STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

July 1993

Equal Mobility of Riverbed Material

One of the objectives of STREAM NOTES is to improve the level of understanding of stream systems. In this issue we would like to provide insight into the controversial theory of "equal mobility," which says that nearly all of the grain sizes in natural rivers begin to move at nearly the same discharge.

The entrainment and transport of bed and substrate materials in naturally sorted, gravel bed streams has become an important hydrologic issue. The habitat value, water supply capability, flood capacity, and multi-land use aspects linked to a stream system are closely tied to channel morphology and stream stability in many mountain and plateau areas. Knowledge of the hydraulic conditions at which bed-material particles begin to move is a crucial element to understanding the river system and predicting channel response. Previous studies by Shields (1936), Hjulstrom (1938), Baker and Ritter, (1975) and Church (1978) have identified most of the information compiled on particle entrainment. Unfortunately, a significant portion of the available information for coarse-particle entrainment has been derived from river studies or extrapolation of results from laboratory flume studies using sand particles.

Perhaps one of the most comprehensive investigations to determine the threshold hydraulic conditions required to entrain gravel and cobbles from a riverbed composed of nonuniform-sized material was conducted by Andrews (1983). The hydraulic conditions necessary to initiate motion of a particle can be described by equating forces tending to entrain the particle with forces tending to keep the particle at rest. The force of the flow acting upon the bed particle can be expressed as a shear stress, τ, and is defined as

$$\tau = \gamma_f DS \qquad (1)$$

where γ_f is the unit weight of fluid (water), D is the depth of flow, and S is the water-surface slope. The entrainment force acting on a single particle size of diameter, d_i, can be equated to the force of gravity tending

STREAM NOTES *is produced quarterly by the Stream Systems Technology Center, Fort Collins, Colorado.*

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

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

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to keep the same particle at rest. Solving the entrainment and gravitational force expression results in a critical shear stress, or the shear stress that causes threshold motion of the particle, τ_{ci}. The critical shear stress can be converted to a dimensionless parameter referred to as the critical dimensionless shear stress, τ^*_{ci}, which can be expressed as

$$\tau^*_{ci} = \frac{\tau_i}{((\gamma_s - \gamma_f)\, d_i)} \qquad (2)$$

where γ_s is the unit weight of the particle. The critical dimensionless shear stress is generally considered a constant for natural rivers in which the bed material is larger than 2 mm.

The value of τ^*_{ci} is quite variable and depends upon the median particle size, grain size distribution, bed composition uniformity, and the presence of bed forms. Flume studies with a sand bed material indicates that a critical dimensionless shear stress of 0.060 should be used to determine the threshold hydraulic conditions. Other studies have reported τ^*_{ci} values ranging from 0.020 to 0.25 based on measurements in natural rivers with a range of different-sized bed-material particles. Factors that contribute to the large range of reported τ^*_{ci} values include subjectivity in determining threshold motion, differing definitions for "the beginning of motion", and uniformity, or non-uniformity, of the particle size distribution of the bed.

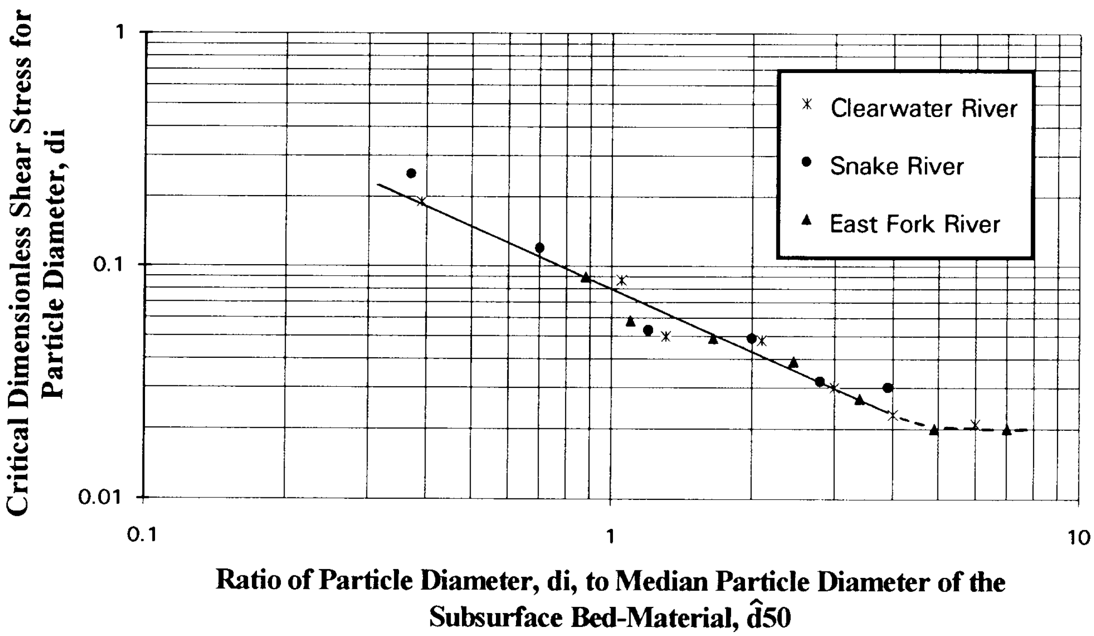
Andrews (1983) collected bedload transport data, discharge data, hydraulic characteristic data, and the particle size distributions of the surface and subsurface bed material data from reports on the East Fork River, Wyoming and on the Snake and the Clearwater Rivers in Idaho. Median particle sizes were determined to be approximately 25 mm, 54 mm and 74 mm for riverbed samples collected on the East Fork, Snake, and Clearwater rivers, respectively. Bankfull discharges ranged from 23 m^3/s to 2,300 m^3/s.

Andrews computed the average critical dimensionless shear stress, $\bar{\tau}^*_{ci}$, for each size class of the bed material. He then conducted an empirical analysis correlating the ratio of the particle diameter, d_i, to median particle diameter of the substrate, $\hat{d}_{50}$, to $\bar{\tau}^*_{ci}$ resulting in a least-squares regression equation

$$\bar{\tau}^*_{ci} = 0.0834 \left(\frac{d_i}{\hat{d}_{50}}\right)^{-0.872} \qquad (3)$$

The relationship is applicable for values of $d_i/\hat{d}_{50}$ between 0.3 and 4.2 (see figure next page). Although the data base used in the analysis was fairly limited, it appears that the minimum $\bar{\tau}^*_{ci}$ approaches a minimum value of approximately 0.020. The analysis indicated that the critical value of $\bar{\tau}^*_{ci}$ for a given particle, d_i, is significantly greater when the particle is surrounded by larger particles than when the particle is surrounded by smaller particles. The effect of relative particle protrusion into the flow nearly compensates for differences in particle weight.

The analysis of particle entrainment in natural gravel-bed rivers suggests that the shear stress required to initiate motion of the relatively coarser particles in a riverbed is smaller than previously assumed. Particle motion is more frequent than realized. Andrews performed a bankfull hydraulic characteristic analysis of 24 self-formed gravel-bed rivers in Colorado (1981). The average critical dimensionless shear



Relation between the ratio of threshold particle diameter to the median particle diameter of subsurface bed material and critical dimensionless shear stress.

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stress for the median particle in the riverbed surface was 0.033. The average bankfull value of $\bar{\tau}^*_{50}$ was 0.047. Bankfull discharge conditions was equaled or exceeded from 0.22% to 6.5% of the time (up to 24 days per year). The entrainment of a majority of the surface bed material in the Colorado gravel-bed rivers was a relatively frequent occurrence. In several instances, particles as large as the 90th percentile were entrained by the discharge equal to the bankfull stage. However, the transport rate is quite small.

Andrews (1983) concluded that the critical dimensionless shear stress, $\bar{\tau}^*_{ci}$, is inversely proportional to the particle diameter, d_i, in a naturally sorted gravel riverbed. Therefore, a large portion of the surface particles are entrained at nearly the same shear stress (and discharge) at a given stream location.

Many of Andrews' findings have been simplified for the sake of brevity. It is certainly not the intent of this presentation to mis-represent his work, but rather to highlight many the results and resources that may assist the hydrologic community in understanding the entrainment processes of riverbed material.

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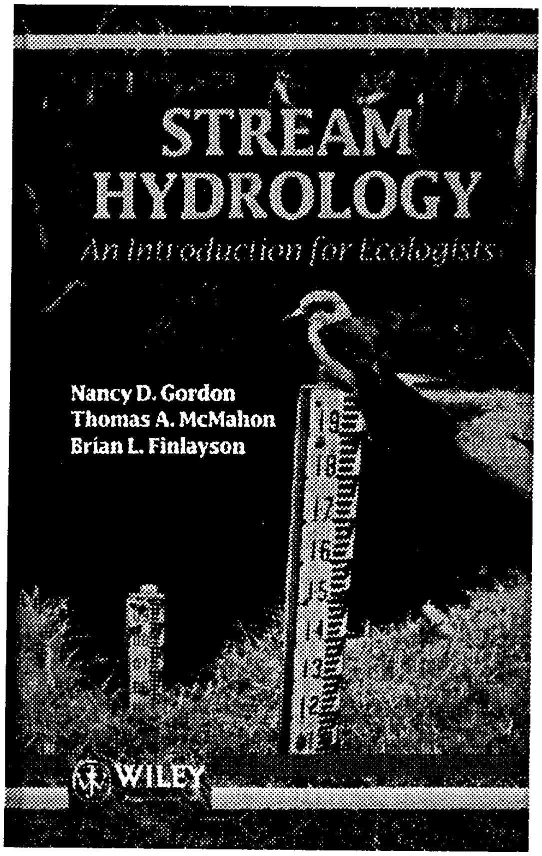
Ask DOCTOR Hydro

Ask Doc Hydro!

Several readers have suggested that we start a question and answer section in STREAM NOTES. The section would answer technical questions you may have about streams, hydrology, or related subjects. While the STREAM TEAM does not presume to have the answers to all of your questions, we can search out someone who does.

Questions should be sent in written form, on the Data General if possible, to STREAM:S28A, addressed to subject "Ask Doc Hydro" . With each issue of STREAM NOTES, we will select at least one question of widespread interest and provide an answer.



Stream Hydrology, An Introduction for Ecologists is one of the more readable hydrology books to come out in a long time. As the subtitle implies, the book is targeted at non-hydrologists. Nevertheless, hydrologists will find this to be an excellent refresher of basic stream hydrology concepts. Devoid of many of the mathematical derivations that one frequently finds in hydrology texts, Stream Hydrology focuses instead on having the reader gain a conceptual understanding of stream processes.

The book was written to help improve communications between hydrologists and ecologists and encourages closer cooperation between the disciplines. Hydrologists and biologists tend to looks at streams from slightly different perspectives. The authors suggest that interdisciplinary interaction provides us with the opportunity to merge information from these differing views to form a more complete understanding of streams. The process often generates new ideas and initiates progress. The hope is to improve communication between researchers in environmental sciences, biology, and others working in riverine environments.

Stream Hydrology was written in Australia. The senior author, Nancy Gordon, is an American trained hydrologist and the co-authors are an Australian agricultural engineer and a geomorphologist. At the time of its writing, the authors were affiliated with the Centre for Environmental Applied Hydrology at the University of Melbourne.

In spite of its foreign genesis, the authors have a remarkable sense of the current state of technology in the United States. In addition, the book is sprinkled with examples from Australia and includes frequent reference to British hydrologic analysis techniques.

The emphasis of the book is on the physical environment. It draws information from the fields of geomorphology, hydrology, and fluid mechanics and then provides examples of the biological significance of the information.

The book is well written, easy to read, and easy to understand. It is generously illustrated and written with a sense of humor. Chapter 5 is entitled, "How to Have A Field

Day and Still Collect Some Useful Information." The section on initiation of sediment motion is subtitled, "Predicting a Particle's Get Up and Go." Interesting tidbits of information are dispersed throughout the book. You'll learn why stream rapids sound the way they do (it's the escaping of air bubbles) and why golf balls have dimples (see page 259).

Field techniques are a central part of the book. Field studies in the Acheron River Basin, located near Melbourne, are a source of information for examples throughout the book. Use of the same river throughout, maintains continuity and illustrates how the authors got to know this river.

Chapter 1 of Stream Hydrology, "Introducing the Medium," discusses the physics of fluids and the physical properties of water.

Chapter 2, "How to Study a Stream," covers the importance of study design and strategic sampling and provides a realistic example of how and how not to conduct a study. The chapter emphasizes the importance of careful thought and planning of the statistics of a study before going out to collect data.

Chapter 3, "Potential Sources of Data (How to Avoid Reinventing the Weir)," discusses sources of data, maps, and photographs useful for hydrologic analysis.

Chapter 4, "Getting to Know Your Stream," is based on the assumption that one needs to understand the current state of the stream and put the individual stream in the context of how its characteristics differs from all other streams. Emphasis is on the stream system. Factors discussed include catchment characteristics, hydrographs, and elementary streamflow statistics.

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Chapter 5, "How to Have a Field Day and Still Collect Useful Information," covers the full range of data collection techniques from basic surveying and stream surveys through measurement of stage, discharge, cross-sections, sediment, and substrate. For many of the parameters, a suite of techniques ranging from the simple to the complex is provided.

Chapter 6, "Water at Rest and in Motion," is one of the better chapters, especially for those without a background in open channel hydraulics or fluid mechanics. The clear presentation can be an excellent refresher for both novices and those who may have had a hydraulics or mechanics course years ago. Numerous examples illustrating the relevance of dynamics and hydraulics to biological phenomena are especially enlightening.

Chapter 7, "Patterns in Shifting Sands," is an introduction to fluvial geomorphology. Included are discussions of channel shaping processes, concepts of channel equilibrium and adjustment, fluvial geometry, channel pattern, and sediment motion.

Chapter 8, "Dissecting Data with a Statistical Scope," covers many of the standard hydrologic analysis techniques including frequency analysis, flow duration curves, and extrapolation of hydrologic data. Also included is a British technique known as flow-spell analysis, which is used to analyze the distribution of low-flow periods.

Chapter 9, "Putting It All Together: Stream Classification and Management," attempts to bridge the gap between the science of hydrology and its practical application. The chapter concentrates on applications of various stream classification systems, reviews instream flow analysis techniques, and encourages a multidisciplinary approach to the rehabilitation of streams combining hydrologic and biological considerations.

The book contains two appendices. Appendix 1 provides a 21 page review of basic statistics. The chapter is an excellent refresher for those who last had statistics years ago and can also serve as a basic reference tool. Topics covered include basic summary statistics, frequency distributions and probability, and correlation and regression techniques. Again, the authors have done a fine job of extracting just the essential material.

Appendix 2 briefly discusses AQUAPAK, a stand-alone package of computer programs, which supplements the text. AQUAPAK is an integral part of the book in the sense that it is referred to throughout the text. Computations for most of the hydrological analyses are not expressly shown in the book, but can be done using this package of computer software. The programs allow readers to carry out computations easily without detailed knowledge of the mathematics involved.

AQUAPAK will run under Macintosh and IBM platforms. The licensed software can be purchased for $20 Australian which converted to about $30 U.S. dollars at the conversion rate in effect when we made our purchase. The address for ordering is in the book.

The programs are not as fancy as the commercial software that we have become accustomed to, but they are a fairly comprehensive set of hydrologic analysis tools that anyone might find useful. Programs of interest include flood-frequency analysis, flow duration curves, Manning's equation, water surface profiles, cross-section data analysis, low-flow frequency, and basic statistics. There is even a program to help you classify streams using Rosgen's stream classification approach.

Stream Hydrology does an excellent job of summarizing engineering hydrology, fluvial geomorphology, and hydraulics for those who have had no previous training in hydrology. The nonmathematical treatment of the subject is especially refreshing as is the emphasis on application. Because of the clear presentation of the technical material, biologists and practicing hydrologists should find this to be a useful reference.

Stream Hydrology can be ordered from:
Wiley Professional Books-By-Mail
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The 526 page book sells for $54.95.

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To make this newsletter a success, we need **voluntary contributions** of relevant articles or items of general interest. YOU can help by taking the time to share innovative approaches to problem solving that you have developed.

Please submit typed, single-spaced contributions limited to two pages. Include graphics and photos that help explain ideas.

We reserve editorial judgments regarding appropriate relevance, style, and content to meet our objectives of improving scientific knowledge. Send all contributions to: Stream Systems Technology Center, Attention: STREAM NOTES Editor.

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