STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station

July 2009

Computing, Interpreting, and Understanding Bed Load Transport in Gravel-bed Streams

The Stream Systems Technology Center is pleased to announce the release of the following publications:

- Pitlick, John; Cui, Yantao; Wilcock, Peter. 2009. ***Manual for computing bed load transport using BAGS (Bedload Assessment for Gravel-bed Streams) Software.*** Gen. Tech. Rep. RMRS-GTR-223. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 45 p.
- Wilcock, Peter; Pitlick, John; Cui, Yantao. 2009. ***Sediment transport primer: estimating bed-material transport in gravel-bed rivers.*** Gen. Tech. Rep. RMRS-GTR-226. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 78 p.

The publication, ***Manual for computing bed load transport using BAGS (Bedload Assessment for Gravel-bed Streams) Software***, provides background information and instructions on BAGS, a spreadsheet-based program for calculating bed load transport in gravel-bed streams using six different equations. The publication, ***Sediment transport primer: estimating bed-material transport in gravel-bed rivers***, is a companion document to the BAGS software and manual, providing the user with background information on sediment transport dynamics, various bed load transport models, and potential errors in bed load transport estimates. These publications and the BAGS program were developed by ***Dr. John Pitlick*** (Professor; Department of Geography; University of Colorado; Boulder, CO), ***Dr. Peter Wilcock*** (Professor; Department of Geography Environmental Engineering; John Hopkins University; Baltimore, MD), and ***Dr. Yantao Cui*** (Hydraulic Engineer; Stillwater Sciences; Berkeley, CA).

BAGS Software and Manual

The ***Manual for computing bed load transport using BAGS (Bedload Assessment for Gravel-bed Streams) Software*** (fig 1.), provides step-by-step instructions for operating BAGS along with explanations of the rationale behind individual steps or model calculations. In addition to

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John Potyondy, Program Manager.

The PRIMARY AIM *is to exchange technical ideas and transfer technology among scientists working with wildland stream systems.*

CONTRIBUTIONS *are voluntary and will be accepted at any time. They should be typewritten, single-spaced, and limited to two pages. Graphics and tables are encouraged.*

Ideas and opinions expressed are not necessarily Forest Service policy. Citations, reviews, and use of trade names do not constitute endorsement by the USDA Forest Service.

CORRESPONDENCE:
E-Mail: rmrs_stream@fs.fed.us
Phone: (970) 295-5983
FAX: (970) 295-5988

Website:
http://www.stream.fs.fed.us

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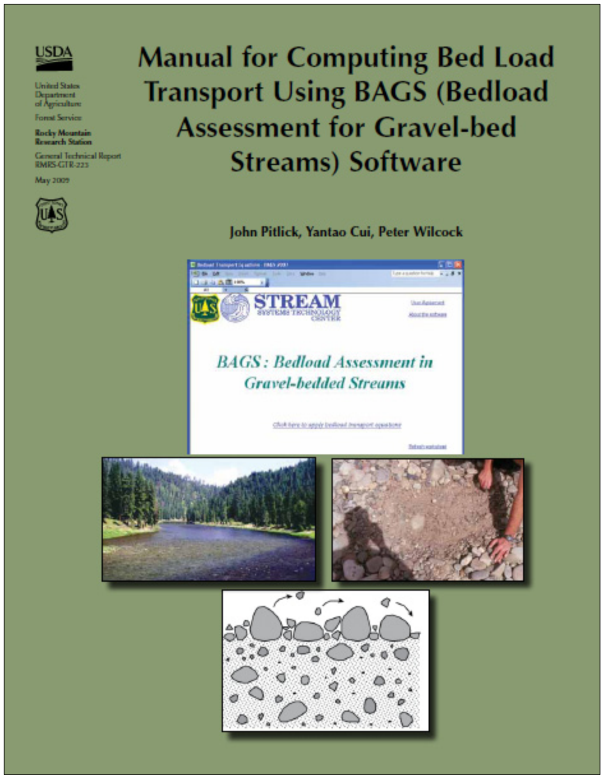

Figure 1. Cover page of RMRS-GTR-223.

the step-by-step instructions, the BAGS manual describes in detail the individual bed load transport equations used in the BAGS model, provides guidance on interpreting the results from the model output, discusses possible strategies for evaluating the reasonableness of model results, and presents several examples from different studies illustrating how and why bed load modeling results can differ from field measurements.

The BAGS software uses six well-known bed load transport equations developed specifically for gravel-bed rivers:

- the surface-based equation of Parker (1990);
- the substrate-based equation of Parker-Klingeman-McLean (Parker and others 1982);
- the substrate-based equation of Parker and Klingeman (1982);
- the surface-based two-fraction equation of Wilcock (2001);
- the surface-based equation of Wilcock and Crowe (2003); and
- the procedure of Bakke and others (1999).

All of the bed load equations listed assess bed load transport as a function of excess shear stress based on some estimate of a reference shear stress. In the Wilcock (2001) and Bakke and others (1999) models, the reference shear stress is calibrated from observations of bed load transport. Table 1 lists the information and input variables needed to run the six sediment transport equations in BAGS. Each of the six equations requires the input of a measured channel cross section, an estimate of the reach-averaged water-surface slope, range of discharges, and varying types of sediment data from the bed surface, substrate or bed subsurface, and/or bed load sample data. These input parameters for the equations are easily collected in the field or obtained from other resources. The primary differences between the various sediment transport models are whether the surface or substrate grain

Table 1. Summary of input variables and data needed to run the different bed load transport equations provided in the BAGS software.

	Equations					
Input Variables	Parker (1990)	Parker-Klingeman-McLean (1982)	Parker and Klingeman (1982)	Wilcock (2001)	Wilcock and Crowe (2003)	Bakke and others (1999)
Channel cross section	X	X	X	X	X	X
Water surface slope	X	X	X	X	X	X
Discharge	X	X	X	X	X	X
Bed surface						
• grain-size distribution	X				X	X
• % fraction of sand, gravel				X		
Substrate						
• grain-size distribution			X			X
• D_{50} particle size		X				
Bed load sample data				X		X

size is used, the number of grain size fractions used, and whether the model uses bed load measurements to calibrate the model (table 1). The equations of Parker (1990), Wilcock (2001), and Wilcock and Crowe (2003) apply surface grain size characteristics as inputs, while the Parker-Klingeman-McLean equation (Parker and others 1982) uses substrate grain sizes (table 1). The Bakke and others method (1999) applies to either the surface or the substrate, depending on circumstances. In addition, the methods of Wilcock (2001) and Bakke and others (1982) use bed load measurements to calibrate certain coefficients in the transport equations and procedures.

The equations and procedures are implemented in an MS-Excel workbook with Visual Basic for Applications. Field data and relevant parameters are entered into the program sequentially through a series of prompts to the user. Results of the calculations are presented in MS-Excel worksheets. The software is designed to be used by professionals (hydraulic engineers, fluvial geomorphologists, and hydrologists) with some familiarity and training in sediment transport processes. As with any hydraulic and sediment transport model, correct interpretation of the results requires a more in-depth knowledge of fluvial processes, especially the dynamics of sediment transport in gravel-bed rivers.

Sediment Transport Primer

The document, ***Sediment transport primer: estimating bed-material transport in gravel-bed rivers*** (fig. 2), was written to provide background information on sediment transport dynamics and as a supplement to BAGS so that the user can more effectively apply the model and interpret the bed load transport estimates. As aptly pointed out by the authors, although BAGS makes it easier to calculate bed load transport rates and reduces the chance of computation error, it cannot prevent inaccurate and unrealistic bed load transport estimates due to the user's lack of understanding of sediment transport dynamics and the various equations used to predict sediment transport. Within this framework, the sediment transport primer was written to help the user of BAGS define relevant and proper sediment transport problems, select appropriate model input data, interpret and apply the model output results in a useful and reliable fashion, and examine sources of error.

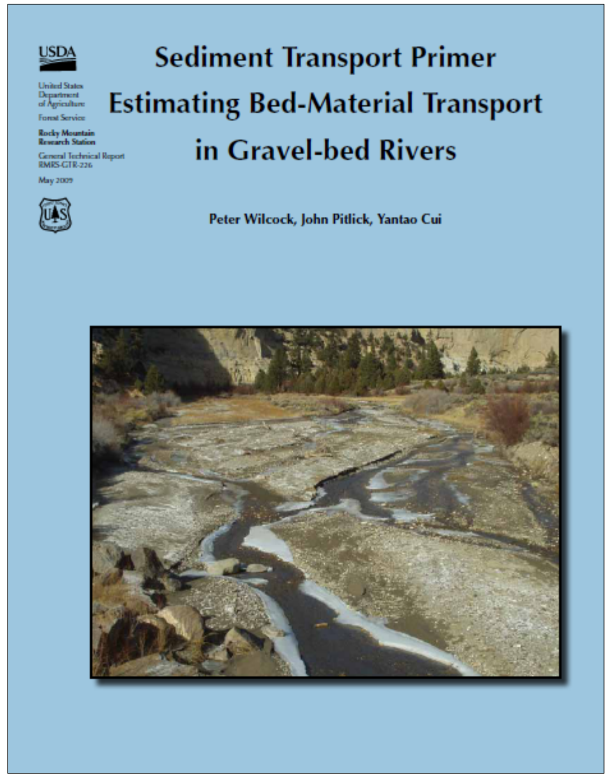

Figure 2. Cover page of RMRS-GTR-226.

The document, ***Sediment transport primer: estimating bed-material transport in gravel-bed rivers***, is organized into seven chapters. Chapter 1 introduces the various challenges and difficulties of accurately estimating bed load transport rates, discusses the importance of understanding the watershed context when addressing sediment transport problems, and provides different examples of sediment transport applications.

Chapter 2 introduces and discusses the various components involved in sediment transport processes in gravel-bed streams such as lateral and vertical channel-bed sediment characteristics, the types and mechanics of sediment transport, the relationship between sediment supply and transport capacity, and sediment rating curves. Included in this chapter are discussions on the various approaches used to quantify local shear stress or grain shear stress acting on the sediment grains and for determining the incipient motion of the different sediment sizes making up the channel bed.

Chapter 3 discusses the primary sources of error in predicting sediment transport:

- The error in quantifying the local shear stress acting on the sediment grains because of unsteady and non-uniform flow, not accurately quantifying local shear stress, and the spatial variability of shear stress along and across the channel.
- The error in determining the grain size to use in estimating sediment transport because of the lateral and vertical variability of grain sizes that make up the channel bed and that the bed load being transported is different in size than the channel-bed sediment.
- The error in determining the incipient motion of the particle because of items discussed in the previous bullets and the wide variation in estimating the critical shear stress or Shields parameter for a given sediment size.

Chapter 4 provides background information on the different sediment transport equations used in BAGS. The discussion focuses on the features and differences that distinguish each of the six sediment transport equations from each other, allowing the user to determine which bed load transport model may be most appropriate for their application.

Chapter 5 discusses the importance of collecting quality field data to make reasonable sediment transport estimates. This chapter provides suggestions for collecting field data to reduce the errors for quantifying local shear stress, determining a representative grain size, and selecting the critical shear stress or Shields parameter for a given sediment grain size.

Chapter 6 examines the various options and choices the user must make when collecting field data and selecting a sediment transport equation(s) in BAGS. The primary choices include collecting representative channel-bed sediments from the surface or substrate, the number of size fractions to use in the analysis, and whether bed load measurements will be used to calibrate the model (table 1).

Chapter 7 presents a basis for estimating the magnitude of error of sediment transport predictions and suggests strategies for handling that error in subsequent calculations and decisions. The authors also recommend using Monte Carlo error analysis of error propagation to calculate uncertainty in sediment transport estimates.

How to Obtain the Software, User's Manual, and Sediment Transport Primer

The BAGS program, the BAGS user's manual, and sediment transport primer can be downloaded from the STREAM website: http://www.stream.fs.fed.us/publications/software.html. BAGS may be updated as features and modeling capabilities are added to the program. Users are encouraged to periodically check the STREAM website for the latest updates to the BAGS program.

Printed copies of Rocky Mountain Research Station General Technical Reports, ***GTR-223 and GTR-226***, can be obtained from the Rocky Mountain Research Station by submitting your mailing information by telephone: (970) 498-1392; facsimile: (970) 498-1122; e-mail: rschneider@fs.fed.us; website: http://www.fs.fed.us/rm/publications; or mail: Publications Distribution, Rocky Mountain Research Station, 240 West Prospect Road, Fort Collins, CO 80526.

BAGS is supported by, and limited technical support is available from, the Streams Systems Technology Center, Fort Collins, CO. The preferred method of contact for obtaining support is to send an e-mail to rmrs_stream@fs.fed.us requesting "BAGS Support" in the subject line.

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Stream Restoration Design Handbook (NEH-654)

Streams are important both ecologically and economically; they provide vital habitat for aquatic and terrestrial species, water supply for municipalities, hydroelectric power for communities, and are an important means for transporting goods. In many watersheds, anthropogenic disturbances such as dams, mining, agriculture, urbanization, timber harvesting, and channelization have altered and degraded streams and ecosystems. To restore a degraded stream channel and ecosystem, various restoration measures are undertaken such as installing structures and planting riparian vegetation to protect stream banks and provide habitat, reshaping unstable stream segments into appropriately designed functional streams and associated floodplains, removing the watershed disturbances that are causing stream instability, and removing barriers that impede the movement of fish and other aquatic organisms.

The effectiveness of these stream restoration efforts has been mixed because the field of stream restoration is still evolving, as well as the supporting science and technology. Recent advances in the fields of hydraulics, geomorphology, and ecology have significantly influenced stream assessment methods and stream restoration design techniques. Within this context, the USDA Natural Resources Conservation Service (NRCS) developed and produced the ***Stream Restoration Design Handbook (NEH-654)*** to provide practitioners involved in stream restoration with a comprehensive document of the most current and best guidelines and tools for designing stream restoration projects (fig. 1). This handbook presents a variety of engineering, geomorphic, and ecological assessment techniques and design tools that are applicable to a wide range of stream restoration work. The focus is on the "how-to," providing the user with specific tools to conduct stream assessments, identify channel stability problems, and develop stream restoration design solutions. However, the handbook does not recommend or prescribe to specific stream assessment methods and design procedures, and does not assume that all stream restorations projects require structural treatments.

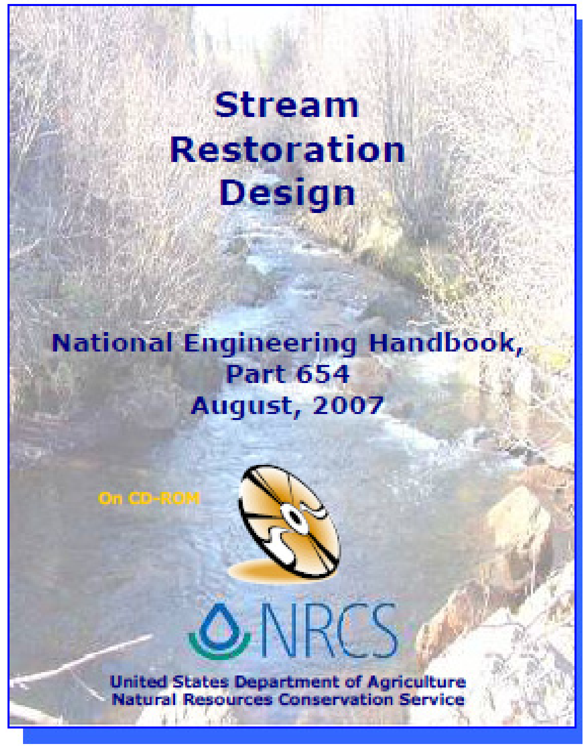

Figure 1. Cover page of NEH-654.

The NRCS ***Stream Restoration Design Handbook (NEH-654)*** is organized into 17 chapters, 28 technical supplements, and 18 case studies (fig. 2). The 17 chapters in the handbook provide background information on fluvial processes and channel morphology, stream hydrology and hydraulics, conducting a site assessment, developing stream restoration design solutions for different channel types, implementing stream restoration designs, and the maintenance and monitoring of stream restoration projects. The 28 technical supplements complement individual handbook chapters by providing specific assessment and analysis techniques and design tools for various types of stream restoration projects. Although many of the design solutions are structural in nature, the handbook emphasizes and recognizes that effective stream restoration designs also include techniques that remove sources of disturbance, allow design elements to function well together, and enhance the stream's ability for ecological regeneration. The 17 case studies represent a wide assortment of stream restoration approaches and design solutions from

Figure 2. The table of contents for the 17 chapters, 28 technical supplements, and 18 case studies in the NRCS publication, ***Stream Restoration Design Handbook (NEH-654)***.

various locations in the United States. The different case studies demonstrate the various challenges that occur in stream restoration projects along with lessons learned. The handbook is not meant to be read linearly as a book, but as a reference with a suite of tools, techniques, and approaches that can be applied to stream restoration projects.

While primarily an effort by the NRCS, stream and aquatic ecology experts from various Federal, State, and local agencies, private consulting, and academia contributed to the content of ***Stream Restoration Design Handbook (NEH-654)***. The technical editors of this publication are ***Jerry M. Bernard*** (Geologist; USDA-NRCS; Washington, DC), ***Jon Fripp*** (Stream Mechanics Engineer; USDA-NRCS; Fort Worth, TX), and ***Kerry Robinson*** (Hydraulic Engineer; USDA-NRCS; Greensboro, NC). The design handbook is not available as a paper document, but a CD version of the document can be ordered, without cost, from the NRCS National Publications and Forms Distribution Center-LANDCARE by e-mailing landcare@usda.gov, calling 1-888-LANDCARE, or visiting the LANDCARE website at http://landcare.nrcs.usda.gov/. The CD contains high quality files for printing selected pages or for extracting graphics and images as needed. Also contained on the CD is the publication, "Stream Corridor Restoration: Principles, Processes, and Practices (NEH-653)" that was released in 1998. The CD contains navigation bookmarks, internal links, and the capability of searching for keywords in the 1600 plus page handbook.

Alternatively, individual chapters, technical supplements, and case studies or all 74 files that make up the document ***Stream Restoration Design Handbook (NEH-654)*** can be downloaded from the eDirectives Website, http://policy.nrcs.usda.gov/viewerFS.aspx?id=3491. However, these files do not contain navigation aids, bookmarks, or other links.

Stream Temperature Modeling

Stream water temperature is an important parameter for monitoring water quality and assessing aquatic health. Inexpensive digital temperature loggers, geographic information systems (GIS), and remote sensing technologies are now facilitating the development of temperature models applicable at broad spatial scales. Statistical temperature models are well suited for broad-scale applications because they are less data intensive than mechanistic stream models, provide estimates of parameter precision, and can often be easily derived from existing databases. The USDA Forest Service, Rocky Mountain Research Station developed a website (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml) that describes three different statistical procedures for predicting suitable fish habitat by modeling or inferring stream temperature:

- ***Air Temperature Based Thermal Stream Habitat Model***: Predicts the distribution of thermally suitable habitat for bull trout as a function of air temperature, elevation, latitude, and longitude. It was developed for the interior Columbia River basin in the Pacific Northwest.
- ***Spatial Statistical Stream Temperature Model***: Predicts stream temperature based on thermograph data, air temperature, solar radiation, elevation, and stream flow. GIS and spatial statistical models are utilized to account for network topology.
- ***Multiple Regression Stream Temperature Model***: Thermograph records, geomorphic predictor variables derived from digital elevation models, and multiple regression are used to predict stream temperatures for individual reaches throughout a river network.

Application of the stream temperature models are highlighted in three research projects that provide a range of modeling alternatives and predictive accuracy. Each project has links to primary publications, detailed methods and metadata, GIS layers, project data, maps, contact information, and other related materials. The website (http://www.fs.fed.us/rm/boise/AWAE/projects/stream_temperature.shtml) also contains information on collecting, processing, and archiving stream temperature data.

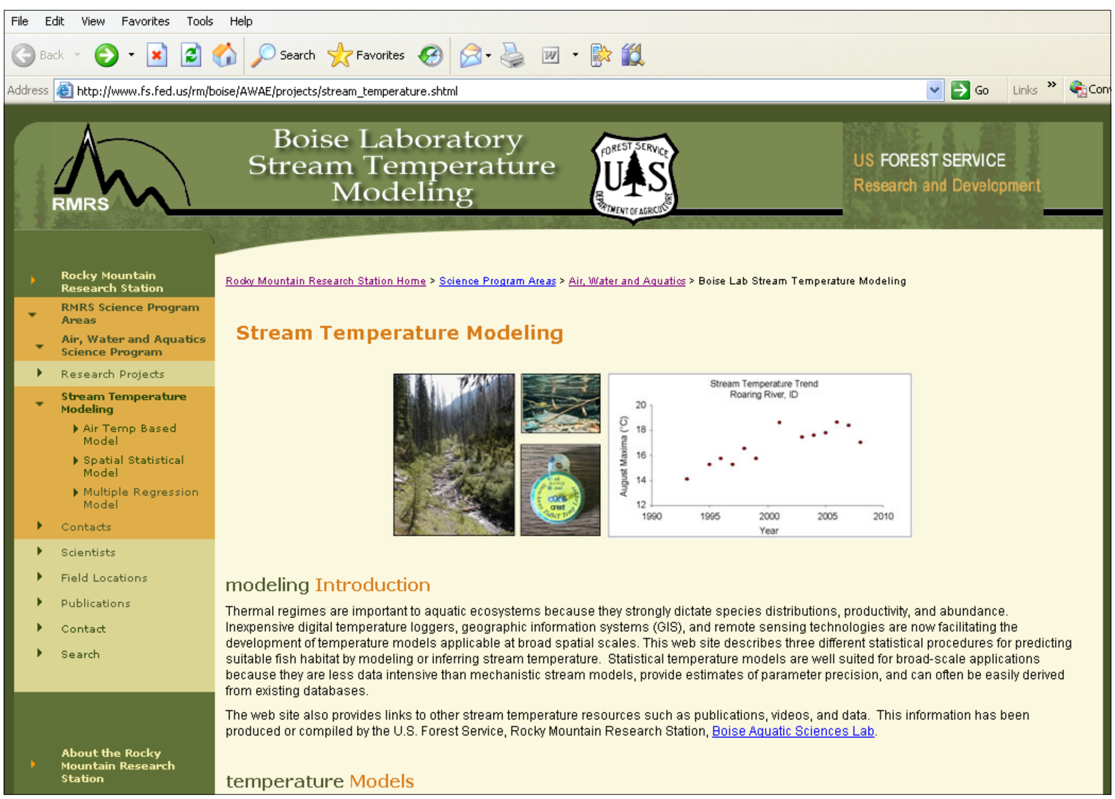

Figure 1. Partial screen shot of the stream temperature modeling website.

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