Development of a portable passive-acoustic bedload monitoring system

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ABSTRACT: A hydrophone-based passive acoustic bed load-monitoring system was designed, tested and deployed by researchers at the University of Mississippi and the National Sedimentation Laboratory in Oxford, MS. The hydrophone system was designed to be easily deployed and operated by non-experts. In addition, the current prototype system allows for deployments of several weeks at a time with minimal intervention. Several field studies have been conducted at various sites: the Elwha River in Port Angeles, WA; the Trinity River in Weaverville, CA; Bear Creek in Denver, CO; the Walnut Gulch Watershed in Tombstone, AZ; and Halfmoon Creek in Leadville, CO. At each field site, acoustic data was collected alongside physical measurements of bed load transport. Results from these efforts will be presented in addition to details regarding the design and operation of the hydrophone system.

1 INTRODUCTION

Passive acoustic methods for monitoring bed load transport have been explored for some time. The acoustic properties of bed load discharge of a single-sized particle was investigated in a laboratory flume (Johnson and Muir, 1969).The acoustic properties of impacting glass spheres of mixed sizes was studied by placing the spheres in a submerged rotating drum (Thorne, 1985). These and other laboratory studies have consistently shown that the sound generated by impacting gravel particles can be used to determine a theoretical relationship between total discharge and acoustic energy. Recent field studies have been conducted using hydrophones to detect gravel movement in the Trinity River (Barton, 2006, Barton et al., 2010). To continue this research, a passive acoustic system was tested at four different field sites: the Trinity River in Weaverville, CA; the Elwha River in Port Angeles, CA; the Walnut Gulch Watershed near Tombstone, AZ at the Lucky Hills sub-watershed; and Bear Creek in Evergreen, CO. The system as it was deployed in the aforementioned field studies was comprised entirely of laboratory-grade equipment. This equipment had a much larger bandwidth than was required, and many of the components were both delicate and unwieldy (Fig 1). The system utilized up to four Reson TC4013 hydrophones each powered by a Reson E6061 preamplifier. A NI-9215 data acquisition module that was interfaced with a laptop computer via a custom Labview script digitized the acoustic data. The preamplifiers required external 12 VDC power, and the laptop had to run on battery power only since the AC adapter caused interference in the signal. For these reasons, the system was only able to run for a few hours at a time and was not suitable to run overnight. This system served to prove the concept of collecting self-generated noise. A more robust and user-friendly system was assembled in order to facilitate future data collection and research efforts.

Figure 1. Original hydrophone system made of lab-grade equipment

2 PORTABLE SYSTEM

2.1 *Design*

The portable data collection system had up to two HTI 96-MIN Exportable hydrophones for receiving acoustic data. A Zoom H4N wave recorder collected the acoustic data as .wav files, sampled at 44.1 kHz using 16-bit resolution. Once set to record, the wave recorder would run until either its battery source expired or the user terminated recording. To maintain useable file sizes, once a data file reached 2 GB in size, it was automatically ended and a new file was begun. A waterproof container housed all of the components except for the hydrophones. Waterproof connections were installed on the box for the hydrophones as well as for an optional external 12 VDC power supply. A custom case for the hydrophones (Fig 2) provided extra protection, streamlining and mounting convenience. The casing was made of a material with a similar acoustic impedance to that of water, thus minimizing the case's effect on acoustic signals.

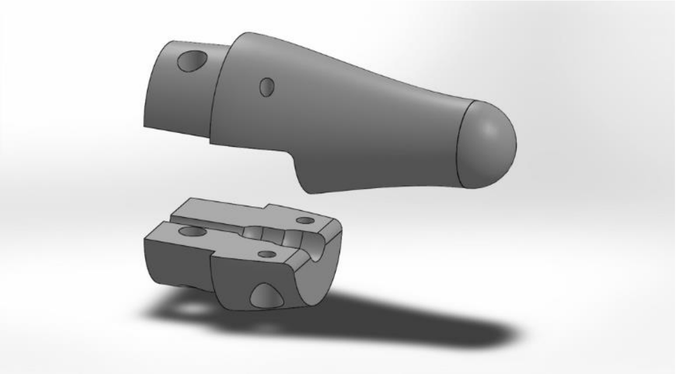

Figure 2. Portable hydrophone casing

The back of the hydrophone casing was designed to fit inside a 1-inch PVC coupling. There was a through-hole in the case for a pin to secure the hydrophone to the coupling. This allowed a wide range of mounting options to fit the requirements of each individual deployment.

2.2 *Deployments*

The portable system has been deployed at two locations. The system was installed on Halfmoon Creek near Leadville, CO during the spring runoff in May and June of 2015. For this deployment, the hydrophones were fitted around a T-post driven into the creek bed. A plastic teardrop fairing was placed around the post to reduce turbulence (Fig 3). To ensure a tight fit of the fairing and to reduce structural vibrations, plastic tubing was placed on the T-post before mounting the fairings. The fairing was cut at the location of the hydrophone mount to allow the hydrophone to protrude from the downstream side of the fairing. The hydrophones were set as close to the bed as possible while remaining high enough to allow passage of the largest expected particles without contacting the hydrophone. For Halfmoon creek, the hydrophones were placed approximately 10 cm above the bed. The cables from the hydrophones ran through the top of the fairings and to the stream bank where the weatherproof box was secured. The cables were fixed high enough above the stream so that any floating debris would not snag the cables. Two locations along the creek were chosen as sampling sites.

Bed load transport was measured using bed load traps developed by Dr. Kristin Bunte (Bunte et al. 2004, Bunte et al. 2007). The traps were made from a square aluminum frame (0.3 x 0.2 m) with a nylon mesh net (3.5 mm opening) behind the frame to retain the bed load. The frame rested on an aluminum plate mounted to the bed. A set of six traps was installed at each testing site. Two hydrophones were mounted approximately one meter upstream of the traps at each site. The hydrophones at the first site took near-continuous data for several weeks, including overnight, while bed load data was collected during the daytime. The second site was only sampled during the highest discharges, and acoustic data was collected only while bed load was being collected.

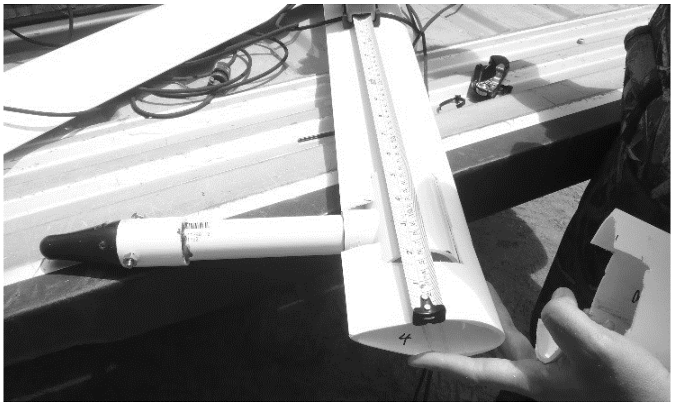

Figure 3. Hydrophone mounted downstream of the teardrop fairing as deployed at Halfmoon Creek, 2015

3 RESULTS FROM DEPLOYMENTS

3.1 *Original System*

The deployments of the original lab-grade system provided useful results. While physical bed load samples occurred in conjunction with each deployment, the nature of the physical sampling varied. Graham Mathews and Associates (GMA) was responsible for sampling at both the Trinity and Elwha rivers. The data from the Trinity River deployment shows positive trends between the root-mean-squared (RMS) voltage and bed load transport (Fig 4).

On the Elwha River, bedload was sampled to calibrate the imapct plates spanning the river, not to determine total cross-sectional bedload transport. Therefore, the hydrophone data could not be directly compared to bedload. Instead, the RMS from the hydrophones was compared to the bed load estimated by the impact plates (Fig 5). Again, the RMS trends with predicted bedload; however, due to the limited duration of the original hydrophone system, a full comparrison could not be made.

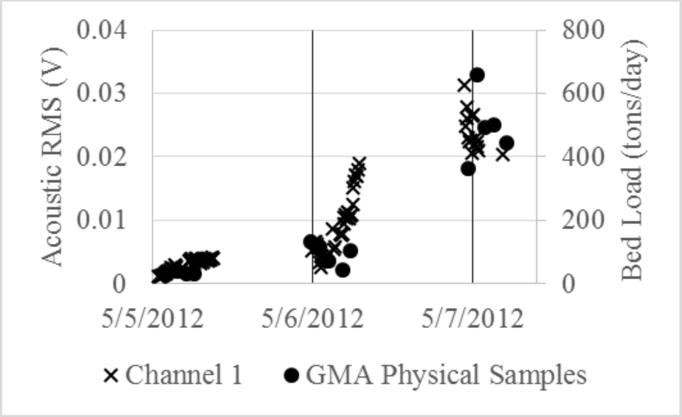

Figure 4. Acoustic rms and physical sampling results from Trinity River deployment of the lab-grade acoustic data collection system.

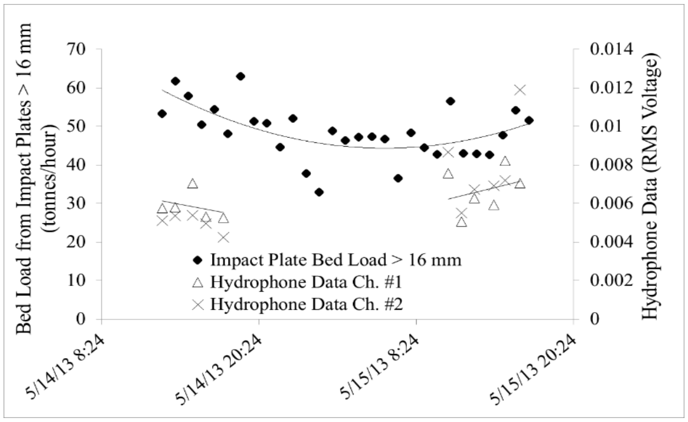

Figure 5. Acoustic rms and estimated bed load from impact plates on the Elwha River

3.2 *Portable System*

For the Halfmoon Creek deployment, nearly 300 GB of acoustic data were recorded. Analysis of this data is ongoing, but preliminary results are presented here. Previous work on this project has focused on the RMS signal as an analogy for acoustic energy. The RMS was calculated for each hour of acoustic data. The total RMS of site one, channel 1, plotted versus discharge from USGS gauge #07083000 and verified by Dr. Bunte (Fig 6), revealed two key points. The first is that RMS was well correlated with discharge. The second is that the period after June 10 required further investigation for possible signal contamination. Channel 1 was the hydrophone in front of the two traps where most of the bed load was collected. The raw RMS data was plotted with the bed load discharge determined by the physical samples (Fig 7).

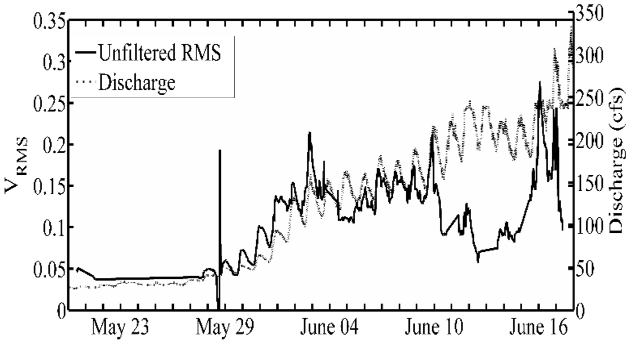

Figure 6. Raw RMS and measured discharge at the upstream testing site on Halfmoon Creek.

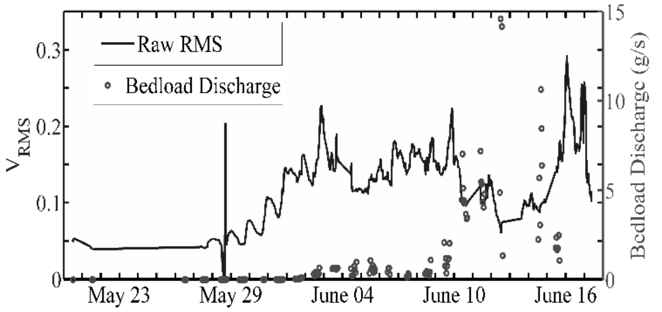

Figure 7. Raw RMS and measured bedload at the upstream testing site on Halfmoon Creek.

4 CONCLUSIONS AND FURTHER WORK

The development of a user-friendly portable hydrophone system was a success. The system is adaptable to many different situations and requirements. The data collection is straightforward and requires minimal operator input. In addition, when connected to an external 12 V battery, the system can operate until the memory is full (approximately 36 hours).

Analysis of the data is still ongoing. Preliminary results indicate that raw RMS voltage may not be a valid metric for determining bed load transport, as it is highly correlated with flow discharge (Fig 6) but not very well correlated with bed load discharge (Fig 7). The flow noise must be removed from the data before an accurate method of estimating bed load transport can be determined.

Previous work on similar data has indicated that flow noise is generally dominant at low frequencies. As an attempt to isolate the sound due to bed load, the raw acoustic data was run through a high pass filter with the band pass set at 10 kHz. This value was determined from previous work, and is a parameter still under investigation. After the filter, the RMS was recalculated using the same processes. The high pass RMS values track with the bed load physical samples much more closely than the unfiltered (or raw) RMS values (Fig 8). Note that in this figure, all data are plotted as normalized values for visual purposes. This method is one of several being pursued as a means of correlating acoustic data with bed load transport. Others include quantile analysis and peak detection analysis.

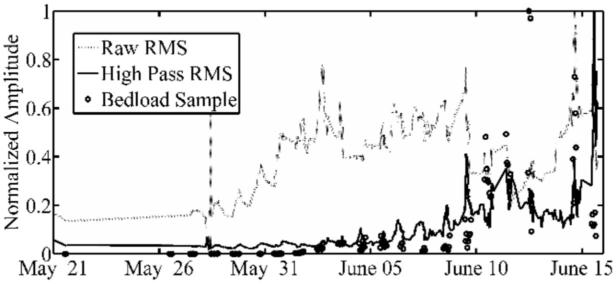

Figure 8. RMS data after passing through 10 kHz high-pass filter alongside bed load physical samples.

Another area of current investigation is the drop in acoustic energy on the site 1 system after June 10. The majority of bed load transport occurred after this date, and so determining the cause of the sudden energy change is crucial.

Data from the second site at Halfmoon Creek is also currently under investigation. This site was only sampled concurrently with bed load sampling and only at the highest flow rates. The sample size is much smaller, but it may provide useful insight.

The system is currently scheduled to be deployed on the Elwha River during the spring or summer of 2016. Bed load measurements will be specifically made to calibrate the hydrophone system.

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