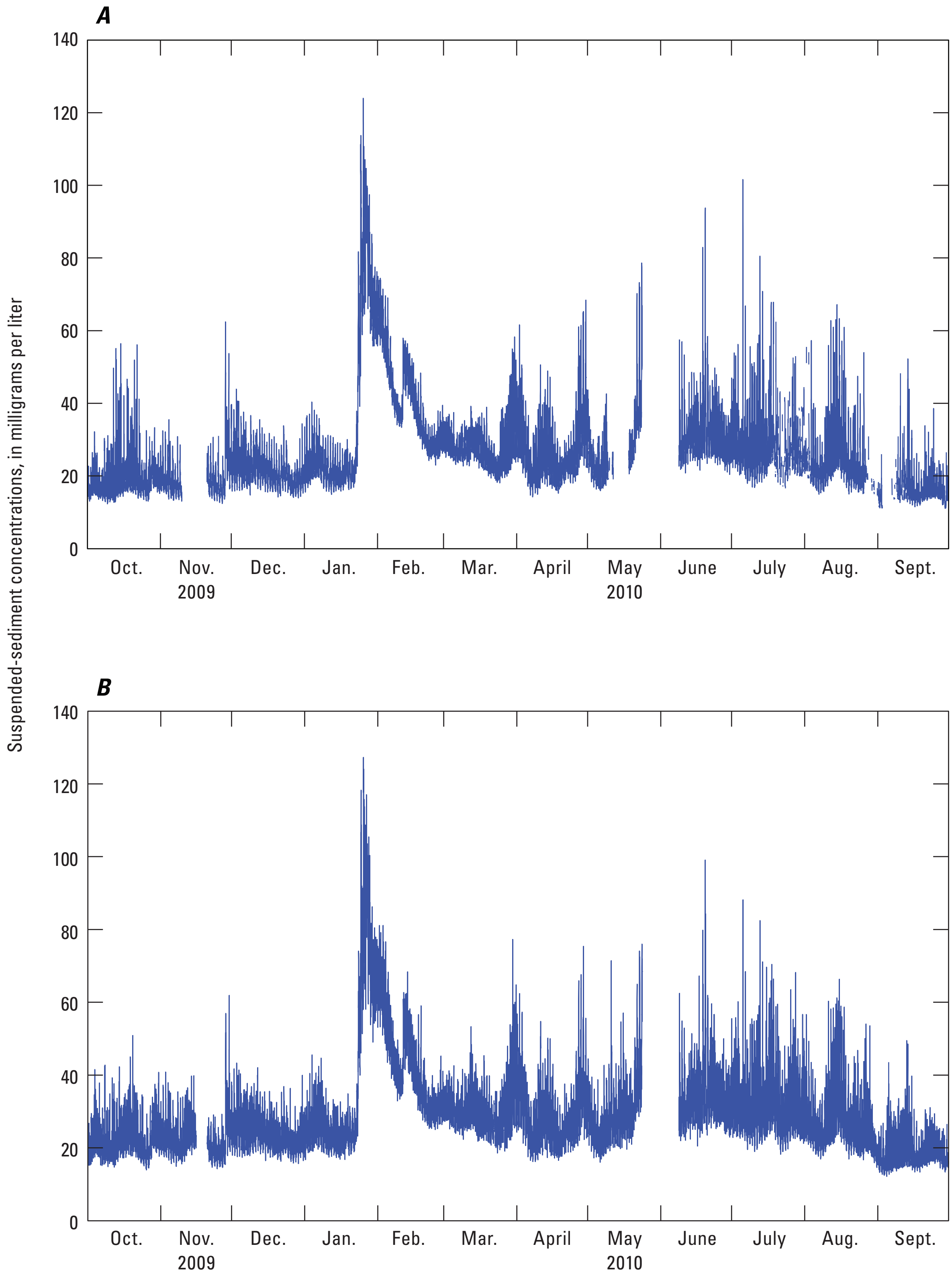

Figure 7. Time series of suspended-sediment concentrations computed from sensor readings at Mallard Island, Suisun Bay, California, water year 2010: *A*, near surface and *B*, near bottom.

Benicia Bridge

Interruptions in the record were caused by fouling or malfunction of the sensing or recording instruments, or both. MLLW was approximately 80 ft at the site, but approximately 60 ft immediately next to it. Therefore, the near-bottom sonde was set approximately 20 ft above the bottom so that the data are representative of the surrounding area. The near-surface turbidity sensor was replaced on November 4, 2009, July 14, 2010, and September 28, 2010. A −3.0 FNU shift was applied to the last 3 days of record to correct an unnatural step in the timeseries that resulted from the change of probes. Because the three turbidity sensors (all YSI, Inc.) deployed at the near-surface position during WY 2010 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Ganju and others, 2007), the calibration was developed by using all water samples collected during each sensor deployment (fig. 8*A*). The near-bottom sonde was replaced on September 28, 2010. A −2.3 FNU shift was applied to the last 3 days of record to correct an unnatural step in the timeseries which resulted from the change of sensors. Because the two turbidity sensors (both YSI, Inc.) deployed at the near-bottom position during WY 2010 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Ganju and others, 2007), the calibration was developed by using all water samples collected during each sensor deployment (fig. 8*B*). The computed SSC time-series data for WY 2010 are presented in figure 9.

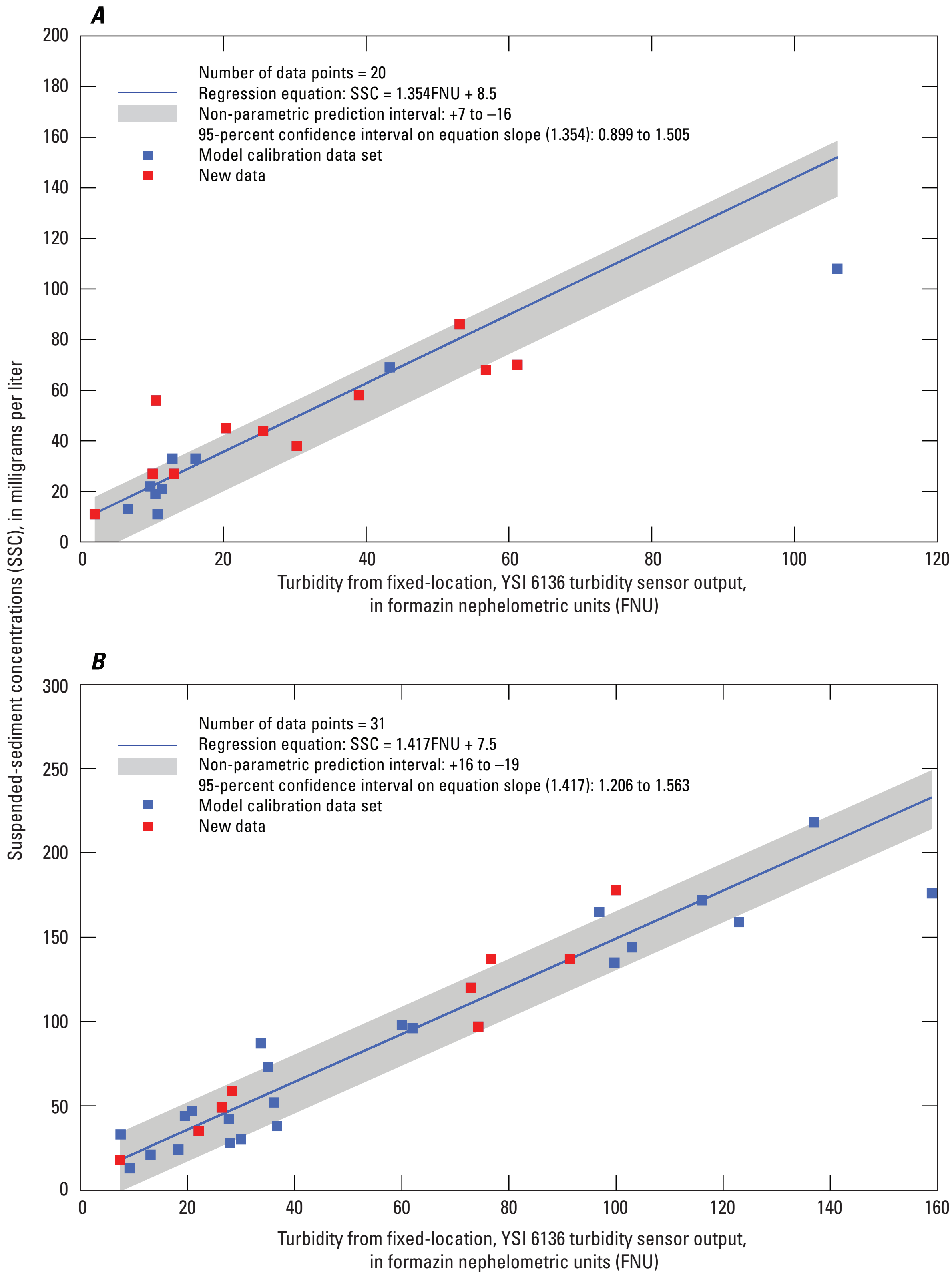

Figure 8. Calibration of turbidity sensors at Benicia Bridge, Suisun Bay, California, water year 2010: *A*, near surface and *B*, near bottom.

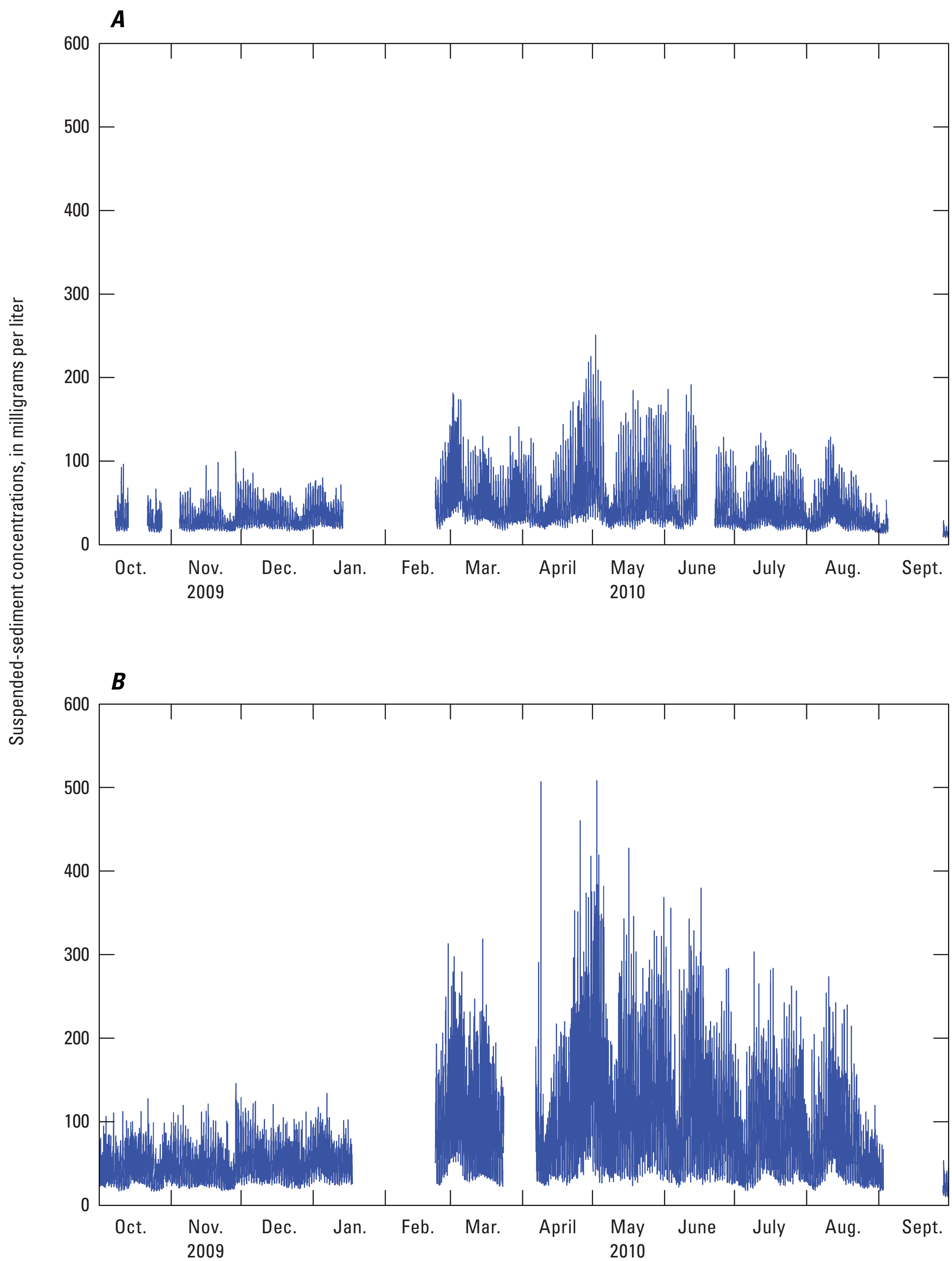

Figure 9. Time series of suspended-sediment concentrations computed from sensor readings at Benicia Bridge, Suisun Bay, California, water year 2010: *A*, near surface and *B*, near bottom.

Hamilton Disposal Site

Interruptions in the record were caused by fouling; malfunction of the sensing or recording instruments, or both; or loss of equipment. During periods of heavy fouling, the turbidity sensor wiper was ineffective in keeping the optical ports clean because biological growth on the wiper itself obscured the optical ports. Sometime after the July 21, 2010, redeployment, the instrument package was lost. The calibration of the turbidity sensor output to SSC and computed SSC time-series data for WY 2010 are presented in figures 10 and 11, respectively.

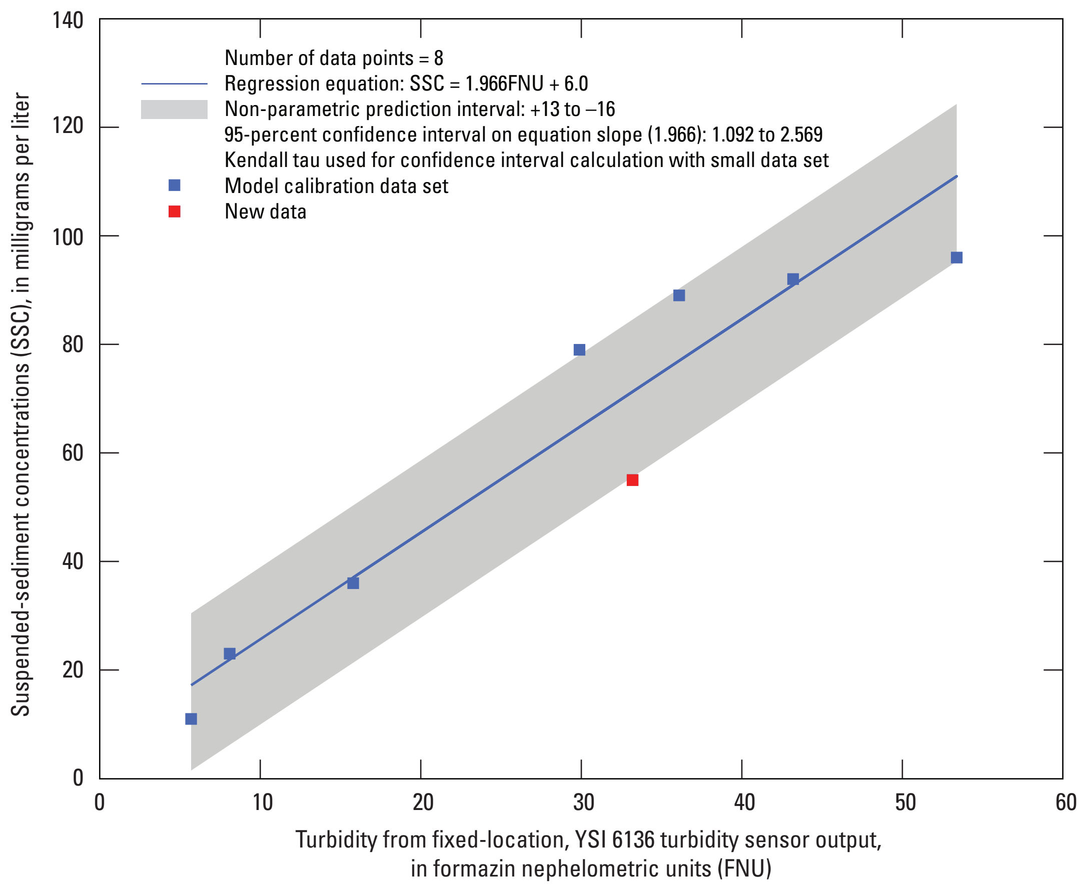

Figure 10. Calibration of near-bottom turbidity sensor at Hamilton Disposal Site, San Pablo Bay, California, water year 2010.

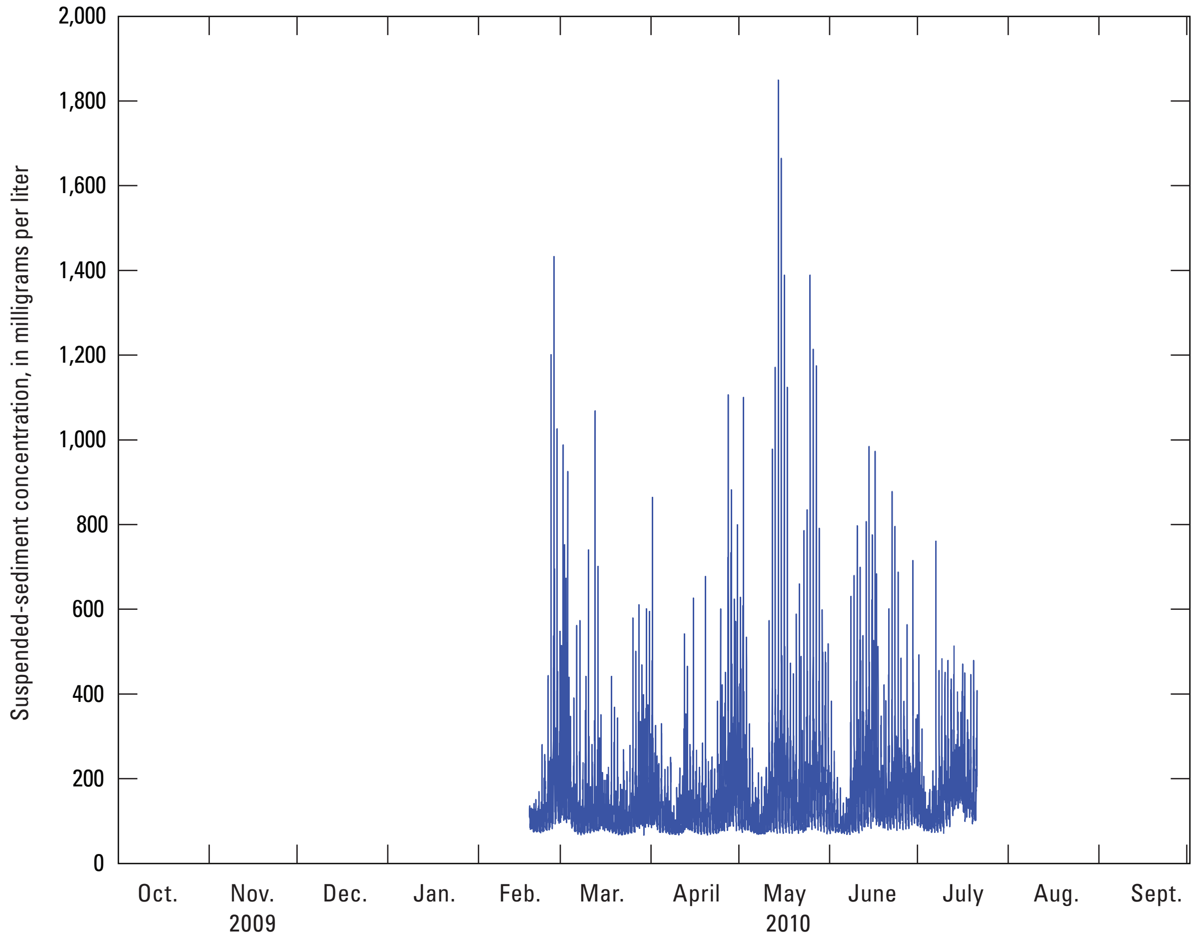

Figure 11. Time series of near-bottom suspended-sediment concentrations computed from sensor readings at Hamilton Disposal Site, San Pablo Bay, California, water year 2010.

Richmond/San Rafael Bridge

Interruptions in the record were caused by fouling or malfunction of the sensing or recording instruments, or both. The turbidity sensors wipers were ineffective during periods of heavy fouling because biological growth on the wiper obscured the optical ports. From January 29 to February 18, 2010, the mid-depth and near-bottom sensors were out of position as a result of severe wrapping of the deployment lines, and the data were deleted. The mid-depth turbidity sensor was replaced on April 7, 2010. Calibration checks indicated a 6.1 FNU shift to the record from April 7 to June 23, 2010, when the probe was recalibrated. The near-bottom sonde malfunctioned and was replaced April 29, 2010. The near-bottom temperature sensor malfunctioned, causing the turbidity data to become suspect (internal processors use temperature as a coefficient), and the data were deleted from May 6 to May 20, 2010. Calibration checks indicated a 3.0 FNU shift to the record from August 13, 2009, to April 29, 2010, when the sensor was replaced. Because the two turbidity sensors (both YSI, Inc.) deployed at the near-bottom position during WY 2010 responded similarly to the uniform sediment characteristics found in San Francisco Bay (Ganju and others, 2007), the calibration was developed by combining water samples collected during each sensor deployment (fig. 12*B*). The computed SSC time-series data for WY 2010 are presented in figure 13.

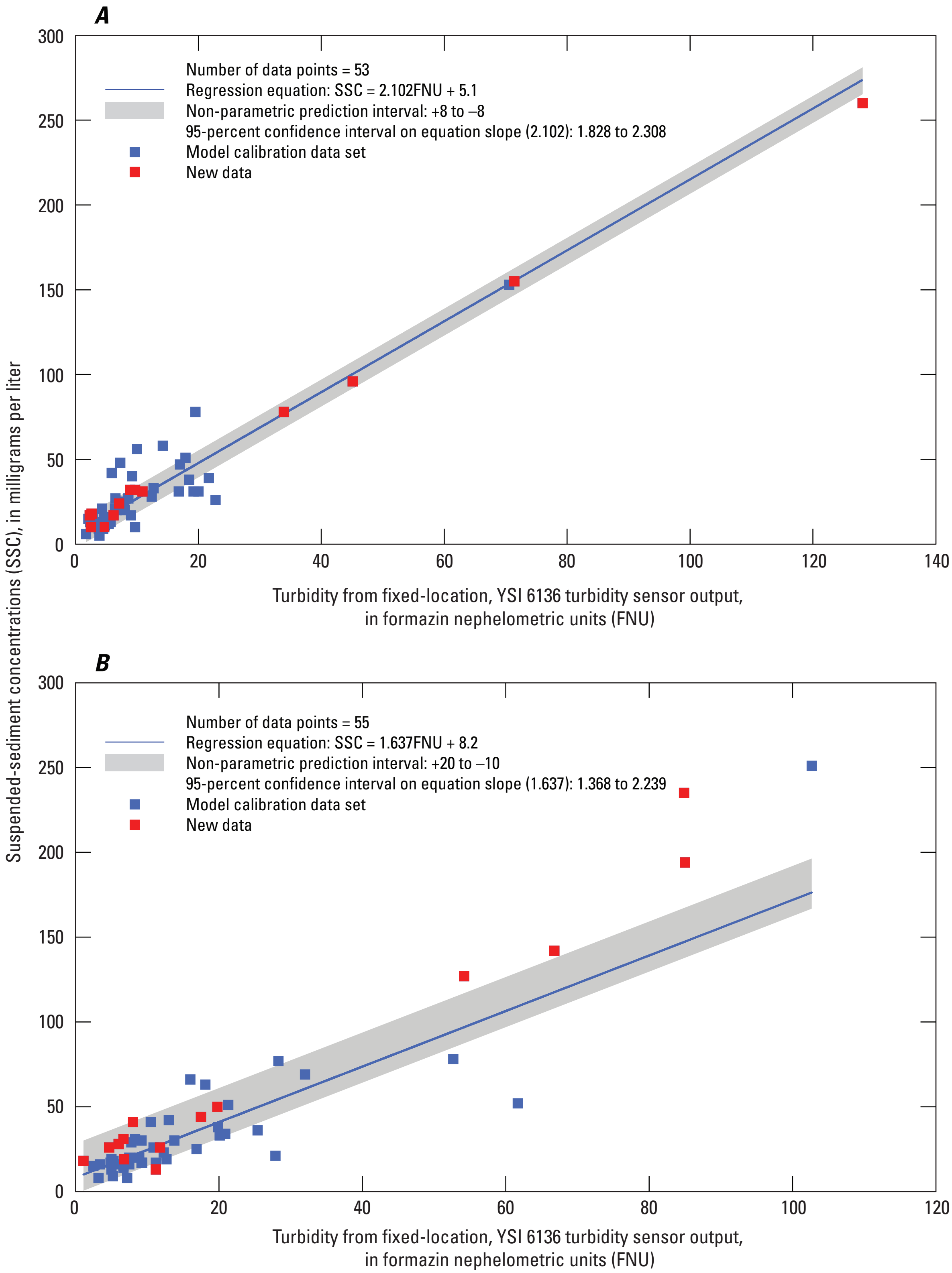

Figure 12. Calibration of turbidity sensors at Richmond/San Rafael Bridge, Central San Francisco Bay, California, water year 2010: *A*, mid-depth and *B*, near bottom.

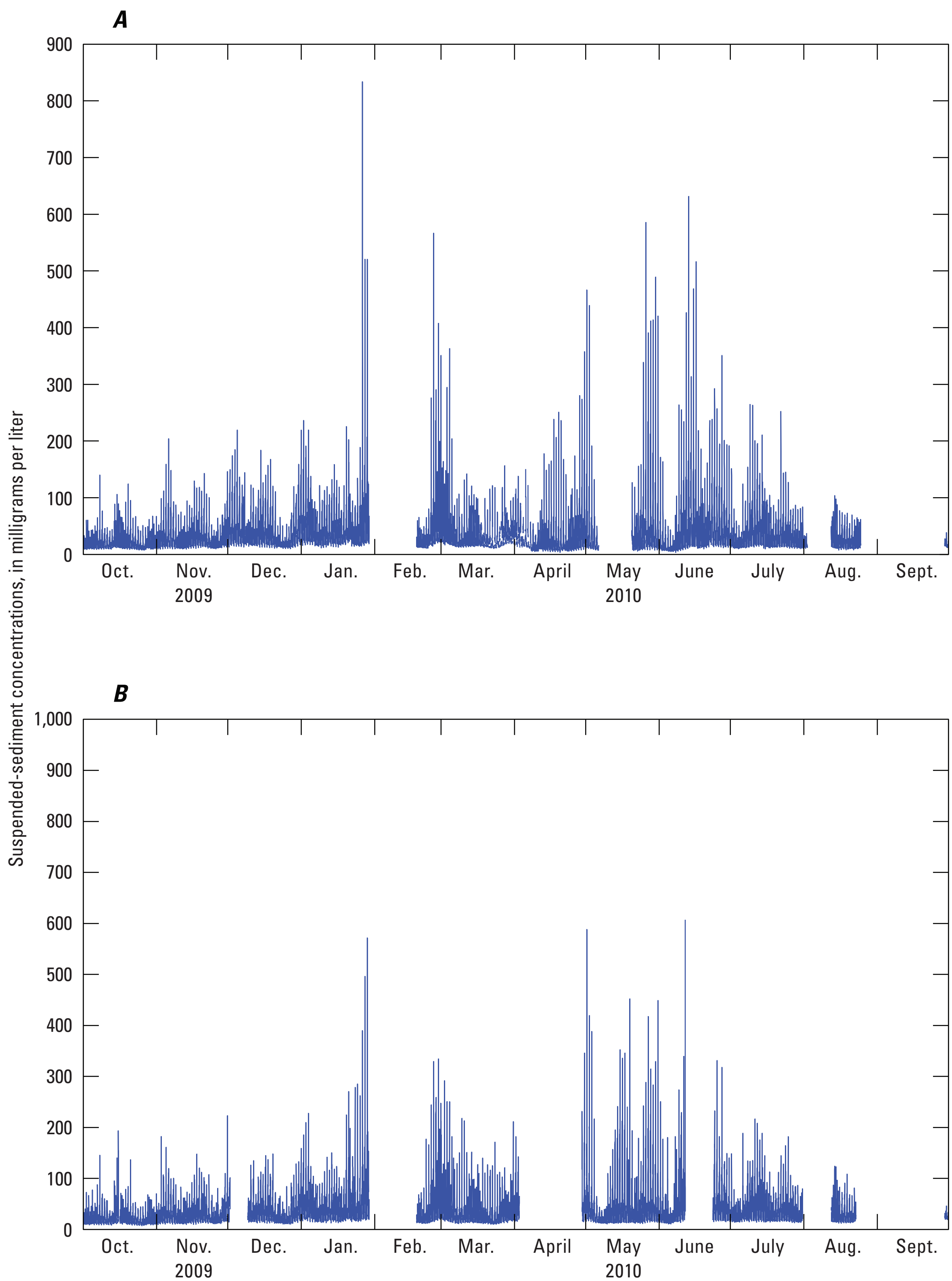

Figure 13. Time series of suspended-sediment concentrations computed from sensor readings at Richmond/San Rafael Bridge, Central San Francisco Bay, California, water year 2010: *A*, mid-depth and *B*, near bottom.

Corte Madera Creek

Interruptions in the record caused by fouling or malfunction of the sensing or recording instruments, or both. The turbidity sensor wiper was ineffective during periods of heavy fouling because biological growth on the wiper obscured the optical ports. The calibration of the turbidity sensor output to SSC and computed SSC time-series data for WY 2010 are presented in figures 14 and 15, respectively.

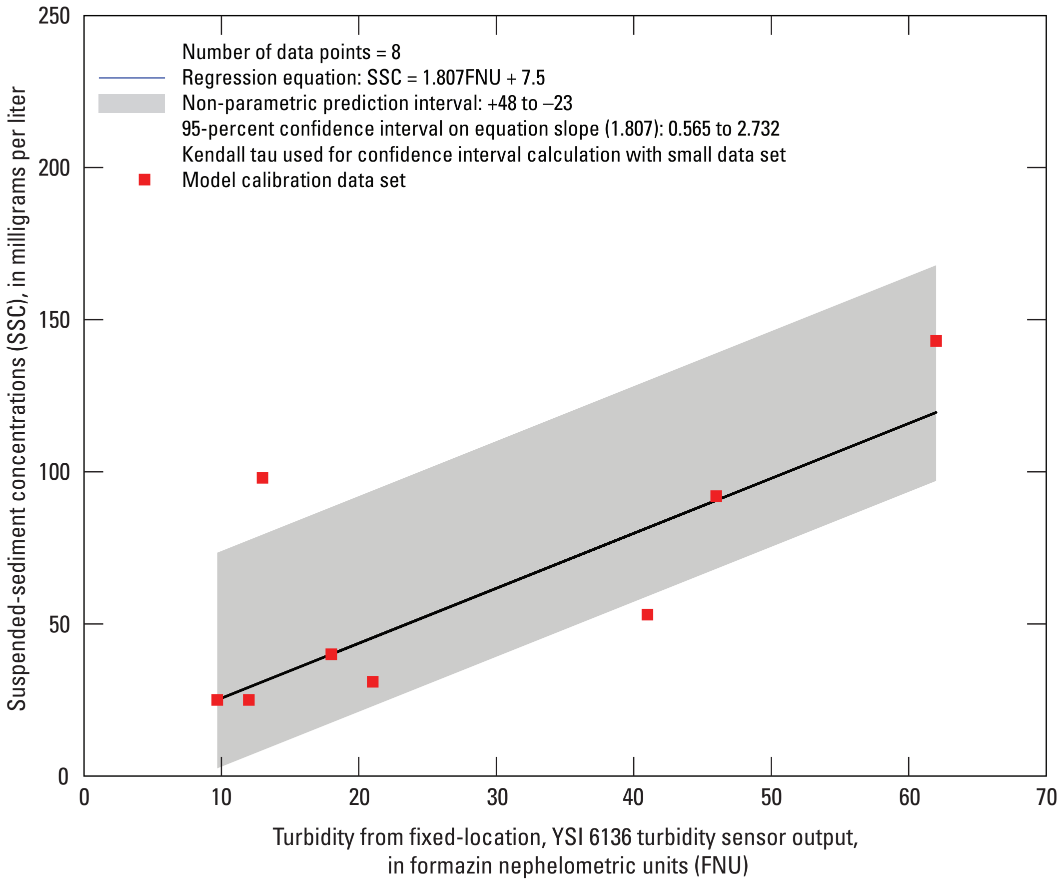

Figure 14. Calibration of mid-depth turbidity sensor at Corte Madera Creek, Central San Francisco Bay, California, water year 2010.

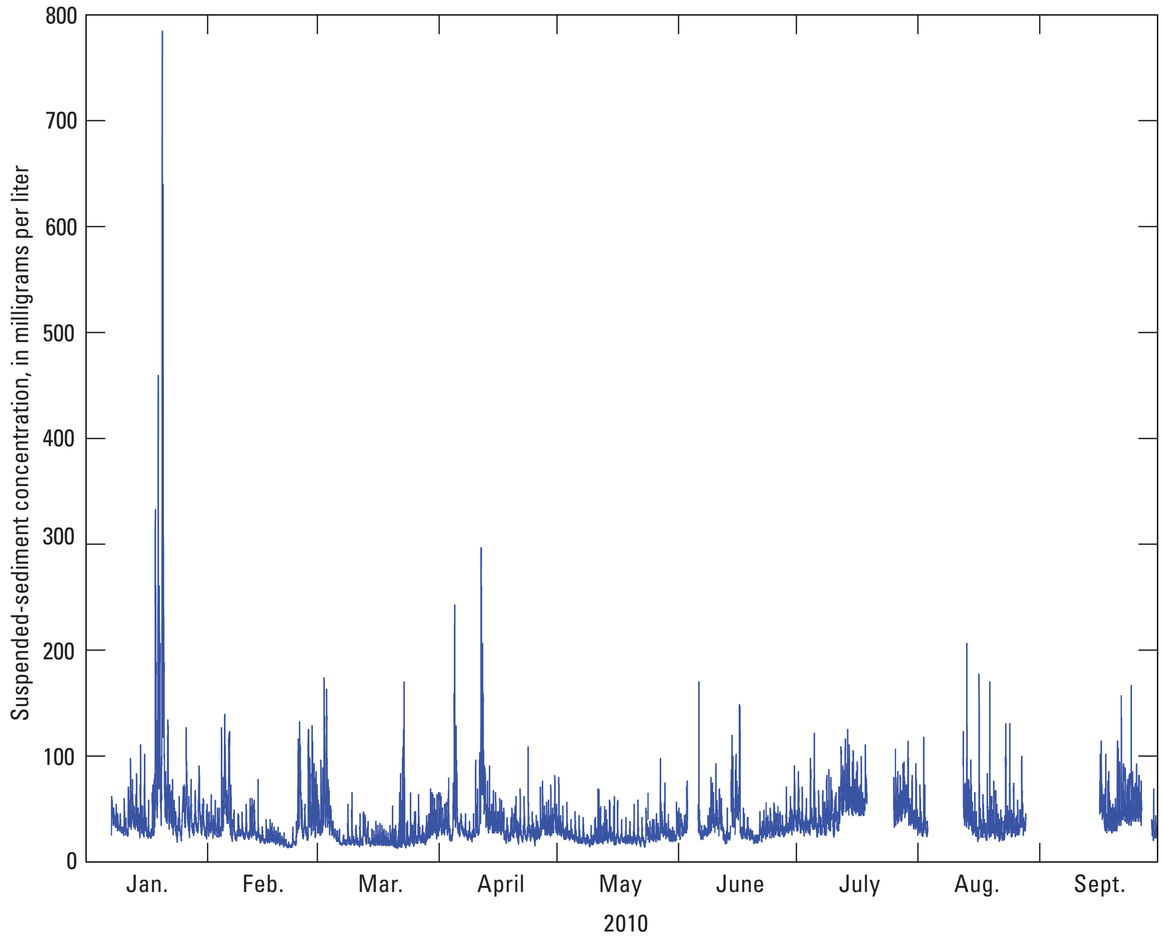

Figure 15. Time series of mid-depth suspended-sediment concentrations computed from sensor readings at Corte Madera, Central San Francisco Bay, California, water year 2010.

Alcatraz Island

Interruptions in the record caused by fouling or malfunction of the sensing or recording instruments, or both. The turbidity sensor wiper was ineffective during periods of heavy fouling because biological growth on the wiper obscured the optical ports. Calibration checks indicated a 2.4 FNU shift to the turbidity record, which was applied to WY 2010. The calibration of the turbidity sensor output to SSC and computed SSC time-series data for WY 2010 are presented in figures 16 and 17, respectively.

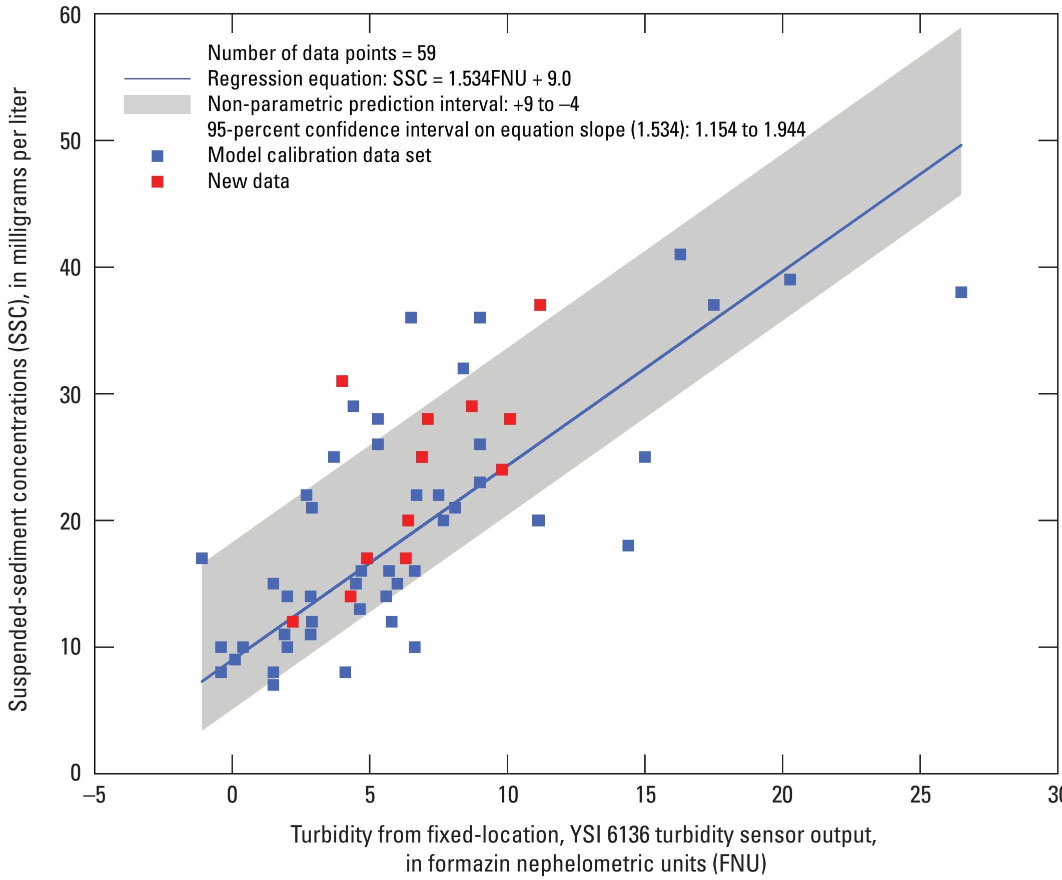

Figure 16. Calibration of mid-depth turbidity sensor at Alcatraz Island, Central San Francisco Bay, California, water year 2010.

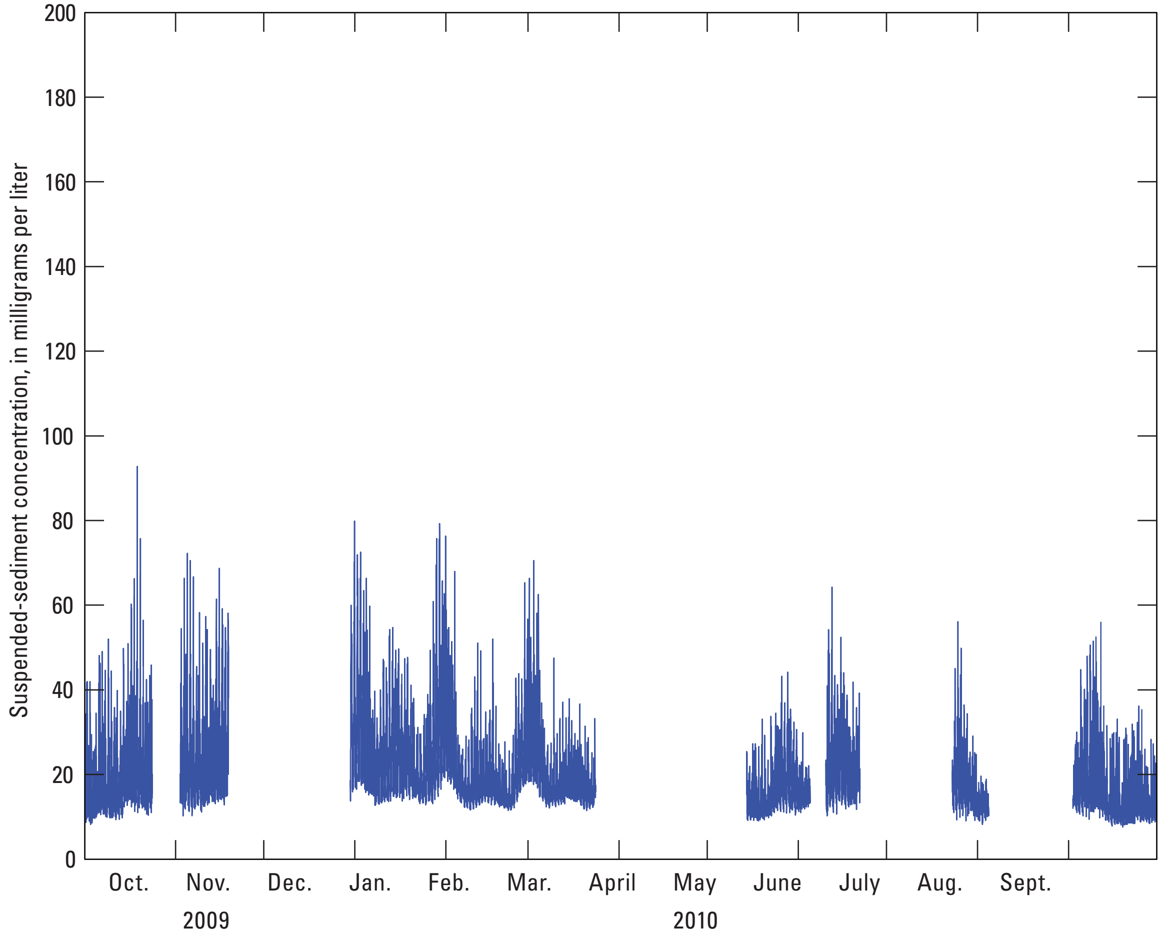

Figure 17. Time series of mid-depth suspended-sediment concentrations computed from sensor readings at Alcatraz Island, Central San Francisco Bay, California water year 2010.

Dumbarton Bridge

Interruptions in record were caused by fouling or malfunction of the sensing or recording instruments, or both. The near-bottom sensor output was shifted on the basis of checks performed against turbidity solutions. The calibration of the turbidity sensors output to SSC and computed SSC time-series data for WY 2010 are presented in figures 18 and 19, respectively.

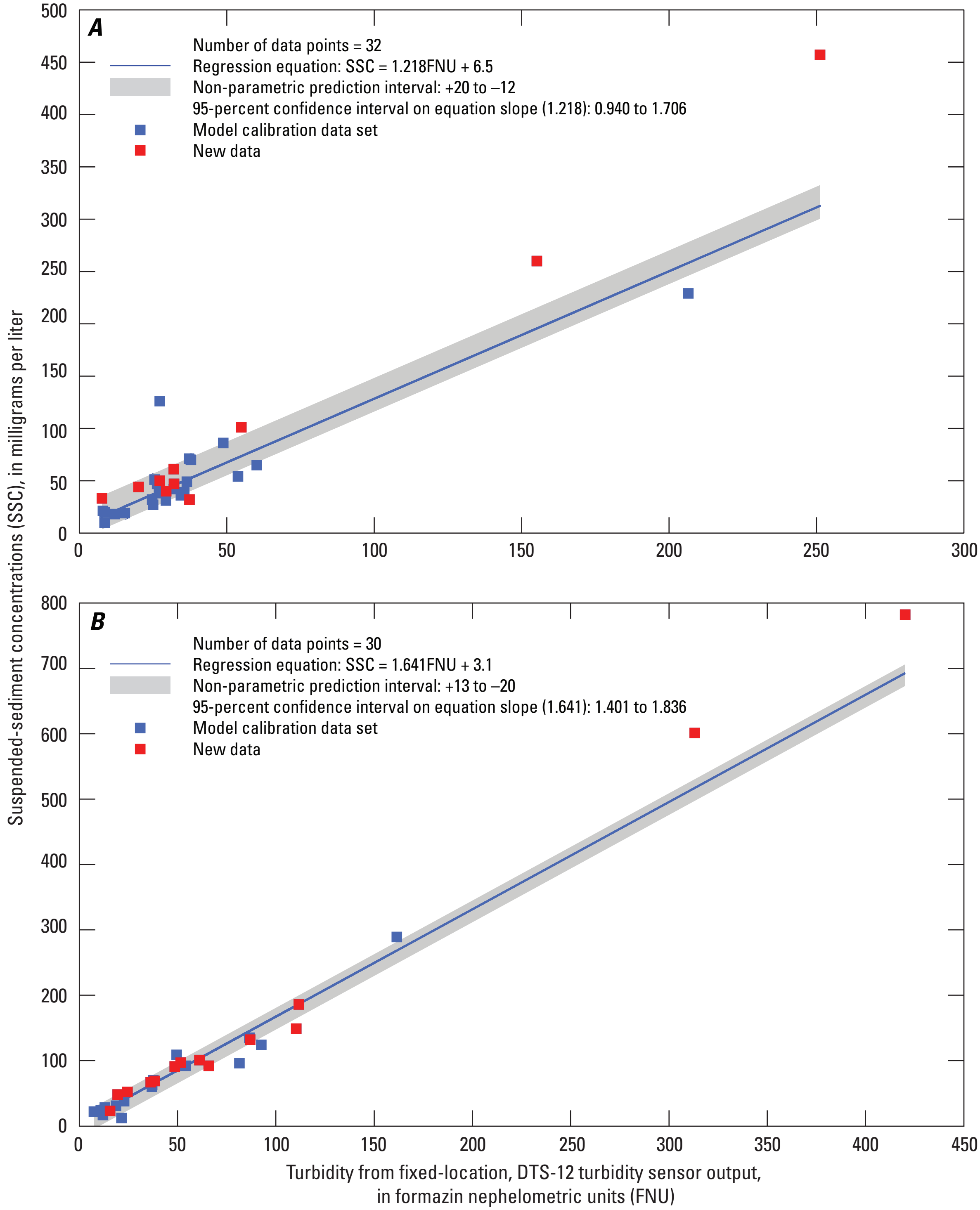

Figure 18. Calibration of turbidity sensors at Dumbarton Bridge, South San Francisco Bay, California, water year 2010: *A*, mid-depth and *B*, near bottom.

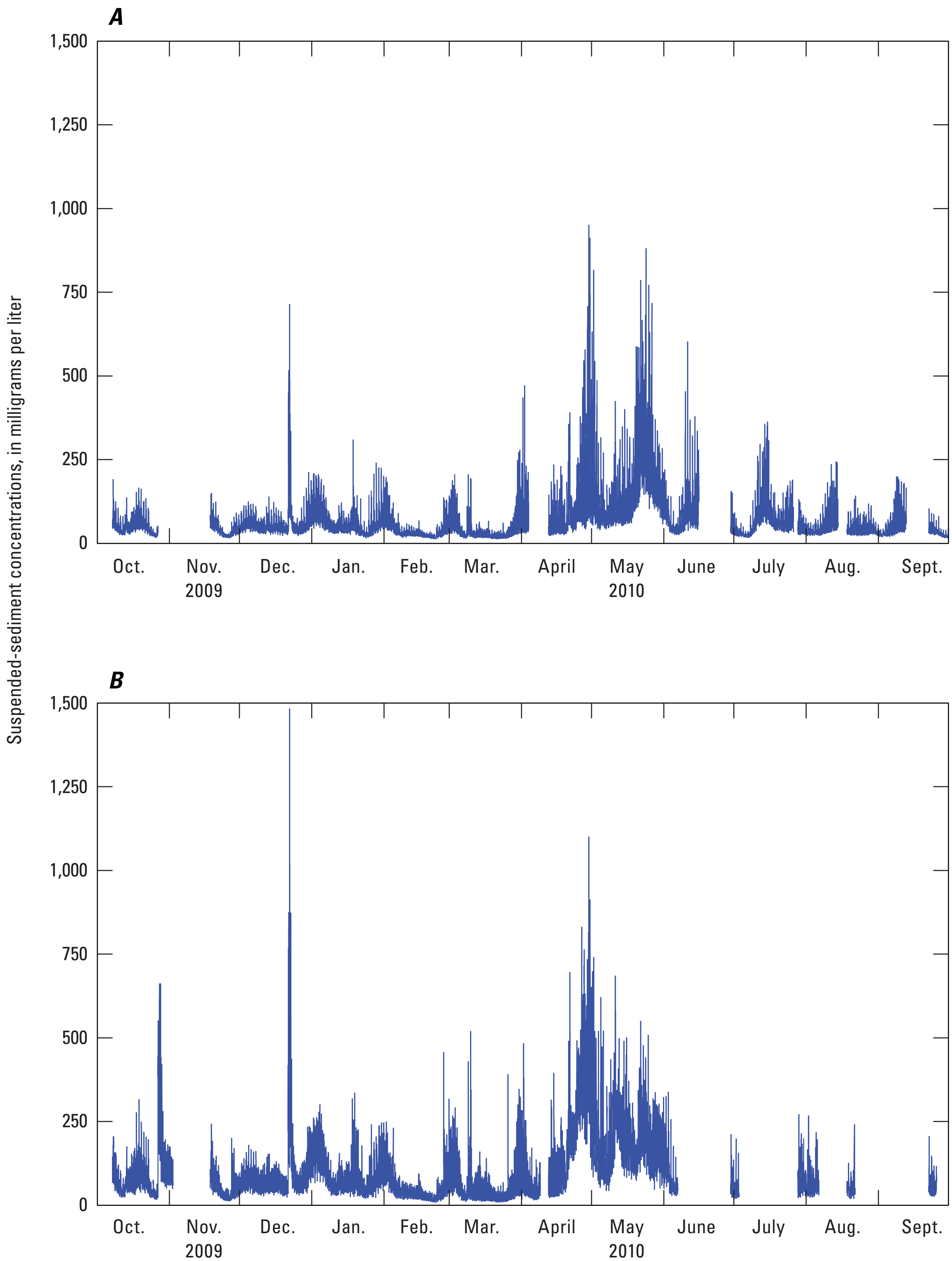

Figure 19. Time series of suspended-sediment concentrations computed from sensor readings at Dumbarton Bridge, South San Francisco Bay, California, water year 2010: *A*, mid-depth and *B*, near bottom.

Summary

Suspended-sediment concentration (SSC) data were collected by the U.S. Geological Survey (USGS) at two sites in Suisun Bay, three sites in Central San Francisco Bay, one site in San Pablo Bay and one site in South San Francisco Bay during water year 2010. Two types of turbidity sensors, each controlled by electronic data loggers, were used to monitor suspended sediment. Water samples were collected to calibrate the output of the turbidity sensors to SSC by using robust, nonparametric regression. Where nonparametric regression was not viable, parametric regression was used. 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 National Water Inventory System.

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Appendix 1. San Francisco Bay Model Calibration Data

Table 1-1. Model-calibration data set for mid-depth sensor, Richmond/San Rafael Bridge, Central San Francisco Bay, California, October 18, 2006–December 8, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location mid-depth, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration mid-depth, in milligrams per liter
10/18/2006	4.5	9
10/26/2006	2.8	11
12/06/2006	6.5	27
12/29/2006	22.8	26
02/15/2007	9.0	17
03/06/2007	14.2	58
03/26/2007	9.7	10
04/19/2007	70.6	153
05/11/2007	6.7	20
06/01/2007	19.2	31
07/18/2007	18.5	38
08/09/2007	8.0	20
08/30/2007	17.0	47
09/18/2007	3.9	5
10/11/2007	5.7	13
10/30/2007	5.4	16
11/15/2007	5.4	12
12/06/2007	7.4	24
01/07/2008	17.9	51
01/22/2008	21.7	39
02/14/2008	20.0	31
03/07/2008	8.6	27
04/11/2008	12.4	28
05/02/2008	5.9	42
05/23/2008	16.8	31
06/10/2008	3.8	9
07/01/2008	7.3	48
07/29/2008	4.1	13
08/28/2008	12.7	33
09/17/2008	7.2	25
10/15/2008	4.6	16
11/25/2008	3.1	11
12/23/2008	6.4	21
02/12/2009	19.5	78
03/17/2009	1.7	6
06/05/2009	10.0	56
07/28/2009	2.4	13
08/13/2009	2.1	15
09/01/2009	9.2	40
09/23/2009	4.3	21
10/16/2009	2.6	18
11/05/2009	8.9	32
12/09/2009	7.1	24
02/18/2010	9.7	32
04/29/2010 (1)	33.9	78
04/29/2010 (2)	128	260
04/29/2010 (3)	71.4	155
05/20/2010	2.3	17
06/23/2010	6.2	17
07/14/2010	45.1	96
09/29/2010	4.7	10
10/21/2010	2.5	10
12/08/2010	10.9	31

Table 1-2. Model-calibration data set for near-bottom sensor, Richmond/San Rafael Bridge, Central San Francisco Bay, California, October 18, 2006–December 8, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-bottom, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration near-bottom, in milligrams per liter
10/18/2006	5.0	13
10/26/2006 (1)	2.5	15
10/26/2006 (2)	4.9	17
12/06/2006	10.5	41
12/29/2006	52.7	78
02/15/2007	9.2	17
03/06/2007	16.0	66
03/26/2007	20.1	33
04/19/2007	103	251
05/11/2007	11.2	17
06/01/2007	61.7	52
07/18/2007	21.3	51
08/09/2007	12.7	19
08/30/2007	27.9	21
09/18/2007	3.2	8
10/30/2007	8.9	20
11/15/2007	7.5	16
12/06/2007	9.2	30
01/07/2008	28.3	77
01/22/2008	20.9	34
02/14/2008	16.9	25
03/07/2008	10.9	26
04/11/2008	19.9	38
05/02/2008	9.3	17
05/23/2008	25.4	36
06/10/2008	7.2	8
07/01/2008	12.3	23
07/29/2008	5.2	9
08/28/2008	13.8	30
09/17/2008	7.5	20
10/15/2008	5.3	18
11/25/2008	5.5	16
12/23/2008	6.7	15
02/12/2009	18.1	63
03/17/2009	6.7	14
04/09/2009	32.0	69
06/05/2009	13.0	42
07/28/2009	5.0	19
08/13/2009	3.4	16
09/01/2009	7.8	29
09/23/2009	8.3	31
10/16/2009	4.7	26
11/05/2009	6.7	31
12/09/2009	6.0	28
02/18/2010	8.0	41
04/29/2010 (1)	66.8	142
04/29/2010 (2)	85.0	194
04/29/2010 (3)	84.9	235
05/20/2010	11.8	26
06/23/2010	6.8	19
07/14/2010	54.2	127
08/12/2010	17.5	44
09/29/2010	11.2	13
10/21/2010	1.1	18
12/08/2010	19.8	50

Table 1-3. Model-calibration data set for near-surface sensor, Mallard Island, Suisun Bay, California, April 20, 2007–October 8, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-surface, in formazin nephelometric units (DTS-12 turbidity sensor)	Suspended-sediment concentration near-surface, in milligrams per liter
04/20/2007	59	43
06/05/2007	34.1	28
07/02/2007 (1)	26.1	28
07/02/2007 (2)	25.4	24
08/03/2007	15.5	16
09/20/2007	20.6	29
10/18/2007	9	9
11/29/2007	13.8	14
01/04/2008	26.2	31
02/15/2008	86	60
04/11/2008	32.9	38
05/29/2008	26.6	27
07/10/2008	24.7	23
08/06/2008	14.5	13
09/19/2008	17	12
10/30/2008	13.4	8
01/07/2009	17.6	20
06/18/2009	32	31
07/15/2009	18.6	14
11/20/2009	12.9	27
01/11/2010	17.2	21
03/10/2010	42.8	36
05/11/2010	22.9	22
06/09/2010	24.1	24
08/04/2010	24.4	24
09/13/2010	13.4	13
10/08/2010	15	16

Table 1-4. Model-calibration data set for near-bottom sensor, Mallard Island, Suisun Bay, California, December 10, 2003–October 8, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-bottom, in formazin nephelometric units (DTS-12 turbidity sensor)	Suspended-sediment concentration near-bottom, in milligrams per liter
12/10/2003	17.8	25
12/29/2003	42.1	36
02/04/2004	25.0	22
02/27/2004	94.4	74
02/27/2004	105	86
03/17/2004	40.5	25
03/17/2004	40.4	35
04/07/2004	52.2	55
05/10/2004	61.3	66
05/26/2004	58.5	60
05/26/2004	65.6	73
06/15/2004	44.6	55
06/15/2004	45.4	50
06/22/2004	24.1	28
07/28/2004	25.0	25
07/28/2004	34.7	28
08/30/2004	29.2	29
08/30/2004	24.4	21
09/24/2004	21.7	24
09/24/2004	26.5	26
10/14/2004	19.5	25
11/04/2004	14.2	17
12/13/2004	20.4	24
01/11/2005	19.3	46
01/27/2005	60.7	29
02/18/2005	41.1	25
02/18/2005	28.1	24
03/10/2005	25.0	22
03/10/2005	23.0	24
03/31/2005	39.0	32
04/21/2005	17.8	16
05/10/2005	16.0	20
06/10/2005	23.5	20
06/28/2005	43.3	27
07/20/2005	37.0	37
08/10/2005	26.1	29
09/13/2005	20.2	17
11/17/2005	37.2	38
01/04/2006	130	86
01/24/2006	37.8	25
01/24/2006	37.4	24
03/02/2006	24.2	23
05/03/2006	19.5	20
05/30/2006	19.5	22
07/13/2006	24.3	27
08/22/2006	36.7	41
09/28/2006	25.7	33
11/02/2006	15.2	20
11/21/2006	15.1	17
12/19/2006	14.4	13
02/02/2007	23.6	23
03/16/2007	24.5	23
06/05/2007	32.6	27
07/02/2007	28.0	23
08/03/2007	15.7	30
09/20/2007	10.5	28
10/18/2007	10.5	18
11/29/2007	18.4	21
01/04/2008	31.3	30
02/15/2008	92.5	61
04/11/2008	35.7	34
05/29/2008	33.4	42
07/10/2008	27.1	28
08/06/2008	14.6	17
09/19/2008	18.1	17
10/30/2008	14.0	14
01/07/2009	17.6	23
06/18/2009	29.6	35
07/15/2009	16.6	9
08/26/2009	22.2	26
10/27/2009	22.3	33
11/20/2009	27.7	36
01/11/2010	16.7	21
03/10/2010	40.3	32
05/11/2010	25.7	24
06/09/2010	22.5	26
09/13/2010	18.2	20
10/08/2010	10.8	17

Table 1-5. Model-calibration data set for near-surface sensor, Benicia Bridge, Suisun Bay, California, October 15, 2008–September 28, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-surface, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration near-surface, in milligrams per liter
10/15/2008	10.5	19
11/18/2008	10.8	11
12/23/2008	11.4	21
02/10/2009	12.9	33
03/16/2009	106	108
04/07/2009	43.3	69
05/06/2009	16.1	33
08/31/2009	9.8	22
09/22/2009	6.7	13
11/04/2009	13.1	27
12/08/2009	20.4	45
01/13/2010	10.1	27
02/22/2010	30.3	38
04/28/2010	61.2	70
04/28/2010	56.8	68
05/19/2010	39.0	58
06/22/2010	10.6	56
07/14/2010	25.6	44
08/13/2010	53.1	86
09/28/2010	2.0	11

Table 1-6. Model-calibration data set for near-bottom sensor, Benicia Bridge, Suisun Bay, California, October 10, 2007–September 28, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-bottom, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration near-bottom, in milligrams per liter
10/10/2007	36.7	38
10/29/2007	36.2	52
11/14/2007	7.5	33
01/23/2008	62.0	96
02/12/2008	159	176
03/06/2008	19.5	44
03/24/2008	123	159
04/11/2008	103	144
05/01/2008	99.7	135
05/22/2008	116	172
06/09/2008	60.0	98
06/30/2008	27.9	28
07/25/2008	9.2	13
09/16/2008	35.0	73
11/18/2008	27.7	42
12/23/2008	30.0	30
02/10/2009	20.9	47
03/16/2009	137	218
04/07/2009	96.9	165
05/06/2009	33.7	87
08/31/2009	13.1	21
09/22/2009	18.3	24
11/04/2009	22.1	35
12/08/2009	26.4	49
01/13/2010	28.3	59
04/28/2010	72.9	120
05/19/2010	74.3	97
06/22/2010	91.4	137
07/14/2010	76.7	137
08/13/2010	100	178
09/28/2010	7.4	18

Table 1-7. Model-calibration data set for near-bottom sensor, Hamilton Disposal Site, San Pablo Bay, California, October 16, 2008–February 18, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-bottom, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration near-surface, in milligrams per liter
10/16/2008	5.7	11
11/25/2008	8.1	23
02/12/2009	43.2	92
02/12/2009	29.9	79
04/09/2009	36.1	89
05/06/2009	53.4	96
06/05/2009	15.8	36
02/18/2010	33.2	55

Table 1-8. Model-calibration data set for mid-depth sensor, Corte Madera Creek, Central San Francisco Bay, California, January 7, 2010–December 18, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location mid-depth, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration mid-depth, in milligrams per liter
01/07/2010	21.0	31
02/04/2010	62.0	143
06/23/2010	18.0	40
08/12/2010	46.0	92
09/29/2010	13.0	98
11/18/2010	9.7	25
12/18/2010	12.0	25
12/18/2010	41.0	53

Table 1-9. Model-calibration data set for mid-depth sensor, Alcatraz Island, Central San Francisco Bay, California, March 23, 2006–September 2, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location mid-depth, in formazin nephelometric units (YSI 6136 turbidity sensor)	Suspended-sediment concentration mid-depth, in milligrams per liter
03/23/2006	2	10
03/23/2006	1.9	11
04/20/2006	14.4	18
04/20/2006	15	25
05/24/2006	1.5	8
07/25/2006	5.3	26
08/16/2006	-0.4	8
10/11/2006	-0.4	10
10/31/2006	-1.1	17
11/21/2006	2.7	22
12/21/2006	9	23
01/10/2007	5.6	14
02/07/2007	5.7	16
02/27/2007	8.1	21
03/22/2007	26.5	38
04/10/2007	5.8	12
05/01/2007	11.1	20
07/10/2007	2.9	21
07/10/2007	8.4	32
07/25/2007	2.9	12
08/15/2007	6	15
09/05/2007	0.1	9
10/02/2007	7.68	20
10/15/2007	4.64	13
11/08/2007	2.85	14
12/12/2007	6.63	16
01/09/2008	16.29	41
02/07/2008	20.28	39
02/28/2008	4.11	8
03/20/2008	11.15	20
04/01/2008	2.85	11
05/15/2008	6.63	10
05/29/2008	4.5	15
06/18/2008	6.7	22
07/30/2008	9	36
09/12/2008	5.3	28
10/10/2008	1.5	7
10/23/2008	0.4	10
12/16/2008	6.5	36
01/14/2009	9	26
03/27/2009	4.4	29
03/27/2009	3.7	25
04/29/2009	17.5	37
05/19/2009	4.7	16
07/02/2009	2	14
08/03/2009	7.5	22
09/09/2009	1.5	15
10/06/2009	4	31
11/02/2009	6.3	17
12/30/2009	8.7	29
02/10/2010	4.3	14
03/11/2010	4.9	17
03/11/2010	6.4	20
05/14/2010	9.8	24
05/14/2010	10.1	28
06/10/2010	11.2	37
06/10/2010	7.1	28
07/23/2010	6.9	25
09/02/2010	2.2	12

Table 1-10. Model-calibration data set for mid-depth sensor, Dumbarton Bridge, South San Francisco Bay, California, July 26, 2007–July 28, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location mid-depth, in formazin nephelometric units (DTS-12 turbidity sensor)	Suspended-sediment concentration mid-depth, in milligrams per liter
07/26/2007	35.6	39
07/27/2007	34.5	36
09/25/2007	25	27
11/01/2007	24.7	32
12/13/2007	60.2	65
02/08/2008	53.8	54
02/29/2008	15.5	19
03/21/2008	207	229
04/02/2008	27.1	38
04/25/2008	29.4	31
06/19/2008	8.6	10
07/31/2008	36.5	49
10/02/2008	8.6	20
12/09/2008	12	18
01/15/2009	37.8	70
03/24/2009	32.1	42
04/21/2009	26.4	47
07/29/2009	8.1	21
09/10/2009	25.5	51
10/07/2009	48.8	86
10/21/2009	27.3	126
11/18/2009	37.2	71
12/02/2009	27.3	50
12/22/2009	251	457
12/22/2009	155	260
01/26/2010	55	101
03/03/2010	32.1	61
03/17/2010	7.7	33
05/03/2010	29.5	40
06/03/2010	32.1	47
06/29/2010	20.1	44
07/28/2010	37.4	32

Table 1-11. Model-calibration data set for near-bottom sensor, Dumbarton Bridge, South San Francisco Bay, California, November 1, 2007–July 28, 2010.

[**Abbreviation**: mm/dd/yyyy, month/day/year]

Date (mm/dd/yyyy)	Turbidity from fixed-location near-bottom, in formazin nephelometric units (DTS-12 turbidity sensor)	Suspended-sediment concentration near-bottom, in milligrams per liter
11/01/2007	18.7	31
12/13/2007	37.6	70
02/08/2008	49.5	109
02/09/2008	10.9	24
03/21/2008	162	289
04/02/2008	22.8	38
04/25/2008	86.6	135
06/19/2008	12.1	17
07/31/2008	37.1	63
10/02/2008	21.5	12
12/10/2008	13.0	28
01/15/2009	54.0	92
03/24/2009	81.4	96
04/21/2009	92.6	124
07/30/2009	7.4	22
09/10/2009	37.0	60
10/07/2009	86.9	132
10/21/2009	36.3	67
11/18/2009	61.1	101
12/02/2009	38.4	69
12/03/2009	65.9	92
12/22/2009	420	782
12/22/2009	313	601
01/26/2010	51.6	97
03/03/2010	112	186
03/17/2010	15.6	23
05/03/2010	110	149
06/03/2010	19.6	48
06/29/2010	24.4	52
07/28/2010	48.6	91

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