Listening to Bedload: A Flume Study Relating Acoustic Response to Bedload Motion

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ABSTRACT

We have designed and built a hydrophone system to quantify the amount of bedload transport in gravel-bed rivers where conventional methods fail to capture their episodic, high flux rates. The system was tested in a 45 foot long flume in which one-inch median diameter gravel was transported at varying rates. Transport rates were measured by digital videography. Results show that the total acoustic intensity measured by a hydrophone placed approximately a decimeter off the bed is positively and statistically significantly correlated with the number of moving grains.

INTRODUCTION

Measuring bedload transport in rivers during high-discharge events remains impossible for high transport rates and for large clast sizes. Previous workers such as Johnson and Muir (1969), Twyniuk and Warnock (1973), Anderson (1976), Millard (1976), Thorne (e.g. 1985, 1986), Baenziger and Burch (1990), Rouse (1994) and Voulgaris et al. (1994, 1995), have pointed to the potential of using the acoustic energy of the colliding clasts, but no quantitative method for using hydrophones for this purpose has come out of these studies. Thorne's work, in particular, suggests that the peak sound generation by colliding gravel grains, in the size range used in this study, should occur at about 2000 Hz. See Hardisty (1993) for a review.

As part of an on-going theoretical, experimental, and field-based study to develop a quantitative method for detecting bedload fluxes using hydrophones and geophones, we have tested a hydrophone system in a flume in which the natural temporal variability of gravel transport is exploited to examine the sensitivity of this system to bedload motion.

METHODS

A glass-walled flume 45 feet long, five feet wide, and three feet deep was constricted to a 29 cm wide channel using plywood sheets with sand piled against their exterior to decrease vibration. One-inch median diameter (i.e. #2) gravel was distributed on the bed of the reduced channel to a depth of five inches. A raised pediment three inches above this level was built up, two feet long, and centered at the hydrophone position. The purpose of this raised bed was to cause gravel to move in this region at much lower flow strengths than elsewhere on the bed, thereby restrict the motion of gravel to the region close to the hydrophone. A Geospace MP-18 hydrophone was encased in a 20-inch section of three-inch diameter PVC pipe, with ¾-inch holes drilled every two inches in six rows along its length. The interior of the pipe, surrounding the hydrophone, was stuffed with one-inch cubes of synthetic sponge. These cubes serve to limit the ability of turbulent flow from the exterior to cause pressure disturbances around the hydrophone membrane, while not substantially altering the acoustic connectivity of the cavity. The ends of the pipe were capped with streamlined wooden endcaps, weighted with lead to improve stability. An amplifier located close to the hydrophone first boosts the voltage by 10x to improve the signal to noise ratio. A second amplifier increases the signal by 100x before it is low-pass filtered, digitized by a National Instruments 6036E DAQCard, and imported into MATLAB using their data acquisition software.

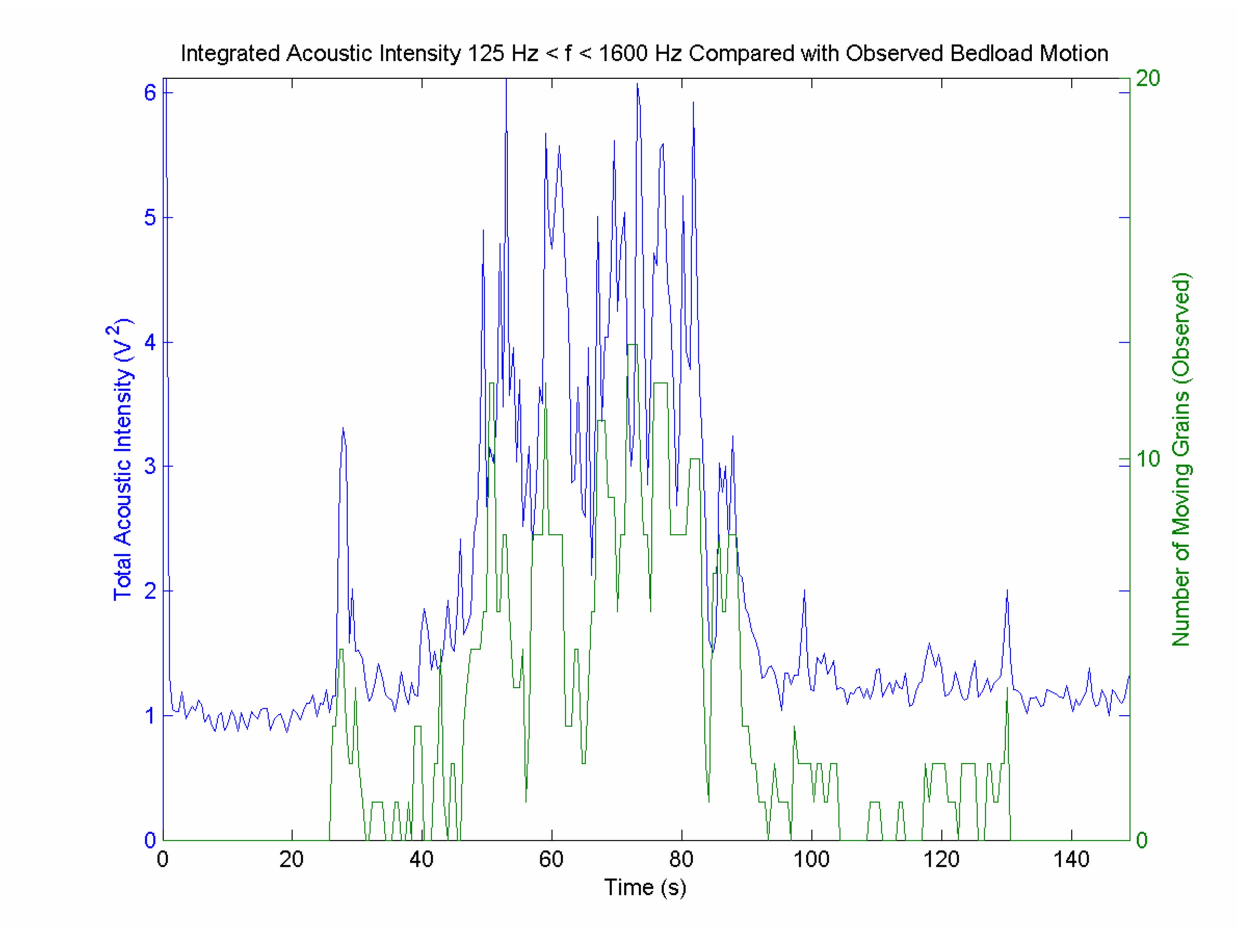

Figure I. Time series showing total acoustic intensity in the 125-1600 Hz band and the number of moving grains. The high intensities at the start of the time series were due to an event used to synchronize the video and sound data. Analysis of the results does not include the first two seconds of data to allow this transient to decay.

To independently measure sediment flux, a digital video camera was positioned to look down at a 30° angle from the horizontal onto the surface of the bed. Floodlights positioned at the top of the flume inside the glass illuminated the bed. Video tapes were converted to Audio-Video Interleave (AVI) format files and particle motions were computed using the commercial motion analysis software VideoPoint (Lenox Softworks). Although we have grain velocity data, we report here only the number of moving grains as a function of time.

The acoustic data were converted to a spectrogram (power spectrum as a function of time), which was then summed in two frequency bands to give a total acoustic energy as a function of time. The lower frequency content (<125 Hz) was contaminated by 60 Hz alternating current noise and the noise of the flume pump and consequently were discarded. In field situations away from powerlines this should not be necessary. The higher frequency content (>1600 Hz) was discarded because modal vibrations of the flume pump excited a fundamental frequency of 2500 Hz and overtones. The addition of the intensities in the frequency range 1600-2500 Hz was found to typically alter the total acoustic intensity by less than 1%.

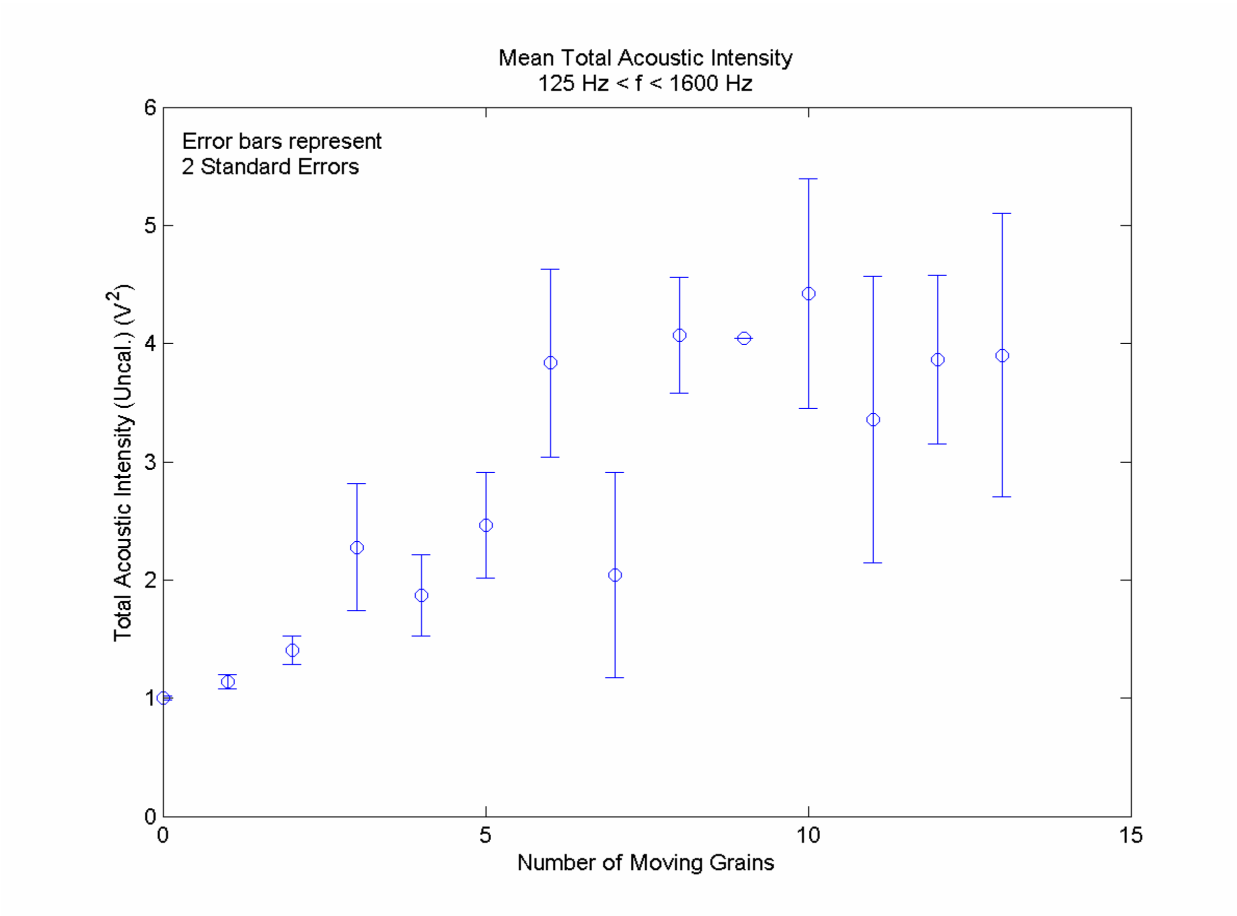

Figure II. Scatter plot showing relationship between total acoustic intensity in the 125-1600 Hz band, and the number of moving grains in video analysis.

RESULTS

Figure 1 shows the number of moving grains and the total acoustic intensity in the 125 to 1600 Hz frequency interval as a function of time during the 175 seconds of a typical experimental run.

Inspection shows that while there are a range of acoustic intensities that can be recorded for a given number of moving grains, there is a positive correlation between the variables.

Figure 2 is a scatter plot of number of moving grains versus acoustic intensity where the acoustic intensity has been averaged for all time points with a given number of moving grains. The error bars show two standard deviations of the mean. The Pearson Product Moment Correlation Coefficient is 0.89, indicating that 79% of the variance in acoustic intensity is attributable to variations in bedload transport rates.

The method of passive acoustic recording of self-generated sediment noise shows potential for use in stream channels with gravel beds. We hope to expand the method, in particular to show how the method may be related to more traditional bedload transport rates, and upon grain velocities, using more sophisticated video analysis.

ACKNOWLEDGEMENTS

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REFERENCES

Anderson, M.G., 1976, An inexpensive circuit design for the acoustic detection of oscillations in bedload transport in natural streams, Earth Surface Processes and Landforms Vol. 1, No. 3: pp. 213-217.

Baenziger, R. and Burch, H., 1990, Acoustic sensors (hydrophones) as indicators of oscillations in bedload transport in a mountain torrent. In: Hydrology in Mountainous Regions I — Hydrological Measurements; The Water Cycle: Proceedings of two symposia held at Lausanne, August 1990, H. Lang and A. Musy (Editors), IAHS-AISH Publication 193. pp. 207-214.

Hardisty, J., 1993, Monitoring and modeling sediment transport at turbulent frequencies. In: Turbulence: Perspectives on Flow and Sediment Transport, N.J. Clifford, J.R. French and J. Hardisty (Editors), New York: John Wiley and Sons. pp. 35-59.

Johnson, P. and Muir, T.C., 1969, Acoustic detection of sediment movement, Journal of Hydraulic Research Vol. 7: pp. 519-540.

Millard, N.W., 1976, Noise generated by moving sediments, In: Proceedings of the Conference on Recent Developments in Underwater Acoustics 31 March-1 April 1976, London, U.K.: Institute of Acoustics.

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

Thorne, P.D., 1985, The measurement of acoustic noise generated by moving artificial sediments, Journal of the Acoustic Society of America Vol. 78: pp. 1013-1023.

Thorne, P.D., 1986, Laboratory and marine measurements on the acoustic detection of sediment transport, Journal of the Acoustic Society of America Vol 80 No. 3: pp. 899-910.

Twyoniuk N. and Warnock, R.G., 1973, Acoustic detection of bedload transport, Proceedings of Hydrology Symposium Vol. 9: pp. 728-735.

Voulgaris, G., Wilkin, M.P. and Collins, M.B., 1994, Shingle movement under waves & currents: An instrumented platform for field data collection, In: Coastal Dynamics '94, A.S. Arcilla, M.J. Stive, N.C. Kraus, (Editors) American Society of Civil Engineers. pp. 894-909.

Voulgaris, G., Wilkin, M.P. and Collins, M.B., 1995, The in situ passive acoustic measurement of shingle movement under waves and currents: instrument (TOSCA) development and preliminary results, Continental Shelf Research Vol. 15 No. 10: pp. 1195-1211.