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Signal Processing From Bed Load Impact Plates Instrumented with an Accelerometer

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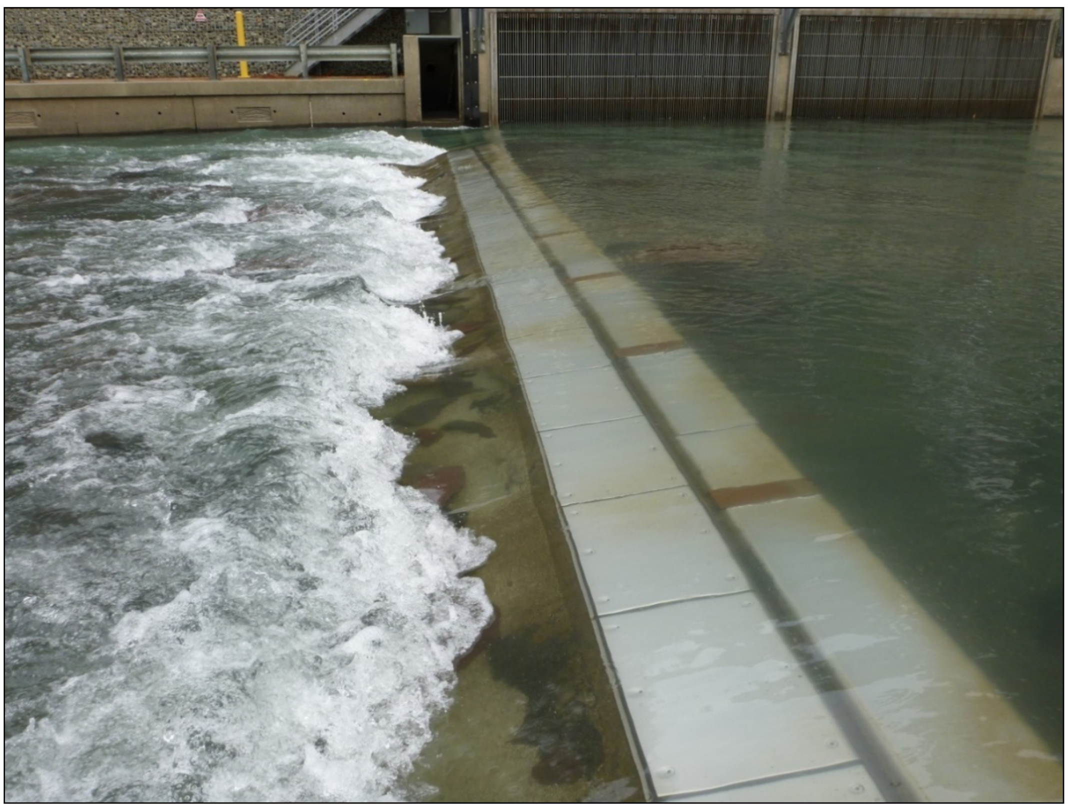

View of the bed load impact plates looking toward the surface water intake structure on river right.

U.S. Department of the Interior

Bureau of Reclamation **September 2015**

Research and Development Office

Mission Statements

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BUREAU OF RECLAMATION
Technical Service Center, Denver, Colorado
Sedimentation and River Hydraulics Group, 86-68240

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Signal Processing From Bedload Impact Plates Instrumented with an Accelerometer

Elwha Surrogate Bed Load Measurement Project, WA
PN Region

9/28/15

Prepared: Robert C. Hilldale, M.S., P.E. Date
Hydraulic Engineer, Sedimentation and River Hydraulics Group, 86-6824000

9/29/15

Prepared: Wayne O. Carpenter Date
Senior R&D Engineer, National Center for Physical Acoustics, U. Mississippi, Oxford, MS

9/30/15

Prepared: Dr. Daniel Wren, Date
Research Hydraulic Engineer, Agricultural Research Service, Oxford, MS

9/30/2015

Peer Review: (David Varyu), M.S.,P.E. Date
Hydraulic Engineer, Sedimentation and River Hydraulics Group 86-68240

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Elwha Bed Load Impact Plate Team

Principal Investigator:

Robert C. Hilldale (Hydraulic Engineer, Bureau of Reclamation, TSC, Denver, CO)

Collaborators:

Dr. James Chambers (Associate Dean for Research and Graduate Studies & Associate Prof. of Mechanical Engineering Senior Scientist, National Center for Physical Acoustics, Department of Mechanical Engineering, U. Mississippi, Oxford, MS)

Brian Carpenter (Senior R&D Engineer, National Center for Physical Acoustics, U. Mississippi, Oxford, MS)

Bradley Goodwiller (R&D Engineer, Department of Mechanical Engineering, U. Mississippi, Oxford, MS)

Dr. Roger Kuhnle (Research Hydraulic Engineer, Agricultural Research Service, Oxford, MS)

Dr. Daniel Wren (Research Hydraulic Engineer, Agricultural Research Service, Oxford, MS)

Dr. J.R. Rigby (Research Hydrologist, Agricultural Research Service, Oxford, MS)

John Cox (Hydrologist, Agricultural Research Service, Oxford, MS)

Introduction

The Elwha Impact Plate System

The Elwha Impact Plate System was installed in 2008 and 2009 at river kilometer (RK) 5, which is downstream of the former Elwha Dam (RK7.9) and Glines Canyon Dam (RK 21.6). The purpose of the impact plate system is to measure coarse bed load during and after the removal of Elwha and Glines Canyon Dams. Concurrent removal of both dams began in September 2011. Elwha Dam removal was completed in April 2012 and the removal of Glines Canyon Dam was completed in August 2014. As of 2013, the Elwha River restoration project involved the largest dam removal project in U.S. history (U.S. Department of the Interior, 1996; Duda et al. 2011).

The Elwha impact plate system consists of 72 instrumented stainless steel plates spanning approximately 38 m of channel width. Of the 72 plates, 46 are instrumented with a GS-20DX geophone in a marsh case (Geospace Technologies, Houston, Texas) and 26 are instrumented with a CMCP-1100 accelerometer (STI Vibration Monitoring, League City, Texas). Each sensor is mounted to the underside of the plate in the geometric center using threads drilled and tapped into the plate. As bed material contacts an impact plate, the deformation of the plate causes the instrument (geophone or accelerometer) to induce a voltage that is sent to the computer system. The geophones provide a measurement of the number of impulses occurring per minute above a specified threshold, leading to a correlation with sediment flux. In contrast, the accelerometers measure the time-varying vertical motion of the plate due to impact from gravel particles. The time-varying signal can be analyzed by using various frequency domain methods. Such information may prove useful to observe particle size distribution, resulting from the dependence of the signal response to particle mass. Signals from each device are collected and managed on three computers, using specifically designed software. The instrumentation system is designed such that the failure of one computer does not result in the loss of instrumentation along a continuous segment of the cross section. Wires from each sensor are routed through a conduit residing within the steel channel beneath the plates to a weatherproof computer cabinet atop the surface-water diversion structure on river right (Figure 1). The computers can be accessed remotely for data access and control of data acquisition parameters (Hilldale et al. 2014).

Each impact plate is 15.9 mm thick, measures 349 mm in the longitudinal (flow) direction, and 517 mm in the lateral (cross stream) dimension. These dimensions differ slightly from the Swiss plate system (Rickenmann et al. 2012). The Elwha impact plates are mounted with the short sides adjacent to one another, such that the entire cross section is instrumented. These plates are mounted to a steel channel that is fixed to the downstream side of the concrete weir. The steel channel houses the wiring and provides physical support for each plate, which is acoustically isolated with a rubber membrane. The small gap between adjacent plates and the steel housing is filled with silicone to prevent infilling with sand and small gravel that could also transmit vibration between plates (Hilldale et al. 2014).

Figure 1: Photograph of the computer cabinet housing the Elwha impact plate system computers. In 2015 a fourth computer was installed and a bad computer was replaced.

An engineered riffle has been constructed immediately downstream of the impact plates to facilitate fish passage across the instrumented diversion weir. The riffle is 200-m long with a slope of 0.015. The impact plates are at the crest of the riffle, preventing significant aggradation (Hilldale et al. 2014).

Geophone impact plate calibration

The on-going calibration process began in November 2012 following a large release of sediment from Glines Canyon Dam. Through 2014, several trips were made to the Elwha River to measure bed load in an effort to obtain an in-situ calibration of the geophone impact plates. A specific methodology was devised for using physical bed load measurements to calibrate the impact plates, whereby bed load is measured at a single station for a 30 minute period, collecting approximately nine individual samples in that time period. These bed load samples are used to develop a unit transport rate for that location in the channel. This methodology was utilized in May 2013 and April 2014 and will be used in any subsequent calibration efforts.

The calibration results of the Elwha impact plate system are detailed in Hilldale et al. (2015) and Hilldale (2015) (Appendix A and Appendix B, respectively). At this time, only geophone impact plates are calibrated (Figure 2). This is considered a preliminary calibration due to the relatively low number of measurement points (16) and a Y-intercept greater than zero. Additional calibration is planned for 2016 for geophone and accelerometer plates.

It is important to note that the impact plates instrumented with an accelerometer have not yet been calibrated. Work in 2015 and 2016 will provide information regarding an appropriate algorithm for measuring mass per unit time and particle size class with the accelerometer plates. Future in-situ calibration of the accelerometer plates is planned.

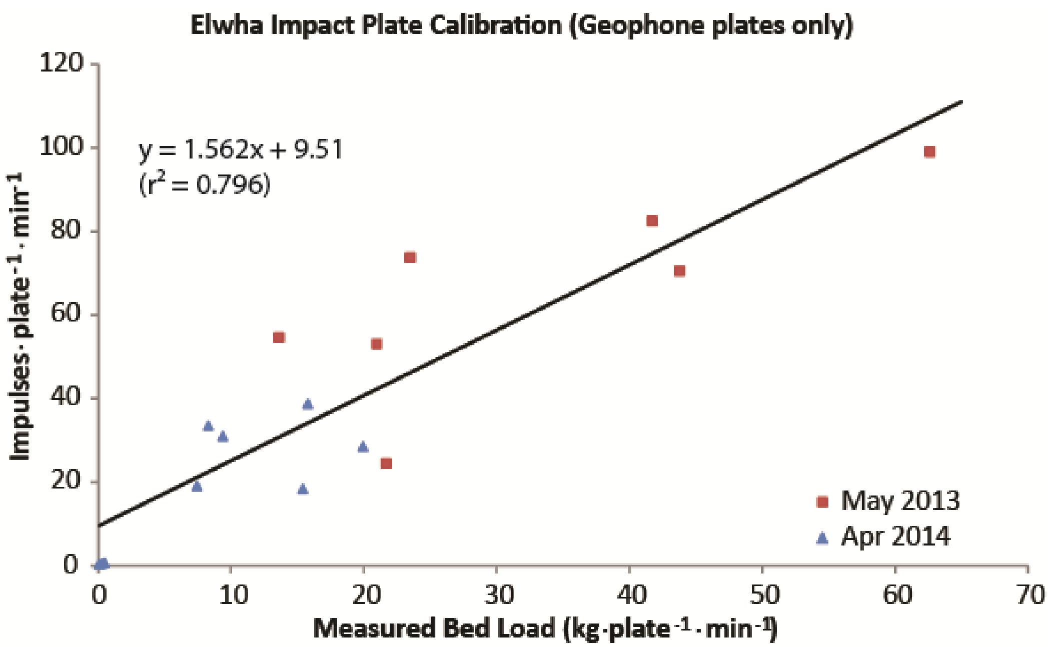

Figure 2: Plot of geophone plate calibration for the Elwha impact plate system.

Utilizing the Impact Plate System for Bed Load Measurement

Using the preliminary calibration, bed load was estimated using the impact plate system on the Elwha River for the first two years of dam removal (Sep. 2011 – Sep. 2013, Magirl et al 2015, Appendix C). A future effort documenting sediment transport over the first four years during and after dam removal is planned. This information is critical for better understanding the impact of a large release of sediment following dam removal.

Proposed Research for FY 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 to determine the appropriate signal processing from the accelerometers so bed load can be measured on the Elwha using those plates instrumented with accelerometers, in addition to the geophone measurement. Accelerometers possess a response across a broad frequency range, providing a very different signal response when compared to the geophone. Using impact plates instrumented with accelerometers to measure bed load may provide a more robust measurement through improved signal thresholding and measurement of the energy imparted to the bed by moving particles. There is also potential to obtain some information regarding particle size using accelerometers. Answers to the following questions will be investigated: What frequency range is appropriate for processing particle impacts to measure bed load? Using a fast Fourier transform to process the accelerometer signal, what sample time and frequency is appropriate? What are the necessary post-processing algorithms to be incorporated into the existing LabVIEW code? What is the minimum size detection for impact plates instrumented with an accelerometer? What is the appropriate field calibration for impact plates instrumented with an accelerometer?

The following excerpt is also from the proposal for 2015 funding and addresses the planned research strategy.

> The primary investigation will be performed in a flume at the National Sediment Lab belonging to the Agricultural Research Service in Oxford, MS. A two-plate prototype impact system instrumented with accelerometers has already been constructed in Reclamation's fabrication facility. The prototype exactly matches the Elwha River impact plate system already installed. The prototype two-plate system will be mounted at the downstream end of a flume where water and coarse sediment will be continually recirculated and measured at the downstream end. The sediment distribution will match field scale very well, with a maximum diameter of 64 mm. By placing the prototype impact plates at the downstream end of the flume, signals generated by the contact of gravel with the plates can be directly correlated with bed load transport. The plan is to obtain a flume calibration for plates instrumented with accelerometers. Once accomplished, the resulting algorithm will be incorporated into the existing LabVIEW code on the Elwha system. At that time a field calibration can be obtained using bed load measured with adjacent geophone plates, which currently have a preliminary calibration and will have a more complete calibration by the end of this year.

Research Progress in 2015

Maintenance and testing of the Elwha impact plate system - methodology

On-site maintenance and testing of the impact plate system took place from August 31 through September 4, 2015. One of the three system computers had failed and was replaced. A fourth system computer was added, which will provide redundancy in the event of another computer failure. Additionally, this computer can provide detailed post processing capabilities in the future if on-site data processing is to be performed. Grounding of the data acquisition boards was checked and repaired as needed.

The software on all four computers was updated to reflect the latest algorithms for data collection using the accelerometer plates. More details on accelerometer plates are included later in this report.

Various testing of both accelerometer and geophone plates took place. River discharge was low enough to allow wading across the weir for most of its length. Testing of individual plates took place by releasing gravel particles by hand upstream of the impact plate and allowing the flow velocity to carry these particles across the plate. These tests were one minute in duration. Much, but not all, of the plate tests used sieved particles in three size classes: 4 – 8 mm, 8 – 16 mm, and 16 – 32 mm (Figure 3). Geophone plates were tested for minimum particle size detection and to gain information about voltage thresholds. Accelerometer plates were tested for aid in determination of particle size.

Figure 3: Photographs of 4-8 mm gravel (left) and 8-16 mm gravel (right).

A primary goal for on-site maintenance of the impact plate system was to replace some of the inoperable sensors on the impact plates. However, on Saturday, August 29th and 30th a large, rare storm for August resulted in river discharge peaking over 1,500 ft^3/s. The river flow did not fall quickly enough to allow proper access to the impact plates for removal and replacement of individual sensors.

Flume research with accelerometer plates - methodology

From March 29 – April 4, 2015 flume experiments were conducted at the Agricultural Research Service's National Sedimentation Lab in Oxford, MS. These experiments were performed with the cooperation of the Agricultural Research Service (Drs. Kuhnle and Wren). Brian Carpenter and Bradley Goodwiller (U. of Mississippi) assisted with data acquisition and signal processing. A field scale prototype impact plate system was constructed using two plates, both instrumented with accelerometers (Figure 4). The purpose of these experiments was to determine the best means for utilizing the information in the accelerometer signal generated by the gravel impacts to measure bed load transport (mass/time) and possibly obtain sediment size information.

The flume recirculates sediment and water, and gravel is recirculated separately using a special non-contact centrifugal pump. Sediment and water are returned at the upstream end of the flume. Users are able to control flow speed. Bed load transport is measured continuously with a series of weigh pans immediately downstream of the impact plates. Two weigh pans are used for this measurement. Flow and sediment are split at the location of the seam between the impact plates, providing the ability to measure sediment flux for each of the two plates in the impact system (Figure 4).

During testing, sediment was retained in a specially designed basket (Figure 5) to retain particles 4 mm and larger. The retained sediment was dried, weighed, and sieved into 0.5 φ size classes. The accelerometer data was collected in a wave file format and sampled at 50 kHz. Due to the ease of processing, the wave file recording format has become the new standard in which our raw data will be collected in the laboratory and field settings.

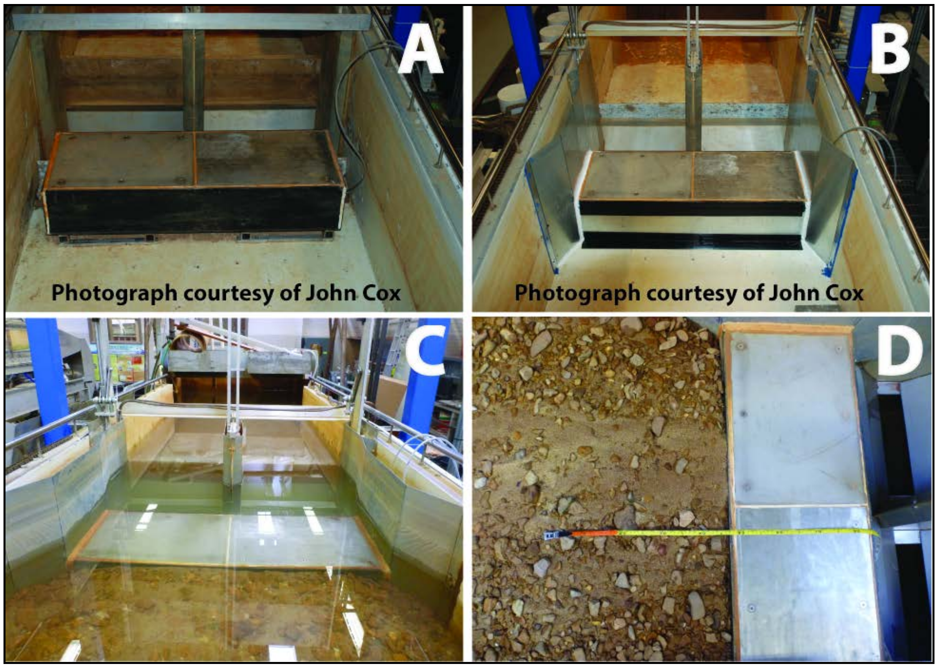

Figure 4: Photographs of the downstream end of the flume, two-plate prototype impact system, and weigh pan system. Flow and sediment are split in the middle of the flume coincident with the seam between the impact plates. A – Impact plate prototype as shipped from Reclamation. B – Impact plate prototype with flanges and sealing to insure all sediment crosses the impact plates. C – Impact plate system with still water in the flume. D – Impact plate system and bed material. Photographs A, B, and C are looking downstream. Photograph D flow is left to right.

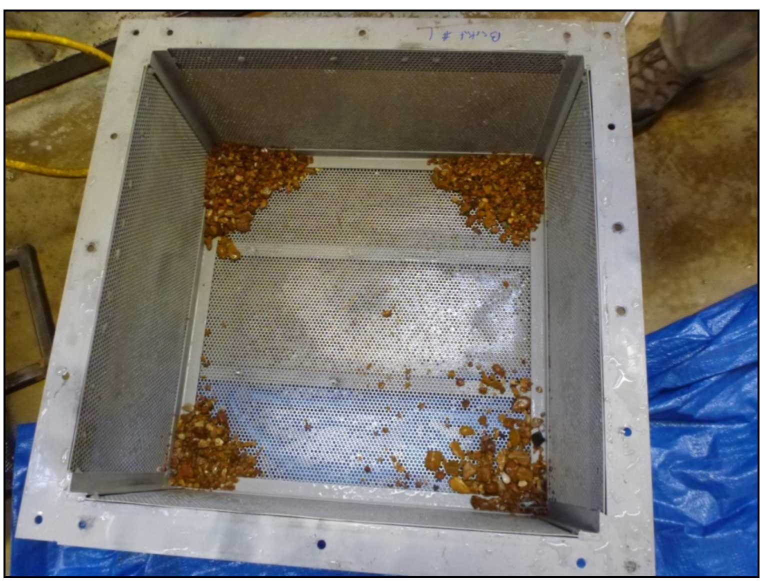

Figure 5: Specially designed basket made to retain sediment passed through the weigh pan system. Round holes in the basket have a 4 mm diameter.

Flume tests were typically run for 10 minutes, although a few tests had a duration of 15 minutes. During the testing periods impulses were recorded on both accelerometers and sediment was retained from one of the two halves of the weigh pan system. The flume was operated over a range of flow rates (Table 1).

Table 1: Flow parameters for the various flow rates over which tests were conducted. Data provided by Dr. Roger Kuhnle (ARS).

Flow Rate	Mean Flow Depth	Mean Flow Velocity	Mean Water Surface Slope
(m^3/s)	(m)	(m/s)	(---)
0.222	0.287	0.643	0.00157
0.265	0.284	0.765	0.00191
0.285	0.284	0.823	0.00222
0.322	0.284	0.930	0.00252
0.368	0.312	0.967	0.00106
0.397	0.328	0.993	0.00138

Findings from 2015 on-site testing

Geophone plate testing

The testing of the geophone plates confirmed that particles less than 16 mm cannot be detected. It was also revealed that it is likely possible, and may be beneficial, to reduce the voltage threshold to +/- 1 V. It was also discovered that there is a significant voltage off-set on several of the channels, both for geophones as well as accelerometers. Some channels also have electrical noise in the signals. Because it is happening on both geophones as well as accelerometers it is presumed that the problem lies somewhere other than with the sensor itself.

Accelerometer plate testing

There were three primary purposes for testing the accelerometer plates in-situ: to examine the noise level compared to what was seen in the lab; to test the sensitivity of the accelerometer plates and determine a minimum detectable particle size; and to collect data with known particle sizes passing over the plates to assist the lab effort to determine particle size.

Similarly to geophone tests, it was determined that the voltage threshold could be reduced to +/- 1 V to gain resolution. The noise level on most of the accelerometer channels is ± 8 mV. Some accelerometer channels are less, as little as 4 mV. During the lab experiments the noise level was about ± 4 mV. It is uncertain at this time why the channels in the Elwha system are noisier than what is being seen in the lab. One thing we're considering is the interference from other sensor wires. There are 72 channels in the Elwha system and only two channels in the lab set-up.

The accelerometer plates are able to detect particles in the 8-16 mm size range, with signals clearly above the noise. It remains uncertain whether or not the 4-8 mm size class is detectable. There were signals above the noise for the 4-8 mm size class but it remains to be seen whether or not the signal amplitude is far enough above the noise for the Hilbert transform to detect. Even if we cannot detect the 4-8 mm size class, the accelerometers provide a large benefit by being able to detect the 8-16 mm size class, still a significant improvement over the geophones.

Accelerometer signal data were collected for various known particle size classes (4 – 8. 8 – 16, and 16 – 32 mm). These files were one minute long and were sampled at 20 kHz, the highest sampling rate permitted on the Elwha River deployed system. These data will assist in creating algorithms to potentially determine the size class of particles striking the plate.

Findings from 2015 Flume Research

The accelerometer data collected from the flume test were analyzed and compared to the mass collected during the same time period. The Hilbert transform, with 100 point smoothing, was used to provide an indicator function for peak finding. The cumulative maximum of the absolute value of sections of data, identified by the transformed data being above a threshold, was used to represent the cumulative energy of particles striking the plate over time. Figure 6 shows a segment of data with threshold, transformed data, and section indicators. Figure 7 shows preliminary results from the data analysis; the high r^2 for the relationship between total mass and total peak voltage is encouraging. One important requirement, revealed during this work, is for a methodology for calibrating individual plates. We also have the particle size distribution for the particles trapped during each data collection period. A goal of the continued work is to consider the distribution of particle sizes to the distribution of peak heights, in the hopes that an estimate of particle size distribution can made from accelerometer data.

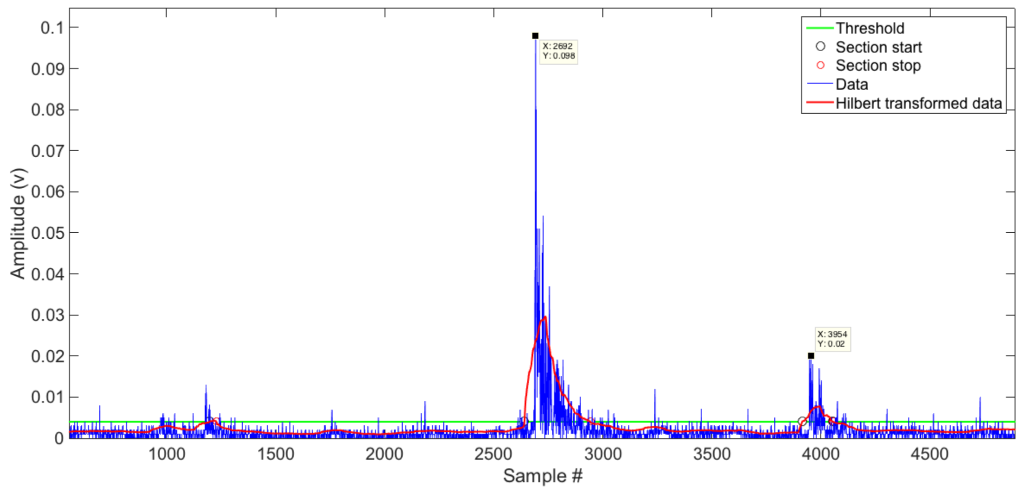

Figure 6: Segment of accelerometer data showing basic data analysis methodology.

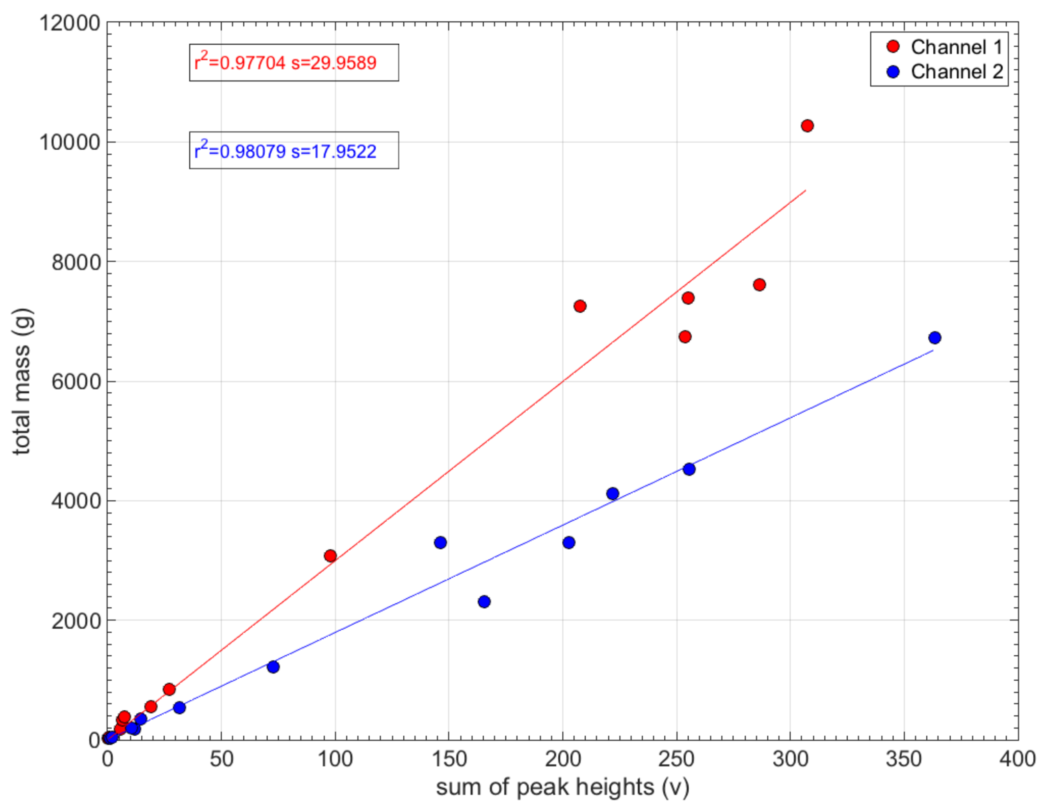

Figure 7: Calibration plot for accelerometers, based particle mass collected in the trap. Note that Channel 1 is about 70% less sensitive than Channel 2, demonstrating the need for individual plate/accelerometer calibrations.

Conclusions and Next Steps

Signal processing techniques than can yield estimates of total mass transported are being developed in collaboration with the USDA-ARS-NSL. It has been shown that the sum of peak voltages is well correlated with the total mass of particles passing over the plates. Future work will focus on refining the data processing techniques and incorporating estimates of particle size distribution based on peak height distribution.

Additional troubleshooting work is needed, with the goal of implementing appropriate data processing techniques on the Elwha impact plate data. A simple calibration method than can be performed in the field on each plate is essential if accurate estimates of load are to be made.

The on-site plate testing in 2015 revealed several plates, housing both geophones and accelerometers, which possess excessive voltage off-sets. Additionally, some other plates were found to have excessive noise. Both of these problems preclude use of that channel (sensor) in the measurement of bed load. These issues will require troubleshooting and repair. Additionally, some instruments have failed and will need to be replaced. Eight geophones and 4 accelerometers were purchased in 2015 with the intent of replacing bad sensors during the September 2015 trip. However, a large storm the day before we left for the trip caused a significant rise in river flow and prevented us from accomplishing this task. Flow depth and velocity were too high to allow the removal of the impact plates and replacement of the sensor. We will again attempt to replace these sensors in FY 2016, although this was not budgeted in the FY 2016 proposal because it was assumed that these instruments would be replaced in 2015.

Additional bed load measurements are planned for May 2016 during spring runoff. The delta sediment released from the dams during and after removal continues to approach equilibrium, and as such, the mobility of coarse sediment occurs less frequently. Greater river discharges are now required to mobilize coarse bed material, making it more difficult to plan a trip for bed load measurement during a time when bed material is mobile. The snow pack in the Olympic mountains and spring weather patterns will determine our window of opportunity for bed load measurements.

As information becomes available from the signal processing (NCPA/ARS collaboration) it will be incorporated into the software for the data collection system. It is expected that the accelerometer plates will come on-line some time prior to the spring calibration effort. We are striving to develop a methodology for not only quantifying the sediment mass, but the size distribution of the sediment crossing the weir.

Likewise, information gained regarding further calibration of the geophone impact plates will result in changes to post processing for continuous bed load measurements, improving the accuracy of the measurement.

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