Breakout Session I, Suspended-Sediment Measurement: Data Needs, Uncertainty, and New Technologies

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Introduction

Accurate determinations of suspended-sediment concentrations are essential to assess the impact of sediment on the watershed. In many stream systems, sediment suspended in the water column constitutes the bulk of sediment transported. Yet collection of suspended-sediment data using standard techniques is labor intensive and expensive, while the amount of uncertainty in estimates or predictions of suspended-sediment loads is rarely known.

Breakout session I was responsible for providing information and recommendations on new technologies that have potential for meeting the data and uncertainty needs of sediment users for in-situ measurement of concentrations, particle-size distributions, and (or) other characteristics of suspended sediment. Current isokinetic samplers may be used to provide an accurate measure of the mean suspended-sediment concentration (excluding the unsampled zone adjacent to the stream bottom), but are expensive, time-consuming to deploy, and may be difficult or hazardous to use during periods of storm runoff. The specific goals of this session were to define the accuracy and frequency needs of sediment-data users, and to identify the most promising new technologies that will be available in the near term—3 to 5 years—to meet those needs. Key questions posed to participants in this breakout session were:

1. What are your agency/group informational needs regarding suspended-sediment transport? What type of data are required to support these needs?
2. What level of uncertainty are you willing to accept in suspended-sediment concentration measurements and flux calculations? Would data of the following accuracy (zero bias, x variance) be unacceptable to you or to your customers? x = 0 percent; 5 percent; 10 percent; 25 percent; 50 percent; 100 percent; 200 percent; 500 percent; order-of-magnitude?
3. What instruments are currently in use to collect these data?
4. Are the derivative data adequate in quality and temporal/spatial density? What spatial and temporal resolution do you consider to be reasonable for your application?
5. What are the strengths and limitations of the current instruments in use for collecting suspended-sediment data?
6. What should be our medium- and long-term goals in the collection of suspended-sediment data?
7. What are the new technologies that will be useful for measuring suspended-sediment transport in the next 3-5 years?
    - Acoustic Backscatter
    - Digital-Image Analysis
    - Laser Diffraction
    - Optical Velocity, Concentration, and Size
    - Pressure Difference
    - Other
8. What are the benefits and limitations of these new technologies?
9. How will new technologies solve limitations of current instruments (e.g. sample the unsampled zone, automatic operation, decrease collection and analysis cost, increase safety)?
10. What are the time frames for these technologies to make an important impact on the collection of suspended-sediment data?
11. Are there any special conditions at sites that you are responsible for or aware of that would specifically preclude any of the new technologies? Are you aware of any sites that might be included in a program such as that described by in "Attributes for a Sediment Monitoring Instrument and Analysis Research Program," by J.R. Gray and G.D. Glysson (listed in appendix 4 of this report)?
12. What would you consider to be a reasonable cost – excluding ancillary data-collection instruments and structures from which instruments will be anchored – for suspended-sediment monitoring at a field site?

13. Would a Sediment Monitoring Instrument and Analysis Research Program, such as that proposed by the Turbidity and Other Sediment Surrogates Workshop (Gray and Glysson, 2003), and expanded upon by J.R. Gray and G.D. Glysson, “Attributes for a Sediment Monitoring Instrument and Analysis Research Program,” listed in appendix 4, be useful for attaining the fluvial-sediment-data needs of the Nation?

Extended abstracts in the proceedings of this workshop (see appendix 4) relating to the measurement of suspended sediment included:

- Agrawal, Y.C., and Pottsmith, H.C., Laser diffraction method: two new sediment sensors.
- Dinehart, R.L., Spatial analysis of ADCP data in streams.
- Gartner, J.W., and Gray, J.R., Summary of suspended-sediment technologies considered at the Interagency workshop on turbidity and other sediment surrogates.
- Gray, J.R. and Glysson, G.D., Attributes for a sediment monitoring instrument and analysis research program.
- Gray, J.R., Melis T.S., Eduardo Patiño, Gooding, D.J, Topping, D.J., Larsen, M.C., and Rasmussen, P.P., U.S. Geological Survey suspended-sediment surrogate research on optic, acoustic, and pressure-difference technologies.
- Kuhnle, R.A., and Wren, D.G., Cross-stream variations in suspended sediment transport over dunes, implications for sampling.
- Martini, Marinna, USGS capabilities for studying sediment transport in the ocean.
- Nichols, M.H., and Renard, K.G., Sediment research and monitoring at the USDA-ARS Walnut Gulch experimental watershed.
- Northby, J.A., New optical instruments for sediment re-suspension measurements.
- Pratt, Thad, and Parchure, Trimbak, OBS calibration and field measurements.
- Parchure, T.M., Sobecki, T.M., and Pratt, T.C., Fine sediment parameter measurement for sedimentation studies.
- Wren, Daniel, Kuhnle, R.A., and Chambers, James, Measurement of suspended-sediment concentration and particle size in laboratory flumes.
- Wright, Scott, Comparison of direct and indirect measurements of cohesive sediment concentration and size.

The discussions of the suspended-sediment breakout group consisted of viewpoints from a diverse group of individuals.

Observations

Suspended-sediment informational needs were found to vary by agency and intended data use. In some instances, such as biological studies, continuous data are required. In other cases, only data during storm runoff are required. Some projects require the collection of physical sediment samples for contaminant or compositional analyses. A continuing need for research into suspended-sediment transport processes was also identified. This research requires highly detailed data sets of sediment concentration and the causative flow field. Additionally, more robust measurements that represent a substantial quantity of the material in transport are desired, or at least measurements that represent more than a point in the cross section.

Uncertainty levels for suspended-sediment flux calculations depend to a large extent on the poorly known temporal and spatial variability (including the unsampled zone) in the transport of suspended sediment, and were considered beyond the scope of this breakout session (for an example of an analysis of estimated sediment flux uncertainty, see Topping and others, 2000, p. 539). Acceptable uncertainty levels for individual suspended-sediment samples were considered (table 1). Gray and others (2002) maintained that greater individual sample uncertainty levels could be offset by an increased frequency and improved spatial coverage of suspended-sediment transport. It was also expressed that constant uncertainty levels in the range of 10-20 percent would be more acceptable to some data users

Table 1. Range of acceptable uncertainties for individual suspended-sediment samples

[milligram per liter is mg/L; < is less than; > is greater than; ± is plus, minus]

Concentration range (mg/L)	Best-Case Isokinetic[1] (percent)	Gray and others, 2002[2] (percent)	Generalized Approach
< 10	±10	±50	±10 to ±20 percent for all concentration ranges
10 to <100	±10	±50 to ±25 (linear shift)	
100 to <1,000	±4	±25 to ±15 (linear shift)	
> 1,000	--	±15	
100,000	±3	--	

[1]Based on a consensus of responses from the breakout session.

[2]Proposed criteria for LISST-SL profiler testing (Sequoia Scientific, 2004)

The current standard samplers used for the collection of suspended-sediment data are the FISP depth-integrating (US D-series) and point (US P-series) isokinetic samplers, for which carefully designed and tested protocols have been published (Edwards and Glysson, 1999; Federal Interagency Sedimentation Project, 2004, Home page). The main weaknesses associated with these samplers are the high cost associated with their manual deployment and the difficulty of getting adequate coverage in space and time. A summary of some strengths and weaknesses of isokinetic samples is contained in table 2.

Table 2. Some strengths and weaknesses of Federal Interagency Sedimentation Project (FISP) suspended-sediment isokinetic samplers

Strengths	Weaknesses
Standard equipment and techniques through the FISP	Cost and logistics of manual deployment; possible hazardous conditions associated with sample collection during storm runoff
Large historical database covering about two-thirds of a century	Difficulty of collecting a sufficient number of samples to adequately characterize temporal and spatial variability of suspended sediment
Extensive design, testing and calibration of samplers	Possible sample contamination if bed material is inadvertently collected
Used in the U.S. and many other nations as standard samplers for collection of suspended-sediment data	Inability to sample the water column below the intake nozzle when the sampler touches the bed

Other samplers in use include non-isokinetic automatic-pumping samplers, single-stage samplers (Federal Interagency Sedimentation Project, 2004), Van Dorn samplers, and various types of grab samplers. For fine sediments (< 0.062 millimeters in diameter) and for flow velocities less than about 0.3 meters per second, the type of sampler used to collect a representative sample is much less critical.

Technologies currently available or emerging in the near term—considered to be the next 3 to 5 years—with the potential for improving the collection of suspended-sediment data include those that operate on the following principles: acoustic (single frequency, table 3a and multi-frequency, table 3b), laser diffraction (table 3c), optical-sediment flux (table 3d), digital-image analysis (table 3e), pressure differential (table 3f), and bulk optics (table 3g). Currently, the LISST series of laser diffraction instruments (Sequoia Scientific, Inc., 2004), acoustic backscatter meters (single frequency acoustic Doppler current profilers from RD Instruments USA (2004), Sontek/YSI, Inc. (2004), and Nortek AS (2004)); Aquascat multi-frequency manufactured by Aquatec (2004), and several types of bulk-optic meters (optical backscatter, nephelometry, and transmission devices; see table 3g), are available commercially. There are only a few instances, however, where these new technologies have been compared directly to the standard FISP isokinetic depth-integrating or point samplers. The LISST series of instruments have been shown to collect continuous point samples of suspended-sediment concentration and size distributions in-situ (Melis, Topping, and Rubin, 2003). The commercially available acoustic backscatter devices yield relative information on suspended-sediment concentration; however, algorithms to calculate quantitative sediment concentrations and size distributions are not provided with these instruments and are still in development. The available optical backscatter, nephelometric, and transmission devices yield only a relative indication of suspended-sediment concentration at a point without extensive site-specific calibration.

Recommendations

1. **Collection of Detailed Data:** The collection of highly detailed (in time and space) suspended-sediment data from a variety of locations should be encouraged and supported. These data are needed to evaluate the uncertainty of flux calculations using conventional means computing suspended-sediment transport. These data also would be valuable for improving the algorithms used in sediment-transport modeling and for the development of more efficient sampling procedures.
2. **Independent Test Development and Evaluations:** As surrogate instruments employing new technologies are developed, an independent agency or group should develop a standard series of tests to evaluate the performance of these devices. Testing should include simultaneous side-by-side testing between new instruments and standard samplers by independent parties in laboratory and field settings. This information will be critical to assure that new devices are producing unbiased and representative measurements of the sediment in suspension, and demonstrate that the data collected by old and new techniques are comparable in quality.
3. **Data Formats**: Standardized data formats for archiving sediment and ancillary data need to be developed. With the rapid change in the types of media and formats that is occurring, there is a critical need to qualify new data by method of collection and to develop protocols that enable storage and retrieval of all sediment and ancillary data from the same databases.
4. **Sediment Monitoring Instrument and Analysis Research Program**: A Sediment Monitoring Instrument and Analysis Research (SMIAR) Program as outlined by Gray and Glysson (listed in appendix 4) should be implemented. A central entity is needed for the selection of sites to concentrate sediment-data collection, to set

standards and test new technology samplers, and to determine sediment data storage and archival standards. An interagency group, such as the FISP, would be a logical choice for implementing and administering such a program.

Suggestions for sites that may be included in a national SMIAR Program include: The Colorado River, Grand Canyon, Ariz., representing large rivers; Paria River, Ariz. representing hyper-concentrated flows; Goodwin Creek, Miss., representing a flashy stream in an agricultural watershed; Duck, N.C., representing a low-concentration marine site; Massachusetts Bay, representing a marine site near an urban area; Walnut Gulch, Ariz., representing a semi-arid agricultural area; and the Elwha River, Wash., representing a largely pristine watershed in which two high-head dams are slated for removal in 2008.

Summary

There is pressing need for suspended-sediment data that are collected at greater frequencies and that encompass more of the cross section at more sites. The level of increase in funds and manpower required using conventional sampling techniques to fill this need is not feasible. New automated technologies that collect continuous data on concentration and size distributions of suspended sediments are needed. Several new technologies are on the verge of fulfilling some of this need; however, standard test procedures and an objective group to test these new techniques are required. New standards for the storage and archiving of sediment data are needed to keep pace with changing technologies and to prevent data loss. An interagency group, such as the FISP, should be charged with developing and implementing these standards and procedures in an organization such as the SMIAR Program.

Table 3. New-technology information matrix for suspended sediment

[º is degree; K is thousand; ± is plus or minus; < is less than; > is greater than; m is meter; µ is micron; mg/L is milligrams per liter; SSC is suspended-sediment concentration; OBS is optical backscatterance]

Table 3a: Single-frequency acoustics

Category	Information
Measurement type:	Particle backscatter
Measurement use:	SSC (volumetric)
Instrument(s):	Acoustic Doppler current profiler (ADCP)
Manufacturer(s):	Nortek AS (2004), RD Instruments USA (2004), Sontek/YSI, Inc. (2004), Aanderaa (2004)
Measurement location:	Vertical/horizontal profile
Status, Progress, trends:	Commercially available, primarily used for flow velocity
Range of size, concentration, flow depth:	Insufficient information available
Sensor(s):	Piezoelectric transducer
Sources of information:	Manufacturer’s literature; Gartner and Cheng (2001); David Topping, USGS, 2003, oral commun.; Nancy Powell, U.S. Army Corps of Engineers, New Orleans District, 2003, oral commun., James Chambers, National Center for Physical Acoustics, Univ. of Mississippi, 2003, oral commun.
Strengths:	Deployed in many locations, profile measurements, non-intrusive
Limitations:	Dual dependency on concentration and particle sizes; assumption of mean particle density for mass computations; air-bubble interference; upper concentration limits unknown
Accuracy:	Insufficient information available
Recommendations/ goals:	Further, careful testing against isokinetic samplers, may be valuable if used in conjunction with additional instrument; theoretically based limits for size/concentration measurement should be established
Calibration requirements:	Calibrations are essential

Table 3b: Multi-frequency acoustics

Category	Information
Measurement type:	Particle backscatter
Measurement use:	SSC (volumetric), grain size
Instrument(s):	Aquascat ($30K)
Manufacturer(s):	Aquatec (2004)
Measurement location:	Vertical or horizontal profile
Status, progress, trends:	Hardware proven and available; software/ algorithms under active development
Range of size, concentration, flow depth:	Hardware specific
Sensor(s):	Piezoelectric transducer
Sources of information:	Smith, (2004), Thorne and Hanes (2002), Thorne and Taylor (2000), Crawford and Hayes (1993), Thorne and others (1991)
Strengths:	Profiling, non-intrusive, no biofouling, good spatial/ temporal resolution
Limitations:	Difficult inversion of data to concentration, including particle-density assumptions; no commercial software currently available to make this conversion, sensitive to air bubbles; upper concentration limits unknown
Accuracy:	±30 percent concentration--needs further testing in various environments; particle-size accuracy unknown
Rcommendations/goals:	Continued development and careful comparison with established techniques, especially field deployment in fluvial systems
Calibration requirements:	Calibrations are essential

Table 3c: Laser diffraction

Category	Information
Measurement type:	Multi-angle scattering of diffracted light
Measurement use:	SSC (volumetric) and grain size
Instrument(s):	LISST series ($5K-$30K)
Manufacturer(s):	Sequoia Scientific, Inc. (2004)
Measurement location:	Point measurement
Status, progress, trends:	Mature technology
Range of size, concentration, flow depth:	1.25-1,500 µ for three models
Sensor(s):	Silicon photo-diode; similar in principle to Beckman-Coulter and other such laboratory instruments
Sources of information:	Agrawal and Pottsmith (2001), Gartner and others (2001)
Strengths:	Particle-size and SSC
Limitations:	Requires dilution >3,000 mg/L (particle-size dependent), may bio-foul, air bubbles
Accuracy:	±20 percent
Rcommendations/goals:	Complete LISST-SL isokinetic profiler development for riverine applications; test in controlled laboratory conditions
Calibration requirement:	Not needed according to manufacturer, but recommended

Table 3d: Optical-sediment flux

Category	Information
Measurement type:	Modulated light
Measurement use:	Particle sizing/counting velocimeter
Instrument(s):	In development
Manufacturer(s):	No units commercially available
Measurement location:	Point (limited profiling capability)
Status, progress, trends:	Under development, proof of concept performed
Range of size, concentration, flow depth:	30 µ and larger; unknown concentration limit—probably better for dilute solutions
Sensor(s):	Laser diode
Sources of information:	Jan Northby, University of Rhode Island, oral commun., 2003
Strengths:	Simultaneous velocity/ concentration measurement, non-intrusive, potential for measuring fluorescent effects; low cost
Limitations:	Concentration limited
Accuracy:	Undetermined—velocity on the order of a few percent
Recommendations/goals:	Continued development; use in sediment resuspension studies
Calibration requirements:	Calibrations presumably will be necessary

Table 3e: Digital-image analysis

Category	Information
Measurement type:	Digital photographic analysis
Measurement use:	Volumetric SSC and size
Instrument(s):	In development
Manufacturer(s):	Not yet available off the shelf
Measurement location:	Point/depth integrated; also laboratory
Status, progress, trends:	Prototype planned for 2004, proof of concept completed in lab
Range of size, concentration, flow depth:	2-4,000 µ, 0-10,000 mg/L
Sensor(s):	CCD, custom lenses
Sources of information:	Dan Gooding, USGS, oral commun., 2003
Strengths:	Discrete information on particles including aggregates, measurements of organics, visual confirmation using archived images; air bubbles not a problem
Limitations:	Fouling
Accuracy:	±10 percent in lab, as yet unknown in field
Rcommendations/goals:	Prototype in 2004
Calibration requirement:	Recommended

Table 3f: Pressure differential

Category	Information
Measurement type:	Fluid bulk density
Measurement use:	SSC
Instrument(s):	Double bubbler, wet differential
Manufacturer(s):	Design Analysis Associates, (2004); Hope Hydrology (2004)
Measurement location:	Integrated range between ports
Status, progress, trends:	Lab-verified proof of concept; limited field verification
Range of size, concentration, flow depth:	All sizes, depths over minimum to cover pressure ports, concentrations from 10 mg/L (lab); no upper limit
Sensor(s):	Differential transducer, pressure ports
Sources of information:	Calhoun and Rasmussen (2001), Larsen and others, (2001), Lewis and Rasmussen (1999)
Strengths:	For medium to high SSC, evidence that signal accuracy improves with >SSC; large observational window
Limitations:	Probably inaccurate at low concentrations (< about 1,000 mg/L); turbulent flow may cause problems; minimum flow depth limitation (to cover pressure ports)
Accuracy:	<5 percent in lab; field, 50 percent; Hope Hydrology (2004) claims at least 10-percent accuracy
Recommendations/goals:	May be able to monitor bedload continuously with more development
Calibration requirements:	Advised

Table 3g: Bulk optics (optical backscatter, nephelometry, transmission)

Category	Information
Measurement type:	Measures backscatter or transmission of light in sample space
Measurement use:	SSC
Instrument(s):	OBS-3, DTS-12, other commercially available meters
Manufacturer(s):	D&A Instruments (2004), Forest Technology Systems (2004), many others.
Measurement location:	Some distance from probe, variable with sediment concentration or color of water
Status, Progress, trends:	Mature technology; relation to suspended-sediment concentration not simple function
Range of size, concentration, flow depth:	Fines dominant, sands 10-40 percent, SSC range 10-3,000 mg/l, flow depth 0.15-5 m
Sensor(s):	OBS, 90º, or transmission probes
Sources of information:	Gray and Glysson (2003)
Strengths:	Ease of use, readily available
Limitations:	Must be calibrated in environment in which it will be used, range up to about 2,000 nephelometric turbidity units, calibrations are site specific, subject to bio-fouling, point measurements
Accuracy:	Dependent on extent of calibration, degree of change of conditions of sediment characteristics
Recommendations/goals:	Effective technology for some cases; well documented; technology is mature
Calibration requirements:	Necessary

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