U.S. Geological Survey Research on Surrogate Measurements for Suspended Sediment

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Abstract

The U.S. Geological Survey is evaluating potentially useful surrogate instruments and methods for inferring the physical characteristics of suspended sediments. Instruments operating on bulk acoustic, bulk and digital optic, laser, and pressure-differential technologies are being tested in riverine and laboratory settings for their usefulness to Federal agencies toward providing quantifiably reliable information on bed-material and bed-topography characteristics, and on concentrations, size distributions and transport rates of sediments in suspension and as bedload. The efficacy of four suspended-sediment surrogate technologies has been demonstrated to varying degrees of success in Kansas, Florida, Arizona, and Puerto Rico.

Keywords: fluvial sediment, turbidity, suspended sediment, monitoring, sediment surrogate

Introduction

A two-thirds decline in the amount of daily sediment data collected by the U.S. Geological Survey (USGS) since 1980 has occurred concomitant with a substantial increase in sediment-data needs and availability of potentially useful but largely untested sediment-surrogate monitoring technologies. Additionally, the Nation lacks nationally accepted standards for the collection or use of data derived from data-collection technologies other than those described by Edwards and Glysson (1999). These factors were instrumental in development of a recommendation by the Federal Interagency Workshop on Turbidity and Other Sediment Surrogates, April 30-May 2, 2002 (Gray and Glysson 2003) to form a Sediment Monitoring Instrument and Analysis Research Program.

The USGS continues to evaluate instruments and methods that show promise for providing reliable data on selected fluvial-sedimentary characteristics in riverine and laboratory settings, on bed-material and bed-topography characteristics, and on concentrations, size distributions and transport rates of sediments in suspension and as bedload (Gray 2002). This paper provides some examples of USGS research using bulk optical (turbidity), acoustic, laser, and pressure-differential technologies to infer selected characteristics of suspended sediments (Gray et al. 2002, Gray et al. 2003).

Turbidity Data as Suspended-Sediment Surrogates in Kansas

Sensors that measure the bulk optical properties of water, including turbidity and optical backscatter, have been used to provide automated, continuous time series of suspended-sediment concentrations (SSC) in marine and estuarine studies, and show promise for providing automated continuous time series of SSC and fluxes in rivers (Schoellhamer 2001). Continuous, in-situ measurements of turbidity to estimate SSC have been made at a stream monitoring site at the Kansas River at DeSoto, Kansas, since 1999.

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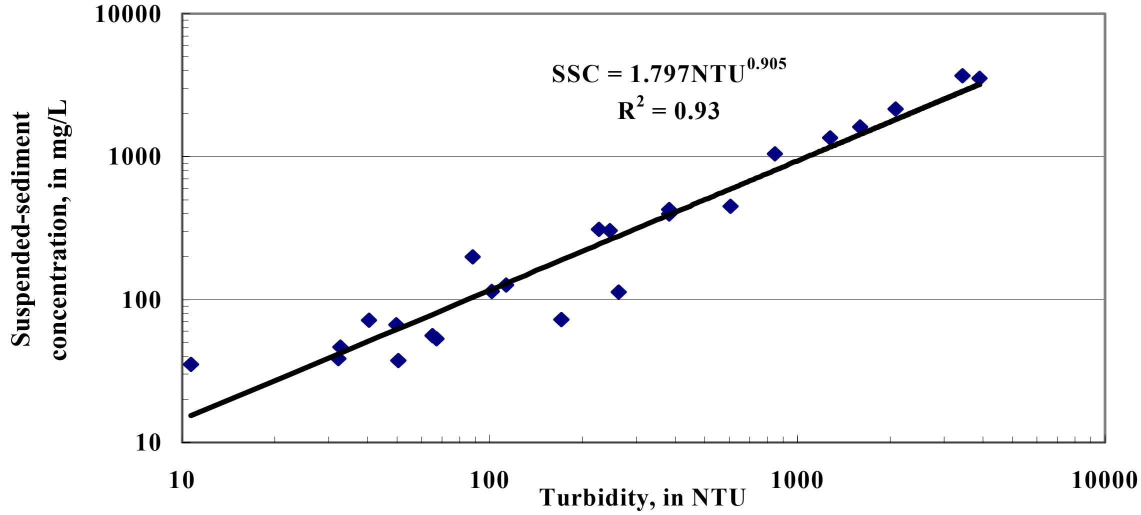

Figure 1. Comparison of field turbidity and suspended-sediment concentrations for the Kansas River at DeSoto, Kansas, 1999 through 2002.

Continuous turbidity measurements have been shown to provide reliable estimates of SSC with a quantifiable uncertainty. Simple linear regression analysis explained in Christensen and others (2000) was used to develop a site-specific model using turbidity to estimate SSC (Figure 1). The model explains about 93 percent of the variance in SSC. Continuous suspended-sediment discharge estimates from the model are available on-line (U.S. Geological Survey 2002). The advantages of continuous regression estimates using continuous turbidity measurements over discrete sample collection are that continuous estimates represent all flow conditions regardless of magnitude or duration, and sediment-discharge estimates are obtained essentially continuously at the interval in which water discharges are recorded.

Acoustic Data as Suspended-Sediment Surrogates in South Florida

Use of acoustic instruments worldwide for the measurement of stream velocities has increased substantially over the last two decades. These instruments are capable of providing information on acoustic return signal strength, which in turn has been shown in some settings to be useful as a surrogate parameter for estimating SSC and fluxes (Gartner and Cheng 2001). Two main types of acoustic instruments have been used extensively in the United States: the acoustic velocity meter (AVM), and the newer acoustic Doppler velocity meter (ADVM). The AVM system provides information on automatic gain control (AGC), an index of the acoustic signal strength recorded by the instrument as the acoustic pulse travels across a stream. The ADVM system provides information on acoustic backscatter strength (ABS), an index of the strength of return acoustic signals recorded by the instrument. Both AGC and ABS values increase with corresponding increases in the concentration of suspended material. SSC is then computed based on site-specific relations established between measured SSC values and information provided by the acoustic instrument.

Data from AVM and ADVM systems were collected in the L-4 Canal in Broward County, Florida, and the North Fork of the St. Lucie River at Stuart, Florida (Byrne and Patiño 2001). In addition to the acoustic instruments, water-quality sensors were installed at both sites to record specific conductance (or salinity) and temperature data. These data were used to monitor the potential effects that density changes could have on the AGC/ABS to SSC relations.

Results shown in Figure 2 suggest that this technique is feasible for estimating SSC in south Florida streams and other streams with similar flow and sediment-transport characteristics. Additional research is progressing on the effects of changes in the physical composition of suspended sediments, including the percent organic material, and the effect that a varying particle-size distribution may have on the established acoustic-SSC relations.

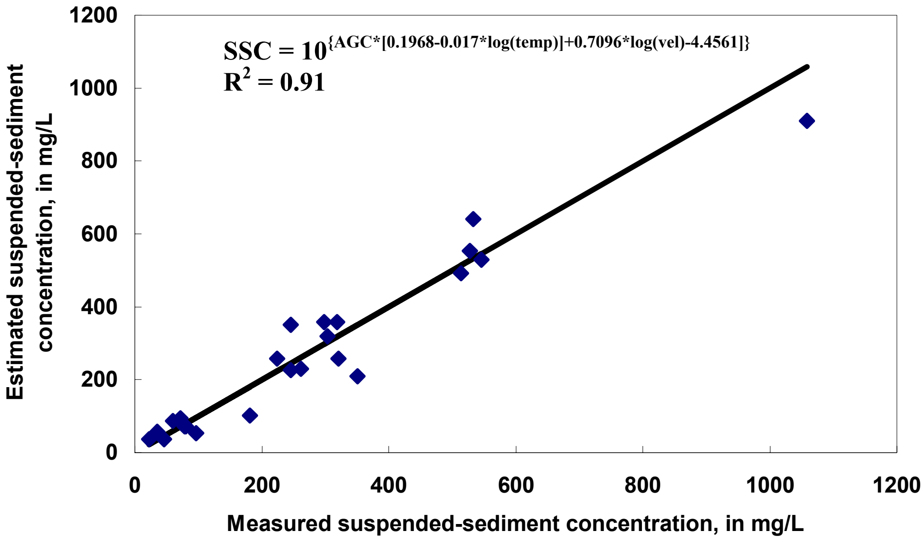

Figure 2. Comparison of estimated and measured suspended-sediment concentrations for the L-4 Canal site, Broward County, Florida.

Laser Data as Suspended-Sediment Concentration and Particle-Size Distribution Surrogates in Arizona

Laser diffraction grain-size analysis, a technique pioneered in the 1970's, is predicated on the concept that light impinging on a particle is either absorbed by the particle or is diffracted around the particle. The diffracted rays appear in a small-angle region. The Laser In-Situ Scattering and Transmissometry (LISST) technology measures the small-angle diffraction of a laser and inverts the signal to infer the in- situ particle-size distribution of the material being measured. Summing the volume of sediment in each particle-size class enables calculation of volumetric SSC (Agrawal and Pottsmith 2001).

Laser sensors are currently being investigated as an alternative monitoring protocol for tracking reach-scale suspended-sediment supply in the Colorado River at Grand Canyon, Arizona, located 164 km downstream from Glen Canyon Dam. This approach provides continuous suspended-sediment transport data that may reduce uncertainty in estimates of the transport of sand and finer material. The LISST data reported here were collected using LISST-100-B manufactured by Sequoia Scientific, Inc. (Agrawal and Pottsmith 2001, Gartner and Cheng 2001, Gray et al. 2002). The LISST-100-B is designed to measure suspended particles over a size range of 1.3-250 µm. The standard sample path of this device is a cylindrical volume with a diameter of 6 mm and a length of 50 mm.

Initial point data collected at a fixed-depth, near-bank site were obtained averaging 16 measurements at 2-minute intervals during a 24-hour deployment on July 19, 2001. The 720 LISST-100-B point measurements shown in Figure 3 compare favorably with cross-sectional data obtained concurrent with some of the laser measurements by techniques described by Edwards and Glysson (1999). In addition to accurately tracking sand concentrations, the LISST-100-B also recorded the expected increase of variance in the concentration of sand-size particles with increasing flows, with peak values ranging up to 150 mg/L (Figure 3).

These initial results, coupled with subsequent testing, suggest that the LISST-100-B is suitable for providing SSC and particle-size data for the Colorado River at Grand Canyon, Arizona. A manually deployable version of the LISST technology is under development (Gray and others 2002).

Pressure-Differential Data as a Suspended-Sediment Concentration Surrogate in Puerto Rico

Estimation of suspended-sediment concentrations from fluid density computed from pressure measurements shows promise for monitoring highly sediment-laden

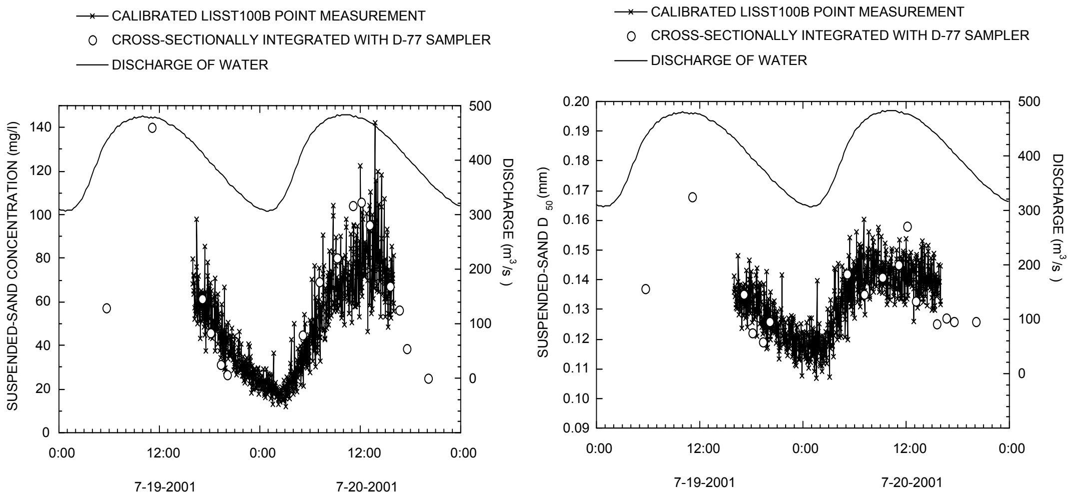

Figure 3. Comparison of sand concentrations and median grain sizes measured in the Colorado River at Grand Canyon, Arizona, using a LISST-100-B and a US D-77 bag sampler.

streamflows. Precision pressure-transducer measurements from vertically imposed orifices at different elevations are converted to density data by use of simultaneous equations. When corrected for water temperature, the density data are used to estimate sediment concentrations from a density-concentration relation (U.S. Geological Survey 1993). Thus, the device provides continuous (typically on 15-minute interval) sediment data that can be transmitted by satellite as stage and other data are currently transmitted. The cost savings and improved data quality can be substantial over those for traditional techniques.

An instrument for continuously and automatically measuring the density of a water-sediment mixture as a surrogate for SSC, referred to as a double bubbler precision differential-pressure measurement system by the manufacturer, was tested in Puerto Rico (Larsen et al. 2001). Continuous double bubbler instrument data were collected during October-December 1999 at a stream gaging station on the Río Caguitas, Puerto Rico. As of 2000, the maximum SSC measured at the site using techniques described by Edwards and Glysson (1999) was 17,700 mg/L, corresponding to a specific gravity of about 1.02, which also represents the signal-to-noise ratio.

The data collected during October-December 1999 at this site showed relatively poor agreement between discharge, SSC, and water density (Figure 4). The 1999 tests indicate that the double bubbler instrument values generally track substantial variations in SSC, but a large amount of signal noise remains.

This test of the double bubbler instrument showed the need for temperature compensation, and possibly the need to deploy the instrument at a site where the signal-to-noise ratio is substantially greater than 1.02. The double bubbler is being tested in Paria River, Arizona, where SSC in excess of 1 x 10^6 mg/L have been measured, yielding a signal-to-noise ratio of as much as 2. If adequate results can be achieved, increases in data accuracy and substantial reductions in costs of sediment monitoring programs for rivers carrying moderate-to-large SSC can be realized.

Summary

The USGS is evaluating surrogate technologies for estimating SSC and fluxes. Those based on bulk optic, acoustic, and laser technologies have been shown to be successful at selected test sites, although the robustness of these techniques must be more fully evaluated. The approach using the pressure-differential principle shows promise for use in highly concentrated streamflows.

Note

Use of trade or firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Government.

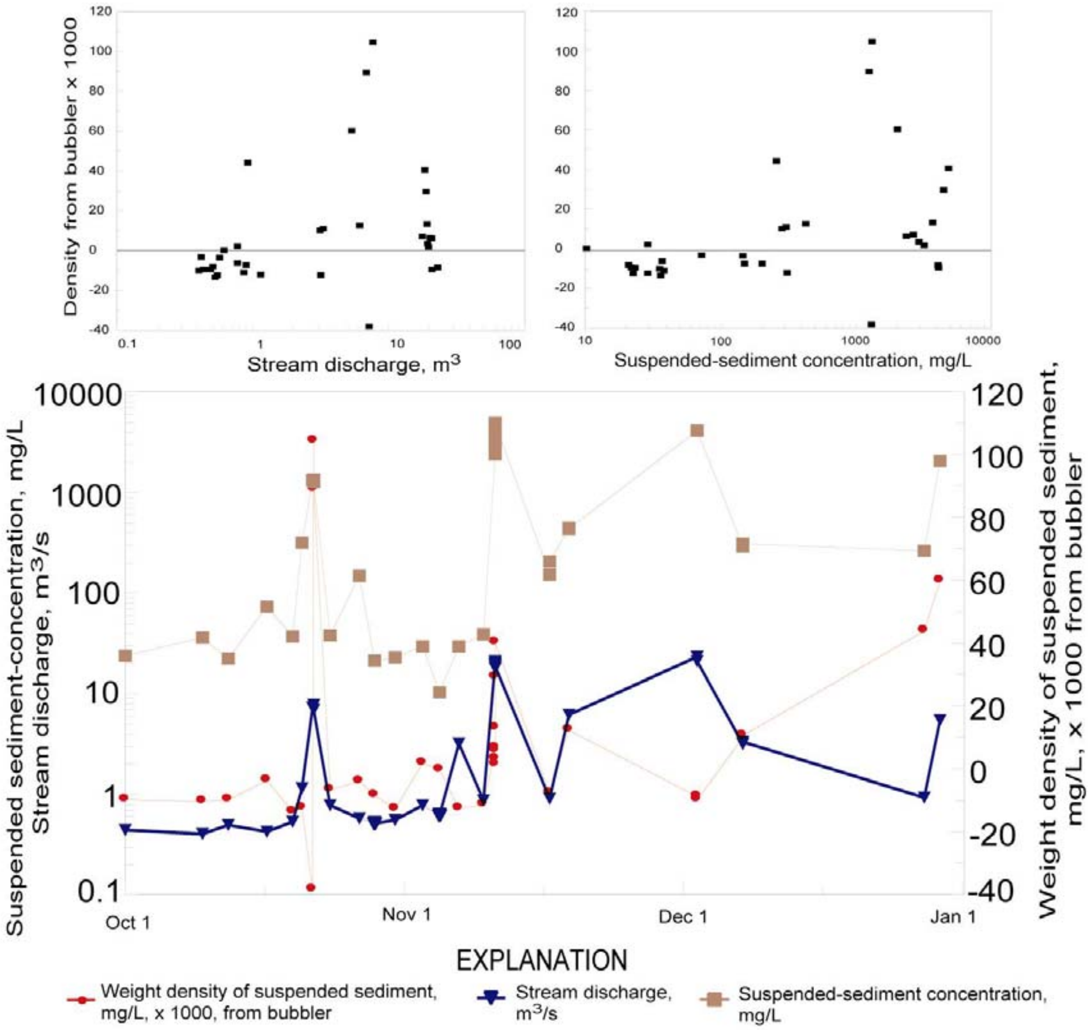

Figure 4. Scatter plots and time series of stream discharges, suspended-sediment concentrations, and weight density of suspended sediments and dissolved solids measured with a double bubbler, October 1, 1999 to January 1, 2000. Discharge and sediment data are instantaneous samples, and the double bubbler weight density value is a 30-minute mean of measurements made at 5-minute intervals.

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