Federal Interagency Sedimentation Project (FISP)
Memorandum 2013.02

May 23, 2013

Subject: FISP Approval of the Use of Field-Deployed LISST-series Laser-Diffraction Analyzers for Volumetric Concentration and Particle-Size Data

Introduction

The purpose of this Federal Interagency Sedimentation Project (FISP) memorandum is to sanction the use of laser-diffraction analyzers for environmental measurement of suspended-sediment volumetric concentration (SSC_V) and volumetric particle size distribution (PSD_V); with important qualifications.

Qualifications of the field-based laser-diffraction instruments recommended in this memorandum require calibration of LISST-measured SSC_V and PSD_V data to obtain estimates of traditional mass suspended-sediment concentration (SSC_M) and mass particle-size distribution (PSD_M) that are needed for most sedimentation studies. The calibration should not be based solely on measurements of sediment density (specific gravity), but on data from gravimetric analyses of suspended-sediment concentrations and (or) particle-size distributions of concurrently obtained physical samples.

This memorandum also characterizes major distinctions between laser-diffraction-based volumetric SSC_V and PSD_V and gravimetric-based SSC_M and PSD_M; and describes instrument-based limitations to the field measurements. This memorandum does not address use of laser-diffraction instruments in the laboratory.

Background

Laser diffraction has been used to measure suspended-particle concentrations and -size distributions in the laboratory for decades (Agrawal, et al., 1991). More recently, the technology has been placed in field-deployable configurations to measure SSC_V and PSD_V in fluvial environments (Topping et al., 2004; Agrawal and Pottsmith, 2006). Although particle-size distributions are highly significant to the engineering, water-quality, and ecological roles of sediment in the environment, it is rarely measured in field studies and no single method provides a complete description of particle sizes (Reynolds et al., 2010).

The availability of this technology for in-situ measurement enables high temporal and spatial resolution measurements of PSD_V and associated $SSC_{v.}$ This unprecedented capability promises to substantially improve and expand upon the amount and usefulness of PSDv and SSCv data collected as part of operational sediment- and water-quality monitoring and (or) research programs. This memorandum recommends use of laser-diffraction devices particularly for those monitoring and research programs where high-resolution PSDv and SSCv data would be valuable.

The Laser In-Situ Scattering and Tranmissometry (LISST) series of instruments developed by Sequoia Scientific, Inc. for use in field conditions are the first such instruments to be commercially available (Agrawal and Pottsmith, 2000). Sequoia Scientific, Inc., has developed a series of LISST devices including those for in-situ measurement (i.e. the LISST-100X), for fixed-location pumped sampling (LISST-Streamside), and for mobile sampling (LISST-SL). A fixed-location laser diffraction sensor provides real-time, high-temporal resolution data, while a deployed mobile laser-diffraction sensor provides both high temporal- and spatial-resolution data in real time. The LISST instruments typically measure SSC_V within 32 log-spaced size bins over an instrument-specific size range. The sum of the SSC_V in each of the 32 bins is the reported SSC_V. It is beyond the scope of this memorandum to describe the technology of laser-diffraction instruments and specifically LISST devices; however good descriptions are provided in the references cited previously, and on the website of Sequoia Scientific, Inc. (sequoiasci.com). Sequoia Scientific, Inc., reports that all LISST instruments are compliant with the ISO-13320 standard for laser diffraction.

Limitations and Assumptions of LISST-series Field Deployed Sediment Analyzers

All monitoring instruments have device-specific deployment and measurement limitations, the performances of which are predicated on basic assumptions. Limitations of laser-diffraction measurements of SSC_V and PSD_V measurements include:

1. the range of sediment sizes measured by a specific instrument,
2. effects of particles outside the instrument's design size range,
3. effects of particle-shape,
4. effects of variable density and flocs in converting SSCv to SSC_M.

The first three of these issues are reviewed by Andrews et al. (2011). In addition to these technological limitations, instrument-specific operational limitations in fluvial environments have been identified.

All LISST-series laser diffraction sediment sensors have upper and lower limits on measured sizes. These size limits are different if presented as equivalent-spheres, or as sieve sizes. The difference arises as irregular shaped particles appear larger to laser diffraction than equal sieve-size sediment grains. When specified as equivalent spheres, the size range of LISST instruments is 1.25-500 microns. The corresponding sieve sizes for irregular grains are 2-381 microns (Agrawal et al., 2008). The LISST-SL and LISST Streamside report sizes for irregular grains. The size range was extended on the low end with the introduction in 2012 of the LISST-Portable |XR instrument, which reports sizes for equivalent spheres. The equivalent-sphere size range of the LISST-Portable |XR instrument is 0.4–500 microns in 44 logarithmic size classes.

All LISST instruments record ancillary data. For example, measurements of depth, optical transmission, temperature, velocity, date and time, and drive current and voltage to the isokinetic control pump are included with each LISST-SL SSC_V and PSD_V measurement. Similarly, the submersible LISST instruments record depth, optical transmission, temperature, battery voltage, and date and time. The LISST-StreamSide records battery voltage along with optical transmission, date and time.

Sediment sizes outside the instrument measurement limits are not reported by LISST devices. This is an important limitation for both SSC_V and PSD_V measurements in fluvial environments where large fractions of the suspended sediment are clay sized (≤2 microns) and/or larger than medium sand sized (≥250 microns). If there are significant fractions of sediment outside the measured size range, the SSC_V will always be biased low and the PSD_V will not represent the sampled streamflow. These problems will be transferred to any uncalibrated estimates of SSC_M or PSD_M based on these metrics. This limitation is one of the reasons that LISST measurements should be compared and (if mass sediment characteristics are needed) calibrated using concurrently collected physical samples that have been analyzed using a method that captures the full size range. Landers (2011, p. 122) describes a simple method to approximate the full PSD_M from a PSD_V of a partial size range using concurrent samples analyzed for full PSD_M.

Suspended particles smaller or larger than the instrument measurement range can affect the reported SSC_V of measured bin sizes (Andrews et al., 2011). Light from particles smaller than the minimum measurement range can 'leak into' and inflate the reported SSC_V in the smallest reported size bins. Light from particles larger than the maximum measurement range similarly can leak in to the largest reported size bins, but are comparatively less influential on reported SSC_V and PSD_V.

Before 2008, data produced by laser-diffraction methods typically were based on the assumption that particles in suspension diffract light similarly to spheres, an assumption that can result in errors in measurement of natural particles. A study by Agrawal et al. (2008) developed procedures to adjust laser-diffraction measurements assuming non-spherical, random-shaped particles. These methods have been implemented in the LISST processing software. Thus, SSC_V and PSD_V reported by LISST instruments are not based on the assumption of spherical particle shapes.

The principal limitation of the LISST devices relates to converting measured SSC_V to SSC_M, and PSD_V to PSD_M. In most applications, SSC_M and PSD_M data are needed for characterization of fluvial sediment processes and impacts, and for continuity with previously collected data to avoid methodologically based bias. In general, results of any analysis of suspended-sediment concentration or particle-size distribution will be affected by the analytical method used in their determination. In fluvial environments, SSC_M historically has been determined by laboratory analysis using approved methods that obtain results with acceptable comparability across methods. If the full range of environmental sediment sizes were included in measured SSC_V and PSD_V and if the densities of the sediment were known for all sizes, then one could convert volumetric to mass sediment characteristics simply by taking the product of the volumetric measure and the specific gravity of the sediment (the specific gravity is the ratio of the sediment density to water density). However, FISP research indicates that these two conditions cannot be assumed to exist.

The ratio of SSC_M to true SSC_V, after adjusting for units, should equal the sediment specific gravity (about 2.65 for most predominantly silica sediments). The median ratio of SSC_M to LISST-SL-measured SSC_v was 1.2 for 196 concurrent samples collected in 16 streams in WA and IL in FISP-sponsored research in 2010-2012. The average specific gravity of the sediments was 2.70 based on densiometric analyses of 23 samples. Also, there were significant fractions of sediment outside the instrument size limits in most of these measurements, which would cause the ratio of SSC_M to true PSD_V to be greater than the sediment specific gravity.

These data indicate that errors averaging more than 100% would occur if SSC_M was estimated by multiplying LISST-determined SSC_V by the sediment specific gravity in these fluvial systems. Separate studies using LISST devices have had similar results (Landers, 2011). Flocculation of fine sediments in the fluvial environment is assumed to be the primary reason for these unreasonable ratios of SSC_M to SSC_V. The LISST measures a floc as a single particle, which would have a bulk specific gravity less than that of the dispersed, composite particles. Differences also may be due to use of dispersants in laboratory analyses and effects of sample storage and handling.

FISP-sponsored research and other studies found excellent correlations between SSC_V and mass SSC_M. Landers (2011) found the relation between SSC_V and SSC_M to be better than relations between turbidity and SSC_M or acoustic metrics and SSC_M based on over 190 measurements at one site in Georgia. Furthermore, the high resolution PSD_V data from the LISST devices are yielding new insights into sediment sources and transport processes, as well as on the effects of PSD on turbidity or sediment-acoustic measurements.

Several investigators have noted operational challenges using laser-diffraction devices (personal communication, U.S. Geological Survey personnel in GA, FL, ID, IN, and WA). The LISST-series instruments are extremely sensitive to fouling and scratching of the sensor window and may require thorough weekly or daily cleaning in biologically productive environments typical of many streams, particularly in warmer waters. The LISST-Streamside is not designed for operation in freezing temperatures and has the limitations associated with any pumping sediment sampler.

Qualified Approval of LISST-series Sediment Analyzers

The LISST-series of sediment analyzers provide valuable, high-resolution PSD_V data that are generally unavailable or impractical to obtain by other operational methods. The FISP recommends use of LISST-series of sediment analyzers in environmental settings in which high-resolution SSCv and PSD_V data would be valuable contingent on the following unequivocal requirement: Any field deployments of a LISST device to quantify SSC_M or PSD_M must include collection of adequate (statistically meaningful), representative, concurrent, collocated, physical samples for subsequent SSC_M and PSD_M analyses in an accredited laboratory in order to calibrate the LISST-measured SSC_V and PSD_V.

Depending on the objectives of a LISST-instrument field deployment there are at least two calibration options. If the objective is to ascertain the performance of the LISST instrument, concurrent samples collected as close as practicable to the LISST sensor are required. Alternatively, if the objective is to monitor suspended-sediment transport rates, representative depth-integrated samples collected over the cross section using methods described by Edwards and Glysson (1999) and Nolan et al. (2005) are required. In the latter case, if a fixed-point LISST device is used (such as the LISST-Streamside or LISST-100X), the calibration would combine point-to-cross-section effects and LISST-to-SSC_M effects. Such a calibration that combines the LISST-to-$SSC_{M,}$ and the point-to-cross section relation should be used with caution and evaluated for changes from any driving explanatory variables.

Calibration of the LISST-derived data using properly collected physical samples should yield excellent mass-based estimates that are comparable to other analytical methods. Also, application of this technology in fluvial environments is still developing and is less robust than many environmental sensors and, as yet, is manufactured by only one company, Sequoia Scientific, Inc.

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