Field Use Of An Acoustic Surrogate System To Monitor Gravel Bed Load Flux

Jarrod Grant Bullen

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FIELD USE OF AN ACOUSTIC SURROGATE SYSTEM TO MONITOR GRAVEL BED LOAD FLUX

A Thesis
Presented To
The Academic Faculty

By

Jarrod G. Bullen

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Mechanical Engineering

University of Mississippi
2016
ABSTRACT

There has long been an interest in monitoring the movement of large particle sediments traveling through fast-moving streams and rivers. However, there have been numerous challenges concerning the methodology best suited to collect these data. Many studies have been done to alleviate this problem, both through physical and surrogate methods. Physical methods include bed load traps that provide data over a specific time frame, but the fluctuation of sediment can change drastically over hours; thus, bed load traps are unable to provide a reliable predictive model. Since studies have shown a relationship between acoustic energy and particle impacts, the field of acoustics has shown potential in providing real-time measurements. These systems employ acoustic sensors such as geophones, sonar, and hydrophones. The research presented here utilizes a passive hydrophone system developed for field deployment. Laboratory testing of the system, utilizing towed sets of rocks, was used to compare acoustic energy to known transport rates and provided a basis for acoustic data processing.

A robust field-ready unit was produced to evaluate the capability hydrophones in real world monitoring of bed load transport. The unit was tested in conjunction with bed load traps to evaluate a relationship between surrogate and physical methods. Tests were conducted on Halfmoon Creek located near Leadville, Colorado. This thesis will center on the background leading to field deployment as well as extensive testing of the passive acoustic system, initial results from data collected, and comparison to physical measurements made alongside the unit. Data collected from field evaluations was processed through a MATLAB® program to produce a root mean square (RMS) average of the acoustic intensity. RMS data was compared with bed
load flux collected by physical samplers and flow discharge provided by a U.S. Geological Survey (USGS) gauging station. Results show that RMS and physical sediment data from this field test are not related due to the presence of flow noise. A more clear relationship was found between RMS and flow discharge. Observation of this indicates that flow noise is a major factor in passive listening for sediment monitoring and additional work should be focused on optimizing data filtering and low-noise installation.
DEDICATION

I am dedicating this thesis to the memory of my advisor and mentor, Dr. Jim Chambers. An inspiring educator, a tremendous mentor, and an amazing friend. I would not be here without his guidance and support. I am a better engineer and a better person for having known him.
ACKNOWLEDGEMENTS

One of the most valuable lessons I have learned in life is that no one achieves anything alone. Every dream, every goal completed is not just the product of one’s own hard work, but also the validation of the support given from those around. So since those supporting me do not put their name on the cover, I will do my best to recognize them here.

First and foremost, I would like to thank my family who has supported and believed in me the longest (yes, partly because they had to). In particular, I would like to thank my mom and dad for always being there to help, listen, and provide those extra pushes of encouragement (Stop procrastinating and do it Jarrod!). I really needed that. Thanks also to my sister for motivating me through her academic domination (you can stop getting degrees already, you have won….for now). In all seriousness, I could not have done this without her. Also, an honorable mention to Andrew for his timely suggestion of the word, accrue. He will get it.

I would like to thank Dr. Jim Chambers who hired me and then encouraged me to attend graduate school. My development as an engineer started with his undergraduate courses and I am so thankful that I was able to continue school and work under his advisement. I will miss him dearly and I hope that what I do hereon would make him proud.

I would also like to thank the research group I have worked with the past two years: Bradley Goodwiller, Brian Carpenter, J.D. Heffington, and Tiffany Gray. Being a part of this group was the best job I have ever had. It was an amazing experience to work with and learn from such exceptional people. Specifically, thank you to Bradley for your patience and seeing me through these last couple months. And thank you to Dr. Cristiane Surbeck, Dr. Daniel Wren,
and Dr. Erik Hurlen for agreeing to serve on my committee and giving me valuable input as well as their approval on my thesis work. Also, a special thanks is to Dr. Surbeck for stepping in as my advisor these final months. This was not an easy situation to step into and I am eternally grateful for your guidance and support.

I would also like to express my gratitude to Robert Hilldale from the Bureau of Reclamation who oversaw the field work at Halfmoon Creek and was always willing to get in the water to help. Also, I want to thank Dr. Kristin Bunte and Kurt Swingle for providing physical bed load measurements as well as Will Earwood for his assistance in the field. This thesis would not have been possible without them.

As always, there are many personal friends to thank, but I cannot name them all here so I would like to add a mass thank you to all my friends for your support and encouragement. I will, however, like to thank some who have contributed to this work. To Daniel Clark and Rhi Daniel, thank you for assisting in the lab experiments and for being around to provide input, suggestions, and company. Although, I know that ferrying rocks back and forth across a tank must have been the real highlight of your days so you are welcome.

I am indebted to all those who have helped me over the years and I hope the work I have done and will do will reward their belief in me. So, finally, thank you to everyone who has helped me, encouraged me, and befriended me. I am going to sleep now. Enjoy!
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CHAPTER 1

INTRODUCTION

1.1 MOTIVATION

Understanding the transport of sediment particles in streams is of great interest to ecological agencies. Sediment is an impactful component of natural water systems. Its size and movement, along with discharge, determine the morphology of alluvial river systems (Church, 2006) and affect ecology such as vegetation and fish habitats (Hauer et al., 2010; Lisle and Lewis, 1992). The movement of sediment through streams can be influenced by structures such as bridges and dams. As rivers are shaped by the water and sediment supplied by the environment, they are also influenced by the presence of man-made diversions. When a structure, such as a dam, controls water flow a river system will begin to lose high variability in sediment and water discharge, affecting natural processes downstream (Williams and Wolman, 1984). This can also extend to situations where dams or reservoirs are removed and release large amounts of sediment, that, due to ecological and river management concerns, need to be measured. Agencies such as the Bureau of Reclamation seek to monitor sediment transport to limit negative impacts on the environment and protect national waterways. Most recently the best way for these agencies to monitor sediment transport has been physically measuring the sediment flux through equipment that captures and measure the particles. However, some of these devices can be invasive to the stream environment and cannot provide continuous measurement due to the need of constant supervision. Sediment transport rates are typically highest during the night (e.g. runoff from a
mountain rises at night from snow melting during the warmest part of day, and feeds into the stream into the night) and during storm events (e.g. rain, snow, landslides, etc.). These times can be hazardous to people near streams and the streams are often unwadeable. This has increased the interest in surrogate techniques that provide continuous measurement and minimal supervision.

1.2 GOALS AND OBJECTIVES

A project has been proposed and approved to test the viability of a ruggedized passive acoustic system for monitoring of bed load transport. The device is expected to be user-friendly, minimize interference with natural sediment movement, and provide dependable, continuous data. This work has been an ongoing collaboration with the Bureau of Reclamation and researchers from Colorado State University, and the USDA Agricultural Research Service Sedimentation Lab. The presented work focuses on the development and initial testing of such a device. The main objectives of this work were as follows:

Objectives:

1. **Develop** the instrument. Based on previous experiments and possible ecological concerns, assemble a field-deployable acoustic monitoring system to measure bed load transport. Establish a procedure to provide consistent data sampling.

2. **Conduct** a test of the system in a stream. Construct a suitable structure to install the system and prevent damage from the surroundings. Observe the acoustic system alongside bedload traps and examine the environment surrounding the hydrophones and how this affects the deployment of the hydrophones.
3. **Analyze** and compare data. Generate a program to process the acoustic data and create a time average result that compares to sediment flux. Compare results to physical measurements and discharge to determine the effectiveness of acoustics as a suitable monitoring technique.

### 1.3 LITERATURE REVIEW

Typically sediment is separated into three categories: suspended, bed load, and wash load material. Suspended sediment is classified as fine grain particles “suspended” in the water column above the riverbed (Church, 2006). This sediment consists of small particles easily moved by the flow. Bedload sediment is defined as sediment moving on or near the bed of the stream by rolling, sliding, and sometimes making short jumps into the flow above the bed (Vanoni, 1975). Wash load is smaller material that may be found in the bed material and may move in conjunction with bed load or suspended load, although almost all wash material moves in suspension (Vanoni, 1975). This thesis will focus on bed load transport consisting of coarse gravel particles that travel along the bottom of gravel-bed streams. These particle and bed collisions create sound that can be quantified by acoustic energy (Bedeus and Ivicsics, 1964).

#### 1.3.1 PHYSICAL METHODS

Physical methods have been more commonly used to study bed load transport. Instruments involved are typically basket samplers and bed load traps (Habersack et al., 2012). Mobile basket samplers typically allow for more spatial evaluation than bed load traps (which require installation into the stream). However, this is dependent on the number of collections performed on the cross-section of the channel. This may lead to inaccuracy depending on
variability in discharge across the stream. Bed load traps allow for a total sediment collection over a specified sampling time; however, they are confined to the space in which they are installed (Habersack et al., 2012). Multiple bed load traps are required to achieve full spatial representation of the river channel.

While physical methods of determining bedload yield useful results, they do possess drawbacks. The use of bed load traps is invasive to stream beds during installation, causing supplanted gravel to become loose and change dynamics in the bed further downstream. The traps must also be monitored for unloading sediment in timely intervals and maintaining trap stability. The use of these physical methods depends on multiple personnel to keep a constant watch on equipment and can only produce reliable calculations on sediment flux within the time measured. This also reduces the chances of measuring sediment flux during storm events, a time during which movement could be accelerated.

1.3.2 ACOUSTIC METHODS

Physical methods have thus far provided a viable option in bedload monitoring. However, physical sampling can only be completed at compatible time intervals (e.g. wadeable flows and adequate weather conditions) and require laborious attention. Due to these constraints, many geological agencies have become interested in surrogate modeling methods. The field of acoustics has provided promising results in alleviating this problem. Studies have shown that self-generated noise (SGN) from coarse gravel collisions is related to bed load transport rate (Barton et al., 2003; Johnson and Muir, 1969; Moen et al., 2010; Thorne, 1983).

Johnson (1969) demonstrated an initial relationship between acoustic energy and sediment impacts by employing a piezoelectric microphone to monitor single-sized gravel with
constant flow velocity over multiple releases of sediment. The gravel collisions cause an acoustic pressure wave that is registered by the piezoelectric element in the microphone and creates a current that can be digitized and recorded. This examination proved that particle collisions could produce a current output from a recording device and could lead to the continuous measurement of bedload discharge.

Thorne (1985) furthered this idea by using glass spheres to observe the relationship between particles of different diameters impacting and the acoustic signal generated by these collisions. This analysis revealed that particle size was related to a specific spectral signature. However, as varying sizes of particles were introduced, spectral signals displayed outputs more closely related to total sediment flux rather than individual signatures. Of greater note, this study demonstrated that as overall mass increased, so did the root mean square (RMS) pressure level derived from the square root of the analyzer bandwidth. The Thorne (1985) study shows that using acoustics as a surrogate technique addresses some of the problems encountered with physical measurements. The employment of hydrophones to detect particle collision reduces the chance ofimpeding natural sediment flow and provides continuous monitoring without intensive management.

1.3.3 ACOUSTIC MONITORING DEPLOYMENT

As successful trials in laboratory experiments started to increase, the research focus shifted into replicating lab results with data collected from field deployment. Acoustic devices have been incorporated in multiple field monitoring instruments, with many different deployment options. These have included geophones with impact plates (Downing et al., 2003; Moen et al., 2010), sonar (Habersack et al., 2012), and passive listening hydrophones (Barton et al., 2006; Thorne, 1983). Thorne et al. (1983) collected field data from the deployment of
hydrophones near seabed under tidal currents. This data was analyzed and compared with physical sediment data estimated from video recordings. While the relationship between acoustic data and visual estimation of sediment were closely related, visual observation of sediment may not be dependable for accurate representation in low visibility streams and during accelerated transport occurrences. Downing et al. [check all references – if there are three or more authors, it should be Lastname et al.] (2003) provided a look into the results made possible by field-testing acoustics alongside bed load samplers. A small pressure plate sensor was used over a sheet of polyvinylidene fluoride (PVDF) film to create an electrical charge to measure particle momentum. These sensors were installed vertically next to bed load traps in the stream. While the results displayed interesting trends to physical samples, the drawbacks from the system setup were apparent. The pressure plate could not provide an overall acoustic sample due to its need for direct impacts from particles, meaning that a total cross-section analysis would have to be extrapolated from the sensors limited coverage. This poses a problem because of the spatial variability of incoming bed load, requiring many more sensors that may interrupt the natural flow of the stream if a cross-section is to be monitored.

Although some of these deployments have yielded useful data, they have not included extended field deployments alongside intensive physical measurements for comparison. One study outlined a yearly deployment of an acoustic plate near a river basin (Banziger and Burch, 1990). However, the bed load discharge was typically caused by floods that occurred sparingly and resulted in minimal data points for analysis. Many acoustic field deployments have either required extensive preparation for equipment or do not sample the full cross-section constantly for extended periods. The research presented here describes development of an easily
deployable acoustic surrogate system for continuous bed load monitoring, including a comparison with extensive physical sediment collection over a month-long deployment.

1.4 FIRST FIELD SYSTEM

During preliminary research, a field-deployable acoustic system was constructed from more delicate equipment (Hilldale et al., 2014). The previous system used to test the quality of the acoustic surrogate monitoring was similar to a system constructed by (Barton et al., 2006). The Reson TC4013 hydrophone was placed into a PVC pipe and then cushioned by foam to reduce movement of the hydrophone and to limit vibration noise. The pipe was then glued to a PVC tee that would slide down a post staked into a river channel to hold the hydrophone in a fixed position. To reduce sliding of the tee on the post, hose clamps were tightened closely on either end of the tee. This also allowed for a fixed position above the bed. The cord of the hydrophone had to be wrapped with a waterproof cover to reduce the impact that could damage the fragile cords and to avoid erroneous signals caused by particles impacting the cord. On the bank, the cord of the hydrophone was connected to a pre-amp which would increase the acoustic signal for greater visibility. For field research, the accompanying pre-amps and data acquisition (DAQ) cards had to be protected from rain and the many instruments had to be consolidated to limit many obstacles around the working area. To prevent harm to the system, the pre-amps and DAQ cards were placed in a hard shell case. Although this case held many devices and provided increased protection, it was a large case that hindered portability.

To gather data for preliminary testing, this system was tested at several locations (Hilldale et al., 2014). Preceding field tests at Halfmoon Creek, a field trial was conducted on Bear Creek in Colorado alongside bedload traps. However, stream conditions did not induce bed
movement to produce usable sediment samples. This result was similar to prior acoustic measurements that rendered constant values, showing no bed load movement (Hilldale et al., 2014). Limitations of this system helped to identify the requirements for a field-deployable system. A portable, weatherproof acoustic monitoring system with simplistic design and rugged hydrophones that continuously monitors bed load flux.
CHAPTER 2

LABORATORY EXPERIMENT

A laboratory experiment was conducted to investigate the relation between the SGN of coarse gravel and acoustic energy that was observed in previous research. This study involved transporting five chosen gravel particles at various speeds across two different gravel beds, creating SGN from a known and controlled mass transport rate. Data was processed through MATLAB®, and the relationship between acoustic intensity and known sediment flux was examined.

2.1 EXPERIMENTAL SETUP

Experiments were conducted in a tank that was twelve feet long, four feet high, and three feet wide, located at the National Center for Physical Acoustics on campus at the University of Mississippi. The tank could be filled with water and allowed for interchangeable artificial riverbeds. A mechanical roller installed on one end of the tank acted as a transport activator, pulling the sediment along the beds. Two artificial gravel beds were constructed from plywood, each containing a different gravel size glued to the boards. One bed was comprised of gravel particles (8-16 mm) (Figure 2.1), and the second had pea-gravel (2-4 mm) (Figure 2.2). To serve as the control sediment, five gravel sediments of varying sizes were chosen (Table 1 and Figure 2.3). Fishing line was used to connect the gravel to the mechanical roller. The acoustic
recording set-up consisted of two hydrophones placed in the middle of the tank one meter apart along the path the gravel traveled (Figure 2.5). The hydrophones were set at a height of about 30 cm from the bottom of the tank for the larger gravel bed and 20 cm for the pea-gravel bed. The hydrophones used were lab grade Reson TC4013 hydrophones along with Reson E6061 preamplifiers. The hydrophones’ output were recorded and digitized through a LabVIEW® program. The tank setup can be seen in Figure 2.4.
Table 1: Chosen Gravel with Accompanying Weights.

<table>
<thead>
<tr>
<th>Rock Weights (grams)</th>
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<tr>
<td>1</td>
<td>658.1</td>
</tr>
<tr>
<td>2</td>
<td>270.07</td>
</tr>
<tr>
<td>3</td>
<td>37.1</td>
</tr>
<tr>
<td>4</td>
<td>14.36</td>
</tr>
<tr>
<td>5</td>
<td>173.63</td>
</tr>
</tbody>
</table>

Figure 2.2: Artificial Bed with Pea-Gravel.
The experiment was performed with five rocks in nine scenarios. Each rock was individually pulled at different speeds to give a representative acoustic signal of the rock as velocity was increased. Another objective of study is how acoustic energy is affected when sediment of different sizes move simultaneously. For this, combinations of two and three rocks were pulled simultaneously with different variations (Table 2). All tests were performed on each surrogate gravel bed at water depths of 58 and 40 cm. The experiment involved many variables and scenarios that can be seen in Table 3.
Table 2: Scenarios of Rocks Transported in Tank.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Rock Number</th>
</tr>
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<tbody>
<tr>
<td>Individually</td>
<td>1</td>
</tr>
<tr>
<td>Individually</td>
<td>2</td>
</tr>
<tr>
<td>Individually</td>
<td>3</td>
</tr>
<tr>
<td>Individually</td>
<td>4</td>
</tr>
<tr>
<td>Individually</td>
<td>5</td>
</tr>
<tr>
<td>Two Rocks</td>
<td>2 &amp; 3</td>
</tr>
<tr>
<td>Two Rocks</td>
<td>2 &amp; 5</td>
</tr>
<tr>
<td>Three Rocks</td>
<td>2 &amp; 5 &amp; 4</td>
</tr>
<tr>
<td>Three Rocks</td>
<td>1 &amp; 2 &amp; 5</td>
</tr>
</tbody>
</table>

Table 3: Database of Tank Experiment.

<table>
<thead>
<tr>
<th>Database for Tank Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Rocks (Individual/Combinations)</td>
</tr>
<tr>
<td>Number of Gravel Beds Used (Gravel and Pea-Gravel)</td>
</tr>
<tr>
<td>Number of Water Depths (58 and 40 cm$^2$)</td>
</tr>
<tr>
<td>Number of Hydrophone Heights (one for each bed)</td>
</tr>
<tr>
<td>Number of Speeds for Each Scenario</td>
</tr>
<tr>
<td>Number of Audio Files Produced</td>
</tr>
</tbody>
</table>

---

1 Corresponds to rock number and weight in Table 1.
2 40 cm depth was used on both gravel and pea-gravel beds. 58 cm only for gravel bed.
Figure 2.4: Tank setup for lab experiment.
2.2 LAB EXPERIMENT RESULTS

Acoustic data was processed through a program in MATLAB®, determining the root mean square (RMS) over the time interval of each audio file (these ranged from 5-45 seconds). RMS is used in acoustic data processing to average the voltages produced by acoustic pressure waves. These waves are recorded as waveforms with varying amplitude (shifting between positive and negative values). Taking a general average of the waveforms typically results in a zero value because the positive and negative amplitudes nullify each other. Calculating the RMS is effective in processing these waveforms because it squares all values present (squaring a negative value produces a positive one) and provides a numerical descriptor for the acoustic energy for a given time interval. Equation 1 below depicts the formula for calculating the RMS
of a given set of voltages, where \( N \) represents the total number of voltages and \( V \) is the voltage corresponding to the \( n^{th} \) term in the summation.

\[
V_{RMS} = \sqrt{\frac{\sum_{n=1}^{N} V_n^2}{N}} \quad \text{(Equation 1)}
\]

Figure 2.6 shows the RMS of the acoustic data against the sediment flux produced by the five chosen rocks and given combinations. This particular graph depicts scenarios performed on the pea-gravel artificial bed at a water depth of 60 cm. The plot shows a linear relationship between RMS in volts and sediment flux in grams per second (g/s). This means that as the transport rate increased, so did acoustic energy. As shown, Rock 4 had a relatively low sediment flux at about 4 g/s and produced the lowest RMS value, 0.017 V, while the combination of Rocks 1, 2, and 5 produced the highest sediment flux at about 308 g/s and therefore the largest RMS value presented (about 0.034 V). Another interesting item to note from this graph is a decrease in the slope relationship between RMS and sediment flux as the total mass transported increased. This observation may lead to further data analysis as research continues. Figure 2.7 displays the same plot of RMS vs sediment flux for individual rocks transported on the larger sediment bed. Overall the relationship between transport rate and RMS is evident; however, this data set shows a few points scattered from the general trend. This is possibly due to the low water depth for the larger gravel bed producing reflection closer to the hydrophone. Another possibility is the rigidness of the artificial bed which caused a few large skips from the larger rocks as the velocity was increased. Skips do occur in natural gravel-bed streams, but the morphology changes with sediment transport, meaning that gravel on the bed will shift and change with transport and water
discharge. However, the glue holding gravel on the artificial bed does not allow for this and can produce skipping reactions as velocity increases.

The results from this experiment verified observations made in previous studies and confirmed that RMS compares well with sediment flux in the lab and may be used in the processing of acoustic data. As lab experiments showed potential, continued work necessitated trying to replicate lab measurements in the field. However, changes were expected to occur from field studies because many factors in natural stream environments cannot be controlled as they are in the lab.
Figure 2.6: Plot of Acoustic Data (Vrms) vs Transport Rate (Sediment Flux).
Figure 2.7: RMS versus Sediment Flux (Individual Rocks over Gravel Bed)
CHAPTER 3

METHODS AND MATERIALS

3.1 LOCATION OF FIELD SITE

The newly developed field system was formally tested in Halfmoon Creek, a stream located approximately 10 miles southwest of Leadville, Colorado. This site was selected from a group of five potential river systems based upon snowpack reports and variety of sampling sites within walking distance of each other (Bunte, 2015). The testing site was positioned 0.5 miles downstream of a USGS gauging station that provided discharge data. To evaluate the efficacy of acoustic measurement, the system was tested alongside bedload traps operated by physical samplers from Colorado State University (CSU). For specific geological analysis of Halfmoon Creek, please see (Bunte, 2015).

3.2 PHYSICAL SAMPLERS

The physical samplers who assisted in data collection developed sampling traps years prior to monitor bedload transport (Bunte et al., 2007). These were constructed from square-shaped aluminum with fish netting sewn around, which produces a net for catching sediment particles. The netting could be changed depending on expected particle sizes (Bunte et al., 2007). These traps were set on top of aluminum plates that were staked into the bed of the river. The number of traps is typically dependent on the size of the river.
On Halfmoon Creek, six bedload traps were set equidistant apart across the horizontal axis of the stream. The traps consisted of a rectangular aluminum frame with an attached net for collection of sediment and straps to hold the traps to the stakes. The frame had a 0.3 by 0.2 m opening with a 0.1 m depth. The net used a 3.6 mm mesh and was about 1.6 m long (Bunte, 2015). When installed, the mouth of the traps faced upstream with the net traveling with the flow downstream (Figure 3.1).

Figure 3.1: Bedload traps deployed on Halfmoon Creek.
3.2.1 PHYSICAL SAMPLING PROCESS

As collection began, the nets were tied by a person traversing across the channel, tying each net with a length of rope. This sequence took about 2 minutes and is included in the collection time. The traps would then accumulate sediment over the allotted sampling time. As time ended, a person would again enter the water and manually empty the traps into a 5-gallon bucket, designated to each trap. This process required two people, one to gather the nets and one to empty sediment into buckets.

To process the physical samples, the contents of the buckets were cleaned of organic material such as leaves, twigs, mud, etc. Smaller sized sediment was thoroughly cleaned and placed in Ziploc bags with detailed classifications written on the bag (date, sampling time, and corresponding bucket number). Particles deemed too large for transport were weighed and measurements were stored in a journal.

3.3 FIELD-DEPLOYABLE ACOUSTIC SYSTEM

The field-deployable acoustic monitoring system is comprised of devices and structures that have reduced the size of the passive acoustic system and increased its field capability. Data is collected and stored on the Zoom-H4DN, a two-channel hand-held recorder. The two channels allow for two hydrophones to record data simultaneously. For data storage, a standard SD card was inserted on the side of the recorder. The recorder and accompanying power source for the hydrophones (two 9-volt batteries set in parallel) were housed in a weatherproof Pelican™ case (Figure 3.2). The inside of the case was lined with foam that was cut to form around the inside contents. This case can be left out for monitoring in inclement weather, protecting the recorder from harsh elements. The recorder was powered by two AA batteries
under the back panel, but they only allow for a non-stop recording length of 3-4 hours. For the system to be left operating over an extended period of time, it was powered from a 12-volt battery. A set of power cables easily attached the system to the larger power source. The system features much more durable hydrophones as well. The hydrophones used were the HTI-96-MIN-Exportable models from High Tech, Inc. (High Tech, 2016). They are encased in a stronger material, increasing impact resistance. The cables were also better prepared for a field environment, with sensitive wires surrounded by more durable and flexible cables. Connectors were installed on the cables to provide a secure attachment to the recorder through the Pelican case. Inside the case, the connectors were wired to plugs that secured into the recorder’s input jacks.
3.3.1 INSTALLATION OF SYSTEM

To properly monitor the movement of coarse gravel, the hydrophones were placed in a stable position on the river bed. Currently, this type of installation process requires the hydrophones be staked into the bed by a post that provided a stable base. A t-post typically provides the best option of ease and stability. However, using only the t-post can create problems in vibration noise and consistent height placement of the hydrophone above the bed. An updated installation strategy was tested along with the new hydrophone system on Halfmoon Creek. Still using the t-posts as a base, ribbed plastic piping was tightly slid over the post to
provide a circular cross-section. This enables better control of the hydrophone’s height above the bed and reduces external noise and vibration from the structure itself.

Another concern in deployable sediment monitoring is the diverging of the river flow around the systems, which creates flow noise that can negatively affect transport data. To reduce this interference, a fairing, typically used for small aircraft, was introduced to the structure design. The fairing possessed a teardrop shape, best fitted to reducing drag and interference of flow noise around the hydrophone. For securing the hydrophone to the post, a holding structure was constructed to support the hydrophone about 12” from the post to further reduce external noise from the structure.

The structure was made from general PVC piping glued together to provide a strong hold. A 2” by 1-1/2” PVC tee secured the structure to the post and provided simplistic installation and removal. To reduce external noise from the post, the hydrophone was funneled through the tee into 1-1/2” piping of about 7” in length ending with a standard 1-1/2” connector. At the end of the connector, the hydrophone was placed into a newly constructed hydrodynamic housing that increased impact resistance against moving gravel and debris (see Figure 3.3 and Appendix A). Made from a polyurethane material, the housing was shown to not impede the hydrophone’s ability to monitor the sound of sediment movement while also protecting from random debris and large particle impacts. The hydrophone was placed 12 inches from the base of the post, facing downstream to reduce impact from upstream debris and further reduce drag.
To receive the benefits of the fairing and hydrophone together, some modifications were made to the fairing incorporating the hydrophones holding structure to provide drag reduction. Measured cuts show in Figure 3.4 were made to the fairing to provide a secure fit around the PVC tee that would rest on the post (Figures 3.5 and 3.6). The cuts were based on a desired height of the hydrophone above the bed. The hydrophone was placed about 4-1/2” above the river bed to decrease the chance of sediment accumulating under the hydrophone structure and adversely affecting sediment movement. Height changes may be made in the future to accommodate varying riverbeds. Once the hydrophone and fairing were placed on the post with the plastic piping, the cable connecting the hydrophone to the recorder was passed from the hydrophone up the inside of the fairing. The cord was raised above the river and stretched to the bank, connecting to the weatherproof casing. Alternatively, a trench could be made to bury the cables along a channel. This could possibly prevent the cables in the air being destroyed by
storms, falling branches, etc. However, for recent field tests, the length of deployment did not necessitate burying the cables and digging into the bed, which could have provided a change in bed material movement and disrupted the data collection for physical sampling. For permanent deployments when the hydrophone no longer requires calibration, burying the cables may provide a better option. While on Halfmoon Creek, two hydrophones and associated structures were deployed in the river channel. The width of the channel (bank-to-bank) was determined and divided into thirds. A hydrophone was installed at the 1/3 and 2/3 mark of the full length across the channel. Two hydrophones were deployed (Figure 3.7) in order to provide comprehensive data collection across the channel and the best chance for comparison to physical sampling. Deploying more hydrophones through this cross-section may have increased the opportunities for debris to gather around the fairings and inhibit clear data recordings. Full site deployment is shown in Figure 3.8.
Figure 3.4: Cuts made in to fairing to stabilize PVC structure and hydrophone.

Figure 3.5: Fairing and hydrophone structure together.
Figure 3.6: Installation of hydrophone with fairing structure.
Figure 3.7: Hydrophones fully installed in stream.
3.4 DAILY PROCEDURE

Before beginning data collection, the settings on the Zoom recorder were verified to ensure consistency in the data. A sampling rate of 48,000 Hz was chosen as the standard setting. This was signified in the corner of the device’s screen by the display “48/16”. The Zoom possessed a two-channel input, allowing the recorder to collect from two hydrophones simultaneously. Once the two-channel input was selected, a file and folder were chosen from the SD card to store data. Once the settings on the recorder were verified, files were started simply by pressing the RECORD button.

Since the project worked in conjunction with physical samplers on Halfmoon Creek, a guideline was established to create the most beneficial relationship between physical and
surrogate data collection. When the bedload traps were ready for collection, a file was started immediately as the first trap’s net was tied. As the last trap was tied (trap 6), the file was digitally marked, while continuing to record. This action dictated the time taken to tie traps and to rule out any possible fluctuations in data that may have resulted from activity in the stream. After this, the system was left to run for the determined sampling time. When using equipment that captures sediment, time of collection is typically determined by the filling capacity of the traps. While on Halfmoon Creek, collection of sediment generally completed every hour. When the traps were ready for collection, the file was stopped during the first trap’s sediment emptying. Immediately following the first trap being re-tied, a new file was started to coincide with the new sampling rotation. These steps were repeated for each collection throughout the day. When all bedload trap collecting was finished for the day, the system was left to run overnight. Before leaving the system, the recorder was linked to a 12-volt battery, and a new SD card was inserted to register data overnight. This process was repeated for each day of sampling.
CHAPTER 4

RESULTS AND DISCUSSION

4.1 DATA ANALYSIS

Early lab experiments were designed to develop a surrogate system to measure bed load transport rates and focused on analyzing the relationship between coarse sediment transport and acoustic energy. Based on (Thorne, 1985) as well as previous lab experiments explained in Chapter 2, the RMS of the acoustic field data was calculated and compared with bed load flux. The RMS was used to compare with physical measurements at specific time periods to validate surrogate measures in bed load transport monitoring. Acoustic data was processed using MATLAB® software to calculate the RMS values associated with acoustic energy (see Appendix E for MATLAB® Code). RMS was calculated over 15 minute intervals (900 seconds) for the entire length of each audio file. This data was plotted against the sampling time (in days) and shown in Figure 4.1. Another interesting analysis was the plot of acoustic RMS and flow discharge vs time because a relationship between these two values can reveal the presence of flow noise, a major inhibitor of acoustic sediment monitoring (Figure 4.2).

4.2 DATA RESULTS

Figure 4.1 displays the RMS voltage of the acoustic data with physical sediment data in g/s. One noted anomaly occurring in the acoustic data appears around the day of May 28th, 2015.
(1). After inspection of the audio data, the outlier seems to result from a collision with a hydrophone resulting in a spike of acoustic intensity. Unfortunately, the graph depicts a poor relationship between surrogate and physical sediment monitoring, most likely resulting from environmental factors in the stream. Physical measurements remained at or close to zero for all of May 2015; however, acoustic intensity began an upward trend at about May 28th. The graph further illustrates that the measurements did follow an equal path (2). After June 10th, 2015, sediment content started to rise dramatically relative to the May measurements. Simultaneously, acoustic data declined to an equilibrium at about 0.1 V_{rms} for five days as sediment fluctuated from between 1-7 g/s to almost 15 g/s (3). This decline in V_{rms} at (3) is peculiar because of the noticeable increase in water discharge during this time interval, which should have increased sediment transport (observed from field notes in Appendix B). The absence of a promising trend between acoustic and physical data could be explained by environmental factors, most notably flow noise. One way this idea was evaluated was through the following comparison of the acoustic RMS against flow discharge from the stream.
Figure 4.1: Acoustic RMS (Vrms) & Sediment Flux (g/s) of physical samples vs time (Days).
Flow discharge was recorded by the USGS gauging station upstream of the sampling site. This information was accessible through the USGS water data website (USGS, 2016). This data allowed comparisons between acoustic RMS and stream discharge in cubic feet per second (cfs) shown in Figure 4.2. This plot shows a much more promising trend (1) and exhibits a likely cause for the incompatibility between RMS and sediment flux previously demonstrated in Figure 4.1. The analogous representation between RMS and discharge indicates a strong presence from flow noise around the hydrophone, suggesting that water velocity may translate to measureable acoustic energy. This could interfere with the energy produced by gravel collisions on the riverbed.

While Figure 4.2 displays a strong relationship between discharge and RMS, there are a few interesting trend deviations. In the time depicted by (2) there is a strong disparity between Vrms and discharge. The audio data was analyzed between these days (about June 10-June 15) and there was no noticeable drop in recording ability from the hydrophone. Thus, this disparity most likely resulted from environmental factors. Assessment from physical samplers in the field suggested the drastic change may have occurred due to increasing amounts of detritus (branches, logs, sand, and clay) moving downstream, picked up by rising water velocity. Journal notes kept by the physical samplers indicate that during this time, large amounts of debris accrued on and around the stakes of the bedload traps overnight. This suggests the hydrophones may have been entrenched closer to the creek bed by sand and small debris that would have prevented the hydrophones from hearing sediment collisions. This is further denoted by Figure 4.3, which shows the relationship between discharge and sediment flux. During this same time interval, the bed load traps received a large amount of sediment around June 12\textsuperscript{th} and 13\textsuperscript{th} and then accumulated little until June 15\textsuperscript{th}. This would coincide with a massive amount of sediment
moving downstream, much accruing in the bed load traps while other amounts along with sand and clay that may have deposited around the hydrophones and traps. This would have impeded future measurements until the discharge increased enough to transport the entrenched sediment.
Figure 4.2: Acoustic RMS (Vrms) & Discharge (cfs) provided by USGS against time (Days).
Figure 4.3: Discharge (cfs) & Sediment Flux (g/s) from physical samplers vs. time (Date).

Similar discrepancy in data to acoustic measurements
CHAPTER 5

CONCLUSIONS

5.1 SUMMARY OF WORK

Following a series of lab experiments that found a promising relationship between RMS and sediment flux, a field-deployable system for the acoustic monitoring of coarse bed load flux was assembled and tested on Halfmoon Creek near Leadville, CO. As this relationship showed promise under known conditions, the next step was field deployment. Tests were performed in conjunction with bed load traps providing a physical sampling method to correlate acoustic RMS with sediment flux. Bed load traps were deployed throughout the stream bed and were more physically intensive than the acoustic field system tested here. For example, six bedload traps were required to encompass the entire stream bed; whereas, only two hydrophone systems were used. In addition, more manpower was necessary for sediment collection of the physical samplers and needed continual monitoring. The acoustic field system could be installed and run continuously without intense physical involvement.

Once field trials were completed, the acoustic intensity data was processed through MATLAB® to compute RMS. The RMS data was compared with both total bed load flux and flow discharge to assess its efficacy in determining sediment transport rates. Analysis of RMS with sediment flux revealed an inadequate trend and indicated an issue occurring in the field experiment. When comparing the RMS and water discharge, this issue is perceived as flow noise, suggesting turbulence produced from high discharge exhibits stronger acoustic energy
than gravel impacts. Therefore, while the acoustic field system tested here provided easy deployment and continuous monitoring, further research is needed to identify the effects of flow noise and possible solutions to limit the impact this has on passive listening hydrophones.

5.2 FUTURE WORK

Future work developing an acoustic hydrophone system in the field should investigate two phases: field deployment and analysis. Because this study found flow noise to be a confounding factor of acoustic energy during hydrophone recording, a possible solution would be to redesign the field-deployment structure. An effort was made to reduce the interference of flow noise by employing a streamlined structure housing the hydrophone. Unfortunately, this particular attempt was futile as flow noise obscured the sediment transport measurements. Also, the current scale of the structure allowed for debris to occasionally collect on the fairings. However, this may be unavoidable in the deployment of a stream-designed device. An alternative would be to reduce the impact of flow noise during data processing. This may be done by using high and low pass frequency filters once the frequency of flow noise is distinguished from bed load impacts.
LIST OF REFERENCES


LIST OF APPENDICES
APPENDIX A: HYDROPHONE CASING
A hydrodynamic casing was designed by John D. Heffington, Research and Development Engineer employed at the National Center for Physical Acoustics (NCPA). The casing was made with a polyurethane material and shaped to fit into a 1-1/2” PVC connector for attaching to an installation structure on Halfmoon Creek. This casing had three major design requirements:

1. Have a streamlined shape to minimize obstruction in the flow.
2. Material used must not have an impedance that affects the hydrophone’s ability to hear particle impacts.
3. Must protect the hydrophone from direct impacts by debris and fast moving coarse gravel.

Figure A-1: Exploded view of hydrophone casing.
Figure A-2: Closed view of hydrophone casing.

Figure A-3: Hydrophone casing in two pieces with HTI hydrophone.
Figure A-4: HTI hydrophone being inserted into casing.
APPENDIX B: DAILY JOURNAL ENTRIES FROM FIELD DEPLOYMENT
Halfmoon Creek Journal Entries:

**Wednesday, May 20, 2015**

First day hydrophones installed
   Started collecting data at 10:54 A.M. MST (Mountain Standard Time)
   Bedload traps not set yet
   Hydrophones just below water surface
   Flow is low

At 11:27 A.M.
   Mark 1-Kristin walking on bridge
   Mark 2-Kurt walking on bridge
   Mark 3-Both walking on bridge (these were done on purpose to see if they showed up on
   data)
   Mark 4-Kurt enters water to set traps
   Mark 5-First trap set, but bag is still open(kurt is talking, not sure if that will show up)
   Mark 6-All traps in, but no bags closed
   Mark 7-First bag closed
   Mark 8-Last bag closed
   Mark 9-Everyone off bridge and out of water (about 11:42 A.M.)
   Mark 10-Kristin on bridge, setting up buckets

At 12:51 P.M.
   Mark 11-Kurt enters water to begin emptying traps
   Mark 12-Trap 1 out
   Mark 13-Everyone off bridge
First File Stopped-12:56 P.M.

New File Began-12:56 P.M.
   Mark 1-Kurt in water using BL-82 trap
   Mark 2-Kurt out of water
   Mark 3-People on bridge (removing traps)
   Mark 4-Everyone off bridge
   Mark 5-Kurt on bridge
Second File Stopped-1:17 P.M.

**Thursday, May 21, 2015**

File Started: 9:55 A.M.
   Mark 1-Kurt in water using BL-82 trap
File ended

File Started: 11:31 A.M.
   Mark 1-Kurt setting bedload traps
   Mark 2-Everyone out of water and off bridges
Mark 3-Emptying traps
File Stopped: batteries went dead at 1:28 P.M.

File Started: 1:31 P.M.
Mark 1-traps set
File Ended: 5:04 P.M.

Observations:
Flow is same as before (low)

Fairings have about an extra foot of length
Could cut to lengthen cord

Possibly build stand or post to put box on

Chain to tree from distance

**Wednesday, May 27, 2015**

10:28 A.M. MDT
Stage is 0.3 feet (not expecting much to happen)

SD Card: Daniel

File Started: 10:31 A.M.-As first trap is tied

Mark 1-Last tap tied
Mark 2-Everyone off bridge
Mark 3-Kurt on bridge
Mark 4-Will on bridge
Mark 5-Kristin on bridge
Mark 6-On bridge
Mark 7-Kurt in water-unloading traps
Mark 8-Traps back in water
Mark 9-Kurt off bridge
Mark 10-Kurt in water (12:29 P.M.)

File Stopped: traps empty (12:35 P.M.)

Arrived at the site at 10:28 A.M. MDT
Flow Stage- 0.3'

SD Card: Daniel

File Started: 10:31 A.M. (first bag tied)
Mark 1- Last bag tied  
Mark 2- Everyone off bridge  
Mark 3- Kurt on bridge  
Mark 4- Will on bridge  
Mark 5- Kristin on bridge  
Mark 6- On bridge  
Mark 7- Kurt in water unloading traps  
Mark 8- traps back in  
Mark 9- Kurt off bridge  
Mark 10- Kurt in water (12:29 P.M.)

Files stopped, traps empty (12:35 P.M.)  
Stage is low, expected to pick up later.

Left system running until about 4 P.M. collecting data

New SD Card: Bennett  
File started 12:43 P.M.

Stage is still low expected to pick up

Left system running until 4 P.M. (Started at 12:43 P.M.)

SD Card: Bennett

*System made two separate files on its own

Checked at 4:12 P.M. (Stage is the same)  
Mark 1-Kristin on the bridge  
Kurt emptying

File Stopped

File Started 4:13 P.M. (number 150527002)-As first trap is set  
Mark 1-Everyone out of water

File Stopped-As Kurt is emptying traps (5:15 P.M.)

New file started for overnight:  
SD Card: Lila

Thursday May 28, 2015

Overnight File stopped: 9:50 A.M.  
SD Card: Lila

Stage at 0.35'
Day SD Card: Rhi

File started: 10:14 A.M.
   First trap tied and collecting
   Mark 1- Out of water/off bridge
   Mark 2- Emptying traps
   Mark 3- off bridge
File Stopped: 12:16 P.M.
   traps being emptied

Leaving on for a time
File started: 12:17 P.M.
   First trap set
   Mark 1- off bridge

5:04 P.M.
File: 150528-001
   Mark 1- emptying traps
   Mark 2- off bridge

Check time 1:51:22

Friday, May 29, 2015

Overnight file stopped
   Kurt using BL84
SD Card: Black (5 files from overnight)

Stage at about 0.41'

Day SD Card: Lila

File started: 10:11 A.M. (150528-000)
   First trap set
   Mark 1- trap 6 set
   Mark 2- off bridge
File stopped: 11:12 A.M. (emptying traps)
*Had to change batteries

New File: 11:22 A.M. (150529-000)
   Still emptying traps
   Mark 1- trap 6 set
   Mark 2- off bridge
File Stopped: 12:21 P.M.

New File (150529-001)
Mark 1- trap 6 set
Mark 2- off bridge
Will leave out until 5 P.M.

Saturday, May 30, 2015

Overnight file stopped: 4:30 P.M.
SD Card: Rhi

Day SD Card: Bennett
Hoping to catch rising limb of stage. Stage did not rise this morning

File Started: 5:00 P.M. (150530-000)
  First trap set
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 6:00 P.M.
  First trap collected

File Started: 6:00 P.M.
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 6:59 P.M.

File Started: 6:59 P.M.
  Mark 1- trap 6 set
  Mark 2- off bridge
  Mark 3- emptying traps
File Stopped: 8:04 P.M.
  Trap 6 empty

Overnight File: SD Card- Daniel
Started: 8:36 P.M.

Sunday, May 31, 2015

Overnight File Stopped: 9:25 A.M.
SD Card: Daniel

Stage: 0.48'

Day SD Card: Lila

File Started: 9:55 A.M. (150530-000)
  First Trap Set
  Mark 1- trap 6 set
Mark 2- off bridge
File Stopped: 10:56 A.M. (first trap collected)

File Started: 10:57 A.M.
  First Trap
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 12:00 noon

File Started: 12:00 noon
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped:

File Started:
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped:

File Started:
  Mark 1- trap 6 set (3:34 P.M.)
  Mark 2- off bridge (3:40 P.M.)
File Stopped: 4:31 P.M.

File Started: 4:31 P.M.
  first trap pulled
  mark 1- trap 6 set
  mark 2- off bridge
  mark 3- nothing
File Stopped: 5:34 P.M.

File Started: 5:34 P.M.
  first trap pulled
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 6:34 P.M.

File Started: 6:34 P.M.
  first trap pulled
  Mark 1- trap 6 set
  Mark 2- off bridge
  Mark 3- trap 1 emptied
File Stopped: 7:39 P.M. (trap 6 emptied)

Overnight:
  SD Card: Bennett
Monday, June 01, 2015

Overnight File Stopped: 9:32 AM
SD Card: Bennett (5 Files)

Day SD Card: Rhi
File Started: 10:01 AM
  First trap set
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 11:02 AM

File Started: 11:02 AM
  Mark 1- trap 6 set
  Mark 2- off bridge
File Stopped: 12:01 PM

File Started: 12:01 PM
  M1- trap 6 set
  M2- off bridge
File Stopped: 1:00 PM

File Started: 1:01 PM (trap 1 emptied)
  M1- trap 6 set
  M2- off bridge

Arrived back a little late: 4:29 PM
  Kurt & Kristin pulled traps btw 4-4:05 PM
  Most likely on file (150601-002)
  next pull is at 5 PM
File Stopped at 5 PM (150601-003)

File Started: 5 PM (150601-004)
  M1- trap 6 set
  M2- off bridge
File Stopped: 6:00 PM

File Started: 6:00 PM (005)
  M1- trap 6 set
  M2- off bridge
File Stopped: 7:00 PM

File Started: 7:00 PM
  M1- trap 6 set
M2- off bridge
File Stopped: 7:31 PM

File Started: 7:31 PM
M1- trap 6 set
M2- off bridge
M3- btw 2&3, had to get in water to fix hydrophone
M4- K&K in water, reset traps 1,2,&3
M5- Out of water, off bridge (7:46 PM)
File Stopped: 8:02 PM

Overnight File:
SD Card: Black (folder 03)

Tuesday, June 02, 2015

Overnight File Stopped: 9:44 AM
SD Card: Black

Day SD Card: Daniel

Stage: 0.90'

File Started: 10:20 AM
M1- trap 6 set
M2- off bridge
M3- Kurt in water to retrieve branch
M4- Kristin checking plates, kurt emptying traps
File Stopped: 11:29 AM (first trap pulled)

File Started: 11:29 AM (150602-000)
M1- trap 6 set
M2- out of water & off bridge
File Stopped: 12:29 PM

File Started: 12:29 PM (150602-001)
M1- trap 6 set
M2- off bridge
File Stopped: 1:31 PM

File Started: 1:31 PM
M1- trap 6 set
M2- off bridge
Returned to site at 3:58 PM
traps were emptied starting at 3:50 PM
trap 6 emptied: 3:58 PM
File Stopped: 3:58 PM

File Started: 3:58 PM  
next empty will be at 4:50 PM  
File Stopped: 4:52 PM

File Started: 4:52 PM  
M1- trap 6 set  
M2- off bridge  
People in water 5:25 to 5:36 PM heightening bridge  
File Stopped: 5:49 PM

File Started: 5:50 PM  
M1- trap 6 set  
M2- off bridge  
M3- emptying trap 1  
File Stopped: 6:36 PM

Overnight File:  
SD Card: Lila  
Started: 7:15 PM

**Wednesday, June 03, 2015**

Overnight File Stopped: 9:38 AM  
SD Card: Lila (5 files)

Kurt and Kristin were in water 9:30 AM  
Fairing 1 is a little misaligned (flow noise may be more noticeable)

Day SD Card: Bennett(Folder 03)

File Started: 10:21 AM  
*Check to see if any Marks on file*  
File Stopped: 11:14 AM  
First Pull at 11:14 AM  
M1- trap 6 set and off bridge  
Retrieving stick 11:43 AM-11:45 AM  
File Stopped: 12:13 PM

File Started: 12:13 PM  
M1- trap 6 set  
M2- off bridge  
File Stopped: 1:12 PM

File Started: 1:12 PM
trap 6 set at 12:18 PM

**Thursday, June 4, 2015**

Overnight File:
Stopped: 9:15 A.M.
SD Card-Rhi

9:40 A.M.-I was in water fixing hydrophone, last 11 minutes probably aren't good

Day SD Card-Daniel
Stage: 0.98 ft.

(1) File Started: 10:26 A.M.
   M1- Trap 6 tied
   M2- off bridge
   M3- Kristin in water looking at traps
   M4- off bridge again
File Stopped: 11:26 A.M.

(2) File Started: 11:26 A.M.(150604-000)
   M1- Trap 6 tied
   M2- off bridge
There is a stick on channel 1 fairing
Retrieving stick-11:33-11:39 A.M.
File Stopped: 12:30 P.M.

(3) File Started: 12:31 P.M.(150604-001)
   M1- Trap 6 set
   M2- Off bridge
File Stopped: 1:30 P.M.

(4) File Started: 1:30 P.M. (Stage-0.96 ft)
   M1- Trap 6 set
   M2- off bridge (Kurt still in water looking at traps)

2:04 P.M.- Kristin is introducing tracer rocks into the creek, they will most likely come through the site within two days. Released 46 feet upstream of traps and hydrophones.
File Stopped: 2:31 P.M.

(5) File Started: 2:31 P.M.
   M1- Trap 6 tied
   M2- Off bridge
File Stopped: 3:31 P.M.
Friday, June 05, 2015

*Man seen fishing at 9:30 A.M. when we arrived. Not sure how long he has been here.

Overnight file stopped: 9:38 A.M.
SD Card: Lila (folder 02)-5 files

Day SD Card: Bennett (folder 02)

(1) File Started: 10:26 A.M.(150604-000)
   M1- 6th trap tied
   M2- off bridge
File Stopped: 11:26 A.M.

(2) File Started: 11:26 A.M.(150605-000)
   Stage(1.02 ft)
   M1- trap 6 set
   M2- off bridge
File Stopped: 12:30 P.M.

(3) File Started: 12:31 P.M.(150605-001)
   M1- trap 6 set
   M2- off bridge
File Stopped: 1:31 P.M.
(4) File Started: 1:31 P.M. (150605-002)
Stage (1.0 ft)
   M1- trap 6 set
   M2- off bridge
File Stopped: 2:30 P.M.

(5) File Started: 2:30 P.M. (150605-003)
   M1- trap 6 set
   M2- off bridge
File Stopped: 3:31 P.M.

(6) File Started: 3:31 P.M.
   M1- trap 6 set
   M2- off bridge
File Stopped: 4:31 P.M.

(7) File Started: 4:31 P.M.
   M1- trap 6 set
   M2- off bridge
File Stopped: 5:30 P.M.
Stage (1.04 ft)

(8) File Started: 5:30 P.M. (150605-006)
   M1- trap 6 set
   M2- off bridge
File Stopped: 6:35 P.M.

Overnight File:
SD Card- Lila

Saturday, June 06, 2015

Kurt getting branch: 9:08-9:10 AM

Overnight file Stopped: 9:12 AM
SD Card: Lila (5 files)

Day SD Card: Daniel (folder 03)
Stage: 1.04'

(1) File Started: 9:40 AM (1st trap tied) (150605-000)
   M1- trap 6 set
   M2- off bridge
File Stopped: 10:39 AM
(2) File Started: 10:39 AM (150605-001)
  M1- trap 6 set
  M2- off bridge
  M3- nothing
File Stopped: 11:39 AM

(3) File Started: 11:39 AM (150606-000)
  M1- trap 6 set
  M2- off bridge
File Stopped: 12:39 PM

(4) File Started: 12:39 PM (150606-001)
  M1- trap 6 set
  M2- off bridge
  M3- 1st trap collected
File Stopped: 1:43 PM
  Last pull of day
  Last trap collected

Overnight File:
SD Card: Black (folder 04)
File Started: N/A

**Sunday, June 07, 2015**

Kurt in water: 9:52 AM

SD Card: Black

Day SD Card: Black (folder 03)

(1) File Started: 10:17 AM (150606-000)
  M1- trap 6 set
  M2- off bridge
File Stopped: 11:18 AM

(2) File Started: 11:18 AM (150607-000)
  M1- trap 6 set
  M2- off bridge
  *Second trap is uneven (not collecting)
  M3- Kurt in water
  *Stick near fairing*
  M4- 2nd trap fixed & collecting
File Stopped: 12:21 PM

(3) File Started: 12:22 PM
M1- trap 6 set
M2- off bridge
File Stopped: 1:18 PM

(4) File Started: 1:19 PM (150607-002)
M1- trap 6 set
M2- off bridge
M3- 1st trap collected
Last collection of the day
File Stopped: 2:28 PM

Overnight:
SD Card: Daniel (folder 01)
File Started: 3:04 PM

Monday, June 08, 2015

Overnight File Stopped: 9:41 AM
SD Card: Daniel

Day SD Card: Rhi (folder 01)

(1) File Started: 10:12 AM (150607-000)
M1- trap 6 set
M2- off bridge
File Stopped: 11:12 AM

(2) File Started: 11:12 AM (150608-000)
M1- trap 5 set
M2- off bridge
*Kristin wants to try only emptying trap 6 once a day. not very much
transport through it.
File Stopped: 12:12 PM

(3) File Started: 12:12 PM (150608-001)
(Stage: 1.06')
M1- trap 5 set
*Kurt staying in water to look for shaft collar
M2- off bridge
File Stopped: 1:12 PM

(4) File Started: 1:12 PM
M1- trap 5 set
M2- off bridge
File Stopped: 2:12 PM
(5) File Started: 2:13 PM (150608-003)
    M1- trap 5 set
    M2- off bridge
File Stopped: 3:13 PM

(6) File Started: 3:13 PM (150608-004)
    M1- trap 5 set
    M2- off bridge
File Stopped: 4:12 PM

(7) File Started: 4:12 PM (150608-005)
    M1- trap 5 set
    M2- off bridge
File Stopped: 5:12 PM

(8) File Started: 5:13 PM (150608-006) Stage: 1.18'
    M1- trap 5 set
    *Stick jammed around trap 3, removed & bag tied right
       before M2
    *Kurt & Kristin get in water to make velocity measurements
       btw. 5:30 & 5:40 PM
File Stopped: 6:1?

Overnight File:
SD Card: Bennett (folder 01)

Tuesday, June 09, 2015

Overnight File:
SD Card: Bennett (5 Files)
File Stopped: 9:19 AM

Day SD Card: Lila (folder 01)

(1) File Started: 10:33 AM (150608-000)
    M1- all traps set
    except (3)
    Btw. M2 & M3 Kurt replacing stake in trap 3
File Stopped: 11:35 AM

(2) File started: 11:35 AM (150609-000)
    M1- trap 5 set
    M2- off bridge
File Stopped: 12:31 PM

(3) File Started: 12:31 PM (150609-001)
M1- trap 5 set
M2- off bridge
File Stopped: 1:32 PM

(4) File Started: 1:32 PM (150609-002)
M1- trap 5 set
M2- off bridge
File Stopped: 2:30 PM

(5) File Started: 2:30 PM (150609-003)
M1- trap 5 set
M2- off bridge
File Stopped: 3:31 PM

(6) File Started: 3:31 PM (150609-004)
M1- trap 5 set
M2- off bridge
File Stopped: 4:28 PM

(7) File Started: 4:28 PM (150609-005)
M1- trap 5 set
M2- off bridge
File Stopped: 5:27 PM

(8) File Stopped: 5:27 PM
M1- trap 5 set
M2- off bridge
M3- first trap collected
File Stopped: 6:35 PM

Overnight File:
SD Card: Rhi (folder 01)
Started: 7:12 PM

Wednesday, June 10, 2015

Overnight File:
Stopped: 8:21 AM
Rhi (folder 01): 5 files

SD Card: Bennett (folder 02)

(1) File Started: 9:07 AM
M1- All set
File Stopped: 10:07 AM
(2) File Started: 10:07 AM
   M1- trap 6 set
   M2- off bridge
File Stopped: 11:08 AM

(3) File Started: 11:08 AM
   *Kurt & Kristin fixing trap two during collection
   M1- trap 5 set
   M2- off bridge
File Stopped: 12:17 PM

(4) File Started: 12:17 PM
   M1- trap 5 set
   M2- off bridge
File Stopped: 1:22 PM

(5) File Started: 1:23 PM
   M1- trap 5 set
   M2- off bridge
File Stopped: 2:22 PM

   *Rain 1:30-2:15 PM

(6) File Started: 2:22 PM
   M1- trap 5 set
   M2- off bridge
File Stopped: 3:38 PM

(7) File Started: 3:38 PM
   M1- trap 5 set
   M2- off bridge
File Stopped: 4:33 PM

(8) File Started: 4:33 PM
   M1- trap 5 set
   M2- off bridge
   M3- first trap collected
File Stopped: 5:45 PM

Overnight File:
SD Card: Black (folder 03)

Thursday, June 11, 2015

1st Site: SD Card-Black (folder 03)
(1) File Started: 9:24 A.M.
   M1- 2nd trap tied
   M2- off bridge
*Only traps 1&2 sampling
File Stopped: 10:25 A.M.

(2) File Started: 10:25 A.M.(150611-000)
   M1- 2nd trap tied
   M2- off bridge
File Stopped: 11:23 A.M.

(3) File Started: 11:23 A.M.
Stage(1.38 ft)
   M1- 2nd trap tied
   M2- off bridge
*traps 1&2 have been developing gaps btw. plates & traps
File Stopped: 12:24 P.M.

(4) File Started: 12:24 P.M.
   M1- 2nd trap tied
   M2- off bridge
File Stopped: 1:30 P.M.

(5) File Started: 1:30 P.M.
   M1- 2nd trap tied
   M2- Rob is pulling traps
   M3- nothing
Rob done: 1:50 P.M.
File Stopped: 2:36 P.M.

(6) File Started: 2:36 P.M.
   M1- 2nd trap tied
   M2- off bridge
   M3- 1st trap emptied
   M4- nothing
File Stopped: 3:45 P.M.

Overnight File:
SD Card: Lila (folder 01)
Started: 4:02 P.M.

Friday, June 12, 2015

Overnight File:
Stopped: 10:03 A.M.
SD Card: Lila (folder 01)
*branches on both fairings & on trap plates

Day SD Card: Rhi (folder 01)

(1) File Started: 10:31 A.M.
   M1- 1st trap tied
   M2- out of water
File Stopped: 11:28 A.M.

(2) File Started: 11:28 A.M.
   M1- 1st trap tied
   M2- out of water
File Stopped: 12:27 P.M.

(3) File Started: 1:23 P.M.
   M1- 1 minute in all traps set
   M2- Kurt in water behind bridge
   M3- Kurt out
File Stopped: 1:52 P.M.

(4) File Started: 1:52 P.M.
   M1- 2nd trap tied
   M2- out of water
*1st trap is off balance, only sampling from 2nd trap
Cancel file (4)

(5) File Started: 2:22 P.M.(150612-004)
   M1- 2nd trap tied
   M2- out of water
File Stopped: 3:23 P.M.

Saturday, June 13, 2015

Overnight File:
SD Card: Bennett
Stopped: 1:14 P.M.

Day SD Card: Rhi (folder 01)
*Channel 1 has a branch on it, fairing is turned

(1) File Started: 2:09 P.M.
   M1- 2nd trap tied
   M2- out of water
File Stopped: 3:13 P.M.
(2) File Started: 3:13 P.M.
*Plates off on trap 2
Kristin and Kurt taking traps out
Branch on fairing 1
    M1- Kristin and Kurt out
File Stopped: 4:09 P.M.

Overnight File:
SD Card: Bennett(Folder 02)
Started: 4:10 P.M.

Sunday, June 14, 2015

Overnight File:
Stopped: 9:43 A.M.
SD Card: Rhi (folder 02)

Day SD Card: Bennett (folder 02)

(1) File Started: 10:10 A.M.
*Traps 1&2 are not sampling
File Stopped: 11:13 A.M.

(2) File Started: 11:13 A.M.
File Stopped: 11:25 A.M.
*Kristin and Kurt working on traps
*Traps put back in
(3) File Started: 11:44 A.M.
    M1- 2nd trap tied
    M2- out of water
    M3- Kurt in water observing taps
File Stopped: 1:21 P.M.

(4) File Started: 1:21 P.M.
    M1- 2nd trap tied
    M2- out of water
File Stopped: 2:22 P.M.

(5) File Started: 2:22 P.M.
    M1- 2nd trap tied
    M2- out of water
File Stopped: 3:22 P.M.

(6) File Started: 3:22 P.M.
    M1- 2nd trap tied
M2- out of water
File Stopped: 4:22 P.M.

(7) File Started: 4:22 P.M.
   M1- 2nd trap tied
   M2- out of water
File Stopped: 4:55 P.M. (Now sampling every 30 minutes)

(8) File Started: 4:55 P.M.
   M1- 2nd trap set
   M2- out of water
   M3- 1st trap emptied
File Stopped: 5:42 P.M.

Overnight File:
SD Card: Bennett(folder 03)
File Started: 5:46 P.M.

**Monday, June 15, 2015**

Overnight File:
SD Card: Bennett (folder 03)
*Clamp came off battery during night (2 Files)*

Day SD Card: Daniel (folder 03)

(1) File Started: 10:26 AM
   M1- 2nd bag tied
   M2- out
File Stopped: 11:26 AM

(2) File Started: 11:26 AM
   M1- 2nd bag tied
   M2- out
File Stopped: 12:26 PM

(3) File Started: 12:26 PM
   M1- 2nd bag tied
   M2- out
File Stopped: 1:28 PM

(4) File Started: 1:28 PM
   M1- 2nd bag tied
   M2- out
File Stopped: 2:26 PM
(5) File Started: 2:26 PM  
M1- 2nd bag tied  
M2- out  
File Stopped: 3:26 PM (Stage Height- 1.31')

(6) File Started: 3:26 PM  
M1- 2nd bag tied  
M2- out  
File Stopped: 4:27 PM

(7) File Started: 4:27 PM (Stage- 1.41')  
M1- 2nd bag tied  
M2- out  
M3- 1st trap emptied  
File Stopped: 5:04 PM- 2nd bag emptied  
Last sample- sample NO GOOD  
SD Card- Daniel(7 Files)

Overnight File:  
SD Card: Lila(folder 02)  
File Started: 5:45 PM

Note: Kristin mentioned trap limit may be around 1.40' in stage  
*stage height stick is only a measuring stick for this purpose

**Tuesday, June 16, 2015**

Overnight File:  
SD Card: Lila(folder 02)  
Stopped: 10:59 A.M.

*Fairing 1 knocked around about 90 degrees

Day SD Card: Black(folder 02)  
File Started: 11:18 A.M.  
*No traps in(flow is too high)

File Stopped: June 17th at 9:18 A.M.(Last file)
APPENDIX C: PHOTO DOCUMENTATION OF PHYSICAL SAMPLING
Figure C-1: Collecting sediments. Net hoisted from stream.
Figure C-2: Sediment is emptied into corresponding bucket.

Figure C-3: Net is retied to begin another hour of sampling.
Figure C-4: Sediment samples are cleaned of organic material.

Figure C-5: Sediment is cleaned and placed in Ziploc bags for future weighing.
APPENDIX D: PHYSICAL METHOD DATA FROM FIELD DEPLOYMENT
Sample time with sediment flux measurements provided by Dr. Kristin Bunte.

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APPENDIX E: MATLAB® CODE USED TO PROCESS ACOUSTIC DATA
Acoustic Data Processing Script:
Filename: Halfmoon.m

```matlab
clear all
%Step 1: Read filenames and start times
%Load Files for Analysis
load ('LeadvilleFiles.mat');
%files{i} = length(FileName);
%Load Start Times and Convert to Numbers
load ('HalfmoonTimes3.mat');
%Adjust time to accommodate 11 hours (12 hours off minus 1 hour for time change
Adj_Hours = Convert_Date(:,1) + (11/24);

%Sseconds in an hour
s=3600;
num_chunks = 0;
k = 0;
%Set number of seconds for each chunk-900 seconds
chunk_time = 900;

%Step 3: Probe files to obtain lengths
for i = 1:length(FileName);
    %Acquire audio information from files: samples and sampling frequency
    file_info = audioinfo(FileName{i});
    file_samples = file_info.TotalSamples;
    fs = file_info.SampleRate;
    chunk_samples = fs*chunk_time;

    %Step 4: Determine the number of chunks in each file
    num_chunks_file(i) = floor(file_samples/chunk_samples);
    %Round up or down or add if statements to keep more data

    chunk_start(1) = Adj_Hours(i);
    chunk_day = chunk_time/(24*3600);
    day = (fs*24*3600);
    for j=1:num_chunks_file(i);
        k = k+1;
        %Step 5: Setting Start and End points and times
        start_point(1)=1;
        %start_point(1)= Num(i);
        end_point(1)=1+chunk_samples-1;

    %Step 7: Analyze Chunk
```
[data, fs] = audioread(FileName{i}, [start_point(j) end_point(j)]);  
total_rms(k) = rms(data(:,1));

% Step 6: Open Chunk
start_point(j+1) = end_point(j)+1;
end_point(j+1) = start_point(j+1)+chunk_samples-1;

chunk_avg(k) = chunk_start(j)+(chunk_day/2);

if j < num_chunks_file(i)
chunk_start(j+1) = chunk_start(j)+chunk_day+(1/(day));
else
    %datestr(chunk_start)
    clear chunk_start
end

% Align RMS data to correct time in Zoom
%      time_chunk(j)
%
%      zoom_start(j+1) = end_point(j)+1;
%      zoom_timestamp(j+1) = start_time(j) + time_chunk(j)/(3600*24);

end

% Step 8: Clear Data
clear data
disp(i)
end
VITA

Jarrod Bullen was born in Slidell, Louisiana, as the second of two children to Robert and Angela Bullen. He began attending the University of Mississippi (UM) in 2009 and was awarded his Bachelor of Science degree in Mechanical Engineering in August 2013. Immediately following he began working at the National Center for Physical Acoustics (NCPA) on the UM campus. Under the supervision of Dr. Jim Chambers, he began work as an assistant research and development engineer before beginning his graduate career in January 2014 where he continued to work under Dr. Chambers’ advisement.

During this time, Jarrod assisted in and conducted many experiments both within the NCPA and at field sites located in Mississippi, Arizona, and Colorado. He also worked in summer STEM camps at the University of Mississippi to educate middle and high school students in the engineering sciences. His thesis research focused on applying acoustics to sediment transport monitoring with the primary project consisting of testing a new field-deployable system to monitor bed load transport and comparing data with other scientists’ physical measurements. Upon receiving his Masters of Science in Mechanical Engineering, Jarrod plans to continue working in the engineering field and endeavors to continue Dr. Chambers’ passion of inspiring and educating young people about the importance and fascination of engineering.