Proceedings of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona

Edited by John R. Gray

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Contents

Executive Summary. 1
Introduction to the Proceedings of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona. 4
Breakout Session I, Suspended-Sediment Measurement: Data Needs, Uncertainty, and New Technologies 8
Breakout Session II, Bedload-Transport Measurement: Data Needs, Uncertainty, and New Technologies 16
Breakout Session III, Bed-Material and Bed-Topography Measurement: Data Needs, Uncertainty, and New Technologies 29
Breakout Session IV, Sediment Data: Management, Sediment-Flux Computations, and Estimates from New Technologies. 36
Appendix 1: Matrix of selected information gleaned from the four breakout sessions as compiled in the second plenary session of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona. 41
Appendix 2: List of registrants and respective affiliation for the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona 43
Appendix 3: Breakout session attendees as recorded by respective breakout session leaders, Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona 46
Appendix 4: Extended abstracts submitted as part of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona. 46

Tables

1. Range of acceptable uncertainties for individual suspended-sediment samples 9
2. Some strengths and weaknesses of Federal Interagency Sedimentation Project (FISP) suspended-sediment isokinetic samplers. 10
3. New-technology information matrix for suspended sediment
   a. Single-frequency acoustics. 11
   b. Multi-frequency acoustics. 12
   c. Laser diffraction. 12
   d. Optical-sediment flux. 13
   e. Digital-image analysis 13
   f. Pressure differential 14
   g. Bulk optics (optical backscatter, nephelometer, transmission) 14
4. Comparison of characteristics of different bedload-sampling technologies with selected references. 17
5. Bed-topography measurement technologies 31

Extended Abstracts (in alphabetical order), available only online at:

http://water.usgs.gov/osw/techniques/sediment/sedsurrogate2003workshop/listofpapers.html

Abraham, David, Quantification of bed-load transport using multi-beam survey data: the ISSDOT Method (Integrated-Section Surface Difference over Time).

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Braatz, D.A., and Tucker, R.L., A new series of sediment collectors for monitoring true bedload.

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Davis, J.E., and Rosati, J.D., Regional Sediment Management.

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.

Jackson, W.L., Regulated river restoration monitoring: The Elwah River dam removal and restoration project.

Kuhnle, R.A., and Wren, D.G., Cross-stream variations in suspended sediment transport over dunes, implications for sampling.

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Proceedings of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona

John R. Gray, Editor

Executive Summary

The Advisory Committee on Water Information's Subcommittee on Sedimentation sponsored the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop on September 9-11, 2003, at the U.S. Geological Survey Flagstaff Field Center, Arizona. The workshop brought together a diverse group representing most Federal agencies whose mission includes fluvial-sediment issues; academia; the private sector; and others with interests and expertise in fluvial-sediment monitoring – suspended sediment, bedload, bed material, and bed topography – and associated data-analysis techniques. The workshop emphasized technological and theoretical advances related to measurements of suspended sediment, bedload, bed material and bed topography, and data analyses. This workshop followed and expanded upon part of the 2002 Federal Interagency Workshop on Turbidity and Other Sediment Surrogates, which initiated a process to provide national standards for measurement and use of turbidity and other sediment-surrogate data.

This executive summary provides a description of the salient attributes of the workshop and related information, major deliberations and findings, and principal recommendations. This information is available for evaluation by the Subcommittee on Sedimentation, which may opt to develop an action plan based on the recommendations that it endorses for consideration by the Advisory Committee on Water Information.

Background

The need for reliable, cost-effective, spatially and temporally consistent data on sediment content and clarity of our Nation's waters has never been greater. Ironically, the amount of daily-value sediment data being collected by the U.S. Geological Survey – which has the national mandate for collecting and archiving Federal water data, including fluvial sediment – has declined by two-thirds over the last two decades. Production of these data by standard techniques originating in the 1940s tends to be manually intensive and time consuming, and hence, costly, and safety risks may be associated with manual data-collection techniques. Although the data produced are widely considered to be the best such data available that describe the sedimentary character of our Nation's waters, their accuracy is largely unquantifiable.

Over the last decade, there has been a marked increase in the availability, measurement capabilities, and research and testing of instruments that purportedly produce continuous and (or) quantifiably accurate sediment-surrogate data that are safer and (or) less expensive to obtain, and (or) more robust than those obtained by traditional techniques. At the same time, data-analysis capabilities have improved or are being developed for converting surrogate measurements and selected ancillary information into estimates of suspended-sediment concentration, bedload transport rates, bed topography, or particle-size distribution statistics.

This convergence of advanced instrument technologies and analytical capabilities represents an unprecedented opportunity to evaluate the capacity to cost-effectively measure and (or) monitor selected characteristics of one or more phases of fluvial sediment with a heretofore unprecedented continuity, temporal density, and (or) known accuracy. If sediment-surrogate data can be shown to meet codified accuracy criteria and appropriate sediment-record computation techniques are applied, then these technologies have the potential to revolutionize the way fluvial-sediment data are collected, analyzed, and made available in the United States. Such was the impetus for holding the workshop.

Workshop

The workshop theme was, "What are the Nation's fluvial-sediment-data needs, and how can those needs be met with:

- substantially increased temporal and (or) spatial resolution,
- a better and quantifiable accuracy,
- an expanded suite of measurement characteristics,

- reduced costs, and (or)
- a greater margin of safety

compared with traditional, manually intensive data-collection techniques?"

The overarching goals of the workshop were to exchange information and provide a forum in which to develop a vision on how to attain the critical fluvial-sediment-data needs of the Nation. Based on these results, the workshop groups were to make recommendations to the Subcommittee on Sedimentation on steps needed to make this vision become a reality. The scope of the workshop focused on the means for measuring, storing, analyzing, and disseminating data for the following sedimentary phases: suspended sediment, bedload, bed material, and bed topography. The degree of uncertainty in the production of fluvial-sediment data was considered with respect to each of the sedimentary phases, including their storage and computational treatment.

Most of the workshop's outcomes emanated from the closing plenary session and from the four breakout sessions, entitled:

- Suspended-Sediment Measurement: Data Needs, Uncertainty, and New Technologies
- Bedload-Transport Measurement: Data Needs, Uncertainty, and New Technologies
- Bed-Material and Bed-Topography Measurement: Data Needs, Uncertainty, and New Technologies
- Sediment Data: Management, Sediment-Flux Computations, and Estimates from New Technologies

An opening session served to introduce the theme, scope, and general goals of the workshop, and to outline workshop expectations. A field trip to sites of fluvial-sediment interest in northern Arizona took place on September 10, 2003.

Overarching Findings and Recommendations

The following information reflects the broad-scoped deliberations, findings, and recommendations from the workshop. They were culled from the more notable findings and recommendations that were largely or fully shared across the sediment and data management categories. Additional detailed information can be found in the breakout sessions summaries, and in appendix 1, a matrix summarizing selected information gleaned from the breakout and plenary sessions.

Summary of Findings:

I. **Data Issues**:

A. All breakout sessions expressed the need for time-series data—in greater quantities and increased temporal density—for all sedimentary phases and for computational purposes. Ancillary data on similar timescales are need, as are calibration data obtained concurrently by traditional techniques.

B. Protocols for data collection, analysis, computation, and storage, which for the most part are available for traditional technologies, must be developed for sediment-surrogate technologies. A clearinghouse for procedures and data standards is needed for bedload data and for data management.

C. Although some criteria for data accuracy on suspended sediment are available, there is a need for this information to be developed and codified for all sedimentary phases.

D. Information regarding uncertainty associated with measurements is needed for all sedimentary phases and for data storage and computations, with the potential exception of bed material. The need for elucidating the uncertainty associated with bedload data was considered paramount.

E. The accuracy (uncertainty) of data produced by all technologies needs to be quantified, with emphasis on the quality of bedload data, and on the quality of data being stored and used for computational purposes.

II. **Traditional Data-Collection and Data-Computation Techniques**:

A. Protocols for traditional data-collection and computational techniques exist across the categories with deficiencies noted for some bedload conditions and for bed material in unwadeable coarse-bedded conditions.

B. The accuracy of bedload data was considered largely uncertain. The accuracy of computational results, considered the best information available, may be inferred in some cases but is rarely quantified.

III. **Surrogate Techniques**:

A. Several relatively mature and commercially available surrogate techniques are in use for monitoring suspended-sediment concentration. Some surrogate technologies are available for bed-material and bed topography characterization. The few that are available for bedload are either in the research phase or their use is limited to a research setting and none are widely operationally deployed. The performance of techniques for measuring bedload transport remains largely unverified and few are routinely used for monitoring by the Federal government.

B. All techniques have applications in fluvial systems. Selected applications are suitable for other freshwater, marine, coastal zone, and estuarine

settings. Computational procedures may be limited to fluvial systems, at least in the short term.

C. For suspended-sediment and bedload measurements, emphasis should be placed on the development of robust technologies that provide measurements representing a substantial proportion of the material in transport streamwide, as opposed to measurements at a single point in a cross section.

IV. **Models**:

A. Although the workshop focused on data collection, applications for improved modeling accuracy were recognized, particularly for models describing bedload transport. The potential for accurate times-series data to increase the usefulness and range of model application in transport computations was highlighted.

V. **Research and Oversight**:

A. Unanimity was expressed regarding the need for basic research in all of the sedimentary categories, but particularly with bedload transport. Each breakout session indicated that formation of a formal Sediment Monitoring Instrument and Analysis Research Program, as described in "Attributes of a Sediment Monitoring Instrument and Analysis Research (SMIAR) Program," by Gray and Glysson (listed in appendix 4), was needed to oversee and coordinate the evaluation of both surrogate and traditional technologies.

B. Unanimity also was expressed regarding the need for organizational oversight and coordination associated with all categories of sediment-surrogate technologies, data storage, and computational procedures. The Federal Interagency Sedimentation Project (FISP) represents an organization with the necessary background for managing a SMIAR Program.

Summary of Recommendations:

1. **Research:** Coordinated research in all sedimentary phases, but particularly on bedload transport and for storage and computational techniques, is recommended. This includes basic process-based research, along with research on collection, analysis, and computational procedures.

2. **Fluvial-Sediment Time-Series Data:** Emphasis, effort, and funding should be directed toward collection of time-series data in each of the fluvial-sediment categories for computation of flux and other sedimentation characteristics. The data need to be supported by protocols for their collection, analysis, and storage and by comparative accuracy criteria, including quantitative uncertainty values. The data should be evaluated against traditional technologies, where feasible. These data should be used to improve estimates of fluxes, particle-size distributions, and other sediment characteristics derived from models. Clearinghouses for data, tools, methods, and models are needed.

3. **Sediment-Surrogate Technologies**: Several of the technologies presented at the workshop were considered sufficiently compelling and potentially tractable to warrant additional research, testing, and calibration. These technologies should be prioritized and those ranking high in priority should be further evaluated. Evaluations should be made against absolute standards where possible, but also against traditional data-collection techniques, where feasible. These efforts should be done as part of a formal program such as that described by Gray and Glysson, "Attributes for a Sediment Monitoring Instrument and Analysis Program," as listed in appendix 4 of this report.

4. **Sediment Monitoring Instrument and Analysis Research (SMIAR) Program:** Formation of a SMIAR Program (Gray and Glysson, listed in appendix 4), or a program that contains its major elements, should be formalized. The Federal Interagency Sedimentation Project, or another sufficiently capable organization, should oversee and coordinate the SMIAR Program.

Introduction to the Proceeding of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona

by John R. Gray, Theodore S. Melis, Gardner C. Bent, and Gary P. Johnson

The need for reliable, cost-effective, spatially and temporally consistent data on sediment content and clarity of our Nation's waters has never been greater. Traditional uses of fluvial-sediment data in the United States (U.S.) have focused on engineering considerations relevant to the design and management of reservoirs and in-stream hydraulic structures, and dredging. Over the last two decades, information needs have expanded to include those related to contaminated sediment management, dam decommissioning and removal, environmental quality, stream restoration, geomorphic classification and assessments, physical-biotic interactions, the global carbon budget, and regulatory requirements of the Clean Water Act, including the U.S. Environmental Protection Agency's (USEPA's) Total Maximum Daily Load (TMDL) Program. The USEPA identifies sediment, including siltation and suspended solids, as the single most prevalent impairment of U.S. rivers and streams (U.S. Environmental Protection Agency, 2004).

Ironically, the substantial increase in the need for fluvial-sediment data has coincided with a general decline in national-level sediment-data collection as inferred by a two-decade decrease in the number of sites at which the U.S. Geological Survey (USGS) collects daily records of suspended-sediment discharge. The number of these sites increased rapidly in the years following World War II, and peaked at 360 in 1982 (Glysson, 1989; Osterkamp and Parker, 1991). By 2003, only 116 daily-record sediment sites were being operated in the 50 States, although suspended-sediment and bedload data were being collected periodically at 767 and 69 sites, respectively (U.S. Geological Survey, 2004). Any decrease in sediment monitoring should be of particular concern to the Nation in that the physical, chemical, and biological sediment damages in North America were estimated to total about $20 billion in 2004 (Osterkamp and others, 2004).

The traditional techniques used to collect and analyze those data, based on standard protocols (Edwards and Glysson, 1999; Porterfield, 1972), result in production of the most nationally consistent and reliable fluvial-sediment data available in the U.S. (Turcios and Gray, 2001). Production of sediment data by traditional techniques, however, can be manually intensive and time consuming; produce data with an accuracy that may be inferred but that is rarely unequivocally known; and require manual field deployment that may entail safety risks. Use of traditional techniques can also be relatively expensive. For example, an informal poll of selected USGS District offices in 2001 yielded estimates ranging from $20,000 to $65,000 to collect and publish a year's worth of daily suspended-sediment discharge values (Gray, 2002).

Over the last decade, there has been a substantial increase in the availability, measurement capabilities, and research and testing of instruments that purportedly produce continuous and (or) quantifiably accurate sediment-surrogate data that are safer, and (or) less expensive to obtain than by traditional techniques. Optical properties of water such as turbidity (nephelometry) and optical backscatter are the most commonly used surrogates for suspended-sediment concentration, but use of other techniques such as acoustic backscatter, laser diffraction, digital photo-optic, and pressure-difference technologies is increasing for concentration and, in some cases, particle-size distribution determinations in the field and laboratory (Gray and Gartner, 2004). Bedload and bed-material characteristics, and bed topography, also are being inferred from surrogate field measurements. At the same time, data-analysis capabilities have improved or are being developed to convert surrogate measurements into concentration and particle-size distribution statistics, suspended-sediment or bedload transport rates, or bed topography (see appendix 1).

This convergence of advanced instrument technologies and analytical capabilities represents an unprecedented opportunity to evaluate the capability to measure and (or) monitor one or more phases of fluvial sediment with a heretofore unprecedented continuity, temporal density, and known accuracy. If sediment-surrogate data can be shown to meet codified accuracy criteria and appropriate sediment-record computation techniques are applied, these technologies have the potential to revolutionize the way in which fluvial-sediment data are collected, analyzed, stored, and made available in the U.S.

In the U.S., the private sector and universities are in the forefront of developing the instruments for collecting the surrogate data, and for some of the analytical techniques. Not surprisingly, however, there are gaps in applicability due in part

to a lack of coordination of developmental activities. Additionally, assertions regarding instrument performance by manufacturers may fail to be substantiated through independent, unbiased evaluations; hence they are not, unto themselves, solely acceptable as proof of performance to the Technical Committee, Federal Interagency Sedimentation Project (Federal Interagency Sedimentation Project, 2004, Home Page). Hence, there is an important Federal role for coordination and performance testing of sediment-surrogate technologies that may enable development of new national guidelines on sediment-data production, storage, dissemination, and use.

The Federal Interagency Sediment Monitoring and Research Analysis Research Workshop ("workshop") was held in recognition of these factors, and also on four recommendations from the Federal Interagency Workshop on Turbidity and Other Sediment Surrogates (Gray and Glysson, 2003) which are summarized below:

- Technology Transfer and Communication: Increase technology transfer between groups and individuals with interests in turbidity and other sediment-surrogate technologies. A steering committee should be formed that includes a coordinator and topical expert advisers on turbidity and other sediment-surrogate technologies. Resources or activities associated with the steering committee may include publishing a newsletter, creating and maintaining a web-based compilation of information, supporting user groups and on-line help, transferring industrial technology to the environmental field, enhancing communication among producers and users of new technologies, and providing guidance to the Advisory Committee on Water Information and its Subcommittee on Sedimentation.

- Stakeholder and Peer Review: Keep the public and users of turbidity and other sediment-surrogate data informed of the issues involved in producing these data, including assumptions, limitations, methods, and applicability.

- Testing and Development Program for Instruments and Methods: Develop a program to foster research, testing, evaluation, and documentation of instruments and methods for measuring, monitoring, and analyzing water clarity and selected characteristics of fluvial sediment by using cost-effective, safe, and quantifiably accurate means. Technically supportable and widely available standard guidelines for sensor deployment, calibration, and data processing, including real-time data are needed. Acceptance criteria for data on selected parameters, such as suspended-sediment concentration, should be developed, endorsed by the Subcommittee on Sedimentation, and widely advertised to encourage methods and instrumentation development.

- Collection and Computation of Sediment-Surrogate Records: Develop standardized procedures for the collection of sediment-surrogate data. This should include protocols for instrument calibration and accuracy criteria for the derivative sediment data. A standard procedure for computation of sediment-discharge records should be developed for all sediment-surrogate records utilizing the fullest set of data.

The workshop was sponsored by the Advisory Committee on Water Information's Subcommittee on Sedimentation and held at the USGS Flagstaff Field Center, Arizona, September 9-11, 2003. The names, professional affiliations, and locations of the 70 participants representing several Federal agencies, universities, and the private sector registered for the workshop are provided in appendix 2.

The theme of the workshop was, "What are the Nation's fluvial-sediment-data needs, and how can those needs be met with:

- substantially increased temporal and (or) spatial resolution,
- a better and quantifiable accuracy,
- an expanded suite of measurement characteristics,
- reduced costs, and (or)
- a greater margin of safety

compared with traditional, manually intensive data-collection techniques?"

The scope of the workshop focused on the means for measuring, storing, analyzing, and disseminating data for the following sedimentary phases: suspended-sediment, bedload, bed-material, and bed-topography data. The degree of uncertainty in the production of fluvial-sediment data was considered with respect to each of the sedimentary phases.

Improved understanding of constituents sorbed to sediments is in part dependent on a better understanding of the mobility and fate of fluvial sediment. Although considerations related to solid-phase chemistry, and sediment-biotic interactions were beyond the scope of the workshop, it is expected that implementation of selected workshop recommendations will ultimately improve the ability to quantify these characteristics.

The overarching workshop goals were to:

- **Exchange Information** on research into new and improved methods and technologies for monitoring fluvial sediment, including suspended sediment, bedload, bed material, or bed topography and related properties; propose new research directions; and provide an opportunity to view field and laboratory techniques for characterizing selected properties of suspended sediment that currently are being used or tested.

- **Provide Forum** to consider the ways and means to achieve an agreed-upon vision for acquiring, analyzing, storing, and accessing the reliable, quantifiably accurate fluvial-sediment data needed by the Nation.
- **Make Clear and Tractable Recommendations** to the Advisory Committee on Water Information's Subcommittee on Sedimentation regarding research on sediment-monitoring instruments and analytical procedures.

The workshop comprised opening and closing plenary sessions, concurrent breakout sessions, and a field trip to the Colorado River at Glen Canyon Dam, and to USGS Arizona streamgaging stations on the Colorado River at Lees Ferry; the Paria River near Lees Ferry; and Moenkopi Wash during a flash flood.

The opening session served to introduce the theme, scope, and general goals of the workshop, and to outline workshop expectations. This was followed by four concurrent breakout sessions, the respective participants in which are listed in appendix 3. The breakout session titles and their respective leaders were:

- **Suspended-Sediment Measurement: Data Needs, Uncertainty, and New Technologies**, led by Roger A. Kuhnle and Daniel G. Wren.
- **Bedload-Transport Measurement: Data Needs, Uncertainty, and New Technologies,** led by Sandra E. Ryan, Kristin Bunte, and John P. Potyondy.
- **Bed-Material and Bed-Topography Measurement: Data Needs, Uncertainty, and New Technologies,** led by Christi A. Young and Vincent C. Tidwell.
- **Sediment Data: Management, Sediment-Flux Computations**, **and Estimates from New Technologies** led by Mark N. Landers and Larry A. Freeman.

The breakout session leaders were charged with providing a summary of their full findings and recommendations to a final plenary session held on the afternoon of September 11, 2003. Summaries of the respective topics included:

- Statements of the background, key elements, and relevant considerations,
- Lists of key problems and limitations, and
- Recommendations on how to proceed, if at all.

This report describes the principal deliberations, outcomes, and recommendations to the Subcommittee on Sedimentation from the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop. This information is available for evaluation by the Subcommittee on Sedimentation which may opt to develop an action plan based on the recommendations that it endorses for consideration by the Advisory Committee on Water Information.

Extended abstracts supporting most of the presentations at the workshop are listed in appendix 4 of this report and are available only online at *http://water.usgs.gov/osw/techniques/sediment/sedsurrogate2003workshop/listofpapers.html*.

All formal workshop accomplishments were summarized through the activities of the four breakout sessions. Owing to differences in subject matter, the nature in which information was shared and the styles of leaders and participants, products from the breakout sessions were addressed and summarized separately. In an effort to avoid losing the intent and thrusts of each breakout session, these summaries are provided in the following sections without consideration to consistency in format. Where appropriate and useful to the reader, information obtained after the workshop is included in this report.

USGS-authored extended abstracts were reviewed and approved for publication by the USGS. Other extended abstracts listed in appendix 4 prepared by non-USGS authors did not go through the USGS review processes and therefore may not adhere to USGS editorial standards.

Acknowledgements: The authors wish to thank the Advisory Committee on Water Information's Subcommittee on Sedimentation for its support for the Sediment Monitoring Instrument and Analysis Research Workshop, and the USGS Flagstaff Field Center for hosting the workshop. The astute logistical support of the USGS's Elizabeth Fuller was critical to the timely execution of the workshop. The outstanding leadership and support of David Topping, Henry Chezar, David Rubin, and Nancy Hornewer, resulted in a most relevent and informative field trip on September 10, 2003.

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

By Roger A. Kuhnle and Daniel G. Wren

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

[° 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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Breakout Session II, Bedload-Transport Measurement: Data Needs, Uncertainty, and New Technologies

By Sandra E. Ryan, Kristin Bunte, and John P. Potyondy

Introduction

Breakout session II was responsible for providing information on current methods for monitoring bedload transport and for evaluating potential surrogate technologies that appear to show some promise in the future. As part of the charge to the group, there was to be an assessment of the uncertainty associated with measurements obtained from current methods, and a consideration of the quality of bedload data required by a majority of data users. The guiding questions posed to the breakout session follow.

1. What are the methods currently available for measuring bedload movement? What new technologies exist or are on the horizon for measuring bedload transport of various particle sizes in different environments?
2. Are there categories or specific physical samplers that need to be further tested, refined, or approved by the Subcommittee on Sedimentation?
3. How do we define the "true" rate of transport against which to test new and upcoming technologies?
4. Is there a need for a national Federal group such as the Federal Interagency Sedimentation Project to assure validation?
5. What are the types of bedload data needed by users?
6. Are there acceptable levels of error and accuracy that can be specified for bedload?
7. What are desirable characteristics of bedload sampling technology?
8. Where and how should Federal agencies invest limited resources to maximize the potential to bring technologies considered "better" (less costly, certifiably accurate, safer) to operational use?

Extended abstracts in the proceedings of this workshop (listed in appendix 4) related to bedload included:

- Abraham, D., Quantification of bed-load transport using multi-beam survey data: the ISSDOT method (Integrated-Section Surface Difference over Time).
- Barton, J.S., Slingerland, R.L., Gabrielson, T.B., Johnson, P.A., Listening to bedload: a flume study relating acoustic response to bedload motion.
- Braatz, D.A. and Tucker, R.L., A new series of sediment collectors for monitoring true bedload.
- Bunte, K., Potyondy, J.P., and Abt, S.R., Development of an improved bedload trap for sampling gravel and cobble bedload in coarse mountain streams.
- Nichols, M.H. and Renard, K.G., Sediment research and monitoring at the USDA-ARS Walnut Gulch experimental watershed.
- Roberts, J.D., James, S.C., and Jepsen, R.A., Measuring bedload fraction with the ASSET flume.
- Ryan, S.E., The use of pressure-difference samplers in measuring bedload transport in small, coarse-grained alluvial channels.

Current Methods and Possible Surrogates

Direct and indirect methods used to measure rates of bedload transport and the characteristics of different sampling technologies are listed in table 4. Current methods used to quantify bedload-transport rates primarily involve physical samplers that trap material in motion near the channel surface over a known time period. The bedload sample obtained from these devices is subsequently analyzed to determine total mass and calculate percentages of the total in grain-size classes ranging from sand to large cobbles. These data are used with information on the size of the sampler and its duration of deployment to compute bedload-transport rates, as a bulk quantity or in selected particle-size classes.

Portable measuring devices include pressure-difference samplers (such as the US BL-84, Helley-Smith, Toutle River, and Elwha River bedload samplers), bedload traps, and instream baskets (table 4, part 2). While most of these devices have provided useful data in a variety of settings, all have some deficiencies that restrict their use and prevent widespread acceptance as the standard method for monitoring bedload. The

Table 4. Comparison of characteristics of different bedload-sampling technologies with selected references

[N/A is not applicable]

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
1. Instream Installations											
Birkbeck sampler[1] (weighable pit trap)	narrow gravel bed channel	no	no, automatically weighs mass in stream	typically not; depends on slot width	depends on slot width	continuous	yes	easy	may change with fill level	additional testing and modifications	high
Vortex sampler[2]	gravel bed channel	no	yes	yes	yes	continuous	yes	depends on flow conditions	depends on experimental setup	additional testing and modifications	high
Pit traps, unweighable[3]	gravel bed channel	yes	yes	typically not	possibly	possibly	yes, small scale	depends on flow conditions	slightly	additional testing	probably not
Net-frame sampler[4]	gravel bed channel	possibly	yes	yes	yes	yes	depends on experimental setup	can be difficult	depends on experimental setup	completed	possible
Sediment detention basins/weir ponds[5]	sand-gravel bed channels	no	periodically	yes	yes	yes	yes	relatively easy	no	completed	high
2. Portable/physical devices											
Pressure-difference samplers (small openings)[6]	sand-gravel bed channel	yes	yes	no	no	no	no	depends on flow conditions	slightly	additional verification	additional verification needed

Table 4. Comparison of characteristics of different bedload-sampling technologies with selected references—Continued

[N/A is not applicable]

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
Pressure-difference samplers (large openings)[7]	gravel bed channel	yes	yes	no	yes	no	no	depends on flow conditions	highly	additional verification	additional verification needed
Baskets (suspended or instream)[8]	gravel bed channel	yes	yes	depends on design	depends on design	yes	no	depends on flow conditions	depends on experimental setup	completed	moderate
Bedload traps[9]	gravel bed channel	yes	yes	depends on number of traps deployed	yes	yes	minor	depends on flow conditions	slightly	completed: testing of modifications	moderate, with additional verification
Tracer particles (painted, magnetic, signal emitting rocks)[10]	gravel bed channel	possibly	no	depends on tracer placement	N/A	yes	no	easy	no	additional verification	lown
Scour chains; scour monitor; scour core[11]	sand-gravel bed channel	possibly	no	no	N/A	yes	yes	easy	no	completed	low
Bedload collector (Streamside Systems)[12]	sand-gravel bed channel	no	yes	depends on number and size of devices deployed	depends on design of device	yes	yes	operation is easy once installed	unknown	needs verification	needs to be tested

Table 4. Comparison of characteristics of different bedload-sampling technologies with selected references—Continued

[N/A is not applicable]

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
3. Surrogate Technologies											
ADCP – acoustic Doppler current profiler[13]	sand bed rivers, experimental in larger gravel bed channels	no	no	yes	N/A	continuous	no	logistics and data reduction are complex	no	moderate (sand systems) early (gravel systems)	additional verification for gravel bed systems
Hydrophones (active and passive acoustic sensor)[14]	gravel bed channel	no	no	depends on deployment	N/A	continuous	possibly	easy	no	early	additional development needed
Gravel impact sensor[15]	gravel bed channel	yes, for hand-held model	no	not as currently designed	N/A	continuous	yes for instream model	easy under many conditions	in fast flow	early	additional development needed
Magnetic Tracers[16]	gravel bed with naturally magnetic particles	no	no	yes	N/A	continuous	yes	relatively easy	depends on experimental setup	additional testing	possible at appropriate locations
Magnetic sensors[17]	gravel bed channel	no	no	yes	N/A	continuous	yes	easy under many conditions	minor; flush with stream bottom	early	additional verification needed
Topographic differ-encing[18]	sand-gravel bed channel	no	no	yes	N/A	episodically or continuous	no	easy	no	early?	additional verification for gravel bed systems
Sonar-measured debris basin[19]	gravel bed channel	no	no	yes	N/A	continuous	with debris basin installation	easy under many conditions	N/A	early	high

Table 4. Comparison of characteristics of different bedload-sampling technologies with selected references—Continued

[N/A is not applicable]

Bedload-Sampling Technology	Stream Type	Requires Wading or Retrieval During High Flows	Physical Sample Obtained for Sieving	High Percentage of Channel Width Sampled	Large Opening Relative to Grain Size	Relatively Long Sampling Duration	Stream Excavation Required	Relative Ease of Use	Disruptive to Flow Fields	Status of Development	Potential Use as Calibration Standard
Underwater video cameras[20]	relatively clear flow	used from bridges or boats	no	no	N/A	continuous	no	easy under right lighting conditions	slightly	early	additional verification needed

[1]**Birkbeck sampler**, Reid and others, 1980, 1985; Reid and Frostick, 1986; Lewis, 1991; Harris and Richards, 1995; Reid and Laronne, 1995; Powell and others, 1998; Garcia and others, 2000; Habersack and others, 2001; Laronne and others, 2003; Sear and others, 2000; Sear, 2003

[2]**Vortex sampler,** Milhous, 1973; Hayward and Sutherland, 1974; Hayward, 1980; O'Leary and Beschta, 1981; Tacconi and Billi, 1987; Atkinson, 1994

[3]**Unweighable pit traps**, Church and others, 1991; Powell and Ashworth, 1995; Bunte, 1997; Hassan and Church, 2001; Sterling and Church, 2002

[4]**Net-frame sampler,** Bunte, 1992, 1996; Whitaker and Potts, 1996; Whitaker, 1997

[5]**Sediment detention basins/weir ponds,** Troendle and others, 1996; Ryan and Porth, 1999; Bunte, 2002; Bunte and Swingle, 2003

[6]**Pressure-difference samplers (small openings),** Helley and Smith, 1971; Druffle and others, 1976; Johnson and others, 1977; Beschta, 1981; Emmett, 1980, 1981; Pitlick, 1988; Childers, 1991; Gray and others, 1991; Gaudet and others, 1994; Hardardottir and Snorrason, 2003; Ryan and Troendle, 1997; Ryan, 1998; Ryan and Porth, 1999; Ryan and Emmett, 2002; Sterling and Church, 2002; Ryan, 2005 (see appendix 4)

[7]**Pressure-difference samplers (large openings),** Hubbell and others, 1985, 1987; Gao, 1991; Childers, 1991, 1999; Dinehart, 1992; Xiang and Zhou, 1992; Yang and Gao, 1998; Childers and others, 2000; Duizendstra, 2001a, b; Habersack and Laronne, 2001, 2002; Ryan, 2001; Hayes and others, 2002

[8]**Baskets (suspended or instream),** Hubbell, 1964; Nanson, 1974; Engel and Lau, 1981; Gao, 1991; Xiang and Zhou, 1992; Nankervis, 1994; Wilcock, 2001

[9]**Bedload Traps,** Bunte; 1998, 1999, 2001, 2002, Bunte and Swingle, 2002, 2003, 2004; Bunte and others, 2001; Bunte and Abt, 2003; Bunte and others, 2004; Bunte and others, 2005a; Bunte and others, 2005b (see appendix 4)

[10]**Tracer particles (painted, magnetic, signal emitting rocks),** Laronne and Carson, 1976; Butler, 1977; Kondolf and Matthews, 1986; Chacho and others, 1989, 1994, 1996; Hassan, 1990; Hassan and Church, 1992; Hassan and others, 1991, 1992, 1999; Busskamp and Ergenzinger, 1991; Schmidt and Ergenzinger, 1992; Busskamp, 1994a and b; Busskamp and Gintz, 1994; Schmidt and Gintz, 1995; Wathen and others, 1995; Sear, 1996; Emmett and others, 1996; Gintz and others, 1996; Thompson and others, 1996; Ferguson and Wathen, 1998; Ferguson and others, 1998; Haschenburger and Church, 1998; Rosenfeld and others, 1996; McNamara and others, 2001; Habersack, 2001, 2003; Hassan and Ergenzinger, 2003; Ergenzinger and De Jong, 2003; Sear and others, 2003

[11]**Scour chains, scour monitor, scour cores,** Laronne and others, 1992; Haschenburger and Church, 1998; DeVries and others, 2001; McBain and Trush, 2004

[12]**Bedload collector (Streamside Systems),** Braatz and Tucker, 2005 (see appendix 4)

[13]**ADCP – acoustic Doppler current profiler,** Rennie and others, 2002

[14]**Hydrophones (active and passive acoustic sensor),** Bänzinger and Burch, 1990, 1991; Taniguchi and others, 1992; Rouse 1994; Rickenmann, 1994, 1997; Rickenmann and Duspasquier, 1994; Rickenmann and others, 1997; Bogen and Møen, 2003; Mizuyama and others, 2003; Froehlich, 2003; Barton and others, 2005 (see appendix 4)

[15]**Gravel impact sensor,** Downing and others, 2003; Richardson and others, 2003

[16]**Magnetic tracers,** Bunte, 1992, 1996; Ergenzinger and others, 1994a, 1994b

[17]**Magnetic sensors,** Tunnicliffe and others, 2000; Gottesfeld and Tunnicliffe, 2003

[18]**Topographic differencing,** Bransington and others, 2000; Dinehart, 2001; Rubin and others, 2001; Abraham, 2005 (see appendix 4)

[19]**Sonar-measured debris basin,** D'Agostino and others, 1994; Lenzi and others, 1990, 1999

[20]**Underwater video cameras,** Dixon and Ryan, 2001; Ryan and Dixon, 2002

use of some devices requires wading in streams at high flows under potentially hazardous conditions in order to retrieve samples. There may be low confidence in the results from some portable devices because they collect samples from discrete widths of the streambed for short time periods, which can be an inferior sampling strategy for monitoring processes associated with exceptionally large spatial and temporal variability. Other devices more effectively and continuously monitor coarse sediment transport (vortex samplers, Birkbeck samplers) but require permanent installations in relatively small streams, and therefore are restricted to a few locations (table 4, part 1).

Potential surrogate technologies were presented and discussed in breakout session II including acoustic devices (Barton and others; listed in appendix 4) and topographic differencing using multi-beam bathymetric data for larger sand-bed rivers (Abraham; listed in appendix 4). Other surrogate technologies discussed included the ADCP (acoustic Doppler current profiler), gravel impact sensors, magnetic field sensors, underwater video cameras, and debris basins outfitted with capabilities for automatically measuring the accumulated volume (table 4, part 3). The breakout session participants generally agreed that surrogate technologies for monitoring bedload are largely in early stages of development and require additional development, testing and verification of surrogate signals against physical samples.

Summary of Deliberations and Observations

A summary of observations and associated group discussion are presented in the following section.

1. The breakout group recognized an overarching need for more thorough testing of the accuracy of existing devices. However, even with the uncertainties regarding the accuracy of the current technologies, existing physical samplers represent the long-term standard for bedload measurement, and so they should be retained for use in comparisons to newer (and presumably superior) technologies. Related to this observation, there was a recognized need for better documentation of existing samplers, including information on limitations and uncertainty of the data obtained.

   Observation 1: There is a need to further evaluate the accuracy of physical bedload samplers, develop new physical samplers, and investigate the use of surrogate technologies for quantifying bedload transport.

2. The group recognized that there are substantial verification issues associated with historical and current bedload-sampler testing procedures and that no standardized, generally accepted, readily available, reliable and robust test procedure exists against which to compare current and new technologies. Consequently, it is difficult to make progress toward development and validation of surrogate technologies until there is a way to adequately quantify the true rates of bedload transport. Ways to determine true transport will depend largely on the stream types and classes of bed materials to be studied and will likely include permanent instream installations that collect all materials moved as bedload, such as weir ponds (e.g., Ryan and Porth, 1999; Troendle and others, 1996), slot-conveyor belt samplers (e.g., Emmett, 1980), vortex samplers (e.g., Milhous, 1973), or Birkbeck samplers (e.g., Reid and others, 1980; Lewis, 1991). Several technologies may be utilized at each of the installations, recognizing that not all methods may be capable of monitoring the full range of materials transported or addressing the questions of concern. For example, collection baskets may be used in conjunction with a weir pond so that information on the timing and amount of gravel movement is obtained in addition to the total volume of sediment accumulated in the pond. Finally, the group recognized that some testing would require more controlled conditions, such as calibration in indoor flumes, in order to obtain measurements from a wider range of conditions than might be observed in a given field season.

   Observation 2: There is a need for nationally recognized calibration field sites in streams representing a variety of bed materials (e.g., gravel bed, sand bed, mixed bed) and hydrologic regimes (e.g., snowmelt and rainfall dominated) for collection of sufficiently detailed bedload and ancillary data to facilitate validation of bedload technologies.

3. While development of new technologies by non-Federal entities was encouraged, the group felt that there should be one such oversight organization responsible for the testing and validation of bedload sampling technologies. This responsibility should rest primarily with a Federal organization (the FISP or another similar organization). This group, however, should request outside peer review and seek the advice of academic and external researchers in developing the testing program. In addition, this group needs to share information among users and developers through forums such as symposia, informational websites, and newsgroup discussions.

   Observation 3: There is a need for a federally based group to oversee testing, validation, standardization, and documentation of bedload sampling technologies and protocols, and for standardized data storage.

4. Information published from bedload transport studies, and particularly data gathered at nationally recognized field sites, should include a high level of comprehensiveness and detail because users of bedload data require a variety of types of information depending on the users' objectives. As a minimum, published bedload data should consist of transported mass measured over a

specified time frame in individual size classes (e.g., ½ to one phi). Bedload mass averaged over short time frames (e.g. hours) would be reported as a mean instantaneous value for that period of time. Total bedload volume may be expressed by event, season, year, or other specified time frame, depending on the nature of bedload-entraining flows. Ancillary data, such as the type of sampler used and flow conditions during the sampling period, are a necessary component of any bedload dataset. Data on the characteristics of the bed material at the sampling site should be published along with the bedload data. Information on the spatial and temporal variability of transport should be published, as available. A continuous real-time record would be desirable and most users of bedload data would be willing to give up some level of accuracy in order to better understand the temporal variability of the transport processes. Regarding acceptable levels of error and accuracy that can be specified for bedload, the group concluded that we are simply not in a position to make recommendations because of the state of the science and our inability to assess the true rate of bedload transport outside of a limited number of sites.

Observation 4a: Users require comprehensive information in published bedload data.

Observation 4b: At this point in time, acceptable levels of error and accuracy cannot be established for bedload samplers because the true rate of bedload transport is rarely known.

Observation 4c: Standards and protocols need to be developed for establishing the accuracy of bedload measurements.

5. The group characterized the ideal sampling technology as one that would ultimately provide accurate measurements and precise data on the amount and sizes of material moved as bedload over a wide range of flow conditions. The device or technology should be portable or easily deployed in a number of types of rivers and streams. It should be reliable, safe to operate, and used without wading in streams at high flow. The device should be foolproof, easy to calibrate, and not disrupt the local transport field to the extent that it affects measurement. Since the technologies are likely to be used in systems moving coarse gravel and cobbles, they need to be rugged, durable, and able to withstand occasional collisions with large grains. Technologies that are automated and have low power requirements would be particularly useful in remote environments. Continuous records are needed to evaluate the temporal variability of the transport process. Several units may be deployed in order to evaluate spatial variability. The technology should be scaleable, with different sized devices available for channels of varying size and bed material. Finally, the technology must be affordable so that monitoring may be carried out at more than one site.

   Observation 5: The developers of bedload sampling technologies are encouraged to incorporate many of the ideal characteristics listed above into a single design. No single technology is likely to serve all data needs and more than one method may be required to assess the full range of bedload transport processes in a wide range of channel types.

6. The cost of developing new bedload technologies in times of decreasing budgets was recognized as a constraint to progress. Yet, there was an expressed need for pursuing the development of improved physical and new surrogate technologies. By focusing efforts at a few designated research sites, Federal agencies could invest limited resources while maximizing the potential to bring improved technologies to operational use. In the meantime, there should be an effort to improve understanding of the advantages and limitations of the current suite of technologies available for monitoring bedload transport.

   Observation 6: There is a need for the development of surrogate bedload technologies. Our ability to measure bedload transport is deficient and physical measurements must be improved to allow the evaluation of new technology.

Primary Recommendations

The items listed here are specific recommendations for developing programs to improve our ability to monitor bedload and to test new instrumentation.

Recommendation 1: The development of nationally recognized sites for field calibrations of bedload sampling technologies should be given high priority to bring "better" (less-costly, certifiably accurate, safer) technologies to operational use. These are sites where true rates of transport are known and the accuracy of sampling technologies can be evaluated.

Recommendation 2: There should be a federally based oversight organization responsible for the field calibration sites, such as the FISP or a similar-type organization. This bedload-research program could be part of the proposed Sediment Monitoring Instrument and Analysis Research (SMIAR) Program, such as that currently operated informally by the USGS, the components of which are described by Gray and Glysson (listed in appendix 4).

Recommendation 3: Additional discussion is needed on selecting the candidate sites for field testing bedload-

sampling technologies and the types of devices to be used in determining true rates of bedload transport. A separate work group that focuses solely on bedload issues should be convened to develop recommendations on how this might be done.

Recommendation 4: A white paper is needed to provide a comprehensive and unbiased evaluation of all existing bedload technologies and potential surrogate technologies. This paper would describe the state of the art in bedload measurement, offer recommendations on the use of devices in different types of stream environments, and provide guidance on desired sampler accuracy requirements for commercial developers.

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Breakout Session III, Bed-Material and Bed-Topography Measurement: Data Needs, Uncertainty, and New Technologies

By Christi A. Young and Vincent C. Tidwell

Introduction

Breakout session III focused on current and emerging bed-material and bed-topography data-collection techniques and methods. How these data are used by each of the represented agencies and uncertainties associated with these data were also discussed. The experience and interests of the participants were skewed more toward measurement of bed topography. Various surveying technologies applicable to bed-topography measurement received considerably more deliberative time and attention than bed-material measurement techniques, although many of the technologies identified were applicable to both types of measurements and to bedload measurements. Discussions focused on new technologies with agreement that traditional technologies are the standards for evaluation of surrogate technologies.

Discussions

Participants were sent key questions prior to the workshop to facilitate discussion. These key questions are similar to those posed in other breakout sessions and are shown below in italics. The responses to each question represent participant consensus.

1. *What are your agency's/organization's/cooperator's (organization) needs for this type of sediment data? How are these data used by your organization?*

Bed-topography and bed-material data are collected and used generally as a basis for resource-management decisions. Monitoring programs are common for reservoir capacity, habitat conditions, navigation routes, channel and coastal evolution (geometry and bed-material size), discharge capacity, sediment transport and contaminant movement. The decisions may involve operation, maintenance, planning, design, construction, or compliance issues. Decisions often must be made that involve multiple issues and constraints. Predictive models used as tools to compare alternatives and project impacts often require bed-topography and bed-material data as independent variables.

2. *Does your organization have any accuracy standards for collecting theses types (bed topography or bed material) of sediment data?*

National and international mapping standards such as those maintained by the USGS National Mapping Program, Federal Geographic Data Committee, the National Institute of Standards and Technology, and the North Atlantic Treaty Organization's Digital Geographic Information Exchange Standard were referred to for topographic and hydrographic data. Survey manuals and guidelines have been published by the U.S. Army Corps of Engineers (2002), American Society of Civil Engineers (1975), ASTM International (2003), and the International Hydrographic Organization (1997).

The accuracy requirements for topographic and hydrographic data usually are based on budget constraints and are spelled out specifically for individual data-collection efforts. The group emphasized that metadata accompanying all terrain/bed data should include data-collection details and documentation of data accuracy. Generally, 0.3- to 0.7-meter contour intervals are sufficient for most large-scale fluvial applications when data are collected via remote methods such as aerial photogrammetry or LIDAR for long reaches. An example of accuracy requirements would be 90 percent of points within ± 0.15 meter, and 100 percent of points within ±0.3 meter. In small-scale, complex situations at least ±0.03 meter accuracy may be required and can be obtained with a good control network using land surveying techniques.

In the U.S. Army Corps of Engineers' (USACE) EM 1110-2-1003 (2002), several error components are described for electronic echo sounding depth measurement methods used in bathymetric surveys of underwater bed topography. These sources of error include: measurement system accuracy, velocity calibration accuracy, sounder resolution, draft/index accuracy, tide/stage correction accuracy, platform stability error, vessel velocity error, and bottom reflectivity/sensitivity. These combined errors result in an estimated accuracy of an individual echo-sounding depth falling between ±0.1 and ±0.3 meter for average river and harbor project conditions. Airborne technologies have similar error sources. Accuracy (closeness of a measurement to the actual value) should not be confused with the precision or repeatability of measurements.

There was little discussion concerning accuracy standards for bed-material data. Depending upon the homogeneity of the

surface and subsurface bed material, the location, density, and timing of sampling can impact the accuracy of bed-material data as much as the sampling and analysis equipment and procedures. Many technical society and government references provide guidance for the collection and analysis of bed-material samples including a USGS publication (Edwards and Glysson, 1999); Forest Service publications (Bunte and Abt, 2001a; 2001b); U.S. Army Corps of Engineers (1995); International Organization for Standardization (1997); American Society of Civil Engineers (1975); ASTM International (2003); and Canadian publications by Yuzyk and Winkler (1991), Ashmore and others (1988), and Yuzyk (1986).

Data uncertainty also was discussed. Participants viewed uncertainty as being inherent in traditional and new technologies. There are many potential sources of error: user, equipment, interpretation, and data processing. Uncertainty also is dependent upon system spatial and temporal variability. As stated previously, accuracy requirements tend to be project-specific and time- and budget-driven. We agreed that data accuracy and uncertainty information should accompany all data.

3. What methodologies and equipment are currently used to collect bed-topography and bed-material data in your organization? What are their strengths and limitations? What uncertainties are associated with them?

Bed topography: The historical standard for bed topography incorporated the measurement of set range lines by conventional land surveying equipment and techniques using stadia rods, transits, and total stations. Traditional methods are labor intensive and require considerable ground access and cleared site distance. Advances in global positioning systems (GPS) have in most applications eliminated the need for manual horizontal measurements. GPS-based methods were considered to be the most accurate (± millimeter range) and are used to calibrate, ground truth, and check other methods.

Photogrammetric mapping or non-contact stereo aerial surveying was considered to be the more established, less costly, passive surveying technology. The accuracy of this technology depends upon the amount of ground truth-data available. The mosaic of individual photographic images can be used to develop cross sections and topographic maps. A limitation of this technology is the inability to obtain underwater prism information or ground surface elevations through dense vegetation.

Light Detection and Ranging (LIDAR) remote sensing systems applications are increasing with advancements in this new technology. This technology also needs clear sight distance so ground surface data cannot be obtained in heavily vegetated areas. Early successful applications were in coastal surveys. More recent applications have incorporated airborne LIDAR bathymetry technology (1-kilohertz laser deployed with a 10-kilohertz topographic laser and a digital camera, e.g. Optech's SHOALS-1000T system) to obtain bathymetry data in addition to topography. LIDAR bathymetry technology is largely dependent upon water clarity; turbidity and turbulent white water conditions can cause problems. The system can detect channel-bottom elevations up to about 2.5 times the Secchi depth, in coastal applications possibly up to 30 meter or more. Underwater data need to be corrected for the adsorption rate of water. The spatial density of points is related to the flight height; flight elevations can be higher for topography data collection than bathymetry.

Bathymetric surveying techniques have developed rapidly in the past decade due to recent developments in multi-beam depth sounders. The multi-beam system provides the option of complete coverage of the underwater areas, thus removing the unknowns of previously unmapped underwater areas. There are high-grade GPS collection systems, real-time kinematic surveying, that accurately measure the altitude of the moving survey platform with obtainable centimeter accuracies for both horizontal and vertical measurements. There also are several versatile commercial software packages capable of simultaneously receiving data from multiple devices during collection and then processing the collected data for complete analyses. In addition to collecting data from numerous instruments simultaneously, the computer and software can be set up to integrate data from various sensors such as gyros, acoustic systems, heave-pitch-roll indicators, magnetometers, and seabed identifiers (Bureau of Reclamation, in press).

Advances in computer systems and surveying technologies in recent decades have dramatically increased the volume of data and the rate of data acquisition and processing. These technologies have become widely accepted because of the increased coverage and reduced costs. Survey productivity has increased by a factor of 75 times since the 1960s and 10 times since 1990s (U.S. Army Corps of Engineers, 2002). The productivity increases are mainly related to the electronic and computer development. Many of these new technologies, instrumentation, and associated software programs continue to evolve rapidly and are designed to be applied by a frequent user as considerable time is required to become proficient in their use.

Bed Material: Most participants reported that their agencies continue to use standard, physical, bed-material sampling equipment (hand-held samplers US BMH-53, US BMH-60, and US BMH-80 and the cable-and-reel US BM-54 sampler; Federal Interagency Sedimentation Project, 2004, Home page) and standard analysis techniques to accurately measure bed-material particles finer than about 16 millimeters. Sampling procedures for larger particles include pebble counts and grid or areal sampling for surface materials. The US SAH-97 hand-held particle size analyzer (Federal Interagency Sedimentation Project, 2004, Home page) and a sampling frame (Bunte and Abt, 2001b) are among recent equipment developments to improve pebble-count accuracy. Submerged surface and subsurface materials are sampled using a shovel or backhoe, pipe or barrel samplers, and freezer or resin core sampling techniques. The cost of collecting, transporting, and analyzing bed-material samples has severely limited the amount of data collected. Several participants had used digital

photographic data and software to determine the size gradations of surface bed material in lieu of pebble counts in coarse-bed streams. Hand rodding and dynamic cone penetrometer testing has been used to locate subsurface layers.

4. What are the new technologies that may be useful in this area?
   - -- Is the new technology on the verge of being deployed at a large scale?
   - -- What limitations of existing equipment or methods would this technology improve on?
   - -- Is the new technology limited to specific application conditions?
   - -- What are the uncertainties associated with the new technology?

Several new technologies and their potential applications to bed-topography or bed-material data collection were discussed. The technologies were divided into three broad categories: acoustic, electromagnetic, and optic. The information presented in table 5 reflects the opinions and experience of the participants, and should be used only as a qualitative assessment of the various technologies. Many of these technologies have been applied successfully in coastal and marine environments, and research is currently being conducted for riverine applications that include greater turbidity, bed variation, and flow velocities than are found in marine systems.

Table 5. Bed-topography measurement technologies

[ADP is acoustic Doppler profiler; ADCP is acoustic Doppler current profiler; ± is plus, minus]

Technology	Accuracy	Cost in dollars (thousands)	Limitations, strengths, weaknesses	Research
Acoustic Technologies				
Normal incident (single beam)	±1 percent depth in marine environments	15-30	Simple, commercial available, minimal processing time, increased acquisition time	Multi-frequency analysis
ADP/ADCP (backscatter)	±1 percent of comparable methods	15-20	Convenient, can infer suspended-sediment concentrations	Main focus currently is on suspended sediment
Multi-beam	±1 percent depth marine environment	100-500	Commercially available, many more data points collected, greater coverage, processing intensive (10x single beam), problems with turbulence and platform motion are magnified from single beam	Backscatter to characterize bed material, evolving on many fronts
Side scan sonar, Dual Frequency Identification Sonar (DIDSON)	Qualitative, well-refined image	30-100	Commercially available; superior image resolution; real-time views of bed-surface features, texture, and object location; works even in turbid water where optical systems would fail; towed in a fish, stability could be an issue	Draping image on georeferenced multi-beam image
Electromagnetic Technologies				
Ground Penetrating Radar (GPR)	±5 percent (precision unknown)	50-60	Non-contact; would be good for monitoring during floods; restricted use; freshwater applications, conductivity affects depth range	Has focused on discharge measurements, applications in sediment just starting
Time Domain Reflectometry (TDR)	< 5 millimeters	10-15	Must be installed in stream; uses a cable to conduct signal; measures continuously air/water/soil interfaces; remote system; probe signal impacted by scour or aggradation	Stream applications are being researched

Table 5. Bed-topography measurement technologies—Continued

[ADP is acoustic Doppler profiler; ADCP is acoustic Doppler current profiler; ± is plus, minus]

Technology	Accuracy	Cost in dollars (thousands)	Limitations, strengths, weaknesses	Research
Optical Technologies				
Laser (LIDAR, Light Detection and Ranging)	Considered "very good"	80-150, 10-20	Vegetation can cause problems; non-contact, above ground or aerial deployment; considerable post-processing usually by contractor; commercially available, purchased less often; potential to obtain underwater prism in some cases; active	In developing stages
Hyperspectral Irradiance		50-70	Non-contact; passive system; currently mainly used for land classification; limited to shallow (10 meter), clear water applications; data must be collected in daylight hours; dynamic range limits resolution	Ongoing for coastal sediment applications, future field applications proposed

New technologies discussed for bed-material measurements included expanding bed-topography acoustic technologies to obtain bands of bed-material size gradations and stratigraphy. Optical technologies including the underwater microscope system and analysis algorithm (U.S. Geological Survey, 2001; Rubin, 2004) were presented in the plenary session. This system has the capability to acquire and analyze digital images of sediment grains on a riverbed or sea bottom eliminating the need to manually collect or physically analyze sediment samples. This type of technology holds the promise of reducing the costs associated with the acquisition of bed-material data. Digital photography and video technologies should be further developed to provide more continuous coverage and to provide the ability to utilize multiple cameras for mixed bed applications. Electromagnetic technologies could be expanded to provide some stratigraphy or gross bed-material identification.

5. Is there any research planned in your organization to improve the collection or analysis of bed-topography or bed-material data?

Presentations, workshop extended abstracts, and discussions about current and planned research and applications of new technologies are summarized below.

Time domain reflectometry for real-time and continuous stream monitoring, presented by Vince Tidwell. Time domain reflectometry (TDR) operates by propagating a radar frequency electromagnetic pulse down a transmission line while monitoring the reflected signal. As the electromagnetic pulse propagates along the transmission line, it is subject to impedance by the dielectric properties of the media along the transmission line (e.g., air, water, sediment), reflection at dielectric discontinuities (e.g., air-water or water-sediment interface), and attenuation by electrically conductive materials (e.g., salts, clays). Taken together, these characteristics provide a basis for integrated stream monitoring; specifically, concurrent measurement of stream stage, channel profile, and aqueous conductivity. Requisite for such application is a means of extracting the desired stream properties from measured TDR traces. Analysis is complicated by the fact that interface location and aqueous conductivity vary concurrently and multiple interfaces may be present at any time. For this reason, a physically based multi-section model employing the S_{11} scatter function and Cole-Cole parameters for dielectric dispersion and loss is used to analyze acquired TDR traces. Tidwell and Brainard (in press) explored the capability of this multi-section modeling approach for interpreting TDR data acquired from complex environments, such as found in stream monitoring.

A series of laboratory tank experiments were performed in which the depth of water, depth of sediment, and conductivity were varied systematically. Results indicate that the measured TDR traces respond to changes in interface position and aqueous conductivity in a manner consistent with multi-section model simulations. In fact, the multi-section model was found to accurately fit the measured traces over a broad range of test conditions. Comparisons between modeled and independently measured data indicate that TDR measurements can be made with an accuracy of $\pm 3.4 \times 10^{-3}$ meter for sensing the location of an air/water or water/sediment interface and ±7.4 percent of actual for the aqueous conductivity.

Recently, TDR monitoring systems have been installed on the Rio Grande in New Mexico and Paria River in Arizona. The USGS streamflow gaging station on the Rio Grande at Albuquerque includes seven TDR probes for monitoring changes in channel morphology, while another probe measures stream stage and aqueous conductivity. The TDR system at the USGS streamflow gaging station, Paria River at Lees Ferry, is designed to measure stream stage and aqueous conductivity. In both cases, TDR measurements are compared directly with

measurements made by the USGS using standard float, pressure transducer, and (or) radar technologies.

Naval Research Laboratory acoustic sediment classification system presented by Don Walter. This system collects bathymetry data and impedance values to output sediment properties such as: attenuation, density, porosity, sediment type, mean grain size, compressional velocity, shear velocity, and shear strength (semi-quantitative) up to a maximum of 4 meters below the bed. The technology was used traditionally for mine location and can be applied from surface ships, submarines, and air-borne craft. Echo-strength lines and segment data time/depth line, represent separation of gradations. An example of a lake bottom application was presented. Gas bubbles and density of bottom material impact the return intensity; bubbles can make the system lose the bottom location. Turbulence also can cause bubble pulse problems. These problems can be overcome by using different frequencies. Bottom roughness is an issue, depending upon beam width; bed forms can be identified. Future application will include using side scanning sonar to cover a swath of the bed.

ADCP bridge scour studies; multi-beam survey applications; CHARTS and SHOALS LIDAR technologies; DIDSON sonar technology; and potential new research in radar applications presented by Dan Eng. Various research studies being conducted by the USACE were presented. ADCP technologies are being deployed remotely with internal pitch and roll compensation for bridge scour studies. LIDAR technologies being jointly research by the USACE and Navy, which incorporate above- and below-water surface topographic data collection, include the currently under-development CHARTS (Compact Hydrographic Airborne Rapid Total Survey) system, an improved version of the SHOALS (Scanning Hydrographic Operational Airborne Lidar Survey) system. DIDSON (Dual Frequency Identification Sonar) technologies obtain high resolution underwater acoustic images for object identification, with some modifications to the sensor array this technology could be used to obtain 3-dimensional data on bed profile and bedload transport especially in turbid waters. Repeat multi-beam surveys are being used to quantify changes in bed topography over time (this work was presented in the bedload breakout session II; see the extended abstract by Abraham (listed in appendix 4). Research into the aerial application of ultra wide-band radar similar in frequency to ground penetrating radar is in the early stages. There is the potential to obtain data quicker and with better resolution than some of the other technologies. The widespread use of these radar frequencies may be limited because of communication interference and health concerns. Synthetic aperture radar, currently used in military mapping applications, is an acoustic technology that could potentially provide information similar to LIDAR without light restrictions.

Underwater Microscope System and bed-topography measurement techniques applied in the Grand Canyon presented by Dave Rubin and Matt Kaplinski. Dave Rubin had presented very promising results on the application of a underwater microscope system in the opening plenary session for the measurement of bed sediments with the location of sampling sites obtained within a few meters. The challenges created by the vertical canyon walls in the Grand Canyon to the application of surveying technologies such as GPS, which rely on satellite communication, were highlighted. Photogrammetry contour errors vary because of vegetation and ground-truthing problems. They typically can obtain photogrammetry data with an accuracy of about 0.25 meter, with reduced accuracy in forested areas.

Bed-topography data are collected in the Grand Canyon about every two years or before and after floods. Although GPS in combination with total stations are used to establish a closely spaced control network on the canyon rim, a robotic range azimuth system is used to establish location in the canyon. Multi-beam bathymetry data are collected at flows of 230 cubic meters per second; gravel bar data are supplemented with data from 850 cubic meter per second flows. Bathmetry data are collected using a RESON 8125 with 240 beams; ½-degree beam width down to a 0.5 meter. This narrow swath is sorted on a 0.6-meter x 0.6-meter grid spacing.

QTC Multiview, a post-processing software, uses backscatter data from the multi-beam equipment with data from known sediments to obtain the distribution of sediment types (for differentiation between gravel versus sand deposits; possibly also between silt versus clay deposits). This technology obtains high-resolution data and can almost measure the texture of the bottom. Some difficulties have been encountered when collecting backscatter data and topography data using the same transducer. Side scanning sonar data have been collected and once registered spatially, a time consuming process, can also be combined with aerial photography. Although bedload is not as significant as the suspended load in Colorado River sediment transport, side scanning sonar data have been used to estimate bedload transport (½ dune height times the dune movement rate). Dave Rubin encouraged participants to explore the possibility of working with a lab sponsored by the National Science Foundation to collect and process LIDAR data.

The following additional extended abstracts listed in appendix 4 contain information on bed-topography and bed-material measurement technologies.

Dinehart, R.L., Spatial analysis of ADCP data in streams: This extended abstract describes using ADCP data to obtain bathymetric data and velocity to infer sediment transport.

Jackson, W.L., Regulated river restoration monitoring: The Elwha River dam removal and restoration project. This extended abstract emphasizes the need for real-time data collection and evaluation especially when dealing with dam removal sediment loading conditions; and provides details on monitoring plan for Elwha River Restoration Project which includes bed-material size measurements and channel geometry as monitoring sub-categories.

Martini, Marinna, USGS capabilities for studying sediment transport in the ocean: This extended abstract describes several technologies being investigated by the USGS

Coastal and Marine Geology Program including: applying side scanning sonar, sector scanning sonar, Differential Global Positioning System (DGPS), and sub-bottom profilers for mapping and coastal and sea bottom imaging; photographic systems that show promise for determining grain size such as a version of underwater microscope system discussed previously which recently underwent its first full field trial and the SEABOSS that can obtain real time video of the bottom, take 35-millimeter still images, and acquire a grab sample; and mechanical sampling systems such as the hydraulically damped slow corer that does not disturb the sediment-water interface during sampling and the Honjo trap, a long-term, in-situ time series settling trap consisting of a large-diameter collecting cone attached to a rotating carousel of collection bottles that collects samples on a preset schedule.

Parchure, T.M., Sobecki, T.M., and Pratt, T.C., Fine sediment parameter measurement for sedimentation studies: This extended abstract describes the need for research of fine sediment parameters and the development of inexpensive equipment and procedures for testing fine sediments.

6. What are the priorities for research in this area?

Many current and suggested research items have been previously discussed. The participants agreed that industry has taken the lead in the development and adaptation of the latest technology for the instrumentation and associated software used to collect and analyze bed-topography data. Research and development of bed-topography technologies should be left mostly to industry with agencies providing consistent feedback. A collective voice in feedback would be more effective. Research priorities include:

- Combining technologies and expanding existing capabilities (e.g. bed-topography technologies expanded to provide bed-material characterizations)
- Applied research on non-contact, continuous systems
- Further investigation of opportunities to adapt coastal/marine or ocean applications to the riverine environment
- Continued development of optical and acoustical surface bed material measuring and analysis technologies
- Shared development and distribution of post-processing applications

The ideal sampler or measurement technology would have the following characteristics:

- Adaptable under a variety of conditions
  - -- Marine, estuarine or riverine
  - -- Clear or turbid
  - -- Soft, fine or hard, gravel/cobble beds
  - -- Steep or flat terrain
  - -- Underwater/shoreline interface
- Provide quantifiably accurate results
- Reliable
  - -- Low maintenance, non-fouling, rugged
  - -- Simple to use, user-friendly
  - -- Easy to calibrate
- Cost effective
- Portable
- Repeatable
- High density output relative to traditional methods
- Continuous, autonomous sampling
- Efficient post-processing and interpretation

7. What recommendations does the breakout session III group have for the Subcommittee on Sedimentation regarding bed-material and bed-topography data needs, uncertainty, and new technologies?

Breakout session III participants recommend that the Subcommittee on Sedimentation thoroughly review the proceedings from this workshop and collectively help support coordination and funding to address the identified research and data needs.

8. Where to from here? 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 on by Gray and Glysson (listed in appendix 4) be useful for attaining the fluvial-sediment-data needs of the Nation?

The participants agreed that a collective effort would help agencies to attain needed fluvial-sediment data. We suggest that FISP or another SMIAR Program group act as a clearinghouse for data and information on successes as well as problems with new technologies; develop or coordinate focused training programs or special sessions in conferences; be available to provide research assistance to develop site-specific solutions to problems encountered with new technologies; and promote effective communication among agencies between workshops. The Subcommittee on Sedimentation or FISP web pages should be expanded to include new technology information for each breakout session topic and pertinent links to data and research. Email groups, user groups, or bulletin boards should be established as needed for specific topical areas.

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Breakout Session IV, Sediment Data: Management, Sediment-Flux Computations, and Estimates from New Technologies

By Mark N. Landers and Lawrence A. Freeman

Breakout session IV had *two major* topics assigned to it that *integrate issues* across breakout sessions I, II, and III. The results are presented in the two following sections: Sediment-Data Management, and Sediment-Flux Computations.

Sediment-Data Management

Background ("Big Picture") Considerations:

I. How are sediment data being used in a broad sense? Principal uses of sediment should be served effectively by sediment-data-management designs. Principal uses of data identified in the breakout session were:
   - A. Deriving reliable sediment-flux data.
   - B. Identifying trends caused by land-use management changes.
   - C. Assessing logging rehabilitation efforts.
   - D. Assisting in establishing Total Maximum Daily Loads (TMDLs; U.S. Environmental Protection Agency, 2004) for "clean" sediment and contaminants.
   - E. Assessing the effects of downstream reservoirs (sediment trapping).
   - F. Predicting or quantifying effects of dam removal.
   - G. Monitoring fisheries habitat and stream restoration efforts.
   - H. Maintaining conveyance of navigation channels.

II. What data-management format(s) are optimal for these sediment-data users?
   - A. Nearly all are using relational database management systems (RDBMS).
   - B. These RDBMS must be (and almost always can be) accessible using Structured Query Language (SQL), an American National Standards Institute standard computer language. SQL statements are used to retrieve and update data in a database, which makes them adaptable for use by other database software, statistical packages, and advanced web software.
   - C. An essential feature for sediment databases is consistent definitions of each specific sediment and ancillary parameter. Valuable data attributes, in addition to site information, dates and times, should include method of sampling, method of analysis, and a quantitative uncertainty associated with the measurement.

III. How do new technologies of sediment measurement and estimations from surrogates challenge sediment-data-management methods?
   - A. The advent of automatically and continuously monitored sediment data requires sediment time-series data storage, with time units of 15 minutes becoming typical.
   - B. New technologies use one of a number of different operating principles and hence yield data that may be biased from or have a different variance than data produced by traditional methods (Edwards and Glysson, 1999). The uncertainty of different methods is not adequately quantified. Differences in sediment characteristics determined by different methods at a site may represent a bias between two methods; or simply greater measurement variance between methods.
   - C. Additional ancillary data that quantify the relation of the surrogate to the target sedimentary property (see below) are essential. For example, ancillary data are needed to define how optical technologies measure water/sediment properties (laser, OBS, turbidity, digital photo-optics; Gray and Gartner, 2004).

Status of sediment-data management and storage:

IV. How are data being managed now?
   - A. Discrete and composite samples, and those collected by the Equal-Width-Increment or Equal-Discharge-Increment methods (Edwards and Glysson, 1999) are stored in typical water-quality sample-data format and databases (Turcios and others, 2001; U.S. Geological Survey, 2004a). Raw analyses of sediment concentrations and particle-size distributions determined from physical samples are also in this database and in individual sediment

laboratory databases. Another example targeting sediment-associated parameters is the USEPA "National Sediment Quality Survey Database: 1980-1999" (U.S. Environmental Protection Agency, 2004). Computed daily values of sediment load are stored in time-series databases. Two examples are Automatic Data Processing System (ADAPS) (U.S. Geological Survey, 2003), and the USGS "Suspended-Sediment Database: Daily Values of Suspended and Ancillary Data" (U.S. Geological Survey, 2004b).

B. Databases are commonly developed and utilized for individual projects. These may offer maximum flexibility to the specific project, but often severely limits the availability and overall usefulness of the data, unless the data also are stored in a more distributed RDBMS.

Details of sediment-data management and storage:

V. What data need to be managed in any database, and which data elements are considered primary or secondary?

Recommendations for primary data elements:

A. Quantitative (model) uncertainty of any computed value.

B. Qualitative remark codes for data where uncertainty cannot be quantified.

C. Store all samples with appropriate quality-control flags.

D. Storage of sediment-surrogate unit values at the same time interval on which they are recorded.

E. Archiving original (raw) electronic data sets.

F. All available particle-size distribution data should be stored electronically.

G. Flag sediment data estimated or computed from surrogate data using a flag specific to the type of surrogate used.

H. Store and archive documentation of descriptions of the surrogate technology, the instrumentation, any calibration techniques or equations/models used.

I. Models and computations should be done in units that are consistent or are easily comparable.

J. Store raw analyses of sediment data in sediment lab database or make provisions to more easily move data from lab database to permanent agency database.

Recommendations for secondary data elements:

K. Original (raw) data should be stored in same database (side by side) as computed data.

L. Archive models or equations used to estimate sediment value from a surrogate value.

M. Document and archive overall uncertainty including model and measurement or calibration errors.

N. General Data-Management Observations

O. There are substantial gaps between current sediment-data-management methods and the methods needed to accommodate newly developing technologies. Developments in instrument technology are moving far faster than efforts to test, evaluate and approve their use.

P. Existing databases generally are not sufficient to manage and archive data collected using new, unique or non-standard methods.

Q. General Data-Management Recommendations

R. Expeditiously establish and approve new protocols for use of new technologies so that data generated by these means can be made available to the wide group of interested parties, not just individual project or internal agency personnel.

S. Make non-standard data – not collected or computed by approved methods – tagged with reliable uncertainty estimates available to the public; otherwise non-standard data should be appropriately flagged as "incomplete."

T. The Subcommittee on Sedimentation should form a task group to establish guidance for sediment-database management. This guidance should include required and recommended characteristics of sediment databases. The guidance should address specific parameters and ancillary data requirements, as well as database functionality, availability, and distribution.

U. The Subcommittee on Sedimentation should consider formation of a sediment-data clearinghouse and establish minimum requirements for those data.

Sediment-Flux Computations

Background ("Big Picture") Considerations:

The potential users and applications of sediment-flux information are increasingly diverse as sediment and sediment-associated constituents become water-quality and habitat-limiting factors in an increasing number of streams nationwide.

I. What time scales are being used and are needed? [Ranging from annual or seasonal to real time]

A. All time intervals are being used and are needed as follows:

1. Real-time data for environmental impact assessment or management, health impacts for recreational users, intake quality for drinking water and other commercial users, and managing for impacts as they occur, including storm events and point source spills.
2. Sediment-flux information during storm runoff and discharge peaks can now be characterized. Traditionally this information was difficult to obtain through collection of physical samples.
3. Use of surrogates to estimate sediment concentrations for flux computations can yield fast turn-around times for peak load estimates and assessments (TMDLs).
4. Daily, seasonal, and annual flux estimates continue to be needed.
5. Decadal or longer climatological studies are needed.
6. The appropriate time scale may depend on the sediment sources.
7. Different time scales for data may be needed to drive models (physical and empirical).

II. What spatial scales are needed and what are the uses?

A. Scales involving multiple cross sections for evaluation of changes through reaches, or to define variations in transport among riffles and pools.

B. Multiple sampling and monitoring locations are needed to define incoming tributary loads or reduced sediment loads from management practices.

C. Adequate spatial resolution is needed to evaluate non-point source affects.

III. How may the sediment characteristics measured or estimated in continuous time series from surrogate measurements change the capabilities and accuracies of sediment-flux computations?

A. Has potential to greatly increase the accuracy of computations due to increased frequency of surrogate measurements to better characterize natural temporal variability in sediment characteristics. Data will provide validation or calibration for models.

B. High temporal resolution data may elucidate sediment processes that can in turn be used to improve physically based models.

C. Some surrogates provide better spatial resolution and are representative of larger sample volumes. For example acoustic backscatterance may ‘measure’ a sample volume of many cubic feet and can do so at a frequency that results in orders of magnitude more streamflow being measured compared to traditional techniques.

D. Laser diffraction devices may provide capability to obtain time-series particle-size distribution information that can lead to improved models, rating curves, and sediment management.

E. Time-series data may allow determination of sediment sources and rates of transport for different particles sizes (suspended sediment and bedload).

F. Surrogates other than water discharge will enable us to observe changes in sediment flux that are not represented by streamflow.

G. Provisional data may be available in near-real time.

H. Has ability to identify and incorporate the sedimentary attributes of floods into computations and models that would otherwise be missed or misinterpreted by collecting only routine samples.

I. Has capability to define sedimentary extremes for runoff periods, particularly maximum values, that could not be determined without collecting numerous physical samples, sometimes in hazardous situations.

J. Some surrogates that may supply sediment-flux information are being collected to obtain other kinds of information. Thus, they have multiple values and they are available without additional cost. For example acoustic backscatterance data are being collected for water discharge in ADCP measurements and Index Velocity stations. Turbidity data are being collected at many stations as a measure of the bulk optical property of water.

IV. What additional data/information are needed when computing sediment flux from surrogate parameters?

A. Ancillary data that can influence the relation of surrogates to sediment parameters.

1. Particle-size distributions
2. Sediment color
3. Water and air temperature
4. Salinity
5. Organic content
6. Stream stage and water discharge

B. Surrogate sensor/instrument calibration information.

1. Instrument make, model, meter identifier
2. Records of instrument recalibration or changes in instrumentation

C. Sensor-to-data calibration: Collect physical samples that represent the immediate vicinity of the sensor and in the cross section and use it to calibrate the sensor output in units of the physical sample.

D. Take independent field measurements of the surrogate being recorded when possible using the same type of instrument.

Details:

V. Models can be grouped by the general methodology on which they are based. These include:

A. Physically based deterministic models.

1. Shear-based Transport formulas: Modified Einstein (Stevens, 1985), Meyer-Peter Müller, and others (Stevens and Yang, 1989)

a. GSTARS (Bureau or Reclamation, 2004)

b. HEC-6 (U.S. Army Corps of Engineers, 2004)

c. CONCEPTS (Langendoen, 2000)

B. Empirical rating-curve models.

1. Regression (linear, non-parametric, LOESS, etc.)

a. LOADEST (can use surrogate data) (Runkel and others, 2004)

b. ADAPS (U.S. Geological Survey, 2003)

c. Sediment-transport curves (Glysson, 1987)

C. Empirical time-series interpolation models.

1. GCLAS (U.S. Geological Survey, 2004c; Mckallip and others, 2001)

D. Other models.

1. Statistical time series can use surrogate data

2. ARIMA estimators

3. Neural net models

VI. Modeling Needs

A. Models that can accept multiple parameters of surrogate data as well as physical samples

B. Ensure that future models/computational software can incorporate multiple parameters of time-series surrogate data

C. Models and computational software should be able to provide estimates of errors

D. Models and computations need to be done in units that are consistent or are easily comparable

General Sediment-Flux Observations

A. Flux computations and estimates based on surrogates should be made based on sufficient calibration sample data collected during the time period being computed or estimated. Strongly encourage collection of actual calibration samples during time period and for entire range of the period of interest, whenever possible.

B. Models and computational software should be able to provide estimates of error, preferably expressed in units of the modeled parameter.

C. Models and computations need to be done in units that are consistent or are easily comparable.

D. All models need to have plotting capabilities.

General Sediment-Flux Recommendations

A. Further research and development on existing surrogates are needed to determine if the data being recorded actually represents the sediment parameter of interest. Examples (Gray and Gartner, 2004):

1. Optical backscatterance

2. Turbidity

3. Acoustics (single- and multi-frequency)

4. Laser diffraction

5. Pressure difference

6. Digital-optic imaging

B. Convene a working group to establish minimal standards and criteria for use of surrogates to compute sediment records.

C. Establish a clearinghouse of models, including a description of proper use and limits of the model.

D. Develop and support models that have the ability to incorporate multiple parameters from surrogate data and physical samples.

E. Ensure that future models/computational software can incorporate multiple parameters of time-series surrogate data as well as physical samples

F. Develop protocols for data collection and flux computations that are based on surrogate data.

G. Create the ability to compute transport rates of different particle-size classes; important for contaminant load estimates.

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Appendices

Appendix 1. Matrix of selected information gleaned from the four breakout sessions as compiled in the second plenary session of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona. Empty boxes indicate that the topic was not addressed in the breakout or second plenary sessions, or was not applicable to the category. [SMIAR is Sediment Instrument and Analysis Research; FISP is the Federal Interagency Sedimentation Project]

Topic	Breakout Session I, Suspended Sediment	Breakout Session II, Bedload	Breakout Session III		Breakout Session IV	
			Bed Material	Bed Topography	Data Management	Sediment-flux Computations
DATA						
Continuous time-series/greater data amount, density	Needed	Needed	Needed	Needed	Need to store original data	Critically needed
Ancillary information	Needed	Needed	Needed	Needed	Considerable need	Considerable need
Physical calibration samples	Needed	Needed	Needed	Needed	Needed	Critically needed
Accuracy criteria	Have some	Needed	Needed	Needed	Needed (to accept/reject data)	Needed
Uncertainty estimates	Needed; available in some cases	Needed		Needed	Needed; also need storage capabilities	Needed in some cases
Protocols for data collection, computation & storage	Available for traditional technologies	Available for traditional technologies	Available for traditional technologies	Needed	Databases generally insufficient	Needed for computations
Clearinghouse, data standards		Establish clearinghouse, data standards			Establish clearinghouse, data standards	
Scale limitations	Yes	Yes	Yes	Yes		Yes
Traditional Techniques						
Extant	Yes	Not for all conditions	Not for unwadeable gravel bed	For most conditions	Yes	Yes
Accuracy	Relatively accurate	Accuracy uncertain	Mostly acceptable	Mostly acceptable	None available	(Standards for computations)
Surrogate Techniques						
Availability of instruments	Many, commercially available	Few, mostly research, in early development	Some, but not for unwadeable gravel bed	Several, Government or commercially available	Create data gaps/ problems; need qualifying data	Need protocols for computations
Quantify accuracy	Some need	Major need	Needed	Some need	Major need	Major need
Applicable environments	Fluvial, coastal zone, estuaries	Fluvial, marine and coastal zones	Freshwater, marine and coastal zones	Freshwater, marine and coastal zones		

Appendix 1. Matrix of selected information gleaned from the four breakout sessions as compiled in the second plenary session of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona. Empty boxes indicate that the topic was not addressed in the breakout or second plenary sessions, or was not applicable to the category. [SMIAR is Sediment Instrument and Analysis Research; FISP is the Federal Interagency Sedimentation Project]

Topic	Breakout Session I, Suspended Sediment	Breakout Session II, Bedload	Breakout Session III		Breakout Session IV	
			Bed Material	Bed Topography	Data Management	Sediment-flux Computations
Models						
Uses and needs		Accurate data needed for better models		Uses and needs		Uses and needs
Research & Oversight						
Basic research sought	Yes	Yes, considerable	Yes	Yes	Yes	Yes
White paper sought		Past, present, future technologies				
Extant focus of current research venues or entities	Many field sites	Need national calibration standard sites	Online interest groups		Need sediment database management task group	
SMIAR Program needed	Yes	Yes	Yes	Yes	Yes	Yes
Organizational oversight of a SMIAR Program	FISP, or FISP-type organization	FISP, or FISP-type organization	FISP, or FISP-type organization	FISP, or FISP-type organization	FISP, or FISP-type organization	FISP, or FISP-type organization

Appendix 2. List of registrants and respective affiliation for the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona.

Last Name	First Name	Affiliation[1]	City	State	Zip Code
Abraham	David	USACE	Vicksburg	MS	39189
Agrawal	Yogesh	Sequoia Scientific, Inc.	Bellevue	WA	98005
Barton	Jonathan	Penn State University	University Park	PA	16802
Braatz	Dave	Streamside Systems, Inc.	Findlay	OH	45840
Banks	William	USGS	Baltimore	MD	21237
Barteaux	Chris	FTS	Victoria	BC	V9B-6B2
Bartlett	Phil	FTS	Victoria	BC	V9B-6B2
Bent	Gardner	USGS	Northborough	MA	01532
Bunte	Kristin	Colorado State University	Fort Collins	CO	80523
Calhoun	Daniel	USGS	Atlanta	GA	30360
Dinehart	Randal	USGS	Sacramento	CA	95819
Eads	Rand	FS	Arcata	CA	95521
Eng	Dan	USACE	Vicksburg	MS	39180
Fenn	Dennis	USGS	Flagstaff	AZ	86001
Fisk	Greg	USGS	Flagstaff	AZ	86001
Flexner	Morris	USEPA	Athens	GA	30605
Freeman	Larry	USGS	Marina	CA	93933
Fulk	Chance	USGS	Flagstaff	AZ	86001
Fuller	Elizabeth	USGS	Flagstaff	AZ	86001
Gooding	Daniel	USGS	Vancouver	WA	98683
Gray	John	USGS	Reston	VA	20192
Hanes	Daniel	USGS	Menlo Park	CA	94025
Hayes	Eugene	USGS	Bay St. Louis	MS	39529
Higgins	Johnna	USGS	Tacoma	WA	98402
Holnbeck	Steve	USGS	Helena	MT	59601
Hornewer	Nancy	USGS	Flagstaff	AZ	86001
Hortness	Jon	USGS	Boise	ID	83713
Jackson	Bill	NPS	Fort Collins	CO	80528
James	Scott	Sandia National Laboratories	Albuquerque	NM	87185
Jepsen	Richard	Sandia National Laboratories	Carlsbad	NM	88220
Johnson	Gary	USGS	Urbana	IL	61801
Kaplinski	Matt	University of Northern Arizona	Flagstaff	AZ	86011
Kenney	Terry	USGS	West Valley City	UT	84119
Krause	Andreas	Trinity River Restoration Prgm.	Weaverville	CA	96093
Kuhnle	Roger	ARS	Oxford	MS	38655
Lewis	Jack	FS	Arcata	CA	95521
Landers	Mark	USGS	Atlanta	GA	30360
Martini	Marinna	USGS	Woods Hole	MA	02543
Matherne	Anne Marie	USGS	Albuquerque	NM	87109
Matthews	Graham	GMA Hydrology	Weaverville	CA	96093

Appendix 2. List of registrants and respective affiliation for the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona.—Continued

Last Name	First Name	Affiliation[1]	City	State	Zip Code
Melis	Ted	USGS-GCMRC	Flagstaff	AZ	86001
Nichols	Mary	ARS	Tucson	AZ	85719
Nolan	K. Michael	USGS	Menlo Park	CA	94025
Northby	Jan	University of Rhode Island	Kingston	RI	02881
O'Halloran	Denis	USGS	Carnelian Bay	CA	96160
O'Neal	Wayne	USGS-FISP	Vicksburg	MS	39180
Parchure	T.M.	USACE	Vicksburg	MS	39180
Phillips	Jeffrey	USGS	West Valley City	UT	80225
Potyondy	John	FS	Fort Collins	CO	80526
Roberts	Jesse	Sandia National Laboratories	Carlsbad	NM	88220
Robertson	Dale	USGS	Madison	WI	53562
Ross	Jerry	USGS	Stennis Space Center	MS	39529
Rubin	David	USGS	Santa Cruz	CA	95060
Ryan	Sandra	FS	Laramie	WY	82070
Schmeeckle	Mark	Arizona State University	Tempe	AZ	85069
Schmidt	Larry	FS	Fort Collins	CO	80526
Schubauer-Berigan	Joseph	USEPA	Cincinnati	OH	45268
Slingerland	Rudy	Penn State University	University Park	PA	16802
Tidwell	Vince	Sandia National Laboratories	Albuquerque	NM	87185
Tucker	Randall	Streamside Systems, Inc.	Findlay	OH	45840
Topping	David	USGS-GCMRC	Flagstaff	AZ	86001
Uhrich	Mark	USGS	Portland	OR	97216
Walter	Don	Naval Research Lab	Stennis Space Center	MS	39529
Wiele	Stephen	USGS	Tucson	AZ	85719
Wilberg	Dale	USGS	Cedar City	UT	84720
Wilcock	Peter	Johns Hopkins University	Baltimore	MD	21218
Wren	Daniel	University of Mississippi	University	MS	38677
Wright	Scott	USGS	Flagstaff	AZ	86001
Yang	Ted	BR	Denver	CO	80225
Young	Christi	BR	Denver	CO	80225

[1]Explanation of acronyms used in Appendix 2.

ARS	U.S. Department of Agriculture, Agricultural Research Service
BR	Department of the Interior, Bureau of Reclamation
FISP	Federal Interagency Sedimentation Project
FS	U.S. Department of Agriculture, Forest Service
GCMRC	Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center
NPS	Department of the Interior, National Park Service
USACE	Department of Army, U.S. Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	Department of the Interior, U.S. Geological Survey

Appendix 3. Breakout session attendees as recorded by respective breakout session leaders, Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona.

Breakout Session I, Suspended-Sediment Measurement: Data Needs, Uncertainty, and New Technologies Led by Roger A. Kuhnle and Daniel G. Wren	Breakout Session II, Bedload-Transport Measurement: Data Needs, Uncertainty, and New Technologies Led by Sandra E. Ryan, Kristin Bunte, and John P. Potyondy	Breakout Session III, Bed-Material and Bed-Topography Measurement: Data Needs, Uncertainty, and New Technologies Led by Christi A. Young and Vincent C. Tidwell	Breakout Session IV, Sediment Data: Management, Sediment-Flux Computations, and Estimates from New Technologies Led by Mark N. Landers and Lawrence A. Freeman
Yogi Agrawal	David Abraham	Gardner Bent	Randal Dinehart
Bill Banks	Jonathan S. Barton	Dan Eng	John Gray*
Chris Barteaux	David Braatz	Elizabeth Fuller	Gary Johnson
Philip Bartlett	John Gray*	John Gray*	Jack Lewis
Dan Calhoun	Steve Holnbeck	Daniel Hanes*	Denis O'Halloran
Rand Eads	Andreas Krause	Bill Jackson	Dale Robertson
Morris Flexner	Graham Matthews	Matt Kaplinksi	Dale Wilberg
Dan Gooding	Mary Nichols	Terry Kenney	
John Gray*	John Potyondy	Jerry Ross	
Dan Hanes*	Jesse Roberts	David Rubin	
Johnna Higgins	Rudy Slingerland	Larry Schmidt	
Jon Hortness	Randy Tucker	Don Walter	
Scott James	Peter Wilcock		
Marinna Martini			
Anne-Marie Matherne			
Ted Melis			
Jan Northby			
Wayne O'Neal			
T.M. Parchure			
Mark Schmeeckle			
Joe Schubauer-Berigan			
David Topping			
Stephen Wiele			
Scott Wright			
Ted Yang			

*Attended multiple sessions

Appendix 4. Extended abstracts submitted as part of the Federal Interagency Sediment Monitoring Instrument and Analysis Research Workshop, September 9-11, 2003, Flagstaff, Arizona

The extended abstracts associated with this report are available only online at the following URL: *http://water.usgs.gov/osw/techniques/sediment/sedsurrogate2003workshop/listofpapers.html*

Extended abstracts by U.S. Geological Survey authors were reviewed and approved for publication by the U.S. Geological Survey. Articles submitted by others did not go through the U.S. Geological Survey review process, and therefore may not adhere to U.S. Geological Survey editorial standards or stratigraphic nomenclature. However, all articles were edited for consistency in appearance. The use of brand, firm, or trade names in any extended abstract does not constitute endorsement by the U.S. Geological Survey. The authors and titles of extended abstracts are listed below in alphabetical order by principle author.

Abraham, David, Quantification of bed-load transport using multi-beam survey data: the ISSDOT Method (Integrated-Section Surface Difference over Time).

Agrawal, Y.C., and Pottsmith, H.C., Laser diffraction method: two new sediment sensors.

Barton, J.S., Slingerland, R.L., Gabrielson, T.B., and Johnson, P.A., Listening to bedload: a flume study relating acoustic response to bedload motion.

Braatz, D.A., and Tucker, R.L., A new series of sediment collectors for monitoring true bedload.

Bunte, Kristin, Potyondy, J.P., and Abt, S.R., Development of an improved bedload trap for sampling gravel and cobble bedload in coarse mountain streams.

Davis, J.E., and Rosati, J.D., Regional Sediment Management.

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.

Jackson, W.L., Regulated river restoration monitoring: The Elwah River dam removal and restoration project.

Kuhnle, R.A., and Wren, D.G., Cross-stream variations in suspended sediment transport over dunes, implications for sampling.

Laronne, J.B., and Gray, J.R., Formation of a Bedload Research International Cooperative.

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.

Roberts, J.D., James, S.C., and Jepsen, R.A., Measuring bedload fraction with the ASSET flume.

Ryan, S.E., The use of pressure-difference samplers in measuring bedload transport in small, coarse-grained alluvial channels.

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.