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Technical Report #SRH-2015-39

Field Testing and Calibration of a Hydrophone System for Surrogate Bed Load Measurement

Research and Development Office

Science and Technology Program
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

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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14. Past research by this team to correlate the movement of coarse bed load with acoustic signals from a hydrophone has shown positive results. However, we are beginning to better understand the challenges facing us regarding the acoustic field and propagation of acoustic signals in a fluvial environment. Past data collection for bed load has taken place on medium sized rivers, where hydrophone deployment is difficult. In our latest effort, we have measured bed load and recorded self-generated noise from gravel particle collisions in Halfmoon Creek, a small stream near Leadville, CO. Physical bed load measurements were collected across the channel using Bunte bed load traps and acoustic data were collected 1 meter upstream for correlation. Additional information was gathered regarding the acoustic environment in Halfmopn Creek. This report details the data collection of both physical bed load measurements and acoustic data. Preliminary conclusions are included however the data are still being analyzed for a correlation between acoustic data and physical bed load measurements. Future plans are included at the end of the document.					
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Field Testing and Calibration of a Hydrophone System for Surrogate Bedload Measurement

Science and Technology Project #9342

9/30/2015

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Introduction

Past research on this subject by this team has shown positive results, correlating coarse bed load transport to acoustic energy. These measurements have taken place in the Trinity River (CA) and the Elwha River (WA) (Figure 1 and Figure 2). Bed load measurements and physical conditions for these two rivers have provided challenges, not providing a means by which definitive conclusions can be made. One reason for this is because bed load measurements on the Elwha River have been collected primarily for the calibration of the bed load impact system (another surrogate bed load measurement research project), not providing a complete bank to bank bed load measurement needed for the hydrophones. Additionally, moderately sized rivers (30 - 100 m wide) present challenges with respect to the measurement area of the hydrophone and the propagation of the acoustic signal. This uncertainty makes is difficult to conduct our research correlating acoustic energy to measured bed load. Also, the timing of bed load transport events on medium and large rivers is difficult to predict when only a single deployment is planned.

In order to address many of these challenges, it was decided to move the research to a small stream. The small stream provides a reasonable environment in which to measure bed load and deploy hydrophones. In a mountain stream bed load traps (Bunte et al. 2004,Bunte et al. 2007) can be used for measurement of bed load. In 2009 the Federal Interagency Sedimentation Project (FISP) provided Federal approval for using bed load traps in small streams to measure bed load (FISP 2009). Moreover, a mountain stream provides dependable bed load transport during most seasons, allowing the research team to reliably set dates for data collection.

Another challenge to the calibration of a passive acoustic bed load surrogate is the variation of acoustic parameters between measurement locations. The shape of the banks, the composition of the bed itself, the noise generated by the flow, and a potential multitude of additional acoustic sources will each have an effect on the propagation and detectability of the sound generated by bed load. Detailed theoretical and experimental work is required to determine the dependence of the measurement technique on these site-specific parameters. A framework must be developed to account for the so-called soundscape of any individual test site. Specifically, the area of investigation of the hydrophones (which will depend on all of the previously mentioned factors) must be determined for an accurate calibration to be made.

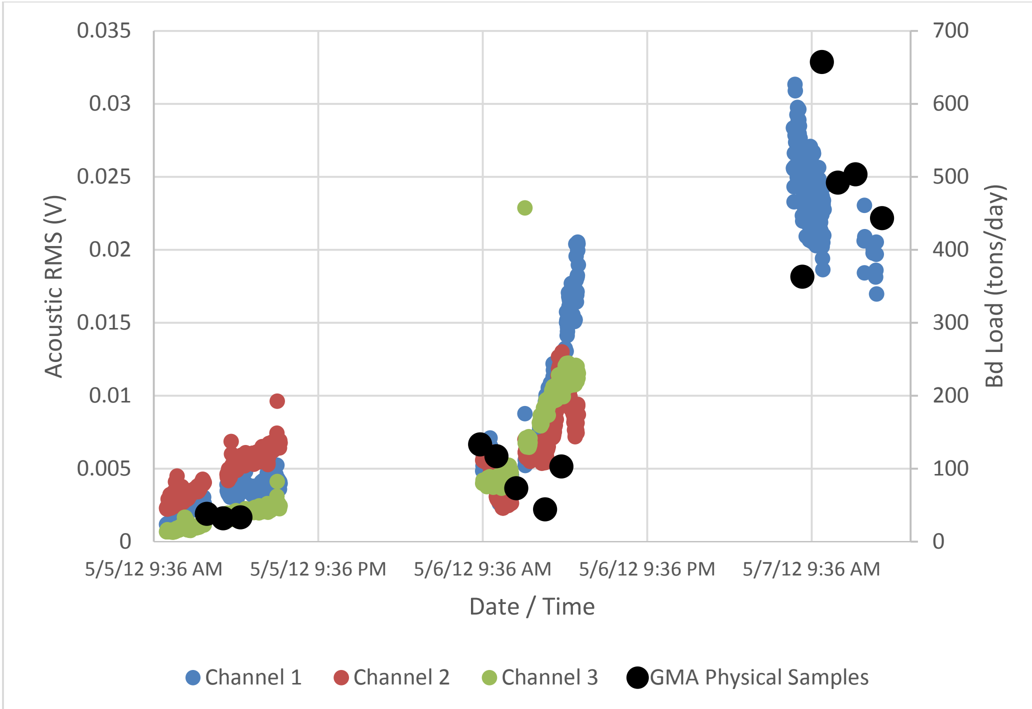

Figure 1: Acoustic RMS (voltage) vs measured bed load at the Douglas City sampling site on the Trinity River, CA

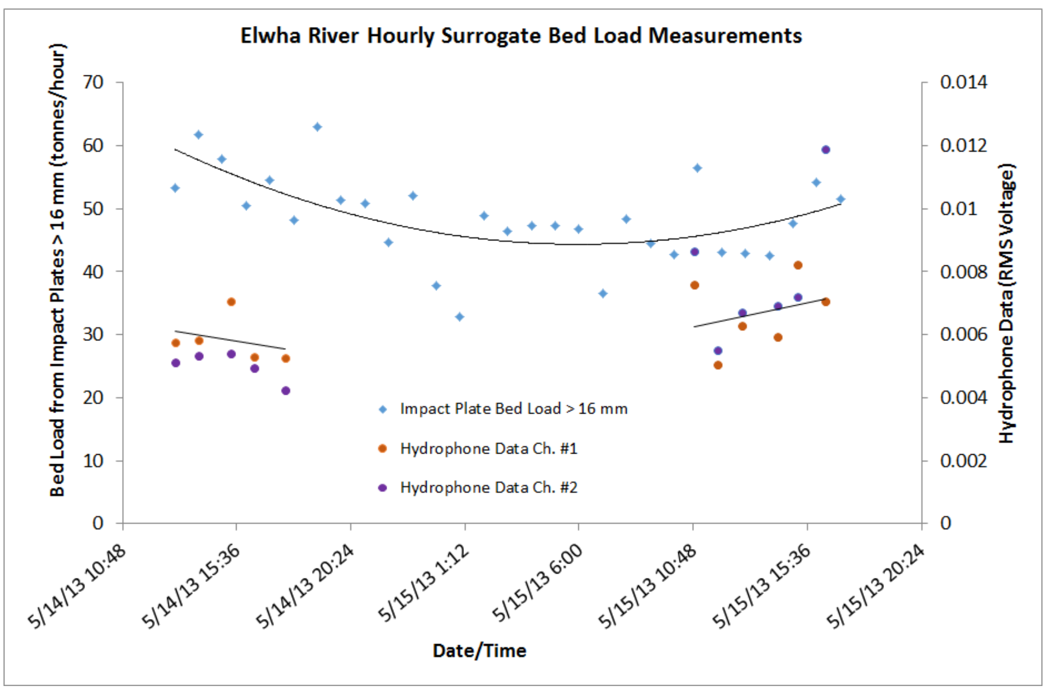

Figure 2: Comparison of bed load transport measured with the Elwha bed load impact plate system using a preliminary calibration and data from two hydrophones deployed approximately 70 meters upstream. Data shown are hourly averages of both systems.

Proposed research for 2015

The following information was taken from the proposal for 2015 funding. It addresses the questions to be answered by the research.

> The proposed research intends calibrate a field-deployable hydrophone system to measure bed load in mountain streams. After a calibration is obtained, it will be necessary to examine the data to determine what sort of recording intervals can be used for long-term deployments. Because hydrophone data are large and require significant storage capacity, there may be times when the data collection is not continuous. What intervals can/should be used? Can we cut out 50% of the data by collecting for a minute and shutting down for a minute? Perhaps a 5 minute interval is more appropriate. At the end of the proposed data collection we should be able to answer these questions as well as provide a calibration for the hydrophone system in small streams.
>
> This project builds on knowledge gained over the past three years of investigation. Recent research funded by the Science and Technology Program (#4864) has advanced the state of the science for measuring bed load with hydrophones. Lab and field deployments have provided answers to questions previously unexplored in this field through collaboration among Reclamation offices, other federal agencies, universities, and private consultants. The research has matured to the point where a field-deployable hydrophone system has been designed and fabrication will be completed in time for testing and calibration during spring runoff in 2015.
>
> The following excerpt is also from the proposal for 2015 funding and addresses the planned research strategy.
>
> Bed load will be measured in gravel bed streams in Colorado using Federally approved bed load traps designed and built by Dr. Kristin Bunte (Colorado St. Univ.). During the physical bed load measurements, a hydrophone system will be deployed in the vicinity of the physical measurements such that direct correlation can be made between the physical measurements and acoustic energy recorded with the hydrophone.
>
> Due to varying lithologies, channel conditions such as bed roughness, cross section shape, flow depth, and flow velocity, it

will be necessary to obtain data in multiple streams. The research team will travel to a region in Colorado where multiple streams or sites in close proximity can be sampled during spring runoff 2015. The region chosen for sampling will be determined based on projected runoff conditions, essentially the location of greatest snow pack.

Assistance with acoustics, signal processing, and related software will be provided by the National Center for Physical Acoustics (NCPA) at the University of Mississippi. The NCPA will provide a field deployable hydrophone system, designed and constructed with funds from the Federal Interagency Sedimentation Project (FISP). The necessary understanding for the design of such a system is a direct result of past funding by Reclamation's S&T program to investigate measurement of bed load using hydrophones as well as coordinated research provided by the Agricultural Research Service (ARS) in Oxford, MS.

Research activity in 2015

Deployment of equipment in Halfmoon Cr.

The bed load traps and hydrophones were deployed at two locations within the study reach (Figure 3), named Measurement Section 1 (upstream location) and Measurement Section 2 (downstream location). Bed load samples were collected from May 13 to June 15, 2015 at Site 1 and from May 29 to June 15 at Site 2.

The hydrophones were deployed May 20 – June 17, 2015 at Site 1 (Figure 4) and from June 10 – June 16 at Site 2 (Figure 5). Acoustic data were recorded at two locations at each site, approximately at distances 1/3 of the channel width from each bank (Figure 4 and Figure 5).

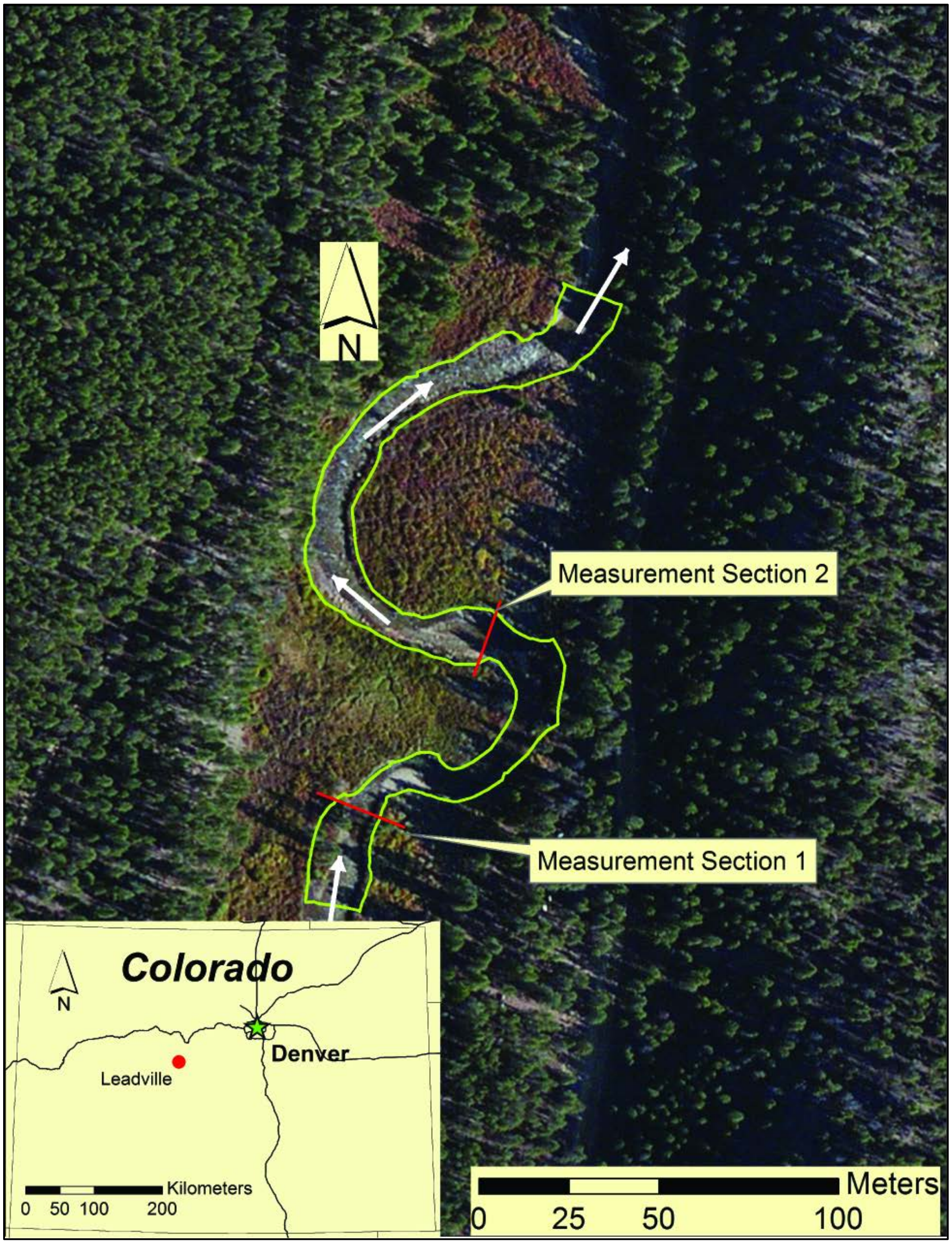

Figure 3: Location map of the study reach. Flow direction is indicated by the white arrows.

Physical bed load measurements using bed load traps

Bed load transport was measured for this project using bed load traps, developed by Dr. Kristin Bunte (Bunte et al. 2004, Bunte et al. 2007). Bed load traps are portable, 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 rests on an aluminum plate mounted to the bed. Figure 4 shows the bed load traps deployed in Halfmoon Creek.

Figure 4: Photograph of the bed load traps deployed at Site 1 in Halfmoon Cr. Flow is from left to right in the photograph. The white posts are the mounting structure for the hydrophones. Photograph courtesy of Dr. Kristin Bunte.

The bed load traps were deployed at the beginning of each day and recovered before leaving the site in the evening. Each trap was emptied every hour and the time was recorded. The sample retained in each trap was cleaned of organics and retained for later sieving and weighing. Accumulating the results and interpolating between the traps provides a complete bed load measurement with 1 hour resolution. These measurements will be used to correlate with acoustic energy registered by the hydrophones. The results of the bed load measurements have been compiled and are in spreadsheet format. Dr. Bunte has provided a detailed report attached to the end of this report (Appendix A).

Figure 5: Picture of Site 2 looking upstream. The blue posts are the mounting poles for the hydrophones without the hydrodynamic fairings yet installed. The bed load traps are visible just downstream of the hydrophone mounts. Photograph courtesy of Dr. Kristin Bunte.

Acoustic bed load measurement using hydrophones

The hydrophones remained deployed for the duration of the experiment and were not removed from the river bed. The hydrophones were mounted to T-posts driven into the bed of the channel. To reduce drag and vibration a plastic aircraft fairing was placed over the T-post. To insure a tight fit of the fairing, 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 (Figure 6).

The hydrophone wires were routed through the fairing to the top of the post, where they were then run to the bank and connected to a modified weatherproof box (Figure 7). The box was modified to contain the data recording hardware. A two-channel Zoom H4N wave recorder was used to record the signals generated by the hydrophones as .wav files at a rate of 48,000 samples per second per channel, and a resolution of 16 bits. The hydrophones (HTI 96-MIN Exportable) had a built-in amplifier that required power anywhere between 6 and 12 VDC. Because the current draw from the hydrophones was minimal, two 9V batteries were wired in parallel to power the hydrophones and placed inside the case. The voltages on these batteries were checked daily. They were replaced whenever the charge was less than 8.5 VDC. The wave recorder was capable of running off of standard AA batteries or from a 5 VDC input. A 12 VDC to 5 VDC stepper was wired inside the box and to the wave recorder power input so that the case could be connected to an external 12 V battery for prolonged use. The system was recording during the day when sediment measurements were being made with the bed load traps and was set to record over night after leaving the site. During the daytime deployments, individual files were created to correspond to the sampling of the bed load traps. By manufacturer's default, the wave recorder automatically starts a new file when the current file reaches 2 GB. This roughly corresponds to 3 hours of recording. Thus for the nighttime recordings, files are automatically created and named numerically. Hydrophone recordings were made for nearly 24 hours each day.

Site 2 hydrophone deployments and bed load measurement are not nearly as extensive. Two reasons drove the need to deploy hydrophones and measure bed load at a second site: 1.) The data can serve as a validation of the methodology used to quantify bed load with the hydrophone, determined at Site 1; and 2.) Measurement at Site 2 will provide additional information regarding the effect of cross section shape and transport of larger particles. Data from Site 2 has yet to be evaluated, but will be in 2016.

Figure 6: Photograph of the fairing adapted to house the hydrophone. The set-up is upside down in this photo. The hydrophone is mounted inside a black housing 12" downstream of the post and 6" off the

bed. The black housing is 'acoustically invisible' with a density very near that of water. Photograph courtesy of Jarrod Bullen.

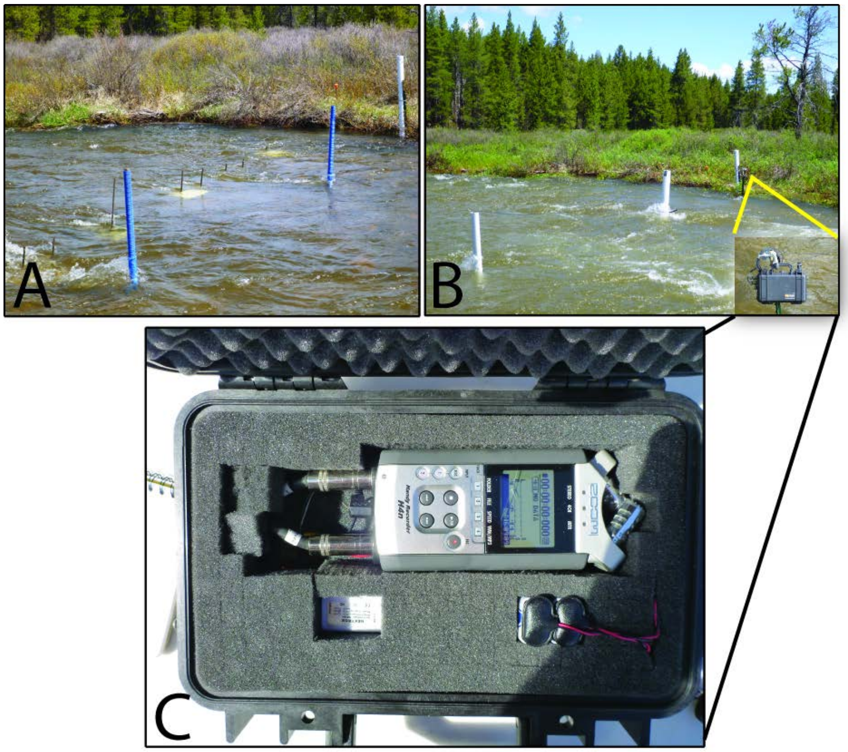

Figure 7: A – Site 2 at low flow prior to installing fairings and hydrophones. B – Site 2 after installing fairings and hydrophones. C – Data recorder and batteries inside a weatherproof case.

Progress on sound field classification

In June 2015 ARS personnel performed acoustic experiments in Halfmoon Creek as part of the collaboration. In conjunction with collocated measurements of bed load and acoustic energy, measurements of the acoustic sound field in a river are necessary to further the effort toward quantification of bed load transport with hydrophones. The acoustic environment in a river provides a broad spectrum of properties that change with flow depth, channel roughness, cross section shape, and are influenced by flow noise.

Several tests were conducted by ARS using passive and active acoustics in Halfmoon Creek. The passive tests were performed to improve our understanding flow noise in a fluvial environment. The active testing involved an acoustic source, a 1,000 Hz speaker placed underwater. This source provides a signal of known frequency and amplitude, providing the ability to test the acoustic field for properties of signal propagation. The results of this testing are still being evaluated by ARS and this effort will continue into 2016.

Results of the 2015 research

Across the entire deployment, nearly 300 GB of acoustic data were recorded. Analysis of this massive amount of data is ongoing, but several preliminary results and findings are presented here. Previous work on this project has focused mostly on the acoustic root-mean-squared (RMS) as an analogy for acoustic energy. The first step of the analysis was to divide the acoustic data into one-hour segments. The RMS of the entire hour was then calculated, and assigned a time stamp of halfway through the hour. The remainder of any file went through the same process, and was assigned a time stamp halfway through its duration. These steps were made possible by the time-stamp on the original file from the wave recorder. This time information (as well as several other parameters of the .wav file) was stored in the header information and was thus preserved along with the file. Figure 8 shows the total RMS of Site 1, Channel 1 versus discharge (cfs) as collected from the USGS website for site 07083000 and verified by Dr. Bunte. Figure 9 shows the unfiltered RMS versus the data from the bed load traps. Note that Channel 1 was the hydrophone on river-right, in front of traps 1 and 2 where a vast majority of the bed load was collected.

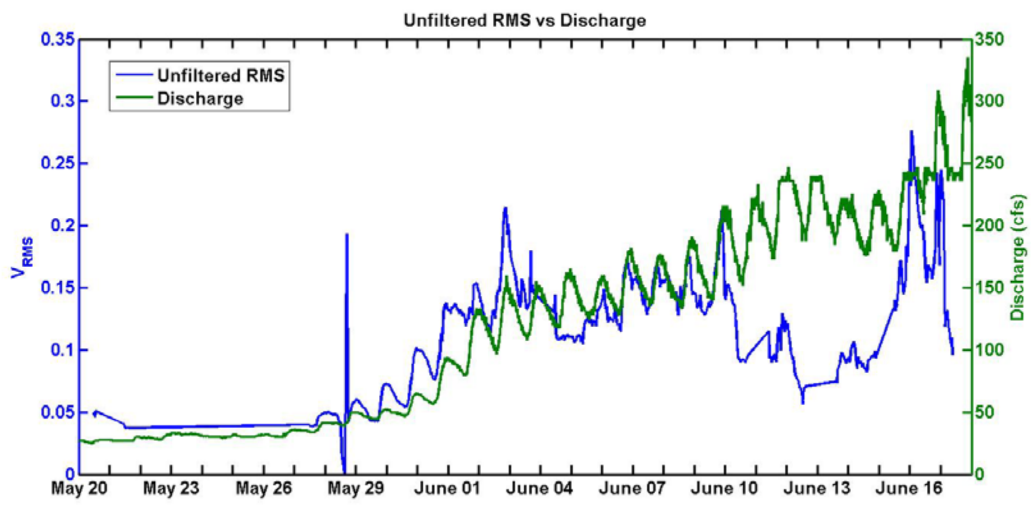

Figure 8: Nominally 1-hour acoustic RMS versus discharge for Channel 1 at Site 1

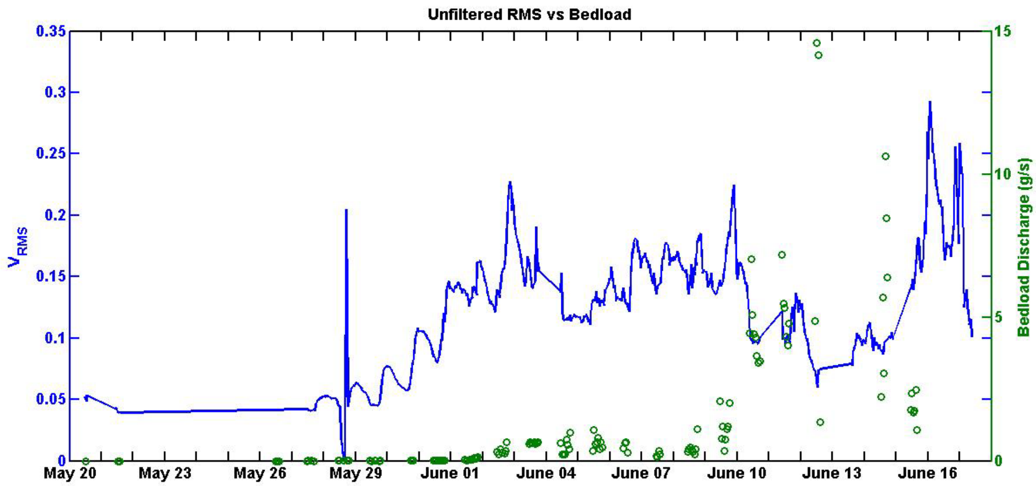

Figure 9: Nominally 1-hour acoustic RMS versus data from bed load traps

Two things of note arose from this analysis. The first is that the acoustic energy trends very highly with flow discharge and not with bedload. This was not unexpected, as flow noise tends to be low frequency and very dominant. The more troubling result is the sudden dip in acoustic energy between June 10 and June 15. The cause of this is still under investigation, and until it is resolved, the data from this time period must be treated with caution. From simple investigations of the frequency content of the data files, it was determined that the flow noise is indeed dominant at lower frequencies. For this reason, the data was run through a high-pass filter with the pass band set at 10 kHz. This frequency was chosen based on similar previous work, and is a parameter still under investigation. Running the data through this filter and then re-calculating the time-based RMS provides the data shown in Figure 10.

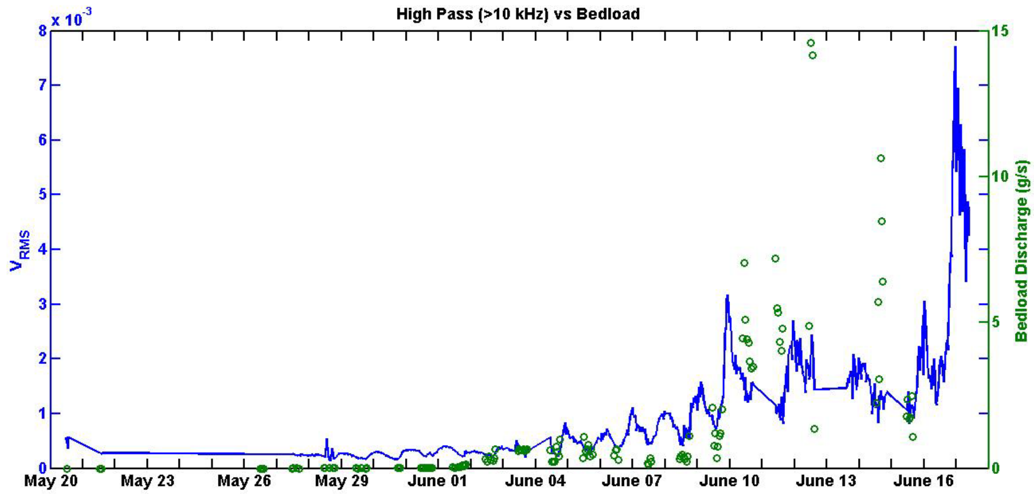

Figure 10: Hourly RMS after a 10kHz high pass filter overlaid with data from the bed load traps.

The high pass data trends more positively with bed load than the unfiltered data. The next step in the ongoing analysis was to take each bed load sample and find its nearest (in time) acoustic RMS point. Figure 11 shows the RMS plotted versus the co-incident bed load sample. At the current time, the data after June 10 is still being treated with caution; these samples are marked with a red x. While the elimination of the cautionary data changes the outlook dramatically, there is still a marked relationship between the acoustic data and the bed load.

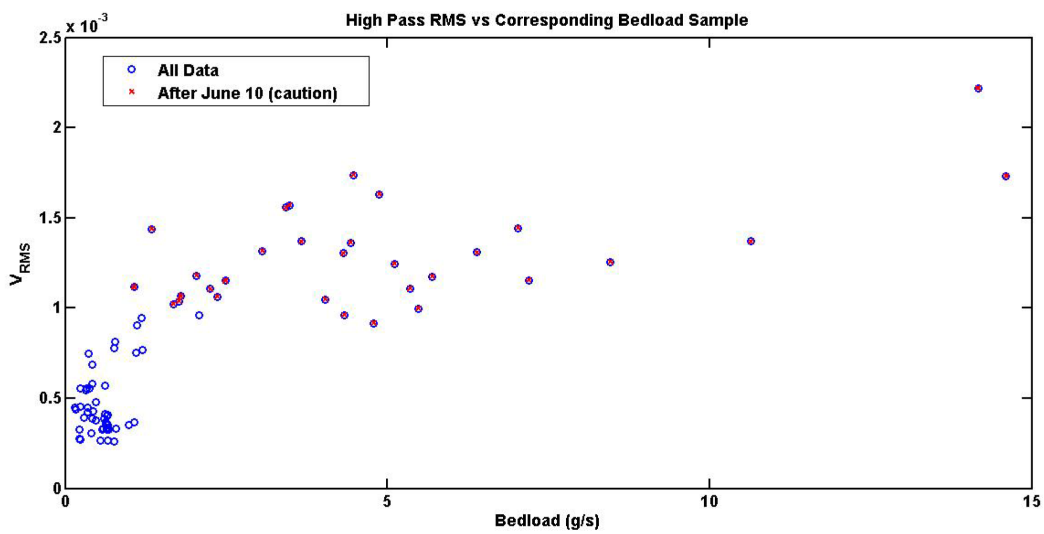

Figure 11: High pass RMS versus corresponding bed load data for Channel 1 at Site 1

Next steps

Work will continue on correlating bed load measurements with acoustic energy. With such a massive amount of data, care must be taken to take small steps and to work in pieces. The cause of the drop in acoustic energy is a key concern; both for the current data, and for the ability to avoid such problems in the future. Further correlation is being investigated using different frequency bands as well as size classes for the bed load. In addition, investigation has begun into the data from the second site which, while not as extensive as the first site, may provide very useful information.

Field testing of hydrophones will take place again in 2016. Hydrophones will be deployed in the Elwha River during bed load measurements taken for the impact plate study. These bed load measurements will serve both research projects, as we plan on sampling bed load using two methodologies specifically intended for each project. We will take our knowledge gained from work at Halfmoon Creek and expand it to a larger river. It is expected that ARS will again perform sound field experiments in the Elwha, similar to what was performed in Halfmoon Creek.

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FISP (2009). "FISP technical committee approval for the use of bedload traps in wadeable coarse-bedded streams", Federal Interagency Sedimentation Project Technical Committee Memorandum 2009.01.
http://water.usgs.gov/fisp/docs/FISP_Tech_Memo_2009-1_Bedload_Traps.pdf

Data Sets that support the final report

The data from all bed load – hydrophone experiments resides on the PI's desktop (H:\Backup\ARS-NSL_Halfmoon_Elwha_back-up\HalfmoonData), on an external drive in possession of the PI, and in multiple locations at the University of Mississippi. There are about 300 GB of hydrophone and bed load data.

The authors are the point of contact for these data.

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