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?

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. <u>Instream Installations</u>											
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. <u>Portable/physical devices</u>											
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	low
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.

References, Breakout Session II:

Atkinson, E., 1994, Vortex-tube sediment extractors. I: Trapping efficiency: Journal of Hydraulic Engineering, v. 120, no. 10, p. 1110-1125.

Bänzinger, R., and Burch, H., 1990, Acoustic sensors (hydrophones) as indicator for bed load in a mountain torrent, *in,* Hydrology in Mountainous Regions.: IAHS Publication 193, p. 207-214.

Bänzinger, R. and Burch, H., 1991, Geschiebetransport in Wildbächen: Messung mittels eines neuartigen Sensors: Schweizer Ingenieur und Architekt, v. 24, p. 576-579.

Beschta, R.L., 1981, Increased bag size improves Helley-Smith bed load sampler for use in streams with high sand and organic matter transport, *in*, Erosion and Sediment Transport Measurement: IAHS Publication 133, p. 17-25.

Bogen, J. and Møen, K., 2003, Bed load measurements with a new passive ultrasonic sensor, *in*, J. Bogen, T. Fergus and D. Walling (eds.), Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 181-192.

Bransington, J., Rumsby, B.T., and McVey, R.A., 2000, Monitoring and modelling morphological change in a braided gravel-bed river using high resolution GPS-based survey: Earth Surface Processes and Landforms, v. 25 p. 973-990.

Bunte, K., 1992, Particle number grain-size composition of bedload in a mountain stream, *in*, P. Billi, R. D. Hey, C.R. Thorne and P. Tacconi, eds.: Dynamics of Gravel Bed Rivers*,* Wiley, Chichester, p. 55-72.

Bunte, K., 1996, Analyses of the temporal variation of coarse bedload transport and its grain size distribution (Squaw Creek, Montana): English translation of Ph.D. dissertation submitted to the Freie Universität Berlin, Germany. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station*,* General Technical Report RM-GTR-288, 123 p.

Bunte, K., 1997, Development and field testing of a bedload trap for sand and fine gravels in mountain gravel-bed streams (South Fork Cache la Poudre Creek, CO): Report prepared for the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., 53 p.

Bunte, K., 1998, Development and field testing of a stationary net-frame bedload sampler for measuring entrainment of pebble and cobble particles: Report prepared for the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., 74 p.

Bunte, K., 1999, Field testing of bedload traps for measuring entrainment of pebbles and cobbles at Little Granite Creek, WY: Report prepared for the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., 78 p.

Bunte, K., 2001, Field testing the sampling efficiency of bedload traps at East St. Louis Creek, CO: Report submitted to the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colo., 84 p.

Bunte, K., 2002, Testing the sampling efficiency of the bedload traps by comparison with sediment collected in the debris basin at East St. Louis Creek: Report submitted to the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colo., 44 p.

Bunte, K. and Abt, S.R., 2003, Sampler size and sampling time affect measured bedload transport rates and particle sizes measured with bedload traps in gravel-bed streams, *in*, J. Bogen, T. Fergus and D. Walling (eds.), Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 126-133.

Bunte, K. and Swingle, K., 2002, Results from testing the bedload traps at Little Granite Creek, 2002: effect of sampling duration and sampler type on bedload transport rates and systematic variability of rating curves with basin area and stream bed parameters: Report submitted to the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colo., 110 p.

Bunte, K. and Swingle, K., 2003, Field testing the sampling efficiency of bedload traps at East St. Louis Creek, May - July 2003: Comparison of annual gravel load between bedload traps and debris basin: Report submitted to the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colo., 86 p.

Bunte, K. and Swingle, K., 2004, Flume and field measurements of flow velocity profiles near the bedload trap entrance: Report submitted to the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colo., 40 p.

Bunte, K., Swingle, K., and Abt, S.R., 2005a, Guidelines for using bedload traps in coarse-bedded mountain streams-Construction, installation, operation and sample processing: Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, 80 pp.

Bunte, K., Abt, S.R., and Potyondy, J.P., 2001, Portable bedload traps with high sampling intensity for representative sampling of gravel transport in wadable mountain streams, *in*, Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., v. 2, p. III 24 - III 31, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Bunte, K., Abt, S.R., Potyondy, J.P., and Ryan, S.E., 2004, Measurement of coarse gravel and cobble transport using a portable bedload trap: Journal of Hydraulic Engineering, v. 130, no. 9, p. 879-893.

Busskamp, R., 1994a, Erosion, Einzellaufwege und Ruhephasenanalyse und Modellierung der stochastischen Parameter des Grobgeschiebetransportes. [Erosion, individual travel distances, and rest phases: analysis and modeling of the stochastic parameters of coarse bedload transport.] Ph.D. dissertation submitted to the Department of Earth Sciences at the Freie Universität Berlin, Germany.

Busskamp, R., 1994b, The influence of channel steps on coarse bed load transport in mountain torrents—case study using the radio tracer technique 'PETSY', *in*, P. Ergenzinger and K.-H. Schmidt, eds., Dynamics and Geomorphology of Mountain Rivers: Lecture Notes in Earth Sciences, Springer Verlag, Berlin, p. 129-139.

Busskamp, R. and Ergenzinger, P., 1991, Neue Analysen zum Transport von Grobgeschiebe—Messung Lagrangescher Parameter mit der Radiotracertechnik (PETSY). [New analyses of coarse bedload transport measurements of Lagrangian parameters with the radio tracer technique (PETSY)], *in*, Deutsche Gewässerkundliche Mitteilungen, v. 35, no. 2, p. 57-63.

Busskamp, R. and Gintz, D., 1994, Geschiebefrachterfassung mit Hilfe von Tracern in einem Wildbach (Lainbach/Oberbayern). [Bedload transport determination using tracers in a mountain torrent (Lainbach/Upper Bavaria)], *in*, D. Barsch, R. Mäusbacher, K.-H. Pörtge and K.-H. Schmidt, eds., Messungen in fluvialen Systemen. Feld- und Laboruntersuchungen zur Erfassung des Wasser- und Stoffhaushaltes: Springer Verlag, Heidelberg, p. 179-193.

Butler, P.R., 1977, Movement of cobbles in a gravel-bed stream during a flood season: Geological Society of America Bulletin, v. 88, p. 1072-1074.

Chacho, E.F., Burrows R.L., and Emmett, W.W., 1989, Detection of coarse sediment movement using radio transmitters: International Association for Hydraulic Research (IAHR), Proceedings of the 23. Congress, Technical Session B, p. B367-B373.

Chacho, E.F., Emmett, W.W., and Burrows, R.L., 1994, Monitoring gravel movement using radio transmitters, *in*, G.V. Cotroneo and R.R. Rumer, eds., Hydraulic Engineering '94, Proceedings of the 1994 Conference, ASCE, New York, v. 2, p.785-789.

Chacho, E.F., Emmett, W.W., and Burrows, R.L., 1996, Motion characteristics of coarse sediment in a gravel-bed river, *in*, Proceedings of the 6th Federal Interagency Sedimentation Conference, Las Vegas, Nev., V 1 -V 8, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Childers, D., 1991, Sampling differences between the Helley-Smith and BL-84 bedload samplers, *in*, Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nev., VI 31 - VI 38, accessed August 31, 2004, *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Childers, D., 1999, Field comparison of six-pressure-difference bedload samplers in high energy flow: U.S. Geological Survey Water-Resource Investigations Report 92-4068, 59 p., accessed January 26, 2005, at *http://pubs.er.usgs.gov/pubs/wri/wri924068/*

Childers, D., Kresch, D.L., Gustafson, S.A., Randle, T.J., Melena, J.T., and Cluer, B., 2000, Hydrologic data collected during the 1994 Lake Mills drawdown experiment, Elwha River, Washington: U.S. Geological Survey Water-Resources Investigation Report 99-4215, 115 p.

Church, M., Wolcott, J.F., and Fletcher, W.K., 1991, A test of equal mobility in fluvial sediment transport—behavior of the sand fraction: Water Resources Research, v. 27, no. 11, p. 2941-2951.

D'Agostino, V., Lenzi, M.A., and Marchi, L., 1994, Sediment transport and water discharge during high flows in an instrumented watershed, *in*, P. Ergenzinger and K.-H. Schmidt, eds., Dynamics and Geomorphology of Mountain Rivers: Lecture Notes in Earth Sciences, v. 52, p. 67-81, Springer Verlag, Berlin.

DeVries, P., Burges, S.J., Daigneau, J. and Stearns, D., 2001, Measurement of the temporal progression of scour in a pool-riffle sequence in a gravel-bed stream using an electronic scour monitor: Water Resources Research, v. 37, no. 11, p. 2805-2816.

Dinehart, R.L., 1992, Evolution of coarse gravel bed forms: field measurement at flood stage: Water Resources Research, v. 28, no. 10, p. 2667-2689.

Dinehart, R.L., 2001, Bedform mapping in the Sacramento River, *in*, Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., v.1, p. III 55 - III 62, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Dixon, M. and Ryan, S.E., 2001, Using an underwater video camera for observing bedload transport in mountain stream, *in*, Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., poster-70-73, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Downing, J., Farley, P.J., Bunte, K., Swingle, K. Ryan, S.E., and Dixon, M., 2003, Acoustic gravel-transport sensor, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances. IAHS Publication 283, p. 193-200.

Druffel, L., Emmett, W.W., Schneider, V.R., and Skinner, J.V., 1976, Laboratory hydraulic calibration of the Helley-Smith bedload sediment sampler: U.S. Geological Survey Open-File Report 76-752.

Duizendstra, H.D., 2001a, Measuring, observing and pattern recognition of sediment transport in an armoured river using a sampler with attached underwater camera: Physics and Chemistry of the Earth, Part B, no. 26v. 1, p. 59-64.

Duizendstra, H.D., 2001b, Determination of the sediment transport in an armoured gravel-bed river: Earth Surface Processes and Landforms, v. 26, p. 1381-1393.

Emmett, W.W., 1980, A field calibration of the sediment trapping characteristics of the Helley-Smith bedload sampler: U.S. Geological Survey Professional Paper 1139, 44 p.

Emmett, W.W., 1981, Measurement of bed load in rivers, *in*, Erosion and Sediment Transport Measurements: IAHS Publication 133, p. 3-15.

Emmett, W.W., Burrows, R.L., and Chacho, E.F., 1996, Coarse-particle transport in a gravel-bed river: International Journal of Sediment Research, v. 11, no. 2, p. 8-21.

Engel, P. and Lau, Y.L., 1981, The efficiency of basket type bed load samplers, *in*, Erosion and Sediment Transport Measurement: IAHS Publication 133, p. 27-34.

Ergenzinger, P. and De Jong, C. 2003, Perspectives on bed load measurements, *in,* J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p.113-125.

Ergenzinger, P., de Jong, C., and Christaller, G., 1994a, Interrelationships between bedload transfer and river bed adjustment in mountain rivers—an example from Squaw Creek, Montana, *in*, M.J. Kirkby, ed., Process Models and Theoretical Geomorphology: John Wiley and Sons, New York, p. 141-158.

Ergenzinger, P., De Jong, C., Laronne, J.B., and Reid, I., 1994b, Short term temporal variations in bedload transport rates: Squaw Creek, Montana, USA, and Nahal Yatir and Nahal Estemoa, Israel, *in*, P. Ergenzinger and K.-H. Schmidt, eds., Dynamics and Geomorphology of Mountain Rivers: Lecture Notes in Earth Sciences, Springer Verlag, Berlin, p. 251-264.

Ferguson, R.I., and Wathen, S.J., 1998, Tracer-pebble movement along a concave river profile—virtual velocity in relation to grain size and shear stress: Water Resources Research, v. 34, no. 8, p. 2031-2038.

Ferguson, R.I., Hoey, T.B., Wathen, S.J., Werritty, A., Hardwick R.I., and Smith, G.H.S., 1998, Downstream fining of river gravels: integrated field, laboratory and modeling study, *in*, P.C. Klingeman, R.L. Beschta, P.D. Komar and J.B. Bradley, eds., Gravel-Bed Rivers in the Environment: Water Resources Publications LLC, Highlands Ranch, CO, p. 85-114.

Froehlich, W., 2003, Monitoring bedload transport using acoustic and magnetic devices, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 201-210.

Gao, H., 1991, The comparison tests of gravel bed load samplers: Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nev., VI 55 - VI 62, accessed at August 31, 2004, a *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Garcia, C., Laronne, J.B., and Sala, M., 2000, Continuous monitoring of bedload flux in a mountain gravel-bed river: Geomorphology, v. 34, p. 23-31.

Gaudet, J.M., Roy, J.B., and Best, J.B., 1994, Effects of orientation and size of Helley-Smith sampler on its efficiency: Journal of Hydraulic Engineering, v. 120, no. 6, p. 758-766.

Gintz, D., Hassan, M.A., and Schmidt, K.–H., 1996, Frequency and magnitude of bedload transport in a mountain river: Earth Surface Processes and Landforms, v. 21, p. 433-445.

Gottesfeld, A.S. and Tunnicliffe, J., 2003, Bed load measurements with a passive magnetic induction device. *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS-Publication 283, p. 211-221.

Gray, J.R., Webb, R.H., and Hyndman, D.W., 1991, Low-flow sediment transport in the Colorado River: Proceedings of the 5th Federal Interagency Sedimentation Conference: Interagency Advisory Committee on Water Data, Subcommittee on Sedimentation, Las Vegas, Nev., v. 1, p. 4-63 to 4-71, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Habersack, H.M., 2001, Radio-tracking gravel particles in a large braided river in New Zealand: a field test of the stochastic theory of bedload transport proposed by Einstein: Hydrological Processes, v. 15, p. 377-391.

Habersack, H.M., 2003, Use of radio-tracking techniques in bedload transport investigations, *in*, J. Bogen, T. Fergus and D.E. Walling, eds., Erosion and Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 172-180.

Habersack, H.M. and Laronne, J.B., 2001, Bed load texture in an alpine gravel bed river: Water Resources Research, v. 37, no. 12, p. 3359-3370.

Habersack, H.M. and Laronne, J.B., 2002, Evaluation and improvement of bedload discharge formulas based on Helley-Smith sampling in an Alpine gravel-bed river: Journal of Hydraulic Engineering, v. 128, no. 5, p. 484-499.

Habersack, H.M, Nachtnebel P.N., and Laronne, J.B., 2001, The continuous measurement of bedload discharge in a large alpine gravel bed river with a slot sampler: Journal of Hydraulic Research, v. 39, p. 125-133.

Hardardottir, J. and Snorrason, A., 2003, Sediment monitoring of glacial rivers in Iceland: new data on bed load transport, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 154-163.

Harris, T. and Richards, K.S., 1995, Design and calibration of a recording bedload trap: Earth Surface Processes and Landforms, v. 20, p. 711-720.

Haschenburger, J.K. and Church, M., 1998, Bed material transport estimated from the virtual velocity of sediment: Earth Surface Processes and Landforms, v. 23, p. 791-808.

Hassan, M.A., 1990, Scour, fill, and burial depth of coarse material in gravel bed streams: Earth Surface Processes and Landforms, v. 15, p. 341-356.

Hassan, M.A. and Church, M., 1992, The movement of individual grains on the streambed, *in,* P. Billi, R.D. Hey, C.R. Thorne and P. Tacconi, eds., Dynamics of Gravel Bed Rivers: John Wiley, Chichester, Great Britain, p. 159-175.

Hassan, M.A. and Church, M., 2001, Sensitivity of bedload transport in Harris Creek – seasonal and spatial variation over a cobble-gravel bar: Water Resources Research*,* v. 37, no. 3, p. 813-825.

Hassan, M.A., and Ergenzinger, P., 2003, Use of tracers in fluvial geomorphology, *in*, Kondolf, G.M., and Piégay, H., eds., Tools in Fluvial Geomorphology: John Wiley and Sons, Chichester, Great Britain, p. 397-423.

Hassan, M.A., Church, M., and Ashworth, P.J., 1992, Virtual rate and mean distance of travel of individual clasts in gravel-bed channels: Earth Surface Processes and Landforms, v. 17, p. 617-627.

Hassan, M.A., Church, M., and Schick, A.P., 1991, Distance of movement of coarse particles in gravel bed streams: Water Resources Research, v. 27, no. 4, p. 503-511.

Hassan, M.A., Schick, A.P., and Shaw, P., 1999, The transport of gravel in an ephemeral sandbed river: Earth Surface Processes and Landforms, v. 25, p. 623-640.

Hayes, S.K., Montgomery, D.R., and Newhall, C.G., 2002, Fluvial sediment transport and deposition following the 1991 eruption of Mount Pinatubo: Geomorphology, v. 45, p. 211-224.

Hayward, J.A., 1980, Hydrology and stream sediments in a mountain catchment, *in*, Tussock Grasslands and Mountain Lands Institute: Special Publication 17, 236 p.

Hayward, J.A. and Sutherland, A.J., 1974, The Torlesse stream vertex-tube sediment trap: Journal of Hydrology (N.Z.), v. 13, no. 1, p. 41-53.

Helley, E.J. and Smith, W., 1971, Development and calibration of a pressure-difference bedload sampler: U.S. Geological Survey Open-File Report 73-108.

Hubbell, D.W., 1964, Apparatus and techniques for measuring bedload: U.S. Geological Survey Water Supply Paper 1748, accessed January 26, 2005, at *http://pubs.er.usgs.gov/pubs/wsp/wsp1748/*

Hubbell, D.W., Stevens, H.H., and Beverage, J.P., 1985, New approach to calibrating bed load samplers: Journal of Hydraulic Engineering, v. 111, no. 4, p. 677-694.

Hubbell, D.W., Stevens, H.H., Skinner, J.V., and Beverage, J.P., 1987, Laboratory Data on Coarse-Sediment Transport for Bedload-Sampler Calibrations: U.S. Geological Survey Water-Supply Paper 2299, accessed January 26, 2005, at *http://pubs.er.usgs.gov/pubs/wsp/wsp2299/*

Johnson, C.W., Engleman, R.L., Smith, J.P., and Hansen, C.L., 1977, Helley-Smith bed load samplers: Journal of the Hydraulics Division, ASCE*,* 103 (HY10), p. 1217-1221.

Kondolf, G.M. and W.V.G. Matthews, 1986, Transport of tracer gravels on a coastal California River: Journal of Hydrology*,* v. 85, p. 265-280.

Laronne, J.B. and Carson, M.A., 1976, Interrelationships between bed morphology and bed material transport for a small, gravel-bed channel: Sedimentology, v. 23, p. 76-85.

Laronne, J.B., Outhet, D.N., Duckham, J.L. and McCabe, T.J., 1992, Determining event bedload volumes for evaluation of potential degradation sites due to gravel extraction, N.S.W., Australia, *in*, Erosion and Sediment Transport Monitoring in River Basins: IAHS Publication 210, p. 87-94.

Laronne, J.B., Alexandrov, Y., Bergman, N., Cohen, H., Garcia, C., Habersack, H., Powell, D.M., and Reid, I., 2003, The continuous monitoring of bedload flux in various fluvial systems, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 134-145.

Lenzi, M.A., Marchi, L., and Scussel, G.R., 1990, Measurement of coarse sediment transport in a small Alpine stream, *in*, Hydrology in Mountainous Regions, 1, IAHS Publication 193, p. 223-230.

Lenzi, M.A., D'Agostino, V., and Billi, P., 1999, Bedload transport in the instrumented catchment of the Rio Cordon. Part I: Analysis of bedload records, conditions and threshold of bedload entrainment: Catena, v. 36, p. 171-190.

Lewis, J. 1991, An improved bedload sampler: Proceedings of the 5th Federal Interagency Sedimentation Conference, Las Vegas, Nev., VI 1 - VI 8, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

McBain and Trush, 2004, Coarse sediment management plan for the lower Tuolumne River, revised final report. Prepared for the Tuolumne River Advisory Committee, McBain and Trush, Arcata, CA, 347 p., accessed January 19, 2005, at *http://www.delta.dfg.ca.gov/afrp/Project.asp?code=2000-41*

McNamara, J.P., Bordon, J.C., and Fitzgerald, F., 2001, Radio-tracking of cobbles in a mountain stream in southwest Idaho: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., v. 1: p. III 63 - III 69, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Milhous, R.T., 1973, Sediment transport in a gravel-bottomed stream: Ph.D. dissertation, Oregon State University, Corvallis.

Mizuyama, T., Fujita, M., and Nonaka, M., 2003, Measurement of bedload with use of hydrophone in mountain torrents, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 222-227.

Nankervis, J., 1994, Summary of fluvial study site data collection. Water Division 1 Water Rights Adjudication, Greeley, CO: Report prepared for the Stream Systems Technology Center, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo., 24 p.

Nanson, G.C., 1974, Bedload and suspended-load transport in a small, steep, mountain stream: American Journal of Science, v. 274, p. 471-486.

O'Leary, S.J. and Beschta, R.L., 1981, Bed load transport in an Oregon Coast Range stream: Water Resources Bulletin, v. 17, no. 5, p. 886-894.

Pitlick, J., 1988, Variability of bed load movement: Water Resources Research, v. 24, no. 1, p. 173-177.

Powell, D.M. and Ashworth, P.J., 1995, Spatial pattern of flow competence and bedload transport in a divided gravel bed river: Water Resources Research, v. 31, no. 3, p. 741-752.

Powell, D.M., Reid, I., Laronne, J.B., and Frostick, L.E., 1998, Cross stream variability of bedload flux in narrow and wider ephemeral channels during desert flash floods, *in*, P.C. Klingeman, R.L. Beschta, P.D. Komar and J.B. Bradley, eds., Gravel-Bed Rivers in the Environment: Water Resources Publications, Littleton, Colo., p. 177-196.

Reid, I. and Frostick, L.E., 1986, Dynamics of bedload transport in Turkey Brook, a coarse grained alluvial channel: Earth Surface Processes and Landforms, v. 11, p. 143-155.

Reid, I. and Laronne, J.B., 1995, Bed load sediment transport in an ephemeral stream and a comparison with seasonal and perennial counterparts: Water Resources Research, v. 31, no. 3, p. 773-781.

Reid, I., Frostick, L.E., and Layman, J.T., 1985, The incidence and nature of bedload transport during flood flows in coarse-grained alluvial channels: Earth Surface Processes and Landforms, v. 10, p. 33-44.

Reid, I., Layman, J.T. and Frostick, L.E., 1980, The continuous measurements of bedload discharge: Journal of Hydraulic Research, v. 18, no. 3, p. 243-249.

Rennie, C.D., Millar, R.G., and Church, M.A., 2002, Measurement of bed load velocity using an acoustic Doppler current profiler: Journal of Hydraulic Engineering, v. 128, no. 5, p. 473-483.

Richardson, K., Benson, I., and Carling, P.A., 2003, An instrument to record sediment movement in bedrock channels, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 228-235.

Rickenmann, D., 1994, Bedload transport and discharge in the Erlenbach stream, *in*, P. Ergenzinger and K.-H. Schmidt, eds., Dynamics and Geomorphology of Mountain Rivers: Lecture Notes in Earth Sciences, v. 52, p. 53-66, Springer Verlag, Berlin.

Rickenmann, D., 1997, Sediment transport in Swiss torrents: Earth Surface Processes and Landforms, v. 22, p. 937-951.

Rickenmann, D. and Dupasquier, P., 1994, Messung des feststofftransportes im Erlenbach. [Sediment transport measurement in the Erlenbach stream]: Beiträge zur Geologie der Schweiz - Hydrologie, v. 35, p. 134-144.

Rickenmann, D., Hofer, B., and Fritschi, B., 1997, Geschiebemessungen mittels hydrophon. [Bedload transport measurements with a hydrophone]: Österreichische Wasser- und Abfallwirtschaft, 11/12.

Rosenfeld, C.L., Castro, J.M., and Childers, E.S., 1996, Individual gravel tracking using a passive radio transponder system: Proceedings of the 6th Federal Interagency Sedimentation Conference, Las Vegas, Nev., V47 - V51, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Rouse, H.L., 1994, Measurement of bedload gravel transport: the calibration of a self-generated noise system: Earth Surface Processes and Landforms, v. 19, p. 789-800.

Rubin, D.M., Tate, G.B., Topping, D.J., and Anima, R.A., 2001, Use of rotating side-scan sonar to measure bedload: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., v. 1, p. III 139 - III 143, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Ryan, S.E., 1998, Sampling bedload transport in coarse-grained mountain channels using portable samplers: Proceedings of the Federal Interagency Workshop "Sediment Technology for the 21st Century", St. Petersburg, Fla., accessed September 2, 2004, at *http://water.usgs.gov/osw/techniques/sedtech21/ryan.html*

Ryan, S.E., 2001, The influence of sediment supply on rates of bedload transport: a case study of three streams on the San Juan National Forest: Proceedings of the 7th Federal Interagency Sedimentation Conference, Reno, Nev., v. 1, p. III 48 - III 54, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Ryan, S.E and Dixon, M., 2002, Bedload movement in a mountain gravel-bed stream: CD-ROM Video, Technology Transfer, Stream Systems Technology Center, Fort Collins, Colo.

Ryan, S.E. and Emmett, W.W., 2002, The nature of flow and sediment movement in Little Granite Creek near Bondurant, WY: USDA Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-90.

Ryan, S.E. and Porth, L.S., 1999, A field comparison of three pressure-difference bedload samplers: Geomorphology, v. 30, p. 307-322.

Ryan, S.E. and Troendle, C.A., 1997, Measuring bedload in coarse-grained mountain channels: procedures, problems, and recommendations, *in*, Water Resources Education, Training, and Practice: Opportunities for the Next Century, American Water Resources Association Conference, Keystone, Colo., p. 949-958.

Schmidt, K.-H and Ergenzinger, P., 1992, Bedload entrainment, travel lengths, step lengths, rest periods, studied with passive (iron, magnetic) and active (radio) tracer techniques: Earth Surface Processes and Landforms, v. 17, p. 147-165.

Schmidt, K.-H. and Gintz, D., 1995, Results of bedload tracer experiments in a mountain river, *in*, E.J. Hickins, ed., River Geomorphology: John Wiley and Sons, Chichester, Great Britain, p.37-54.

Sear, D.A., 1996, Sediment transport processes in pool-riffle sequences: Earth Surface Processes and Landforms, v. 21, p. 241-262.

Sear, D.A., 2003, Event bed load yield measurement with load cell bed load traps and prediction of sediment yield from hydrograph shape, *in,* J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 146-153.

Sear, D.A., Damon, W., Booker D.J., and Anderson, D.G., 2000, A load cell based continuous recording bedload trap: Earth Surface Processes and Landforms, v. 25, p. 689-672.

Sear, D.A., Lee, M.W.E., Carling, P.A., Oakley, R.J., and Collins, M.B., 2003, An assessment of the accuracy of the Spatial Integration Method (S.I.M.) for estimating coarse bedload transport in gravel-bedded streams using passive tracers, *in*, J. Bogen, T. Fergus and D. Walling, eds., Erosion and Sediment Transport Measurement in Rivers—Technological and Methodological Advances: IAHS Publication 283, p. 164-171.

Sterling, S.M. and Church, M., 2002, Sediment trapping characteristics of a pit trap and the Helley-Smith sampler in a cobble gravel-bed river: Water Resources Research, v. 38, no. 6, 10.1029/2000WR000052, 2002.

Tacconi, P. and Billi, P., 1987, Bed load transport measurement by a vortex-tube trap on Virginio Creek, Italy, *in*, C.R. Thorne, J.C. Bathurst and R.D. Hey, eds., Sediment Transport in Gravel-Bed Rivers: Wiley, Chichester, Great Britain, p. 583-615.

Taniguchi, S., Itakura, Y., Miyamoto, K., and Kurihara, J., 1992, A new acoustic sensor for sediment discharge measurement, *in*, Erosion and Sediment Transport Monitoring in River Basins: IAHS Publication 210, p. 135-142.

Thompson, D.M., Wohl, E.E., and Jarrett, R.D., 1996, A revised velocity-reversal and sediment sorting model for a high-gradient, pool-riffle stream: Physical Geography, v. 17, no. 2, p. 142-156.

Troendle, C.A., Nankervis, J.M., and Ryan, S.E., 1996, Sediment transport from small, steep-gradient watersheds in Colorado and Wyoming: Proceedings of the 6th Federal Interagency Sedimentation Conference, Las Vegas, Nev., v. 2, p. IX 39 - IX 45, accessed August 31, 2004, at *http://water.usgs.gov/pubs/misc_reports/FISC_1947-2001/*

Tunnicliffe, J., Gottesfeld, A.S., and Mohamed, M., 2000, High resolution measurement of bedload transport: Hydrological Processes, v. 14, p. 2631-2643.

Wathen, S.J., Hoey, T.B., and Werritty, A., 1995, Unequal mobility of gravel and sand in weakly bimodal river sediments: Water Resources Research, v. 31, no. 8, p. 2087-2096.

Whitaker, A.C., 1997, The initiation of coarse bed load transport in gravel bed streams: Ph.D. dissertation, University of Montana, Missoula.

Whitaker, A.C., and Potts, D.F., 1996, Validation of two threshold models for bedload initiation in an upland gravel-bed stream, *in*, Watershed Restoration Management - Physical, Chemical, and Biological Considerations: Proceedings of the Annual Symposium, 1996: American Water Resources Association, p. 85-94.

Wilcock, P.R., 2001, Toward a practical method for estimating sediment transport rates in gravel-bed rivers: Earth Surface Processes Landforms, v. 26, p. 1395-1408.

Xiang, Z. and Zhou, G., 1992, Measuring techniques of bed load in the Yangtze River, *in*, Erosion and Sediment Transport Monitoring in River Basins: IAHS Publication 210, p. 175-180.

Yang, X. and Gao, H., 1998, Development of AYT gravel bed-load sampler and method for bed-load measurement, *in*, Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes: IAHS Publication 249, p. 345-352.