

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

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## 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?
- 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.

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).

## 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
<b>1. Instream Installations</b>											
Birkbeck sampler <sup>1</sup> (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 <sup>2</sup>	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 <sup>3</sup>	gravel bed channel	yes	yes	typically not	possibly	possibly	yes, small scale	depends on flow conditions	slightly	additional testing	probably not
Net-frame sampler <sup>4</sup>	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 <sup>5</sup>	sand-gravel bed channels	no	periodically	yes	yes	yes	yes	relatively easy	no	completed	high
<b>2. Portable/physical devices</b>											
Pressure-difference samplers (small openings) <sup>6</sup>	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]

<b>Bedload-Sampling Technology</b>	<b>Stream Type</b>	<b>Requires Wading or Retrieval During High Flows</b>	<b>Physical Sample Obtained for Sieving</b>	<b>High Percentage of Channel Width Sampled</b>	<b>Large Opening Relative to Grain Size</b>	<b>Relatively Long Sampling Duration</b>	<b>Stream Excavation Required</b>	<b>Relative Ease of Use</b>	<b>Disruptive to Flow Fields</b>	<b>Status of Development</b>	<b>Potential Use as Calibration Standard</b>
Pressure-difference samplers (large openings) <sup>7</sup>	gravel bed channel	yes	yes	no	yes	no	no	depends on flow conditions	highly	additional verification	additional verification needed
Baskets (suspended or instream) <sup>8</sup>	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 <sup>9</sup>	gravel bed channel	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
Tracer particles (painted, magnetic, signal emitting rocks) <sup>10</sup>	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
Scour chains; scour monitor; scour core <sup>11</sup>	sand-gravel bed channel	possibly	no	no	N/A	yes	yes	easy	no	completed	low
Bedload collector (Streamside Systems) <sup>12</sup>	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
<b>3. Surrogate Technologies</b>											
ADCP – acoustic Doppler current profiler <sup>13</sup>	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) <sup>14</sup>	gravel bed channel	no	no	depends on deployment	N/A	continuous	possibly	easy	no	early	additional development needed
Gravel impact sensor <sup>15</sup>	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 <sup>16</sup>	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 <sup>17</sup>	gravel bed channel	no	no	yes	N/A	continuous	yes	easy under many conditions	minor; flush with stream bottom	early	additional verification needed
Topographic differencing <sup>18</sup>	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 <sup>19</sup>	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 <sup>20</sup>	relatively clear flow	used from bridges or boats	no	no	N/A	continuous	no	easy under right lighting conditions	slightly	early	additional verification needed

<sup>1</sup>**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

<sup>2</sup>**Vortex sampler**, Milhous, 1973; Hayward and Sutherland, 1974; Hayward, 1980; O'Leary and Beschta, 1981; Tacconi and Billi, 1987; Atkinson, 1994

<sup>3</sup>**Unweighable pit traps**, Church and others, 1991; Powell and Ashworth, 1995; Bunte, 1997; Hassan and Church, 2001; Sterling and Church, 2002.

<sup>4</sup>**Net-frame sampler**, Bunte, 1992, 1996; Whitaker and Potts, 1996; Whitaker, 1997

<sup>5</sup>**Sediment detention basins/weir ponds**, Troendle and others, 1996; Ryan and Porth, 1999

<sup>6</sup>**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 Porth, 1999; Ryan and Emmett, 2002; Sterling and Church, 2002; Ryan, 2005 (see appendix 4)

<sup>7</sup>**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.

<sup>8</sup>**Baskets (suspended or instream)**, Hubbell, 1964; Nanson, 1974; Engel and Lau, 1981; Gao 1991; Xiang and Zhou, 1992; Nankervis, 1994; Wilcock, 2001.

<sup>9</sup>**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, 2005 (see appendix 4)

<sup>10</sup>**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

<sup>11</sup>**Scour chains, scour monitor, scour cores**, Laronne and others, 1992; Haschenburger and Church, 1998; De Vries and others, 2001; McBain and Trush, 2004;

<sup>12</sup>**Bedload collector (Streamside Systems)**, Braatz and Tucker, 2005 (see appendix 4)

<sup>13</sup>**ADCP – acoustic Doppler current profiler**, Rennie and others, 2002.

<sup>14</sup>**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 Moen, 2003; Mizuyama and others, 2003; Froehlich, 2003; Barton and others, 2005 (see appendix 4).

<sup>15</sup>**Gravel impact sensor**, Downing and others, 2003; Richardson and others, 2003

<sup>16</sup>**Magnetic tracers**, Bunte, 1992, 1996; Ergenzinger and others, 1994a, 1994b

<sup>17</sup>**Magnetic sensors**, Tunnlicliffe and others, 2000; Gottesfeld and Tunnlicliffe, 2003

<sup>18</sup>**Topographic differencing**, Bransington and others, 2000; Dinehart 2001; Rubin and others, 2001; Abraham, 2005 (see appendix 4).

<sup>19</sup>**Sonar-measured debris basin**, D'Agostino and others, 1994; Lenzi and others, 1990, 1999.

<sup>20</sup>**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 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, Observations, and Recommendations

A summary of observations and recommendations and associated group discussion are presented in the following section. Observations are essentially problem statements, and recommendations are specific actions required to improve our capabilities for monitoring bedload transport.

1. The breakout group recognized an overarching need for more thorough testing of the accuracy of existing devices. Even with the uncertainties regarding the accuracy of the current technologies, however, existing physical samplers represent the long-term standard for bedload measurement, 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. There was general agreement that the development of both physical and surrogate samplers by non-Federal entities (private sector/academic community) should be encouraged while testing and accuracy requirements should be established by a Federal entity such as the FISP.

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.

Recommendation A: 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 should be convened to develop recommendations on how this might be done.

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

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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.,  $\frac{1}{2}$  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.

Recommendation B: Establishing standards and protocols could be accomplished through the designation of calibration field sites where true transport rates can be quantified to assess the accuracy of new technologies.

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.

## Summary of Themes and Primary Recommendations

1. 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.

**Recommendation C1:** 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. 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 (Gray and Glysson; listed in appendix 4).

**Recommendation C2:** A white paper is needed to provide a comprehensive and unbiased evaluation of all existing bedload technologies and 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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