RECLAMATION

Managing Water in the West

Measuring Coarse Bed Load Using Hydrophones

Research and Development Office
Science and Technology Program
Closeout Report SRH-2014-37

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Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acronyms and Abbreviations

ARS – Agricultural Research Service, U.S. Dept. of Agriculture, Oxford, MS
FISP – Federal Interagency Sedimentation Project
GMA – Graham Matthews and Associates
NCPA – National Center for Physical Acoustics, University of Mississippi, Oxford, MS
NI – National Instruments, manufacturer of electrical components
PVC – Polyvinyl chloride, commonly used polymer
RMS – Root Mean Square, mathematical method to define a continuously changing voltage over time
SGN – Self Generated Noise, produced when gravel particles collide when driven by fluvial currents
TRRP – Trinity River Restoration Program
USDA – U.S. Department of Agriculture

Executive Summary

This research project began with a request from the Trinity River Restoration Program (TRRP) to continue developing the science that would enable the use of hydrophones for accurate quantification of coarse bed load transport. The TRRP, among many others, are interested in bed load transport because of the impact it has on channel morphology and aquatic habitat. Regulated rivers often undergo severe changes to the natural transport of sediment, resulting in the potential for significant change to the river's morphology and ecology.

Current methods used to measure bed load require the deployment of a specially designed pressure difference sampler on the bed of a river to capture a physical sample over a known time period, most often between 20 seconds and 2 minutes depending on transport conditions. This must be done at many locations across the channel and integrated to obtain a complete measurement at a single cross section. This process is labor intensive and presents a risk to operators, as bed load is only transported at high discharges that typically only occur for a small fraction of the year and sometimes not at all in a given year. The deployment of a measurement system that is portable and allows for long term (single event to seasonal time frame) deployment will provide continuous data (as opposed to discrete measurements using current methods) and has the potential to be deployed at several locations of interest, providing valuable information for practitioners to greatly improve their understanding of bed load transport. Knowing and understanding the flow conditions under which bed load is transported in a fluvial system

is critical for efforts to improve degraded conditions for the improvement of ecology and aquatic habitat as well as protection of riverine and riparian infrastructure (e.g. diversion dams, surface water intakes, bridges, levees, etc.).

Many researchers have deployed hydrophones to capture qualitative information about bed load transport, e.g. initiation and cessation of bed motion during a flood event and relative transport intensity during the event. However, accurate quantification of the bed load transport in terms of mass per unit time has been elusive. This is primarily due to the lack of understanding of the underlying physics of acoustic propagation in fluvial environments. Sound propagation in rivers is primarily affected by flow depth and bed roughness. Flow noise and signal processing are other areas where research is required to achieve the goal of bed load measurement with hydrophones.

This research project has primarily focused on understanding the underlying acoustic processes required for accurate quantification. Although there were field deployments of hydrophones during concurrent physical measurement, much of the effort has been in a lab setting under controlled conditions, working to understand the acoustic propagation of self-generated noise (SGN) produced by submerged particle collisions and how that can be used toward accurate quantification. SGN exists across a spectrum of frequencies, which presents opportunities for signal processing using the frequency domain as well as using the more simplified composite signal amplitude as a measurement metric. Although the composite signal voltage generated by the hydrophone has been used in this report for correlations with measured bed load, it has not yet been determined to be the most appropriate or most informative metric for quantifying bed load with hydrophones.

This report will detail the research efforts over a three-year period of investigating bed load measurement with hydrophones. Both laboratory and field investigations have been undertaken to improve the understanding of the acoustic processes and signal properties as well as the nuances of hydrophone deployment for the purpose of measuring bed load in rivers. Progress has been made in the areas mentioned above, however many questions remain, many of which have developed over the course of this research.

Contents

Introduction

The measurement of sediment transport in rivers provides scientists and engineers valuable information that can be applied toward protecting our nation's waterways and associated infrastructure. Accurately quantifying sediment loads in rivers remains a significant challenge in spite of decades of development. The transport of sediment in rivers is generally classified as either bed load or suspended load. In the case of bed load, particles roll, slide, or saltate along the bed, never traveling far above the bed. In the case of suspended sediment, particles are carried higher into the water column by turbulent action (ASCE 2008) and do not maintain contact with the bed.

In 1943, the Federal Interagency Sedimentation Project (FISP) began developing sediment samplers, techniques, and laboratory procedures for measuring fluvial sediment. Since the development of the FISP in 1939, dozens of samplers have been developed and federally approved for measuring suspended sediment concentration, yet only two bed load samplers have garnered Federal approval. In recent decades, significant advancements have been made using surrogate sediment measurement methods for quantifying suspended sediment concentrations with development of methods for surrogate measurement of bed load once again lagging behind. There are a few reasons for this disparity, chief among them are: 1) under a vast majority of conditions, suspended sediment transport rates are is many times greater than bed load transport rates and as a result, receives greater attention; 2) obtaining a representative sample of suspended sediment concentration is more easily accomplished than for bed load; 3) chemical constituents can sorb to fine sediment particles that are transported in suspension and the transport and fate of chemical contaminants is often a serious concern. However, quantifying bed load is important for those studying channel morphology because the coarsest fraction of the sediment in a river system is responsible for its form and adjustment (Knighton 1998).

This research project focuses specifically on recording self-generated noise (SGN) resulting from gravel on gravel collisions that occur as gravel particles are transported along the bed. Many past research efforts using hydrophones for measuring bed load relied on gravel colliding with a metal object (plate or pipe) placed on or near the bed (e.g. Mühlhoffer 1933, Richards and Milne 1979, Downing et al. 2003, Froehlich 2003, Mizuyama et al. 2003). Early research on using SGN was performed by Bedeous and Ivicsics (1963) and Johnson and Muir (1969). Using video and hydrophones deployed in coastal regions, underwater collisions of ridged bodies was examined by Thorn (1986) who determined that measuring bed load flux based on SGN was feasible. Building on prior research, Barton (2006) showed that total acoustic power was well correlated with coarse bed load transport using a portable hydrophone deployed during concurrent physical bed load measurements on the Trinity River, CA. Barton (2010) concluded that further research was needed in order to quantify bed load transport using a hydrophone recording SGN.

In 2011 Reclamation, funded by the Science and Technology program, began an effort to continue and expand upon the body of work performed by previous researchers. Reclamation has a need for obtaining accurate sediment measurements, both suspended and bed load, to better understand sediment transport in rivers associated with Reclamation dams, diversion structures, canals, and other related infrastructure as well as meeting our need to address ecological concerns. Calibrating and validating numerical models is an important step toward gaining confidence in a sediment transport model and helps determine the uncertainty in sediment transport predictions. However, sediment measurement using classical means remains an expensive and time consuming endeavor, often precluding our means to properly validate sediment transport models. Surrogate sediment measurement using acoustics shows promise in supplanting traditional sediment data collection methods based on routine collection of discrete physical samples and subsequent laboratory analysis (Anderson et al. 2010).

Research Partners

The timing of Reclamation's research is coincident with increasing interest by others desiring a portable, field deployable system for continuously measuring bed load, specifically, the Federal Interagency Sedimentation Project (FISP) and the USDA - Agricultural Research Service (ARS) are direct partners in this research project. Additionally, the US Geological Survey, USDA Forest Service, and other Federal agencies have demonstrated an interest in surrogate bed load measurements.

Since 2011 the NCPA and ARS, located in Oxford, MS, have been funded through Reclamation's Science and Technology program to assist with researching a means to quantify coarse bed load transport using hydrophones. ARS provides expertise in sediment transport and has laboratory facilities that include a sediment and water recirculating flume. ARS and NCPA personnel utilize these facilities as well as laboratory facilities at the University of Mississippi to conduct research. Additionally, there is on-going field testing taking place at research sites of interest to the ARS (Walnut Gulch, AZ; Goodwin Creek, MS), Reclamation (Trinity River, CA; Elwha River, WA), and the Forest Service (Bear Creek, CO). The field testing has taken place in conjunction with physical sampling of bed load, using either a TR-2 pressure difference sampler (Hubble et al. 1985, Childers 1999) (data collected by Smokey Pittman et al., Graham Matthews and Associates) or bed load traps (Bunte et al. 2007) (data collected by Dr. Kristin Bunte and Kurt Swingle, Colorado State University). The field testing provides real world application of the hydrophones to help determine field application needs, preliminary calibration parameters and define continuing research needs. The combination of laboratory and field testing of the hydrophone system over the past three years has provided many answers to questions posed at the outset of this research project and has shed light on some previously unidentified questions that need to be addressed.

Research Focus

The current research investigated the following topics in an effort to advance the state of the science toward application.

1. *Deployment.*
2. *Signal and data processing.*
3. *Field calibration.*
4. *Underlying physics.*

Issues arising from various deployment methods suggest investigation into the optimum placement in the river channel for an acoustic system intended for field use. The sound generated from gravel collisions is dependent on particle size and velocity. Additionally, sound will lose amplitude as is propagates from where it is generated to the hydrophone. Rivers and streams act as waveguides which tend to trap sound waves and provide multiple echo paths between sources and receivers. The waveguide properties are dependent on several factors, including channel cross-section and flow depth as well as bank and bottom roughness. All these factors act to modify the signal and make correlations difficult and/or provide larger error bars. Therefore, an understanding of the underlying physics is necessary to produce meaningful trends between acoustic signals and sediment transport.

Lab Experiments

Lab experiments were conducted to help clarify some of the issues noted above. Specifically:

1. Various hydrophone mounting methods were qualitatively tested for: ease of deployment, acoustic isolation, and overall protection from debris
2. Controlled environment experiments were conducted in a flume to measure the sound levels of individual gravel at known velocities (i.e. implying known sediment flux) over a constructed gravel bed.
3. Experiments began investigating the effects of river morphology on acoustic propagation at the frequencies of interest. In addition, these experiments were designed to help determine the ‘area of investigation’ of the hydrophones.

Lab Experiments: Methodology

Several Reson TC4013 hydrophones and accompanying Reson E6061 preamplifiers were already owned by NCPA. These hydrophones have a very flat frequency response, but are delicate and very sensitive to physical impacts. In order to turn these lab-based hydrophones into a field-deployable system, a mounting system was devised following previous researchers (Barton 2006).

Using the gravel recirculation flume at ARS, which is fitted with a programmable motorized carriage, experiments were conducted by dragging rocks of known mass at varying velocities to provide variable sediment flux. Individual rocks of various size and mass were tethered to a string which was attached to a motorized cart. Individual rocks and multiple rocks were dragged for this experiment, which was performed to investigate the acoustic properties of SGN. Five different rocks were dragged at three different speeds across a constructed gravel bed, see Table 1. It was observed that the majority of the runs produced a ‘skipping’ motion; wherein the test rock would bounce from one location to the next.

Various experiments have been conducted in an attempt to determine the effects of river morphology on acoustic propagation. The majority of these experiments consist of an acoustic source transmitting a known signal down a flume. The signal is recorded by several hydrophones at various points within the flume.

The source used for the majority of these experiments was a B&K 8103 powered by a B&K 2713 Power Amplifier. By using different constructed beds, various frequencies, multiple source and receiver parameters, and multiple depths, these experiments provided a vast set of data.

Table 1: Rock-Dragging Experiment Parameters. This table only includes information for single rock dragging experiments.

Run #	Rock #	Rock Mass (kg)	Rock Dimensions (mm)	Speed (m/s)	Flux (kg/s)
1	1	0.1846	66 x 56 x46	0.082	0.0071
2	1	0.1846		0.3	0.0260
3	1	0.1846		0.56	0.0485
4	2	0.0894	61 x 35 x 31	0.082	0.0034
5	2	0.0894		0.3	0.0126
6	2	0.0894		0.56	0.0235
7	3	0.1249	65 x 47 x 28	0.082	0.0048
8	3	0.1249		0.3	0.0176
9	3	0.1249		0.56	0.0328
10	4	0.1767	80 x 50 x 33	0.082	0.0068
11	4	0.1767		0.3	0.0249
12	4	0.1767		0.56	0.0465
13	5	0.3236	85 x 70 x 47	0.082	0.0125
14	5	0.3236		0.3	0.0456
15	5	0.3236		0.56	0.0851

Lab Experiments: Results

Figure 1 shows a schematic of the hydrophone mount. The hydrophone was mounted at the center of a PVC pipe. The back portion of the pipe was filled with open-cell foam which helped stabilize the highly sensitive hydrophone cable. The PVC pipe provided great flexibility with respect to mounting in the field.

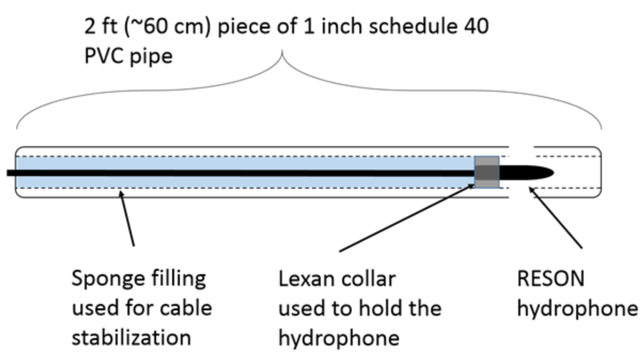

Figure 1: Mounting Apparatus for field deployment of the hydrophone.

The rock dragging experiments provided three key results. First, they verified that the majority of the frequency content generated by gravel impacting itself is in the audible range (<20 kHz). Second, they showed that in a controlled environment, acoustic power (in this case root-mean-squared voltage) has a linear correlation with total sediment flux. Third, they showed that this correlation is greatly dependent on the particle size in motion; or the particle size distribution, see Figure 2. It is not immediately clear exactly why the trend is dependent on the constituent particles. As shown in Figure 2, rocks 1 and

4 produced nearly identical trends, while the rest appear to differ greatly with particle size. This result requires additional investigation. An internal NCPA grant has been awarded to further explore this dependence of particle size on the acoustic RMS-sediment flux correlation.

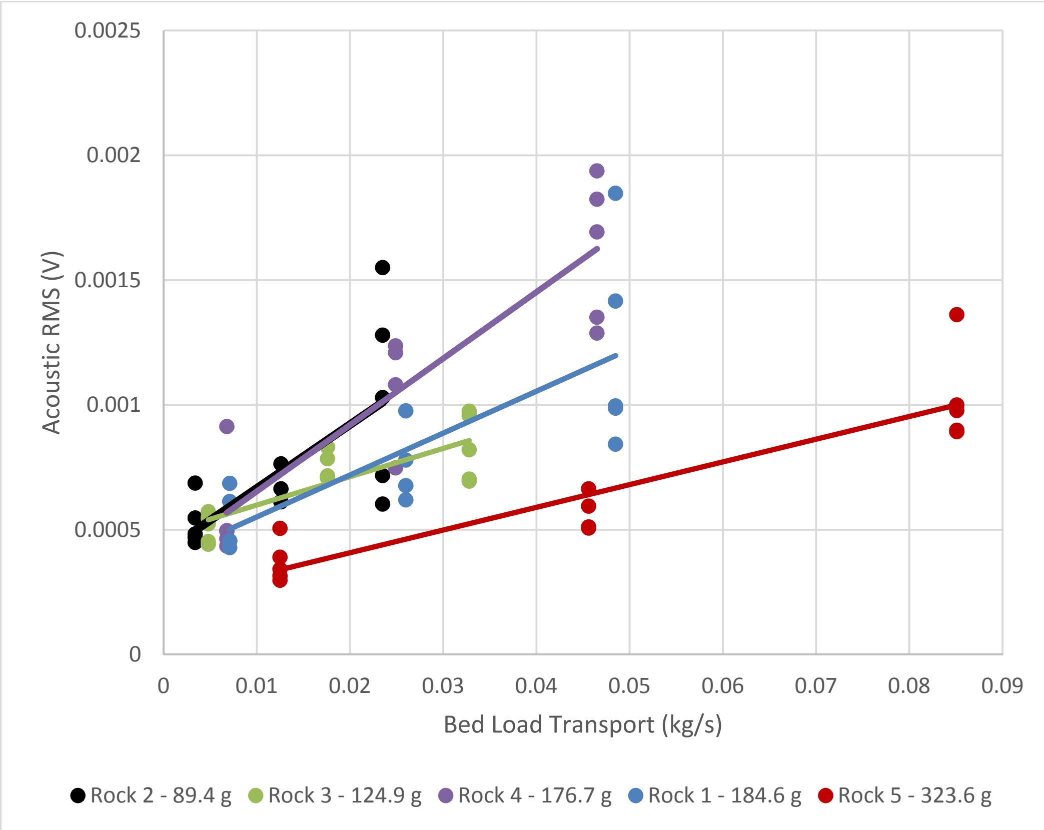

Figure 2: Results from rock dragging experiment showing linear correlation between RMS and bed load transport which is dependent on particle size.

The experiments to determine the effect of river morphology and to determine the area of observation have been increasingly difficult to design and implement. Replicating the acoustic properties of a natural river in a controlled manner such as a flume is neither easy nor straightforward. Particularly, the anechoic (sound absorbing) condition expected in an earthen fluvial environment is extremely impractical to reproduce at the frequency range of interest. Another difficulty arose from the lack of scientific-grade underwater audible-range acoustic sources. As such, several of these experiments are still underway and have been funded through the NCPA and the FISP.

Field Deployments With Concurrent Physical Bed Load Measurement: Methodology

Various hydrophone deployments were made on the Trinity River (CA), the Elwha River (WA), and Bear Creek (CO) during the research period (Trinity Spring 2012, Elwha Fall 2012, Spring 2013, Bear Creek 2014). During field deployment of the hydrophone system, bed load was measured using classical means (physical sampling with a TR-2 pressure difference sampler).

The passive acoustic prototype system

The researchers at NCPA had prior experience with using passive acoustic data collection systems. For this reason, the system deployed at the field sites consisted of equipment already owned by the NCPA. Figure 3 shows a picture of the system deployed at the Douglas City site on the Trinity River. The system consisted of up to four hydrophones mounted in the river. Each hydrophone was connected to a preamplifier and the outputs were connected to an NI-9215 data acquisition module. This module was interfaced with a laptop via custom written LabView code. The amplifiers require external power and so were connected to a car battery.

Figure 3: Photograph of the first iteration of the passive acoustic bed load monitoring system, deployed at Douglas City on the Trinity River, CA

Hydrophone deployment in the Trinity River

From May 4 to 7 2012 personnel from the NCPA and Reclamation deployed two of the passive acoustic prototype systems at various locations on the Trinity River near Weaverville, CA. One system was deployed at Douglas City for three days. The second system was deployed at Lewiston for the first two days, and then moved to the Grass Valley Creek site for the last day. The decision to move the system arose when the researches noticed that the hydrophones at Lewiston did not seem to be detecting any gravel movement. This was later confirmed by further analysis, and it is believed that the hydrophones were in an ‘acoustic shadow zone’ with respect to the moving bed load. At all three sites, the hydrophones were mounted downstream of the physical sampling. Additional deployments of the hydrophones with concurrent bed load measurements were planned for 2013 and 2014. Unfortunately, the spring releases from Lewiston Dam in these years were not sufficient enough to mobilize coarse bed load.

Hydrophone deployment in the Elwha River

The hydrophone system was deployed on the Elwha River (November 27, 28 2012; May 14, 15 2013) when bed load was measured for the purpose of calibrating the impact plate system. As with the Trinity River deployment, Graham Matthews and Associates measured the bed load. Although some bed load measurements were made with the intent of obtaining a complete cross section measurement, most of the bed load data were collected for the purpose of calibrating the bed load impact sensors, the primary goal of the physical measurements by GMA. As such, there were limited complete measurements of total bed load during the Elwha deployments.

Some minor improvements were made to the acoustic system deployed at Elwha. These changes were all related to the logistics and mounting. The actual workings of the system remained unchanged from the system deployed on the Trinity River. In order to not interfere with the physical measurements and to avoid excessive flow noise caused by flow over the weir, the hydrophones were mounted upstream of the sampling location and were placed as close to the center of the river as possible.

Hydrophone deployment in Bear Creek, Colorado

The current hydrophone system was recently deployed in Colorado May 24 and 25, 2014 while concurrent physical measurements of bed load flux were measured with bed load traps developed by Kristin Bunte (Bunte et al. 2007) (Figure 4). These bed load traps have been given Federal approval by the FISP as an accepted means for measuring bed load in wadeable streams. Dr. Bunte and Kurt Swingle volunteered their time so we could perform the measurements at Bear Creek in May 2014.

The measurements were taken during 80% bankfull (May 24) and 100% bankfull (May 25) discharges. In spite of these very competent discharges, bed load transport rates were extremely low, with only a few particles > 4 mm captured over the two day deployment. It is likely that the September 2013 flood eroded the bed material available for transport under bankfull conditions. The stage during the September 2013 flood was approximately 3 feet higher than the stage during our deployments based on high water marks.

Figure 4: Photograph (looking upstream) of bed load traps (foreground) and hydrophones (background) deployed on Bear Creek near Evergreen, CO.

Field Deployments With Concurrent Physical Bed Load Measurement: Results

Trinity River – May 4-7, 2012

The results from the Trinity River deployment were mixed, but still informative . Preliminary analysis of the data from the Douglas City site shows positive correlation between RMS and bed load, see Figure 5.

The data from the Lewiston site indicate that the hydrophones were placed in such a way that they were unable to detect the moving particles. The morphology of the river at the sampling site (Figure 6) is such that the hydrophones had to be mounted in a portion of the channel that did not have a line-of-sight to the portion of the channel where coarse sediment was being transported. This effectively created an acoustic shadow zone.
The Grass Valley data looks promising, but because the hydrophones were not placed there until the last day, there is only one overlapping physical sample.

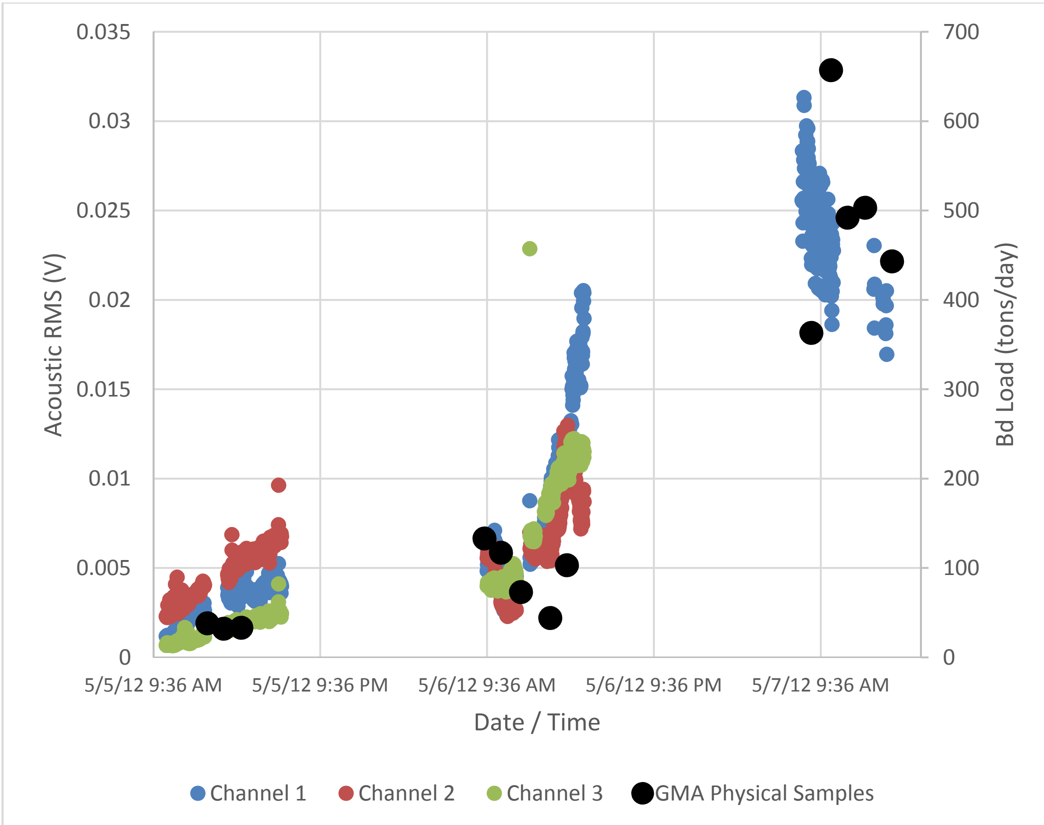

Figure 5: Acoustic data (colored circles) shown with physical measurements of bed load (black circles) at the Douglas City site on the Trinity River, CA. Graham Matthews and Associates collected the physical bed load measurements.

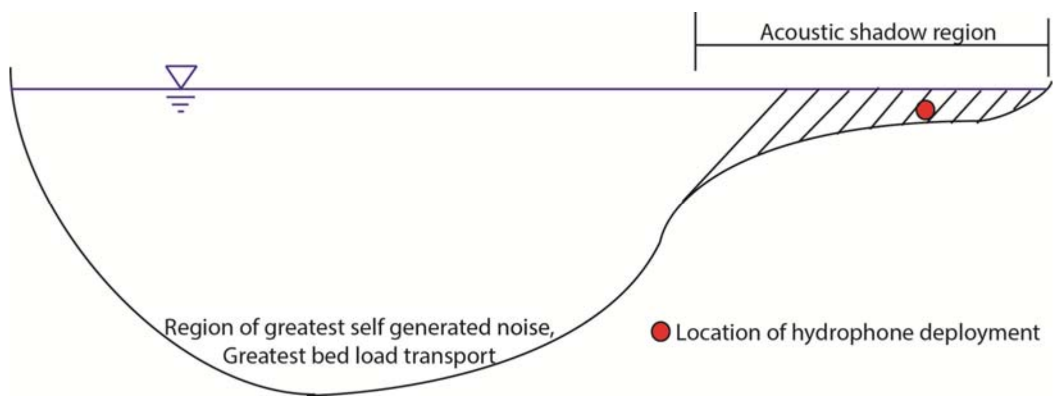

Figure 6: Approximate shape of the cross section at the Lewiston sample site on the Trinity River. The approximate wetted width of the channel is 70 meters. The view is looking downstream. The acoustic shadow prevented a direct propagation of self- generated noise from gravel collisions from reaching the hydrophone.

Elwha River – November 27, 28 2012

Sediment transport, including bed load, during the November 2012 deployment was heavily dominated by particles < 2 mm, as indicated by the physical measurements taken by GMA. Although fine delta deposits from the former Lake Mills had reached the measurement site due to on-going dam removal processes, coarse sediment was being transported at a slower rate and had not reached the site. These transport conditions provided a 'calibrated zero' for the acoustics. It was a unique opportunity to capture the flow noise and overall soundscape of the river minus gravel transport. Analysis of the data shows a relatively constant RMS which was to be expected since there was no change to the bed load transport rates.

Elwha River – May 14, 15 2013

The primary purpose of the physical bed load measurements on the Elwha River during this sampling period was to calibrate individual impact plates. The sampling protocol and limited time did not produce the necessary data for direct correlation of physical bed load measurements and hydrophone data. However, a correlation between the bed load impact plate system using a preliminary calibration of the geophone plates and the hydrophone data has been made (Figure 77).

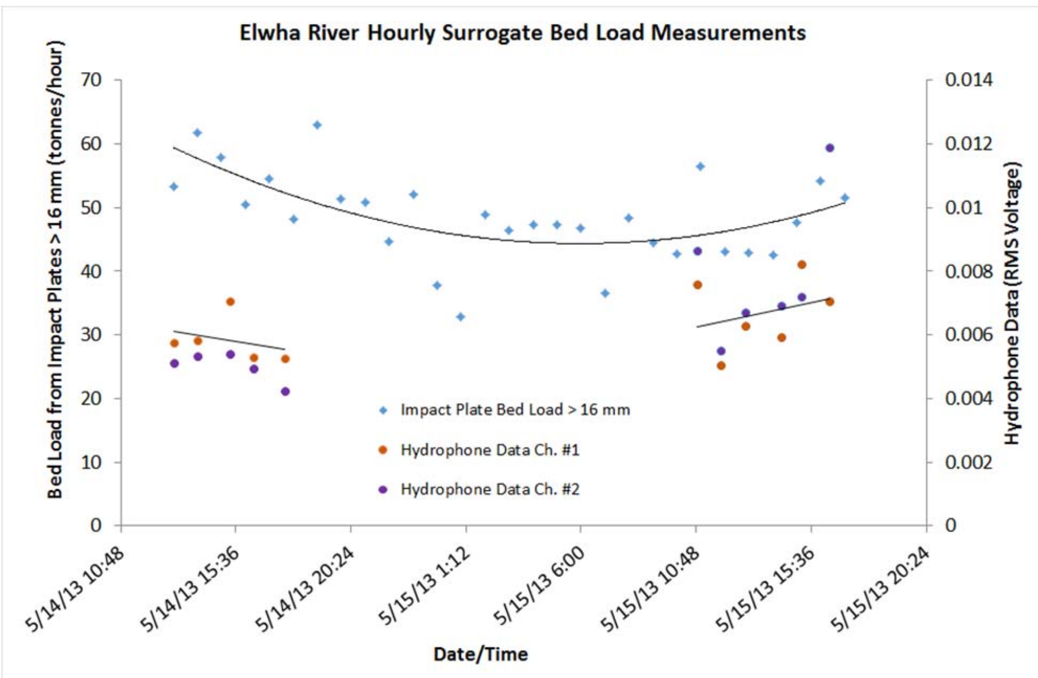

Figure 7: Comparison of bed load transport measured with the Elwha bed load impact plate system using a preliminary calibration and data from two hydrophones deployed approximately 70 meters upstream. Data shown are hourly averages of both systems.

Data in Figure 77 seem to indicate reasonable agreement with trends in sediment transport. Slopes of a linear best fit of the hydrophone data are similar to the slope of a polynomial fit of the bed load impact plate data. The comparison is not ideal due to the appreciable physical separation of the two systems. It is likely that transport conditions at the two locations are somewhat different. However, considering a long term (several hours) analysis should negate this effect to some degree. Hydrophone deployments during the May 2013 sampling period were 5 and 6 hours, during day one and day two, respectively.

An area of concern regarding any correlation between bed load measurements and the hydrophone data is the distance from the hydrophone to the correlated measurement. Because bed load transport is highly variable in space and time and tends to travel in waves, travel time may need to be considered as well as potentially different transport conditions at each location. Sampling over long periods of time will help resolve this variation.

Bear Creek, CO – May 24, 25 2014

As with the November Elwha data collection trip, the physical samples showed little to no bed load transport. Likewise, the acoustic data shows relatively constant rms voltage values.

The purpose of the recent bed load measurements on Bear Creek was to gather additional field deployment information toward the continuing development of obtaining a quality correlation between acoustic energy and bed load. Having deployed the bed load traps together with the hydrophones we have a good understanding of the requirements for future bed load measurements to answer our remaining research questions. This work has been proposed to Reclamation's Science and Technology Office for funding in 2015. All surrogate technologies require site specific calibration. As the developers of this hydrophone system, we must be able to develop guidelines for a proper calibration and identify uncertainties in the measurement across a range of geomorphic, hydraulic, and sediment transport conditions.

Summary of Field Testing Results

To date, there have been four deployments of the acoustic system on three different rivers. Two of the deployments (Elwha River, November 2012 and Bear Creek, May 2014) unexpectedly yielded no measureable bed load transport. In both cases, the acoustic data shows no significant changes across the sampling duration. The May 2013 deployment in the Elwha River coincided with physical sampling, but not total bed load measurements. Thus, the only correlation possible is with an impact plate system using the preliminary calibration (Figure 7). The May 2012 deployment to the Trinity River provided solid bed load measurements and acoustic correlation at one of the sites tested (Figure 5).

Cooperative Research by ARS Not Funded by Reclamation's S&T Program

Using funding from the FISP, ARS is studying SGN with an ARS group from Walnut Gulch, Arizona (an ephemeral stream). A pre-existing stream bed load measurement system is being used to help advance the understanding of the relationship between SGN and gravel transport. We are collecting physical samples of bed load just downstream of a hydrophone system. The physical samples and the SGN data will be related to one another to help establish improved relationships between recorded acoustic emissions and bed load transport. This effort began in May 2014 and is continuing through the summer and into the fall of 2014 to capture events related to recent hurricane activity near the Baja Peninsula.

In another FISP funded project, ARS is working to define the size of the measurement area covered by a hydrophone system. This project should provide valuable information needed for determining how much of a stream channel is acoustically sampled and for evaluating quality of data. The main component of this research is laboratory investigations of sound movement over rough beds in shallow water. This is an acoustically complex environment that has not be addressed in previous research efforts and is a principal obstacle in efforts to move beyond simple calibration relationships for converting acoustic data into bed load transport rate. This project began in January 2014 and research is ongoing.

ARS is also working with NCPA personnel on interpreting data generated in calibration experiments, including rock dragging experiments performed in laboratory flumes.

Future Work

In November 2013, the Federal Interagency Sedimentation Project (FISP) awarded a proposal put forth by the NCPA to develop a portable, field-deployable system to measure bed load transport with a hydrophone. The development of this system will be based on the findings over the past 3 years of the current research funded by Reclamation's Science and Technology Office. Using this system and the knowledge gained over the current research project, data will be gathered over multiple sites for the purpose of determining a calibration protocol. As with other surrogate sediment measurement systems, the hydrophone will have to be calibrated at each site it is deployed.

Unresolved questions to be answered by future research are:

1. How many physical bed load measurements are required to calibrate the hydrophone system?
2. How does particle size distribution affect the calibration?

    An internal NCPA grant has been awarded to begin this investigation
3. What recording time intervals on the hydrophone system are appropriate? Is sampling 50% of the time sufficient? If so, is every other minute appropriate, or will longer time intervals be required?

    This question may become moot with the FISP awarded project. Different methods of data acquisition are being investigated; one of which being constant streaming to file.
4. What large scale time intervals are needed to capture bed load transport events?
5. How do flow characteristics (depth, discharge, turbidity, etc) affect the calibration?
6. What benefits can be gained by deploying multiple hydrophones versus a single hydrophone?
7. How does channel morphology affect data collection?

Future Field Testing

Future plans for this research include additional lab and field testing to continue research on the propagation of SGN through water in a shallow, rough bedded stream. This includes improving our understanding of the waveguide effect, which can limit lower frequencies; and determining the "listening area" of the hydrophones under various conditions in natural rivers. Both of these topics are critical to understanding the physics behind passive acoustic measurements of bed load.

The FISP has funded the NCPA to develop a field deployable hydrophone system, which will replace the bulky, fragile, and overly sensitive lab equipment currently deployed in the field. The field deployable system will not require a laptop and will be able to be deployed for long periods of time unsupervised. Preliminary post-processing will be handled by a data logger, which will also store the data for subsequent download and further processing.

A proposal has been written to Reclamation's Science and Technology Office to continue this research, investigating the above mentioned topics and working toward calibrating the hydrophone for bed load measurements. We will propose to concurrently collect physical bed load measurements while deploying the hydrophone on several streams in Colorado. This effort will include the expertise of Dr. Kristin Bunte (Colo. St. Univ.), who has developed the federally approved bed load traps for measuring bed load in wadeable streams. Dr. Bunte will add years of bed load measurement expertise and an in-depth knowledge of Colorado streams that are appropriate for these measurements. It is expected that we will be able to sample at least 3 to 5 streams in Colorado during the run-off period in 2015. These field deployments will provide valuable information toward the goal of being able to quantify coarse bed load with a portable passive acoustic device.

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Appendices

1. Passive Acoustics Bed Load Measurement Team

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Dr. James P. Chambers – NCPA, U. Miss.
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2. Publication of this research

Carpenter, W.O., Hilldale, R.C., Chambers, J.P., Goodwiller, B.T., Kleinert, D.E., Randle, T.J. (2012). “Surrogate Bed Load Measurement on the Elwha River” National Water Quality Monitoring Conference, April 30-May 4, Portland, OR.

Goodwiller, B.T., Chambers, J.P., Carpenter, W.O., Wren, D.G., Kuhnle, R.A., Rigby, JR., Hilldale, R. (2013). “Design and Implementation of a Hydrophone-Based Passive Acoustic Bedload-Monitoring Surrogate”, Proc. of the 166th Meeting of the Acoustical Society of America, December 2-6, San Francisco, CA.

Goodwiller, B.T., Chambers, J.P., Carpenter, W.O., Wren, D.G., Kuhnle, R.A., Rigby, JR., Hilldale, R. (2013). “Design and Implementation of a Hydrophone-Based Passive Acoustic Bedload-Monitoring Surrogate”, Invited presentation, International workshop of acoustic and seismic monitoring of bedload and mass movements, Swiss Federal Research Institute WSL, September4-7, Birmensdorf, Switzerland.

Goodwiller, Bradley T., Wren, Daniel T., Rigby, JR., Carpenter, Wayne O., Hilldale, Robert C., Chambers, James P., Kuhnle, Roger A. (2015). “Design and Implementation of a Field Deployable Passive Acoustic Bedload-Monitoring Surrogate”, Abstract accepted for presentation at the 10th Federal Interagency Sedimentation Conference to be held April 19-23, Reno, NV.

At an appropriate point in the research, the team of researchers will submit at least one publication to a refereed journal. It is likely that perhaps two publications will result from this research, with one focused on the application toward collecting bed load data being submitted to a river morphology journal (e.g. Earth Surface Processes and Landforms, Water Resources Research, Journal of Hydraulic Engineering*, etc.) and the other with a primary focus on the theory of the propagation of SGN in a natural stream with shallow water and a rough bed (e.g.* Journal of Acoustics*).*

3. Data Sets that support the final report

The data is stored on an external hard-drive named 'Trinity Harddrive'. The paths to the different data sets are:

Trinity Harddrive\May 2012 Trinity Data
Trinity Harddrive\November 2012 Elwha Data
Trinity Harddrive\May 2013 Elwha Data
Trinity Harddrive\May 2014 Bear Creek Data

Point of Contact: Bradley Goodwiller, email: btgoodwi@olemiss.edu, phone: (662) 915-7224

Short description of the data:

The field data has been stored in two formats: raw binary (each file contains data from all active channels) and converted .wav files (each .wav represents one channel for the selected duration; usually 6 seconds). Each data collection trip has its own folder, with date and location in the folder name.

Keywords: Raw and processed field data

In total, the field data takes 380 GB of storage space.