Testing laser-based sensors for continuous, in-situ monitoring of suspended sediment in the Colorado River, Arizona

THEODORE S. MELIS & DAVID J. TOPPING

U.S. Geological Survey, Grand Canyon Monitoring and Research Center, 2255 N. Gemini Dr., Flagstaff, Arizona 86001, USA, tmelis@usgs.gov

DAVID M. RUBIN

U.S. Geological Survey, Coastal & Marine Geology, Santa Cruz, California 95064, USA

The Grand Canyon Monitoring and Research Center (GCMRC) was established in 1995, following completion of a major environmental impact statement on the operation of Glen Canyon Dam. The GCMRC supports the Glen Canyon Dam adaptive management program (AMP) by providing research and monitoring data on a variety of Colorado River ecosystem resources within Grand Canyon National Park (fig. 1). Resources of special concern include native fishes, cultural and recreational resources, as well as numerous eroding fine-grained sediment deposits located along the river's margins. Owing to the ecosystem's supply-limited sediment-transport behavior (Rubin et al. 1998, Topping et al. 2000a), intensive monitoring of fine sediment below Glen Canyon Dam is an AMP requirement for environmental management (Rubin et al. in press). One objective of the GCMRC's monitoring program is to measure the enrichment and depletion of the ecosystem's fine-sediment supply. This is done by estimating the system-wide sand mass balance between influx from tributaries, such as the Paria and Little Colorado River and efflux downstream to Lake Mead. Daily or near-daily measurements of suspended-sand concentration and grain size using standard suspended-sediment sampling methods is currently required to estimate monthly to seasonal sand flux below the dam. The current mass-balance protocol is logistically complicated, costly and provides limited spatial and temporal resolution. In-situ, laser-based sensors are being investigated as an alternative for measuring sand flux downstream to Lake Mead.

RESULTS OF 2001-2002 LISST TESTING

Initial point data collected at a fixed-depth, near-shore site were obtained by averaging 16 measurements at 2-minute intervals during a 24-hour deployment starting at 16:00 on July 19, 2001. These data were collected using a LISST-100 "Type-B" sensor (Laser In-Situ Scattering and Transmissometry). The Type-B is a laser-diffraction based sensor designed to detect suspended particles over a size range of 1.3-250 microns. The LISST can also determine suspended concentrations over a variable range, depending on grain size and adjustment of the instrument's sample-path length. The standard sample path of the LISST-100B is a cylindrical volume with a diameter of 0.6 cm and a length of 5.0 cm. Additional description of this technology is reported by Agrawal & Pottsmith (2001). The LISST-100B used during the July 2001 test was previously evaluated under laboratory and field conditions and its performance is reported by Gartner et al. (2001). The 720 LISST point measurements collected at the Grand Canyon gage in July 2001, compare very well with cross-sectionally integrated suspended-sand and silt & clay data collected at a cableway near the test site using a D-77 bag sampler. During the July test, fluctuating releases from Glen Canyon Dam ranged from about 320 to 480 cubic meters per second (typical summer pattern of discharge related to hydropower generation at the dam). In addition to accurately tracking the sand concentration, the LISST-100B also recorded the physically expected increase in sand-concentration variance as flow increased, with peak values ranging from 60 to 140 mg/l (fig. 2a). As predicted, concentrations of silt and clay obtained by the LISST-100B were a factor of two less variable, ranging from about 50 to 90 mg/l (fig. 2b). It is worth noting that the highest concentrations of fines occurred during the daily minimum discharge, which at this location occurs at night.

A second field test was conducted from September 22, 2001 to February 8, 2002 to explore performance characteristics of both the LISST-100B and a LISST-25 during longer, continuous deployments. Both the LISST-100B and the LISST-25 measure only the volumetric concentration and grain size of suspended particles. However, mass concentration can be estimated by the user once a suitable density conversion is gravimetrically determined. Our LISST-25 had a size range similar to the LISST-100B, however, the standard LISST-25 provides only a Sauter mean grain size (see Agrawal & Pottsmith 2001) rather than the full size distribution provided by the LISST-100B. During fall 2001, the LISST-100B was fitted with a path-reduction module (PRM) to expand the instrument's concentration range by a factor of four (optical path of 5 cm reduced to 1 cm). Although the PRM allowed for higher-concentration measurements, introduction of this optical accessory in the beam path altered the raw data in ways that were not trivial to resolve. The PRM's influence was most pronounced on scattering related to the sand-sized particles (inner rings of the detector). Use of a PRM with LISST is therefore not recommended on the basis of our tests. In contrast to the LISST-100B with the PRM, the LISST-25 (with a standard 2.5 cm optical path) measured higher concentrations of suspended sediment with no discernable complications over the four-month long test. Despite complications introduced by the PRM, the January 10-18, 2002 concentration data obtained from the LISST-100B also compared well with cableway samples for sand (fig. 3a) and silt & clay (fig. 3b) collected with the D-77 bag sampler.

Suspended-sediment grain size is an important component of the Grand Canyon monitoring protocol. For the July 2001 test, the LISST-100B provided median grain size data for sand that closely matched sand sizes obtained using the D-77 sampler (fig. 4a). Grain-size data for sand from the January 2002 test also compared well with the D-77 data (fig. 4b). Our five-week deployment of the LISST-25 provided the most compelling results about how well these optical instruments perform during continuous deployments (fig. 5). Even during September 2001, when the LISST-25 was technically out-of-range (less than 0.2 transmission), these data generally tracked the D-77 samples. Preliminary results from these field tests indicate that in-situ, laser-based sensors can provide continuous suspended-sediment point data in fluvial settings with appropriate maintenance, albeit under a limited range of grain-sizes and concentrations.

Monitoring sediment supply using LISST and *beta*

Our previous work has shown that suspended-sediment concentration and grain-size data can be used to back-calculate grain size of sediment on the bed upstream (Rubin & Topping 2001). The ***beta*** value, derived by the above method, is a surrogate for how enriched a river segment is in fine sediment, and thus provides an indirect, reach-integrated measure of a river's sediment mass balance (in non-armored conditions). The approach can also be applied to other sediment transport environments. Within a period of less than 24 hours on January 11, 2002, the LISST-100B recorded about a factor of seven increase in sand concentration and about a 50 percent decrease in median grain size of sand. This abrupt change in sand-transport occurred in response to enrichment of the river's sediment supply following tributary inputs (figs. 3a and 4b), rather than a change in discharge. Preliminary results such as these suggest that LISST data will be suitable for calculating ***beta*** at higher spatial and temporal resolutions than those that are presently obtained using conventional suspended-sediment sampling methods.

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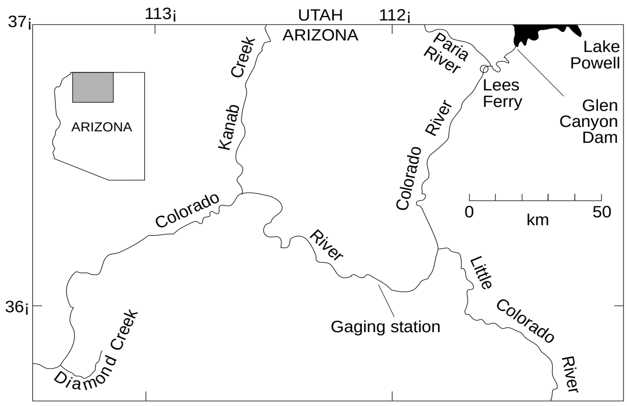
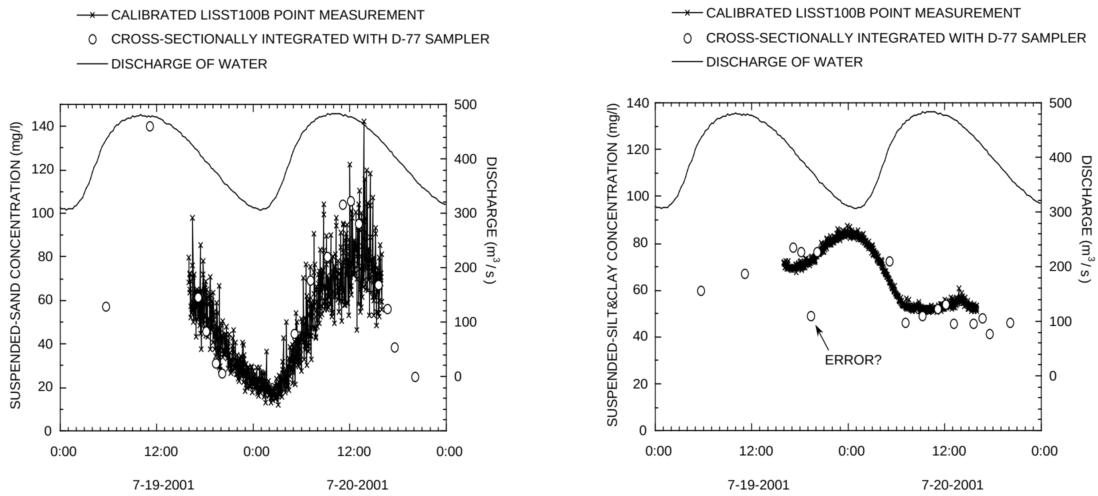


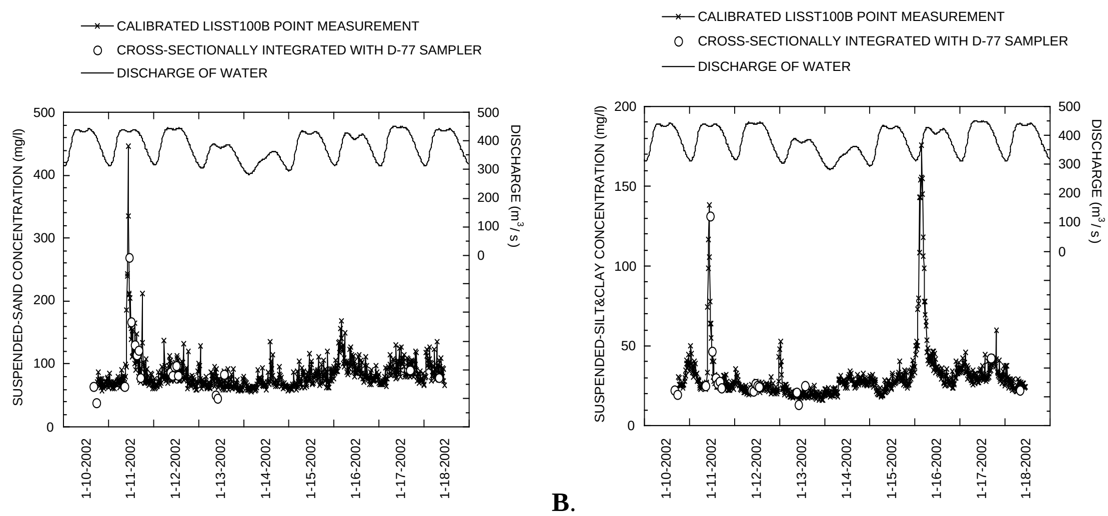
Figure 1. Map of the Colorado River downstream from Glen Canyon Dam.



A.

B.

Figure 2. A. Comparison of sand concentrations and **B.** Silt & clay concentrations measured at the Grand Canyon gage using LISST-100B and a D-77 bag sampler during the 1-day July 2001 test. Discharge data are from the Grand Canyon gage.



A.

B.

Figure 3. A. Comparison of sand concentrations and **B.** Silt & clay concentrations measured at the Grand Canyon gage using LISST-100B (with 80% PRM) and the D-77 bag sampler during the multi-day January 2002 test. Discharge data are from the Grand Canyon gage.

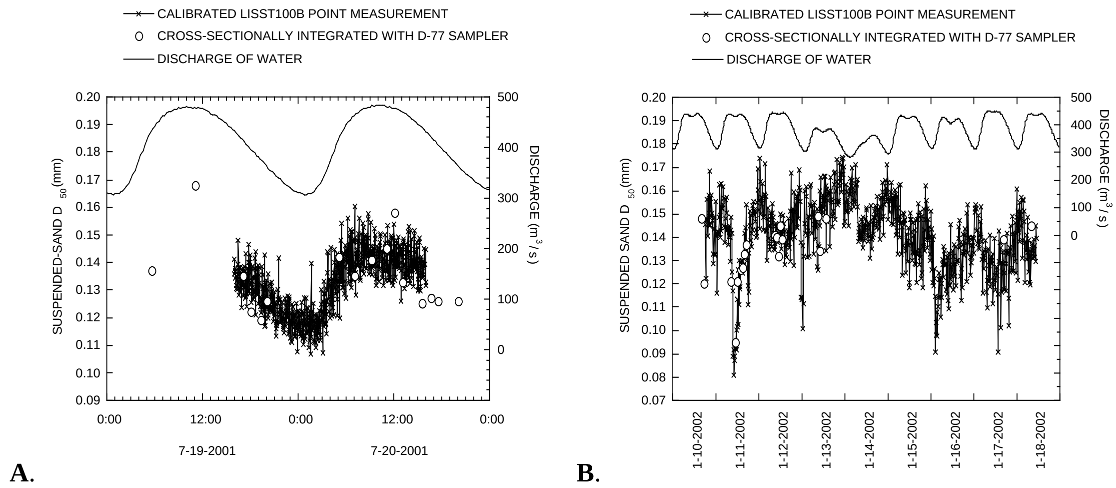


Figure 4. Comparison of median grain size (D_{50}) of sand measured at the Grand Canyon gage using LISST-100B and the D-77 bag sampler during **A.** the 1-day July 2001 test, and **B.** the multi-day January 2002 test. Discharge data are from the Grand Canyon gage.

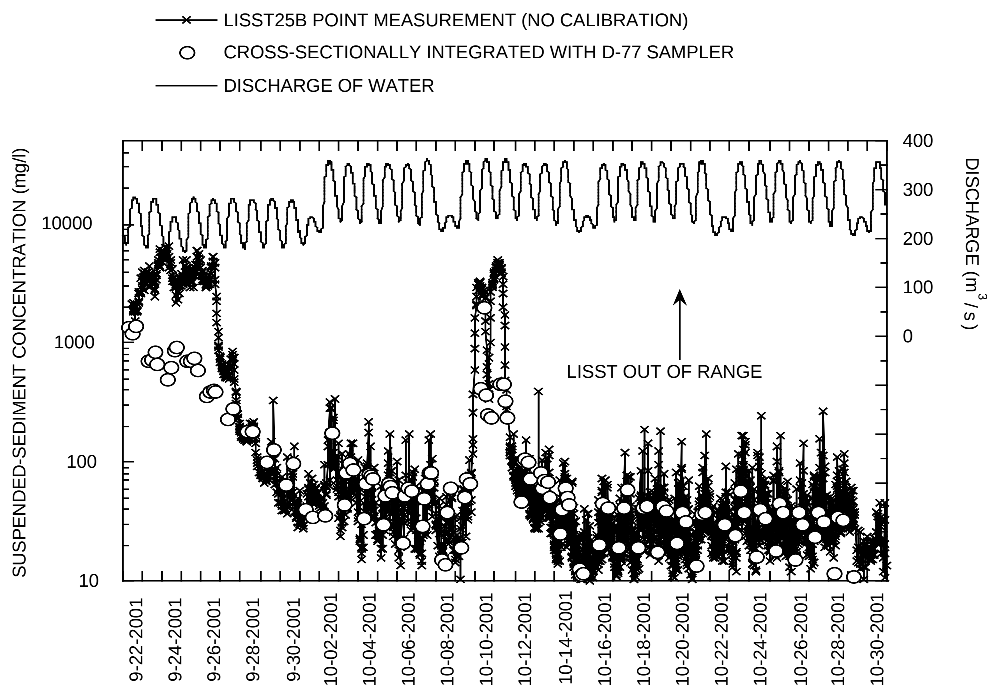


Figure 5. Comparison of total suspended-sediment concentrations (1-250 micron sizes) measured at the Grand Canyon gage using LISST-25 and the D-77 bag sampler during the multi-day fall 2001 test. Discharge data are from the Grand Canyon gage.