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Surrogate Bedload Monitoring Using Hydrophones in the Gravel-Bedded Cedar River, Washington

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ABSTRACT

Continuous measurement of bedload transport in gravel-bedded rivers is often desired in geomorphic studies, yet few techniques exist to collect such data. Hydrophones were used at two sites in the Cedar River, Washington, during the 2010–2011 flood season to continuously monitor bedload. At each site, two hydrophones were installed with commercially available audio equipment controlled by a low-power computer. Maximum detection distance of bedload particle movement was found to be between 15 and 20 meters at both sites. The use of replicate hydrophones allowed for correction of audio data impacted by hydrophone movement, obstruction, or other issues affecting the acoustic signals detected by the hydrophones. Sound produced by collisions of bed particles was recorded at both sites and the loudness of the collisions increased with increased discharge. Mean acoustic intensity was calculated between 600 and 3,700 Hertz, and in the absence of physical bedload samples, was used as a qualitative indicator of bedload. For each increase in flow of 1 cubic meter per second, the acoustic intensity increased by an average of 0.78 decibels at one site and 0.42 decibels at the other site (Pearson's coefficient of linearity r of 0.90 and 0.80, respectively). Hydrophones can be used in a flood-season deployment to provide low-cost, continuous bedload data.

INTRODUCTION

Collection of physical bedload samples is expensive and difficult (Gomez, 2006; Gray *et al.*, 2010), and sampling intervals are often too infrequent to capture adequately the temporal variability inherent in bedload transport rates (Gomez *et al.*, 1989). Surrogate technologies show promise for providing continuous monitoring of bedload, which may lead to a better understanding of sediment-transport mechanics and improved bedload modeling (Gray *et al.*, 2010). The use of hydrophones to detect the sound generated by collisions of particles moving along the riverbed (for example, Barton *et al.*, 2010; Belleudy *et al.*, 2010) is one such type of surrogate technology.

The use of hydrophones as a bedload-surrogate monitoring technology is currently considered to be in the developmental stage and needs additional testing to become fully operational (Barton *et al.*, 2010; Gray *et al.*, 2010). Current challenges to using hydrophones for continuous bedload monitoring fall into three categories: instrumentation capabilities, data collection, and data analysis. For example, devices used to record and store audio data for bedload-transport monitoring have either required access to alternating current (AC) power or relied on short-term battery power (for example, laptop computer). Additionally, little is known about the bedload detection distance of hydrophones. Published studies employed only a single hydrophone for short deployments, and changes in detection limits may not be identified easily using a single hydrophone. Finally, there are no standardized methods to analyze audio data of bedload.

In an attempt to address these challenges, replicate hydrophones were deployed at two sites along the Cedar River, Washington, to monitor bedload continuously during a flood season. We report techniques for deploying hydrophones in a remote area, distances at which the instruments can detect bedload movement, a method for data analysis, and methods for correcting data using replicate hydrophones. We conclude by reporting the experimentally-derived relations between acoustic intensity and streamflow discharge in two different study reaches.

STUDY AREA

The Cedar River is a regulated, gravel-bedded river draining the western slopes of the Cascade Range in Washington State. The hydrophones were installed in two study reaches, where bedload was anticipated during the 2010-2011 flood season. One reach was confined predominately by revetments and levees, while the other reach was largely unconfined and has a history of large channel-migration rates.

METHODS

Instrumentation

Two types of hydrophones were installed at each study reach. The first was a Geospace[1] model MP-18, the same type used by Barton (2006) in the Trinity River, California. Barton (2006) identified a rapid decrease in sensitivity at frequencies above 2,000 Hertz (Hz) as a potential limitation of this hydrophone. To overcome this limitation, a second type of hydrophone was deployed, a Cetacean Research Technology™ model CR-1, that maintains a linear response for frequencies between 50 and 48,000 Hz. Each hydrophone was enclosed in a perforated polyvinyl chloride (PVC) pipe and weighted to the bed in water approximately 0.5 meter deep. The hydrophone pairs were installed approximately 1 meter from the bank in areas away from riffles to avoid major sources of noise related to turbulence.

To operate the equipment without external AC power and minimize the frequency of site visits, a power-efficient computer was reconfigured to use a 12-volt deep-cycle marine battery, supplemented with a 30-watt solar panel, as a power source. A programmable timer was used to limit computer on-time to 15 minutes per hour.

Hydrophone detection distance

In a wide channel, the sound generated by particle collisions on one side of the channel may be too far away to be detected by a hydrophone located on the other side of the channel. Therefore, the maximum distance at which particle collisions can be

[1] Any use of trade, product, or firm names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Government.

detected is an important consideration in experiment design. The detection distance was tested at both reaches by generating particle collisions at known distances from the hydrophones during wadable conditions (0.75 meter water depth). The maximum detection distance at both reaches ranged from 15 to 20 meters, which meant that it was likely that particle collisions were detected across the entire width of the channels.

Data analysis

The acoustic signals were first transformed to the frequency domain using a fast Fourier transform. The values of acoustic intensity were then averaged between a range of frequencies. Collisions of gravel- and cobble-sized bed particles have been shown to produce audio waves with frequencies between about 600 and 3,700 Hz (Belleudy *et al.*, 2010). In a previous study, Barton (2006) calculated total acoustic power by numerically integrating the acoustic energy between 125 and 1,600 Hz; and later increasing the range to frequencies between 10 and 14,809 Hz (Barton *et al.*, 2010). In another study, Belleudy *et al.* (2010) counted the number of detectable particle collisions between frequencies of 1,000 and 3,000 Hz. In this study, the mean acoustic intensity was calculated between frequencies of 600 and 3,700 Hz and was compared to the full recorded range of frequencies between 1 and 22,050 Hz. The mean acoustic intensity, measured in decibels (dB), was used as an indicator of bedload.

Pairs of hydrophones were used to identify discrepancies in the audio data by comparing the time series of mean acoustic intensity at each site. In doing so, changes in the detection distance of one hydrophone (resulting from factors such as hydrophone movement, burial, or obstruction) became easier to identify. These changes resulted in an increase or decrease in the calculated acoustic intensity relative to the other hydrophone. The acoustic intensity time series of the affected hydrophone was then corrected based on the detected difference.

RESULTS AND DISCUSSION

During the 2010–2011 flood season, the largest peak-flow event in the Cedar River occurred in mid- to late-January with a peak discharge of 159 m^3/s (7-year recurrence interval). Two smaller events also took place, one in mid-December and the other in early April, with peak discharges of 65 and 79 m^3/s, respectively.

Audio data were collected at the unconfined reach (fig. 1a) at discharges between 18 and 80 m^3/s, and at the confined reach (fig. 1b) between 23 and 79 m^3/s. Audio samples from both sites representing a range of flows were qualitatively evaluated through listening. In general, the number and loudness of particle collisions increased with streamflow discharge. We concluded that the sound detected by the hydrophones was dominated by particle collisions.

Throughout the deployment, batteries were exchanged approximately every 2 weeks. Battery life was heavily dependent on the computer on-time required to record the audio sample. In this study, audio data were collected using a 10-minute sample duration at an hourly sample interval. Because shorter sample durations can reduce computer on-time and thus extend battery life, the optimal sample duration was investigated at the end of the flood season. Optimal sample duration was determined to be 1 minute. The mean acoustic intensity calculated from a 1-minute audio sample was within ±1 dB of the 10-minute mean 95% of the time.

The maximum detection distance of particle collisions was measured to be between 15 and 20 meters. For this reason, multiple hydrophones are recommended to achieve adequate spatial coverage for channels wider than 15 meters.

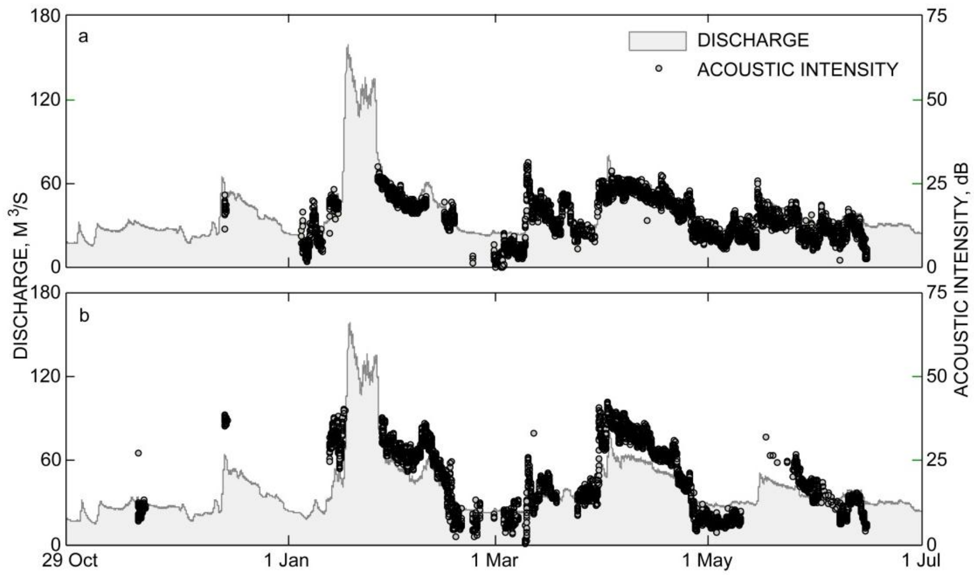

Figure 1. Acoustic intensity data from replicate hydrophones at the (a) unconfined reach and (b) confined reach, overlaid on the 2010-2011 flood season hydrograph.

The datasets from replicate hydrophones generally were similar at a site. Occasionally, the amplitude of the response of one hydrophone changed relative to the other hydrophone. Some of these changes may have been caused by debris occasionally blocking and later clearing from around the hydrophone or by hydrophone movement resulting from an impact by large wood or a large sediment particle. Approximately 10 amplitude changes were identified at each study reach. In the absence of physical bedload samples, acoustic intensity was compared to discharge (the assumption being that bedload transport increases generally with discharge). The acoustic intensity, without bedload measurements, can provide an indication of the duration of bedload and the relative variability in bedload at the two sites. The Pearson's coefficient of linearity, r, was used to evaluate the correlation between mean acoustic intensity and streamflow discharge. Data corrections from the use of replicate hydrophones resulted in an average increase of Pearson's r from 0.80 to 0.90.

To determine if the frequency range selection affects correlation of mean acoustic intensity to discharge, the mean acoustic intensity was calculated using a frequency range of 600 to 3,700 Hz (figs. 2a, 2c) and compared to that calculated using the full frequency range recorded of 1 to 22,050 Hz (figs. 2b, 2d). Data processed using the narrower frequency range had a higher correlation to discharge and resulted in an average increase in Pearson's r from 0.85 to 0.90. Finally, the mean acoustic intensity versus discharge calculated for the unconfined reach (fig. 2b) was compared to the confined reach (fig. 2d). The acoustic intensity at the unconfined reach had greater scatter (Pearson's r of 0.86) compared to the confined reach (Pearson's r of 0.94). The channel bank adjacent to the hydrophones at the unconfined reach retreated approximately 1 meter during the flood season. It is unknown how much of the variability in the mean acoustic intensity was associated with bank erosion and how much was attributable to temporal variability of bedload. The confined reach experienced little channel change in the vicinity of the hydrophones.

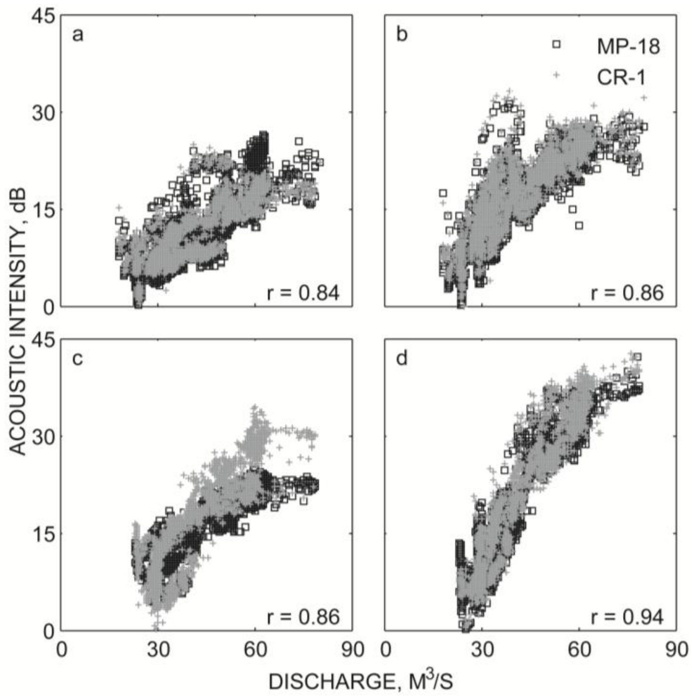

Figure 2. Mean acoustic intensity calculated between frequencies of (a) 1 and 22,050 Hz and (b) 600 and 3,700 Hz at the unconfined reach; and between frequencies of (c) 1 and 22,050 Hz and (d) 600 and 3,700 Hz at the confined reach.

CONCLUSIONS

Replicate hydrophones with power-efficient computers and commercially available audio equipment were deployed for seven months at two gravel-bedded river sites. Audio data were analyzed between frequencies of 600 and 3,700 Hz, which was shown by Belleudy *et al.* (2010) to be in the range of sounds produced by gravel- and cobble-sized particle collisions. The results were compared to the same data analyzed between 1 and 22,050 Hz. Acoustic data in the narrower frequency range are more closely correlated to discharge (average Pearson's r of 0.90) than data in the full range of detected frequencies (average Pearson's r of 0.85). An analysis that uses the narrower frequency range may reduce the influence of noise from sources other than bedload. The use of replicate hydrophones provided a means of detecting and correcting differences in recorded acoustic intensity among hydrophones.

The hydrophones detected acoustic signals generated by bedload at both study reaches as well as acoustic signals that may be related to bank erosion at the unconfined reach. The acoustic intensity measured at the confined reach was more closely correlated with streamflow discharge. For each increase in discharge of 1 m^3/s, the acoustic intensity increased by 0.78 decibels at the confined reach and 0.42 decibels at the unconfined reach. However, the unconfined reach had greater variability in acoustic intensity, which may be related to a combination of greater variability in bedload discharge and sound generated by bank erosion.

Physical samples of bedload may be supplemented with hydrophone data to develop a time series with high temporal resolution and enhance estimates of bedload transport. While data from hydrophones alone cannot be used to quantify bedload transport, hydrophone use may be a useful tool which can provide a qualitative assessment of the temporal or spatial variability of bedload.

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REFERENCES

Barton, J.S. (2006). “Passive Acoustic Monitoring of Coarse Bedload in Mountain Streams.” University Park, Pennsylvania State University PhD Dissertation, 107p.

Barton, J.S., Slingerland, R.L., Pittman, S., and Gabrielson, T.B. (2010). “Monitoring Coarse Bedload Transport with Passive Acoustic Instrumentation: A Field Study.” *in* Gray, J. R., Laronne, J. B., and Marr, J. D. G., *Bedload-surrogate monitoring technologies: U.S. Geol. Surv. Scientific Investigations Report 2010-5091*

Belleudy, P., Valette, A., and Graff, B. (2010). “Passive Hydrophone Monitoring of Bedload in River Beds: First Trials of Signal Spectral Analysis”. *in* Gray, J. R., Laronne, J. B., and Marr, J. D. G., *Bedload-surrogate monitoring technologies: U.S. Geol. Surv. Scientific Investigations Report 2010-5091*.

Gomez, B., Naff, R.L., and Hubbell, D.W., (1989). “Temporal Variations in Bedload Transport Rates Associated with the Migration of Bedforms.” *Earth Surf. Proc. and Lndfms.* 14, 135-156.

Gomez, B. (2006). “The potential rate of bed-load transport.” *Proc. of the Nat’l. Acad. of Sci*. 103(46), 17170-17173.

Gray, J.R., Laronne, J.D., Marr, J.D.G., (2010). *Bedload-surrogate monitoring technologies. U.S. Geol.Surv. Scientific Investigations Report 2010-5091*, 37p.