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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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,
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- reduced costs, and (or)
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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.

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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?