TEN YEARS OF CONTINUOUS SUSPENDED-SEDIMENT CONCENTRATION MONITORING IN SAN FRANCISCO BAY AND DELTA

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ABSTRACT

Oceanographers began to commonly use optical sensors for measuring turbidity or suspended-sediment concentration (SSC) in the 1980s on the continental shelf, in nearshore waters, and in estuaries (Sternberg 1989). In December 1991, the U.S. Geological Survey (USGS) installed the first optical sensor for continuous monitoring of SSC in San Francisco Bay. Suspended sediment is an important component of San Francisco Bay and the tributary Sacramento-San Joaquin River Delta because it transports adsorbed toxic substances, provides habitat for benthic organisms, limits light availability and photosynthesis, contributes to wetland restoration, and deposits in ports and waterways that require dredging. In December 2001, SSC was monitored at 13 stations in the Bay and Delta. As of 2002, 159 sensor years of data have been collected, and the network is believed to provide the longest, continuous SSC time series collected in an estuary. Despite data losses due to biological fouling, the network provides a wealth of data that are used to monitor SSC and to determine the processes that affect SSC at tidal to annual time scales. A complete listing of publications describing the data-collection methods and data analyses is available at http://ca.water.usgs.gov/abstract/sfbay/sfbaycontbib.html.

Sampling Design: The SSC monitoring network is designed to capture the spatial and temporal variability of SSC (Buchanan and Ruhl 2001). Stations were established in each major subembayment of San Francisco Bay and in the primary Delta channels. Bay stations originally were established in a deep channel (depth about 25 - 50 feet), often at salinity monitoring stations. Near-bottom and mid-depth optical sensors were deployed in the deep channel. In 1998 a shallow water station (mean lower low water depth about 6 feet) in San Pablo Bay was added to the network. Semidiurnal tides and lower-frequency tidal constituents drive temporal variability of SSC, so measurements are recorded every 15 minutes. In addition to the continuous monitoring network, we have deployed optical sensors at as many as 14 sites for periods of several months as part of focused studies of sediment transport in shallow subembayments and Bay locales of special interest.

Installation, fouling, and maintenance: Optical sensors are positioned in the water column using polyvinyl chloride (PVC) pipe carriages coated with an antifoulant paint to impede biological growth (Buchanan and Ruhl 2001). Carriages were designed to align with the direction of flow and to ride along a stainless steel or Kevlar-reinforced nylon suspension line attached to an anchor weight, which allows sensors to be raised and lowered easily for servicing (fig. 2, Buchanan and Ruhl 2001). The plane of the optical window maintains a position parallel to the direction of flow as the carriage and sensor align itself with the changing direction of flow. An electronic data logger controls data acquisition.

The greatest problem in using optical sensors in San Francisco Bay and Delta is biological fouling that invalidates about one-half of the data. Fouling begins 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 is greatest during spring and summer and at stations in saltier water. Optical sensors require frequent cleaning but, due to the difficulty in servicing some of the monitoring stations, they are cleaned every 1-5 (usually 3) weeks. Self-cleaning sensors have proven to reduce data loss only in relatively fresh water because they are ineffective when fouling is excessive and they are prone to leak and malfunction in saltier water.

On-site checks of sensor accuracy are done using 50 to 200-nephelometric turbidity unit (NTU) solutions prepared from a 4,000-NTU formazin standard. Solutions are prepared by diluting the 4,000-NTU stock standard with high-purity water in a clean, sealable bucket. At the field site, the cleaned sensors are immersed in the solution and the sensor output is recorded on the station log to help identify output drift and sensor malfunction.

Calibration: Calibration is needed to determine the relation between sensor output and SSC. This relation varies according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated for each site using suspended material from the field (Levesque and Schoellhamer 1995). Water samples are collected before and after sensor cleaning during site visits (Buchanan and Ruhl 2001). The water samples are analyzed to determine SSC, which ranges from nearly zero to more than 1,000 mg/L.

At Bay and Delta sites, suspended particles primarily are fine sediments and particle size variability does not affect calibration of the sensors (Schoellhamer 2001) and sensor output is proportional to SSC (Buchanan and Ruhl 2001). (Schoellhamer 2001, presents a contrasting example of particle size variability affecting sensor calibration in the Colorado River). The output from the optical sensors is converted to SSC using the robust, nonparametric, repeated median method (Siegel 1982, Buchanan and Ruhl 2001). We no longer use ordinary least-squared regression because the calibration data usually are not homoscedastic (Helsel and Hirsch 1992). Bay sensors are calibrated to point SSC measurements and Delta sensors are calibrated to discharge-weighted cross-sectionally averaged SSC, which can be multiplied by water discharge to determine suspended-sediment discharge (Schoellhamer 2001). Data from several years are used to develop the calibrations if the same sensor has been operating at a site and there is no evidence of sensor output drift. At some of the landward sites, the calibration line shifts slightly during periods of relatively large freshwater inflow.

We prefer to use a relatively unprocessed signal to determine SSC rather than a calculated value, such as turbidity in NTU. The benefit of this approach is illustrated by the following. A commercially available multiprobe, which was used at some stations, included a software error in the interpolation table that converted the raw signal to NTUs (the unit's standard output). Scatter plots of the turbidity data from all identical probes indicated that there were minimal data between 50 to 70-NTUs due to an incorrect value in the table for the 60-NTU conversion, resulting in too few values in the 50 to 70-NTU range and too many values in the 0 to 50-NTU range. The manufacturer corrected the error and subsequent data do not display this characteristic.

Data processing: The raw time series data are archived and edited to remove invalid data. Recorded data are downloaded from the data logger onto a data storage module or laptop computer during site visits. Raw data are loaded into the USGS automated data-processing system (ADAPS).

The time series are retrieved from ADAPS and edited. As biological growth accumulates on the optical sensors, the output of the sensors increases or decreases, depending on the type of sensor. Invalid data collected prior to cleaning cannot be corrected because fouling masks the desired signal. Such data are removed from the record (fig. 3, Buchanan and Ruhl 2001). A correction is applied to the data, however, on the rare occasions when incomplete cleaning of a sensor causes a small, constant shift in sensor output that can be corrected using water-sample data. Spikes in the data, which are anomalous outputs probably caused by debris temporarily wrapped around the sensor or by large marine organisms (fish, crabs) on or near the sensor, also are removed from the raw data record. Processed SSC data are stored in ADAPS, published (Buchanan and Ruhl 2001), and are available on the Internet at http://sfports.wr.usgs.gov/Fixed_sta/ .

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