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THE NEED FOR SURROGATE TECHNOLOGIES TO MONITOR FLUVIAL-SEDIMENT TRANSPORT

John R. Gray, Hydrologist, U.S. Geological Survey, Reston, VA
415 National Center, 12201 Sunrise Valley Drive, Reston, VA 20192

The need for reliable, nationally consistent fluvial sediment data in the U.S. arguably has never been greater since the U.S. Army's Captain Talcott first sampled the Mississippi River in 1838. In addition to the traditional uses for these data, which focused on the engineering aspects related to design and management of reservoirs and instream hydraulic structures, and on dredging, information needs over the last two decades have also included those related to the expanding fields of contaminated sediment management, dam decommissioning and removal, environmental quality, stream restoration, geomorphic classification and assessments, physical-biotic interactions, and legal requirements such as the U.S. Environmental Protection Agency's Total Maximum Daily Load (TMDL) Program.

Ironically, the dramatic rise in the Nation's sediment-data needs has occurred more or less concomitant with a general decline in the amount of sediment data collected by U.S. Geological Survey (USGS). After the end of World War II, the number of sites at which the USGS collected daily suspended-sediment data increased rapidly, peaking at 360 in 1982 (Glysson, 1989; Osterkamp and Parker, 1991). By 1998, the number of USGS-operated daily sediment stations had fallen by 65 percent to 125, with an average of 140 over the 5-year period ending in September 2001 (USGS, 2002). This substantial decrease in sediment monitoring is of particular concern in that the USGS bears primary responsibility for acquisition and management of the Nation's water data including suspended-sediment, bedload, and bottom-material data (Glysson and Gray, 1997). This paper examines some factors behind the decline in collection of new suspended-sediment data, and presents a vision and proposed first step toward reversing the general trend toward reduced Federal sediment-data acquisition.

Traditional Methods for Collecting Suspended-Sediment Data: The samplers, deployment techniques, and methods of sample processing and analysis used to produce the bulk of Federal sediment data have their roots in the Subcommittee on Sedimentation, a Federal cooperative effort that started in 1938, and its subordinate Federal Interagency Sedimentation Project (FISP) (Skinner, 1989; FISP, 2002). The FISP's calibrated depth- and point-integrating isokinetic samplers collect a water sample at a rate within ten percent of the flow velocity incident on the sampler nozzle. When deployed using the Equal-Discharge Increment or Equal-Width Increment Methods, these samplers provide representative samples for subsequent processing and (or) analysis (Edwards and Glysson, 1999). When processed and analyzed using standard methods (USGS, 1998, 1999; American Society for Testing and Materials, 1999), and served online from a nationally consistent database, the most reliable and consistent set of fluvial sediment data are made available to the widest audience.

The previously described equipment, deployment techniques, and analytical methods have been used to provide the bulk of USGS fluvial-sediment data collected since the 1940's (Turcios and Gray, 2001; Turcios and others, 2002). Although these data are widely considered the "best" available – the most accurate, reliable, and comparable – their cumulative accuracy is unquantified, and the manually intensive data-collection techniques are in some cases considered too expensive and, under some circumstances, potentially unsafe to collect. Continuous monitoring using sediment-surrogate technologies may provide a viable alternative to traditional equipment and techniques.

Accuracy: The accuracy (bias and variance) of suspended-sediment concentration and particle-size distribution data is dependent on a number of factors, including instream spatial and temporal variability; the computational time frame; the ability to representatively sample and quantify flows of interest; proper deployment of an appropriate sampler; use of reliable sample-processing and shipping procedures; and use of quality-assured analytical techniques by a certified, reliable laboratory to analyze samples collected in open-channel flows (USGS, 1998). Two key problems associated with traditionally computed daily sediment records are the need for interpolating between dozens or hundreds of sediment-concentration values to estimate concentration values for unit values (35,040 values per 365-day year for data computations at 15-minute intervals); and the need to estimate concentration values for periods lacking samples. Continuously measured surrogate technologies would provide the unit-value data that could be adjusted based on periodic calibrations to yield more reliable and consistent sediment-load data. Statistical methods could be applied to provide an estimate of the accuracy of those time-series data.

Cost: The cost to collect and manage USGS sediment data is also dependent on a number of factors. These include the gage location, site accessibility, safety requirements, the range in size distribution of suspended sediments, the variability in runoff at the site, and the human and mechanical resources required to collect and process the data. An informal poll of selected USGS offices in 2001 yielded a estimated range of about $20,000 to $65,000 gross funds to provide a year's worth of daily suspended-sediment discharge values. Although Osterkamp and others (1998) showed that a sediment monitoring network in the U.S. consisting of 120 daily sites and 2,000 periodic sites would exceed a cost-benefit ratio of unity forty-fold if the data produced by the program resulted in a 1-percent decrease in sediment-related damages, some consider perceived high sediment-data costs to be partly responsible for the decline in Federal data production. Use of appropriate sediment surrogate technologies at a gage would probably reduce the cost of producing sediment data by reducing the number of water-sediment sample analyses and site visits, in both cases from as many as hundreds to about one or two dozen annually. Other benefits would be reduction in time and effort because time-consuming interpolations and concentration estimates would no longer be a common part of the computational process.

Safety: Although equipment and techniques for collection of sediment and flow data are generally quite safe, site conditions may render safe collection of these data difficult or impossible. For example, sampling in poor lighting conditions, from a narrow bridge, and (or) in a debris-laden stream can be unsafe. There are conditions where sediment data cannot and should not be collected manually. Unfortunately, these conditions tend to occur at times where the sediment data would be most influential in a transport computation or managerial decision. Monitoring by sediment-surrogate technologies would automatically provide a continuous concentration time series under many of the circumstances considered unsafe for manual sampling.

In summary, although the traditional equipment and techniques used by the USGS nationwide to collect fluvial sediment data may seem ill-suited for many of the limitations and needs of the 21st century, no alternatives have been documented to work under the range of stream and transport conditions characteristic of the Nation's rivers.

A Vision for Future Federal Sediment-Data Production According to Osterkamp and others (1992; 1998) and Trimble and Crosson (2000), the Nation needs a permanent, based-funded, national sediment monitoring and research network for the traditional and emerging needs described previously, and to provide reliable values of sediment fluxes at an adequate number of properly distributed streamgages. The short-term benefits would include relevant and readily available data describing ambient sedimentary conditions and loads, and the requisite data to calibrate models for simulating fluvial sedimentary processes. The long-term benefits would include identification of trends in sedimentary conditions, and a more complete data set with which to calibrate and verify simulation models. Fundamental requirements for an effective national sediment monitoring and research program would include:

- **A CORE NETWORK OF SEDIMENT STATIONS** that is equipped to continuously monitor a basic set of flow, sediment, and ancillary characteristics based on a consistent set of protocols and equipment at perhaps hundreds of sites representing a broad range of drainage basins in terms of geography, areal extent, hydrology, and geomorphology. The focus of these sites would be measurement of fluvial-sediment yields. It would be most beneficial to collect these data at sites where other water-quality parameters are monitored.

- **A SUBSET OF THE SEDIMENT STATION NETWORK FOR SEDIMENT RESEARCH** at which testing on emerging sediment-surrogate technologies and new methodologies can take place at a minimum of additional expense. A major focus of this effort would be to identify technologies that provide a reliable sediment-concentration time series that can be used as the basis for computing daily suspended-sediment discharges. A secondary focus would be to identify surrogate technologies for measuring characteristics of bedload, bed material, and bed topography.

- **AN EQUIPMENT AND METHODS ANALYTICAL COMPONENT** that addresses development of equipment and techniques for collecting, processing, and laboratory analysis of sediment samples.

- **A DATA-SYNTHESIS RESEARCH COMPONENT** that focuses on identifying or developing more efficient methods of measuring and estimating selected fluvial sediment characteristics; developing a means to estimate the uncertainty associated in these measurements and estimates; and on performing syntheses on historical and new sediment and ancillary data to learn more about the sedimentary characteristics of our Nation's rivers.

- **A COMMON DATABASE** that can accept all types of instantaneous and time series sediment and ancillary data collected by approved protocols, including specific information on the instruments and methods used to acquire the data.

A First Step: Development and Verification of Sediment Surrogate Technologies for the 21'st Century

Traditional techniques for collecting and analyzing sediment data do not meet all of the above-stated requirements of a national sediment monitoring and research network. Before such a program can become operational, new cost-effective and safe approaches for continuous monitoring that include uncertainty analyses are needed.

An ideal suspended-sediment surrogate technology would automatically monitor and record a signal that varies as a direct function of suspended-sediment concentration and (or) particle-size distribution representative of the entire stream cross-section for any river in any flow regime with an acceptable and quantifiable accuracy. Although there is no evidence that such a technology is even on the drawing board, let alone verified and ready for deployment, the literature is rife with descriptions of emerging technologies for measuring selected characteristics of fluvial sediment (Wren, 2000; Gray and Schmidt, 1998). Considerable progress is being made to devise or improve upon available new technologies to measure selected characteristics of fluvial sediment. Instruments have been developed that operate on acoustic, differential density, pump, focused beam reflectance, laser diffraction, nuclear, optical backscatter, optical transmission, and spectral reflectance principles (Wren et al., 2000). Although some surrogate technologies show promise, none is commonly accepted or extensively used.

Formal adoption of any sediment-surrogate technology for use in large-scale sediment-monitoring programs by the Subcommittee on Sedimentation must be predicated on performance testing. Isokinetic samplers – primarily those developed by the Federal Interagency Sedimentation Project (FISP) and described by Edwards and Glysson (1999) – generally are considered the standard against which the performance of other types of samplers are compared. Ideally, a controlled setting such as a laboratory flume would provide flow and sedimentary conditions enabling direct assessments of the efficacy of the new technology. Even in that case, direct comparisons between an adequate amount of comparative data from the surrogate technology and isokinetic samplers collected for a sufficient time period over a broad range of flow and sedimentary conditions, would be needed to determine if any bias, or change in bias, would result from implementation of the new technology (Gray and Schmidt, 2001).

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