

Continuous monitoring of suspended sediment in rivers by use of optical backscatterance sensors

DAVID H. SCHOELLHAMER AND SCOTT A. WRIGHT

*U.S. Geological Survey, Placer Hall, 6000 J Street, Sacramento, California 95819 USA
dschoell@usgs.gov*

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). Optical sensors transmit a pulse of light and measure the intensity of light transmitted, scattered 90°, or backscattered 180°, depending on sensor design. The sensor processes the signal so that its output is in units of turbidity or is proportional to SSC if the particle size and optical properties of the sediment remain fairly constant. Calibration of the sensor output voltage to SSC will vary according to the size and optical properties of the suspended sediment; therefore, the sensors must be calibrated in the field or a laboratory using suspended material from the field. If the optical window is fouled by biological growth or debris, the sensor output is invalid.

Use of optical sensors in rivers for continuous monitoring of suspended sediment is becoming more common in the United States and a workshop on the topic was held in spring 2002 (Glysson & Gray 2002). The primary reasons for increased continuous monitoring are regulatory requirements of the U.S. Clean Water Act and improved technology for real-time monitoring for environmental, drinking water, and public health needs.

The purpose of this abstract is to demonstrate that optical backscatterance sensors (OBS, Downing *et al.* 1981) successfully can monitor suspended sediment in rivers if the effects of particle size do not preclude sensor calibration. The issue of the effects of particle size on OBS is addressed first, followed by an example calculation of suspended-sediment discharge with an OBS. This abstract updates a previous paper on this subject (Schoellhamer 2001).

PARTICLE-SIZE EFFECTS

The relationship between SSC and sensor output is dependent on particle size, which can confound calibration of a sensor. In estuaries like San Francisco Bay, particle size is fairly constant and sensor calibrations are remarkably invariant with time (Buchanan & Ruhl 2001). In channels with a variable suspended particle size, however, sensor output depends on particle size and SSC. Finer sediment has more reflective surfaces per unit mass, so, for constant SSC, sensor output increases as the suspended sediment becomes finer. Particle-size effects on OBS were minor in the Sacramento River at Freeport, California, but were more pronounced in the Colorado River at Cisco, Utah.

Freeport

Flow at Freeport is unidirectional but is affected by tidal backwater during low discharge. An OBS was installed to measure the effect of tidal fluctuations and flood pulses on suspended-sediment discharge and, therefore, sensor output was calibrated to discharge-weighted, cross sectionally averaged SSC. Point OBS measurements have been collected continuously near the right bank of the river every 15 minutes at 3 feet above the bed beginning in July 1998. The sensor was cleaned every 1-8 weeks. The linear equation for SSC, as a function of sensor output (fig. 1), was determined using the robust, nonparametric, repeated median method (Buchanan &

Ruhl 2001). Scatter of the calibration data is caused by comparing a point OBS measurement with a cross sectionally averaged SSC, particle-size effects, and any other source of error including possible effects of water and sediment color, bubbles, plankton, and organic sediment.

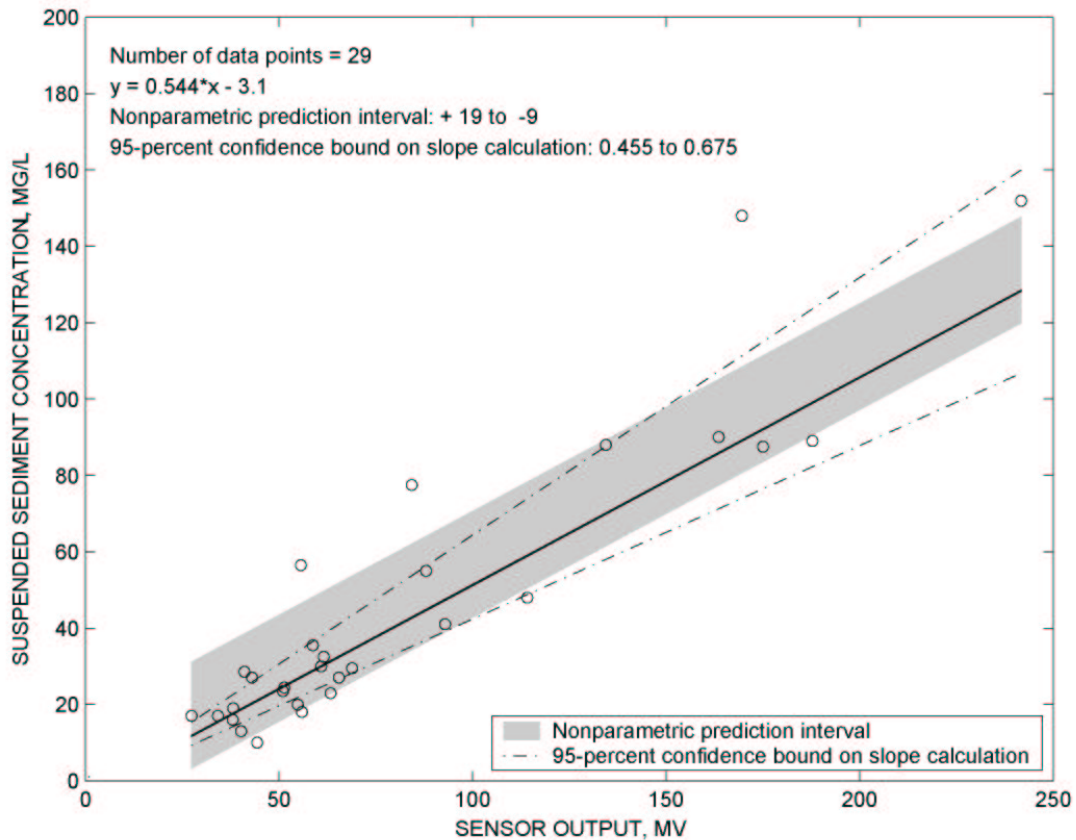


Figure 1. Calibration of an OBS at Freeport, Sacramento River, California, water years 2000 and 2001. Mg/L, milligrams per liter; mV, millivolts.

Particle-size variations had only a small effect on the calibration of the OBS at Freeport. The output of an OBS is virtually zero when SSC is zero, so the ratio of concentration to voltage (C/V) for any data point is approximately equal to the slope of a calibration line through that point. At Freeport, the fraction of fine sediment ranged from 49 to 98 percent and C/V decreased slightly as the fraction of fine sediment increased, but with considerable scatter (fig. 2).

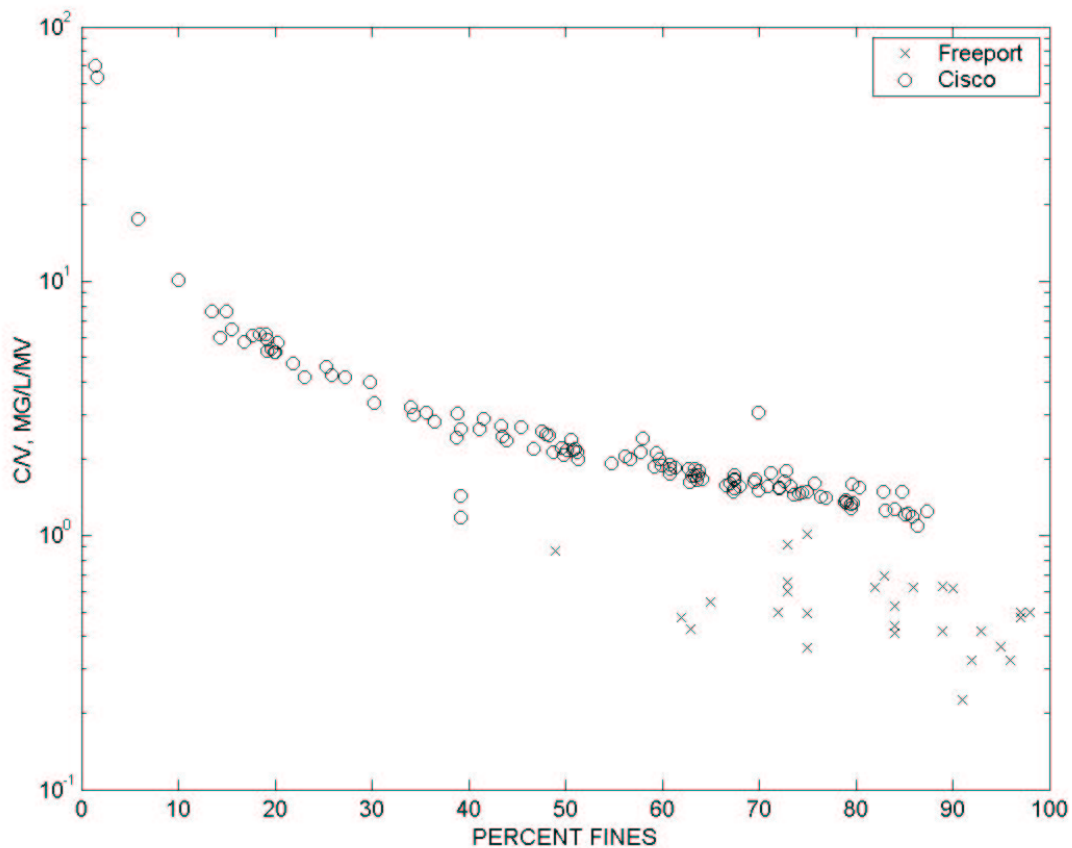


Figure 2. Ratio of suspended-sediment concentration to voltage (C/V) as a function of the fraction of fine sediment, at Freeport, California, on the Sacramento River and Cisco, Utah, on the Colorado River. C/V for any data point is approximately equal to the slope of a calibration line through that point. A different OBS was used at each site and each OBS has slightly different optical characteristics, so the difference in the trend of C/V should be compared between the two sites, not the absolute value of C/V . $Mg/L/mV$, milligrams per liter per millivolt.

Cisco

Vertical profiles of OBS measurements and suspended sediment were collected from the Colorado River near Cisco, Utah, from May 10-12, 1995. While measuring vertical profiles at 3 stations, 118 pairs of point OBS measurements and suspended-sediment samples were collected from near the bed to near the water surface with an OBS attached to the side of a US P61 suspended-sediment sampler (Edwards & Glysson 1999) close behind the nozzle. Near the bed almost all of the suspended sediment was sand, and very little suspended sand was near the surface. SSC ranged from 480 to 40,000 mg/L .

Particle-size variation precluded successful calibration of the OBS at Cisco. As the fraction of fine sediment increased from 1 to 87 percent, C/V decreased exponentially by almost two orders of magnitude (fig. 2). The Cisco data have less scatter than the Freeport data because the Cisco OBS was very close to the nozzle of the point sampler, whereas the Freeport OBS was near the right bank and the samples were collected over the entire cross section.

CALCULATION OF SUSPENDED-SEDIMENT DISCHARGE

The calibrated OBS on the Sacramento River at Freeport has been used successfully to measure suspended-sediment discharge. Output from the sensor was converted to a time series of discharge-weighted, cross sectionally averaged SSC and the calibration line is shown in figure 1. This concentration is multiplied by the water discharge measured hourly by a calibrated ultrasonic velocity meter (Anderson *et al.* 2001) to calculate the suspended-sediment discharge.

The hourly suspended-sediment discharge from the OBS compares well with daily suspended-sediment discharge from a sediment station operated by the U.S. Geological Survey at Freeport (fig. 3, Anderson *et al.* 2001). Thus, the output of the OBS can be used as an index value that is calibrated to cross sectionally averaged SSC and multiplied by discharge to determine the suspended-sediment discharge.

The primary advantage of optical sensors is better temporal resolution, compared to a typical daily sediment station. The primary disadvantage of optical sensors is fouling, as only 52 percent of the Freeport OBS data were valid due to fouling. More frequent cleaning and self-cleaning sensors can reduce the effect of fouling. Despite fouling, the OBS made 50 times more successful measurements than the daily station, providing the ability to monitor sediment pulses on the order of hours rather than days.

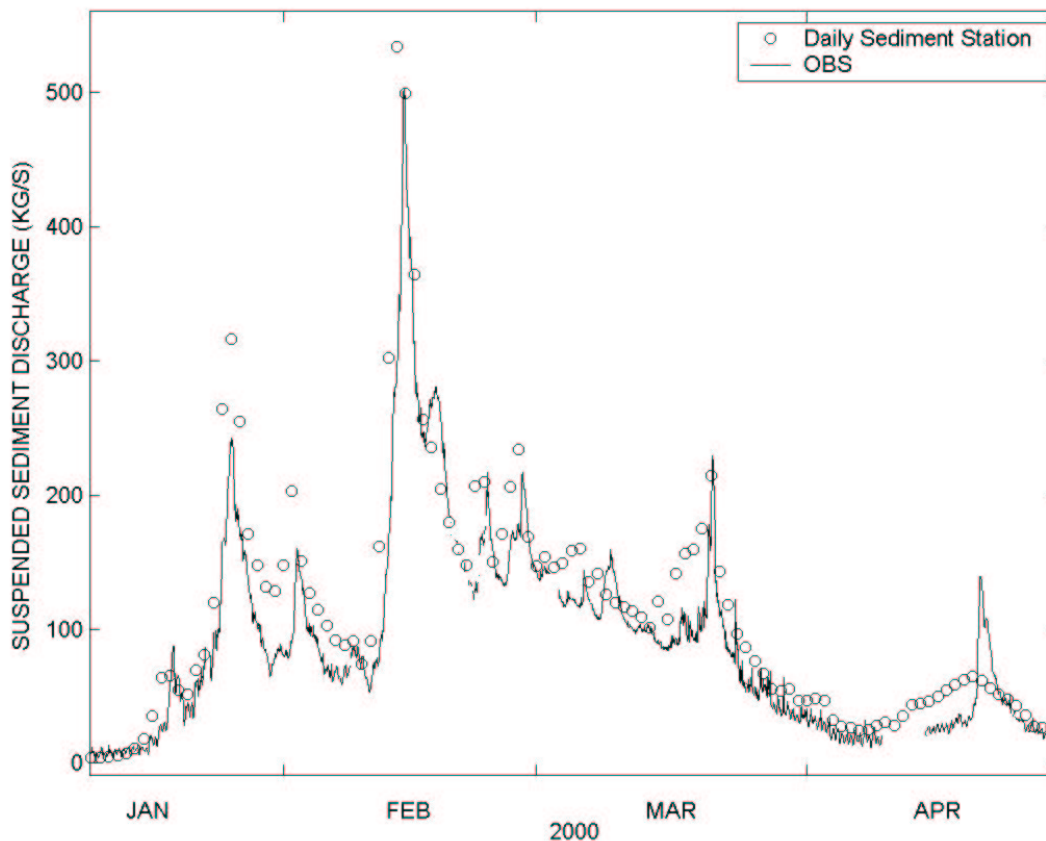


Figure 3. Suspended-sediment discharge at Freeport, Sacramento River, California, January - April 2000. Sediment station data are daily (Anderson *et al.* 2001) and optical backscatterance sensor (OBS) data are hourly. Kg/S, kilograms per second.

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