Calibration of Bed Load Impact Sensors for Surrogate Sediment Measurement

Research and Development Office
Science and Technology Program
Close-Out Report SRH-2014-32
Project ID Number 0115

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Mission Statements

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

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

PEER REVIEW DOCUMENTATION

Project and Document Information

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Review Certification

Peer Reviewer: I have reviewed the assigned items/sections(s) noted for the above document and believe them to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer Mike Soto (Signature)

Date reviewed 9/11/2014

Executive Summary

Problem Statement

A series of bed load impact sensors has been fabricated and installed on the Elwha River in WA (Science and Technology proj. # 6499). The purpose of the bed load impact sensors is to continuously measure bed load passing the site, which is downstream of the Elwha and Glines Canyon Dams. Concurrent deconstruction of these dams began in September, 2011. Elwha and Glines Canyon Dams are completely removed. The bed load measurements will be part of the sediment monitoring program being conducted by the Bureau of Reclamation during and after dam deconstruction. Implementation of the bed load impact system was accomplished in May, 2011, when we completed writing software for sampling and processing the data and PCs, and related hardware were installed (Science and Technology proj. # 9562). A field calibration is needed to make the system fully operational. The calibration will require the collection of physical bed load samples deploying a pressure difference bed load sampler (Elwha or Toutle River-2) from a raft. These data need to be collected over a range of discharges to provide a valid calibration. Two research questions will be addressed by this research. 1.) Are bed load impact sensors a viable surrogate method for continuously measuring bed load transport? 2.) What process is required to completely calibrate the bed load impact system?

Research Activities

Five separate bed load measurement campaigns took place during the research period. The purpose of which was to obtain a correlation between bed load measured using classical means (deploying a pressure difference sampler) and signals provided by the bed load impact system. This correlation has provided an algorithm, from which bed load can be quantified with the surrogate impact plate system. Although many bed load samples were collected, only data from May 2013 and April 2014 are suitable for use toward obtaining a system calibration. In November 2012 no coarse bed load was being transported, thus there was no useable data obtained. During the March measurement campaign it was discovered that a new protocol is required in order to properly compare bed load measurements and signals from the impact plates. May 2013 measurements resulted in the first useable bed load measurements using the new protocol. Bed load data were collected in June 2013, however the impact plate system malfunctioned during the measurements. Bed load measurements were again collected in April 2014 using the new protocol, rounding out a preliminary calibration.

Research Results

Thus far a preliminary calibration has been obtained. Using these results two manuscripts have been written and submitted to professional journals (*Journal of Hydraulic Engineering* and *Geomorphology*).

The preliminary calibration for the impact plates is obtained only for the 46 impact plates instrumented with a geophone. The remaining 26 impact plates are instrumented with an accelerometer. The signal processing for the accelerometer plates has yet to be determined. Measuring bed load with an accelerometer rather than a geophone provides a more robust signal across a broad frequency range. It is expected that the information gained with an accelerometer will provide more detailed information about the particles in transport, primarily the mode of transport (rolling, sliding, or saltating) and particle size.

Next Steps

A two-plate impact system has been fabricated by Reclamation and shipped to the Agricultural Research Service's National Sediment Laboratory in Oxford, MS. There it will be placed in a water and gravel recirculating flume so that the signal processing can take place to provide appropriate algorithms with which to measure bed load. Once those algorithms have been obtained an on-site calibration will be required.

Automation of the post-processing of surrogate data needs to accomplished. It is necessary to wait for a calibration of at least the geophone the impact plates prior to automating the process with specifically written software (MatLab). Automation of the post processing for those plates with accelerometers will also need to take place once a calibration of these plates is obtained.

Work needs to be done regarding remote access from my desktop. I am currently accessing the remote computers using means outside the DOI network. Additionally, data from the impact plates should be published and available on the internet for researchers to access. The data could be placed on Reclamation's Hydromet site. I've been waiting for cooperation from Reclamation's IT services for over a year to accomplish these tasks and no progress has been made.

Abstract

A series of 72 steel impact plates have been installed across the Elwha River, Washington for the purpose of continuously measuring coarse bed load. Each plate is instrumented with either a geophone (46 plates) or an accelerometer (26 plates). The plates are mounted on a concrete diversion weir, which is downstream of both Elwha and Glines Canyon Dams. The primary purpose of the installation is to monitor and quantify bed load movement during and after the removal of both dams. A secondary benefit is the knowledge gained regarding the movement of coarse bed load in a moderately sized gravel bed river using continuous measurements, as opposed to infrequent, discrete measurements using classical means. From 2012 - 2014 work was performed toward calibration of a bed load impact plate system installed on the Elwha River, Washington. Physical bed load measurements were made using classical means by deploying a TR-2 bed load sampler from a raft. Signals from the impact plate system were concurrently monitored in order to obtain a correlation between the two values. This report will describe the protocol developed for system calibration, preliminary calibration parameters, and future needs for complete system operation.

Main Report

The main report consists of a PowerPoint presentation and abstracts for two draft manuscripts submitted to professional journals (Appendix A and B).

RECLAMATION

Managing Water in the West

Calibration of Bed Load Impact Sensors for Surrogate Sediment Measurement

Report # SRH-2013-32

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U.S. Department of the Interior
Bureau of Reclamation

September 2014

Acknowledgements

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- The authors would also like to acknowledge Dane Cheek for fabricating the impact plate system.

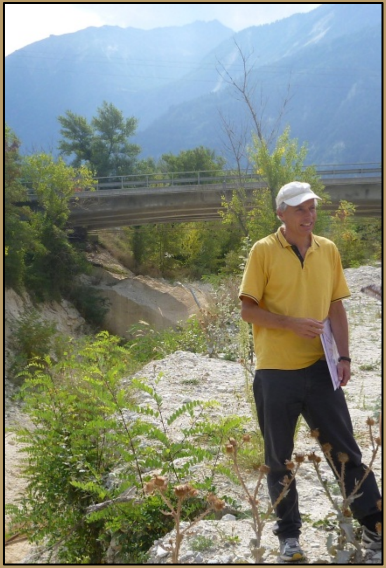
Acknowledgements

- The authors would like to acknowledge the tremendous effort put forth by Graham Matthews and Associates, collecting bed load measurements on five separate trips to the Elwha River.

TR-2 Pressure Difference Sampler

Acknowledgements

- The authors would like to thank Dr. Dieter Rickenmann (Swiss Federal Institute) for his guidance during the design and implementation of the Elwha impact plate system. His support is much appreciated.



Impact plate system on the Erlenbach, Alptal, Switzerland, one of the Swiss impact plate systems after which the Elwha impact plate system is patterned.

Introduction

- The Elwha River bed load impact plate system was installed in 2008 and 2009 downstream of Elwha and Glines Canyon Dams
  - Patterned after the Swiss impact plate system (Banziger and Burch 1990, Rickenmann and McArdell 2007)
- The purpose of the installation is to measure coarse bed load downstream of the dams during and after their removal.

2008 installation of plates 1-12

2009 installation of plates 13-72

Introduction

- The removal of Elwha and Glines Canyon dams began in September 2011
  - Concurrent removal strategy with periodic notching planned to last for 2 to 3 years
  - Elwha Dam removal was completed April 2012
  - Glines Canyon Dam removal was completed August 2014

Elwha Dam, constructed 1913

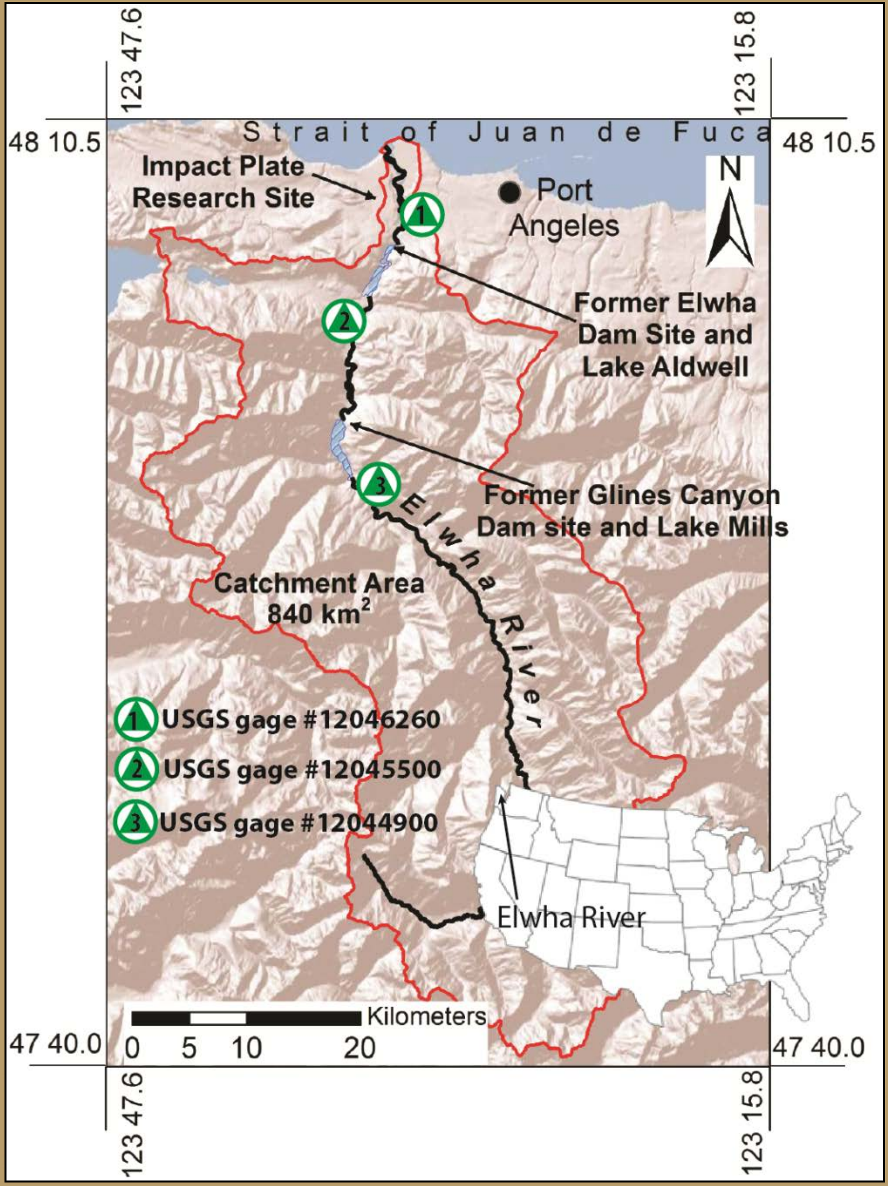
Glines Canyon Dam, constructed 1927

As of 2013, the Elwha River restoration project involved the largest dam-removal project in U.S. history in terms of dam size, sediment volume released, and complexity of the removal strategy (U.S. Department of the Interior, 1996; Duda et al. 2011)

RECLAMATION

Introduction

- The Elwha River flows north from the Olymic Mountains and terminates at the Strait of Juan de Fuca
- The impact plate system is installed at river kilometer 5
- Elwha Dam was located at river kilometer 7.9 (former Lake Aldwell)
- Glines Canyon Dam was located at river kilometer 21.6 (former Lake Mills)



Catchment Area	830 km^2
River length	110 km
Typical channel width	40 – 70 m
Channel width at site	39 m
Channel gradient downstream of Elwha Dam	0.0043
Water surface slope upstream of weir	~ 0.0022
Sediment volume accumulated in Lake Aldwell	~$5x10^6$ m^3
Sediment volume accumulated in Lake Mills	~$16x10^6$ m^3
Total accumulated sediment volume	~$21x10^6$ m^3
Volume of gravel and cobble	~$3x10^6$ m^3

Introduction

- The decision to install an impact plate system to measure bed load was based on:
  - The maturity of the Swiss impact plate system installed in Switzerland, Austria, and Israel
  - Ability to continuously measure bed load without the need for operating personnel
  - Robust construction and demonstrated longevity
  - Limited maintenance of the physical system
  - Ability to measure bed load with 0.5 m resolution across the river
  - Non-intrusive and compatible with an ecologically sensitive river

Introduction

Note tree floating by raft

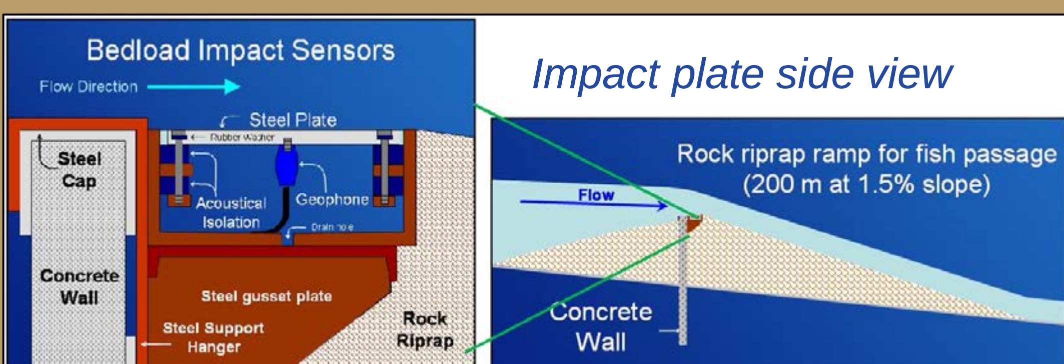
- Why continuous measurement with a surrogate method?
  - Safety
    - Bed load is transported only during high flow events, increasing the risk to practitioners when collecting physical measurements
  - Better Data
    - Continuous bed load measurements will provide the means for a much greater understanding of bed load movement
      - Ability to define inter-/intra-event and seasonal variability in bed load transport
      - Initiation and cessation of motion
    - Data from this system will improve our understanding of bed load transport for moderately sized gravel bed rivers under dam removal (near term) and equilibrium (long term) conditions

The Elwha Impact Plate System

- The system consists of 72 stainless steel impact plates
  - 46 are instrumented with a geophone
  - 26 are instrumented with an accelerometer
- The plates are mounted on the downstream side of a concrete weir, constructed for surface water diversion
- Wiring is routed to a stream side computer cabinet

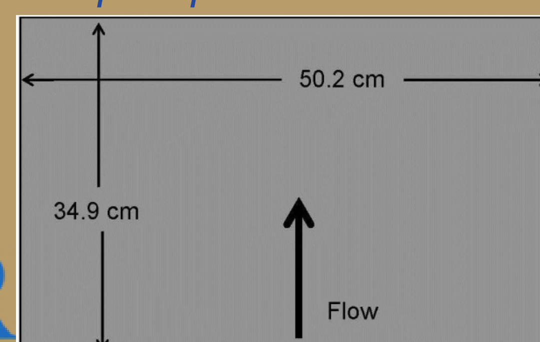
Accelerometer

Geophone



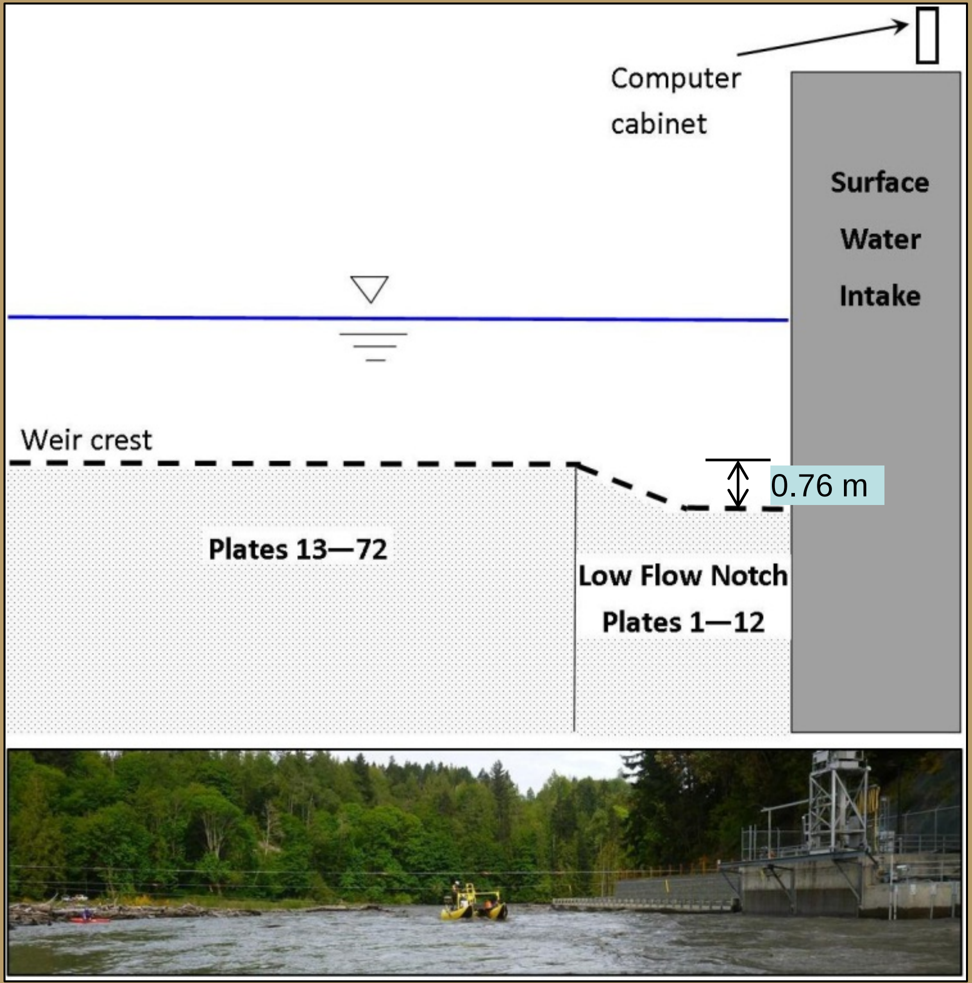
Impact plate side view

Impact plate dimensions



The Elwha Impact Plate System

Cross section diagram and photograph of the measurement weir during calibration (looking downstream)



Oblique view. Flow is from left to right

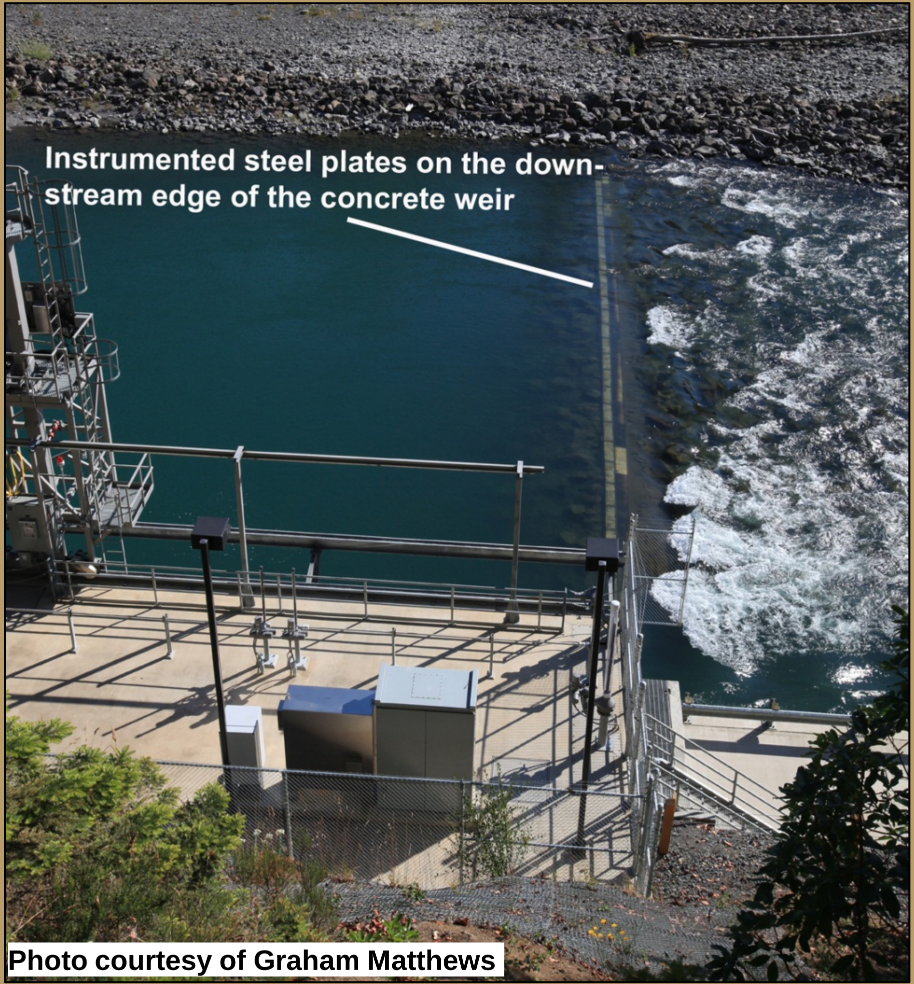
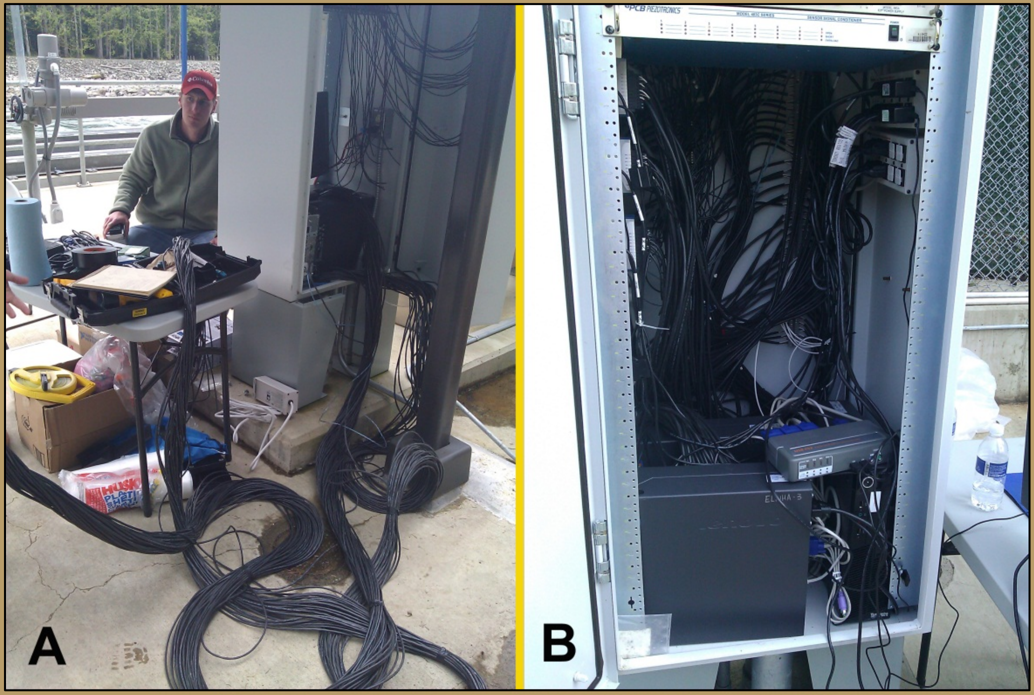


Photo courtesy of Graham Matthews

The Elwha Impact Plate System

- Three stream-side computers operate the impact plate system, collect, pre-process, and store the bed load data
- The computers are able to be remotely accessed to adjust parameters and download data



Panel A – Connecting wires from individual impact plate sensors to three chassis that route signals to the computers

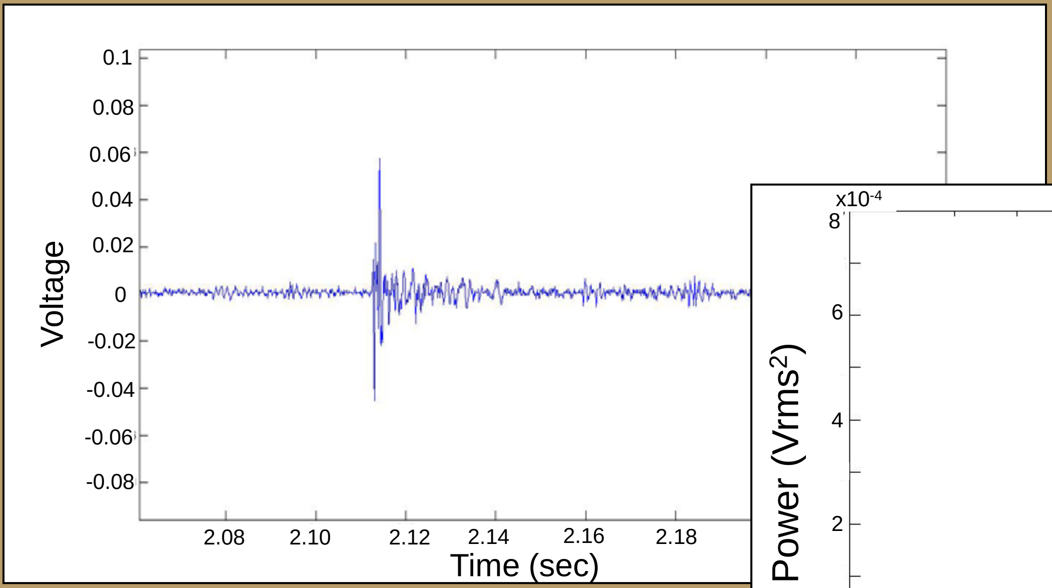
Panel B – The completed computer cabinet

The Elwha Impact Plate System

- The computer hardware and software were installed by personnel from the National Center for Physical Acoustics (U. of Miss.)
- LabView software operates the system, collecting data from all sensors and providing initial post-processing functions
- Accelerometers and geophones are sampled at 20kHz to obtain one minute sampling intervals
- Final post-processing is currently done off-line using MatLab

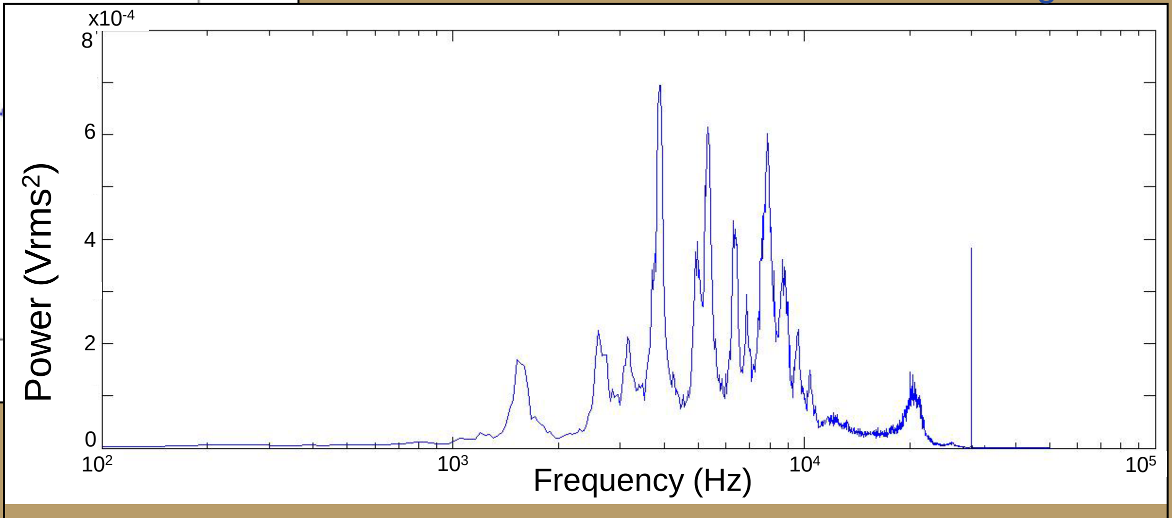
The Elwha Impact Plate System

- Gravel particles cause a slight deformation as they contact the steel plate
  - This deformation is registered on either a geophone or accelerometer
  - The signal generated by the instrument as a result of the impact is sent to the computers for initial post-processing and storage
    - Voltage and Power plots generated by St. Anthony Falls Lab, Univ. of Minn.



Geophone Signal

Accelerometer Signal



The Elwha Impact Plate System

- In-situ system calibration requires a correlation between the signals generated by the sensors and measured bed load
- Calibration requires the development of an algorithm that will use the signals to calculate bed load
  - Geophone signals provide a measurement of the number of impulses occurring over a given time frame above a specified threshold (noise level), leading to a correlation with sediment flux
  - Accelerometer signals measure the time varying vertical motion of the plate due to impacts. The time-varying signal can be analyzed using various frequency domain methods (e.g. FFT)

System Calibration

- Prior to dam removal, sensitivity of the impact plate system was tested
  - Gravel was sieved on site into three separate size classes
    - Particles from each size class were released upstream of the impact plates while they were monitored from the bank
  - Geophone plates are capable of registering impacts from particles > 16 mm
  - Accelerometer plates are capable of registering impacts from particles > 8 mm

System Calibration

- The system calibration of the geophone impact plates has begun and a preliminary calibration obtained

Bed load measurements for calibration

Date	Discharge (m^3/s)	# bed load samples	Composite D50 (mm)
Nov. 27, 2012	54.7	13	0.6
Nov. 28, 2012	56.4		
Mar. 13, 2013	95.4	34	3.5
Mar. 14, 2013	75.3		
Mar. 15, 2013	68.5		
May 14, 2013	90.0	86	5.4
May 15, 2013	78.4		
Jun. 12, 2013	59.3	73	5.9
Jun. 13, 2013	55.5		
Apr. 23, 2014	56.6	84	5.6
Apr. 24, 2014	70.8		

System Calibration

- Nov. 2012 – no coarse bed load in transport. Elwha River was overwhelmed by sudden release of sediment from Glines Canyon Dam, with finer sediment (< 2 mm) heavily dominating transport conditions
- Mar. 2013 – Collected 34 samples, bed load coarsened significantly, recognized the need for a new measurement protocol
- May 2013 – Successfully developed and employed new data collection protocol

System Calibration

- <u>Jun. 2013 </u>– Bed load data were collected, however a computer malfunction prevented these data to be used for calibration
- <u>April 2014 </u>– A successful bed load data collection for calibration using the protocol developed in May 2013
- Bed load data from May 2013 and April 2014 have been used to provide a preliminary calibration

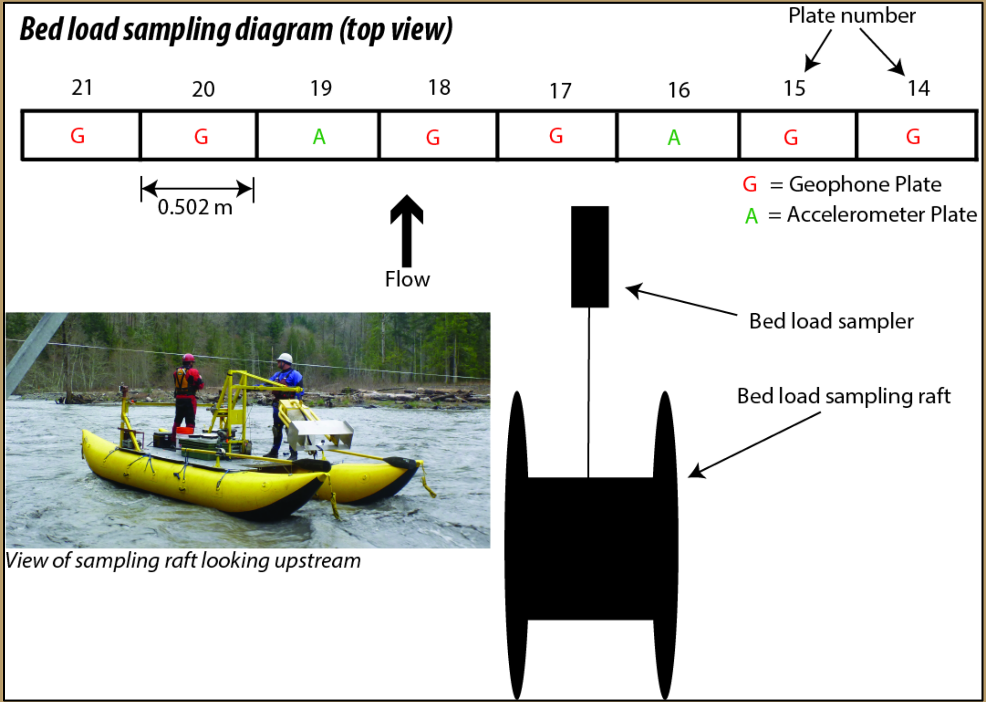
System Calibration

- Bed load data collection protocol
  - Use temporal and spatial averaging to resolve high variability in both the physical measurement and the number of impulses registered on the impact plates
  - Remain at a single station for 30 minutes, collecting approximately 9 physical measurements for temporal averaging
    - **Physical Samples** - Temporally average the physical samples to get a unit bed load transport rate over the 30 minute period
    - **Impact Plate Impulses** - Spatially average the impulses from the impact plates using neighboring plates up to 1 meter from the sampler location, and temporally average the impulses over the 30-minute sample period

System Calibration

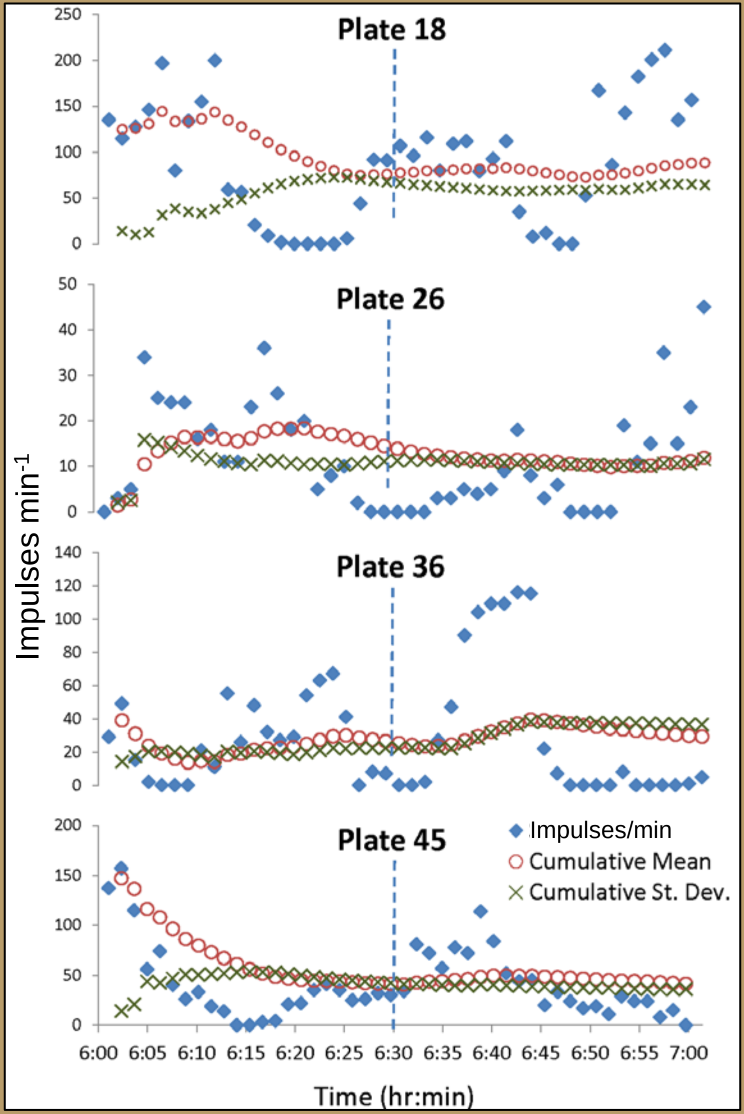
- Bed load sampling example for calibration
  - Physical samples are collected with a TR-2 upstream of the impact plates
    - Made necessary by flow and bed conditions downstream of the plates
  - Protocol
    - Collect many physical measurements at a single station for 30 minutes to obtain a temporal average
    - Collect geophone data for 30 minutes across 3 spatially coincident geophone impact plates to obtain a temporal and spatial average

In this example, impulses from Geophone plates 17, 18, and 16 would be used to obtain a spatial average



System Calibration

- The purpose of the temporal and spatial averaging of data is to obtain a reliable mean value of measured bed load and the number of impulses indicated by the geophone impact plates
- A reliable mean value is required because bed load transport is known to be a stochastic process
  - Fluctuations are > 2 order of magnitude
  - 30 minutes was determined to be a sufficient period of time based on the cumulative mean and standard deviation over the measurement period



Preliminary Calibration Result

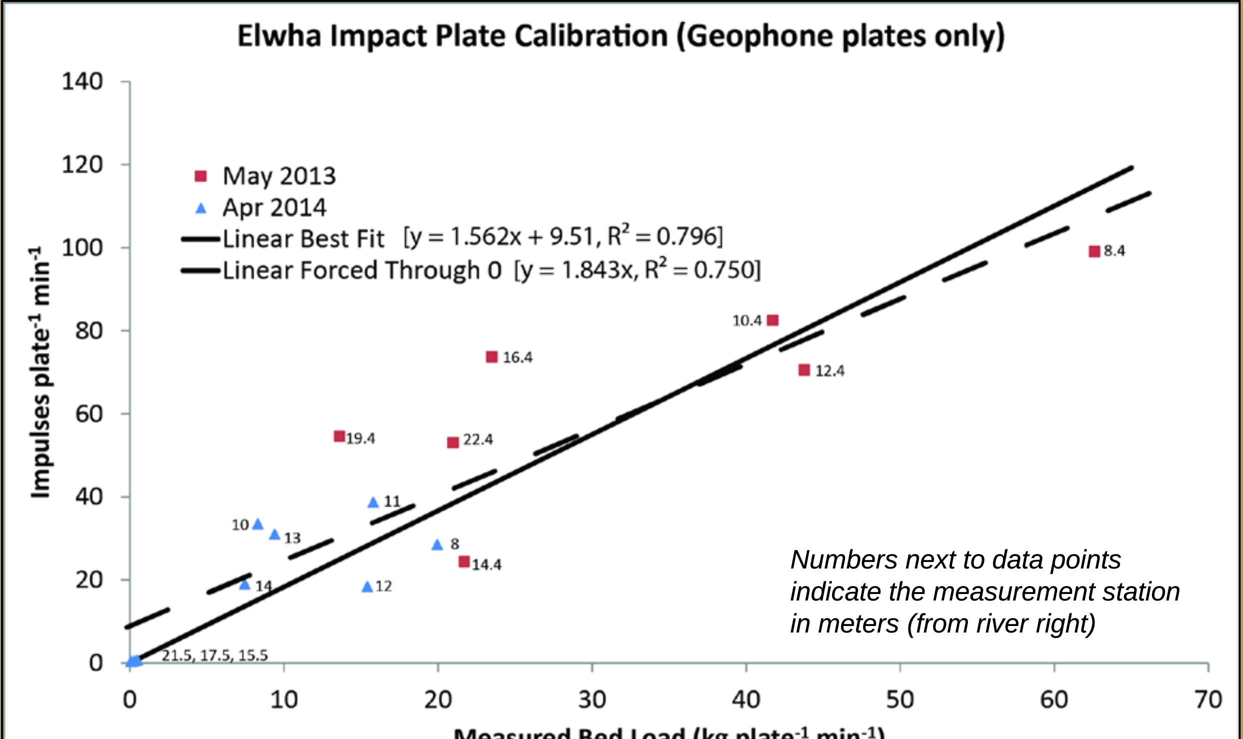
- Correlation between measured bed load and surrogate measurement from geophone impact plates – preliminary calibration

$$y = k_b * M$$

where M = bed load mass > 16 mm and k_b is the calibration coefficient

River Name	k_b	R^2
Eshtemoa	0.42	0.99
Elwha	***1.84***	***0.75***
Rofenache	3.87	0.78
Erlenbach	5.45	0.97
Reutz	16.3	0.85
Fischbach	22.9	0.97

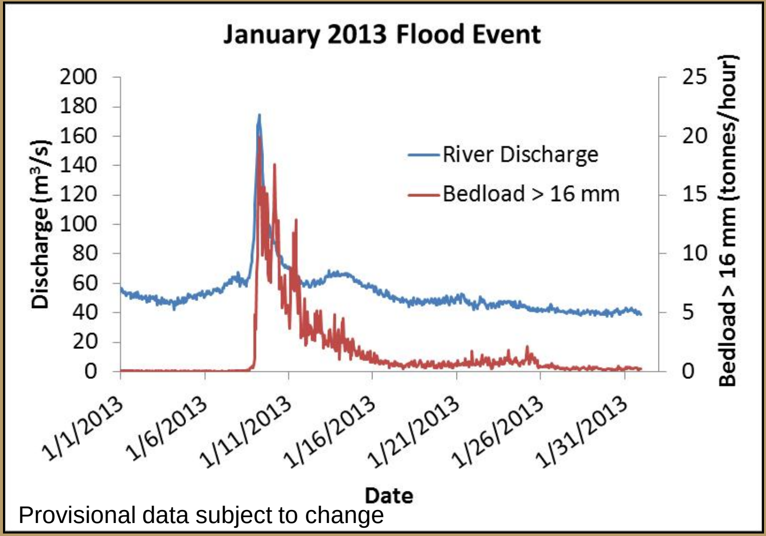
Data from rivers other than the Elwha are from Rickenmann et al. (2013)



Provisional data subject to change

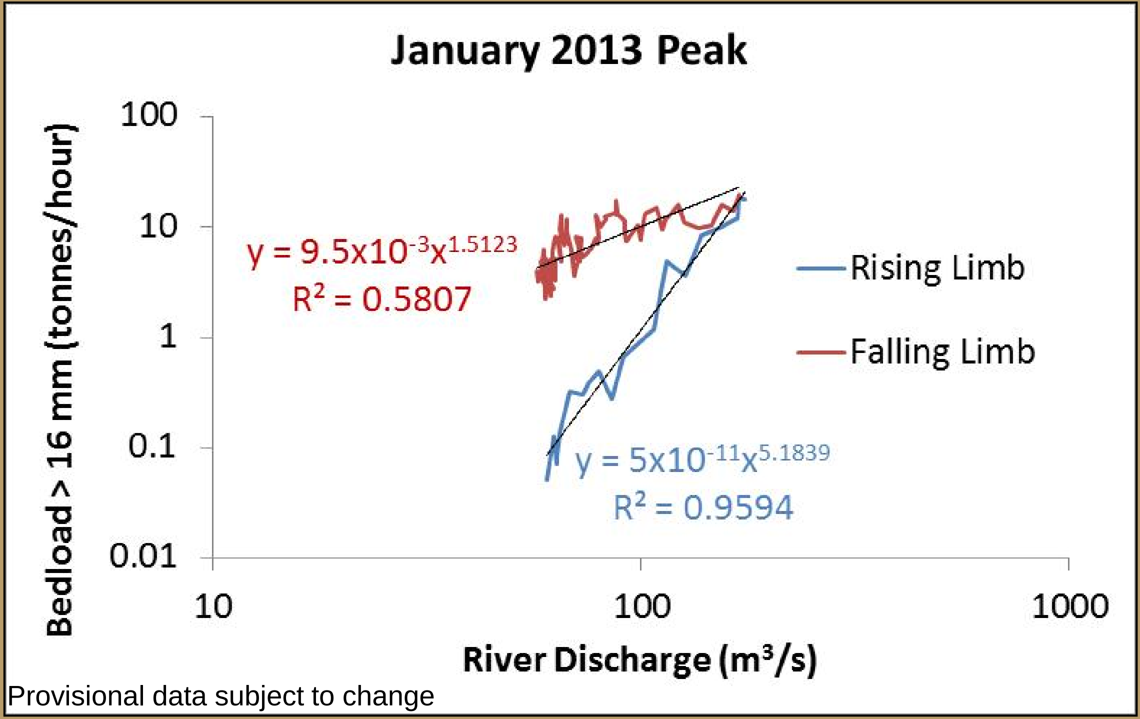
Using the Data

- Examining hysteresis in bed load transport



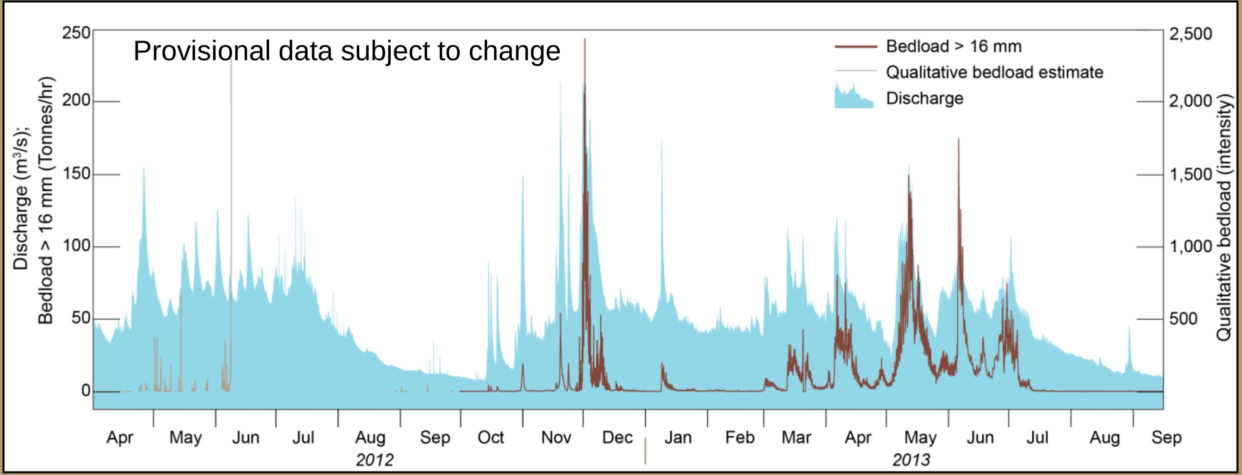
- Bed load transport is well correlated with discharge on the rising limb, indicating a steep rating curve
- Bed load is not as well correlated with discharge on the falling limb indicating a shallower rating curve

Evaluating 108 hours of a flood event, January 7-11, 2013

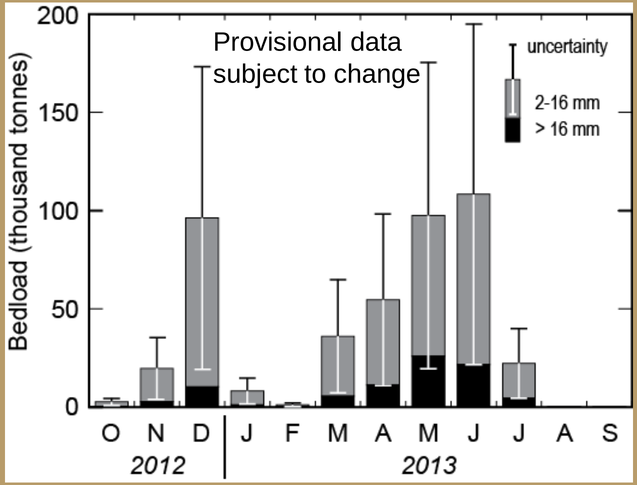


Using the Data

- Bed load transport during the first two years of dam removal on the Elwha River
  - Data from geophone impact plates only



Monthly bed load for 2–16 mm and > 16 mm size classes in the Elwha River at the diversion-weir gauge for year 2 of the dam-removal project. Uncertainty of total bed load greater than 2 mm is one standard deviation.



Transport of bed load greater than 16 mm for year 2 of the Elwha River dam-removal project. Qualitative data of bed load transport from year 1, based on the number of impulses on the impact plates, are also shown along with the gauged discharge during the study period.

Plots taken from Magirl et al., submitted to Geomorphology, July 2014, MS# S-14-00578

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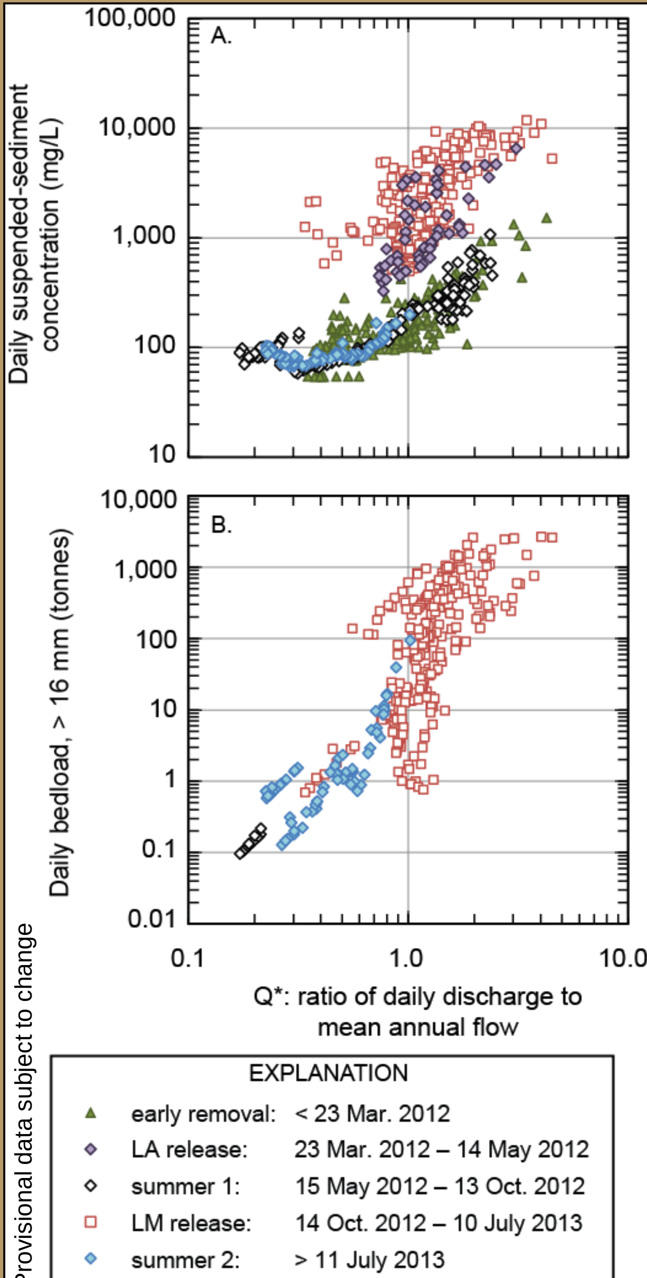
Using the Data

- Sediment transport during the first two years of dam removal using surrogate sediment measurement technologies
  - – USGS WA-WSC collecting suspended sediment data with acoustic and optic surrogates



Panel A - Daily suspended-sediment concentration, as determined with the sediment-surrogate instruments, plotted against daily discharge normalized to mean annual flow.
Panel B - Daily bed load > 16 mm as determined with the bed load-surrogate impact plates, plotted against daily discharge normalized to mean annual flow.

Taken from Magirl et al., submitted to Geomorphology, July 2014, MS# S-14-00578

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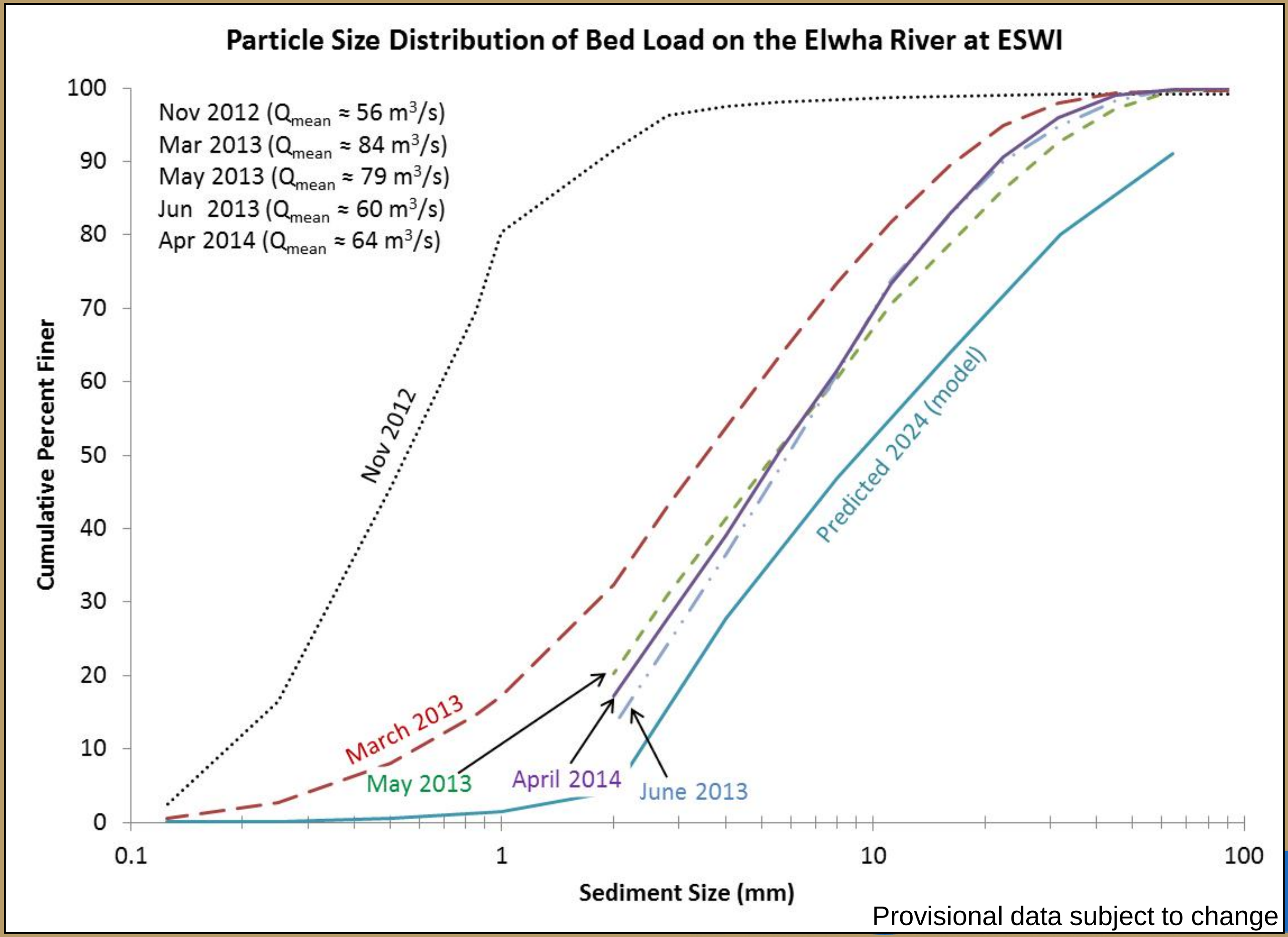
Using the Data

- Changing size distribution of bed material
  - Data from physical sampling with the TR-2



Future Work

- For geophone plate calibration:
  - More data are required to improve the calibration
    - Unsettled transport conditions during dam removal may not provide adequate calibration data
  - Additional analyses are required regarding the flow velocity at each measurement location
    - Lateral (cross-channel) flow exists in a portion of the channel, possibly affecting the calibration methodology (selecting appropriate plates to match to the physical measurement)
  - Investigate the influence of particle size, shape, and mode of transport (Turowski and Rickenmann 2009, Rickenmann et al. 2013)

Future Work

- For accelerometer plate calibration
  - A two-plate system, equipped with accelerometers, has been fabricated and shipped to the USDA-ARS National Sedimentation Lab in Oxford, MS
  - Flume experiments will take place to determine the appropriate algorithms for measuring bed load with accelerometers
    - Will obtain a flume calibration
  - Transfer this knowledge to the Elwha impact plate system so that an in-situ calibration of the accelerometer plates can be obtained
    - Incorporate this algorithm into the data collection system
  - Accelerometer plates have been shown to be more sensitive, allowing the measurement of a greater portion of the bed load
  - Using accelerometers to measure particle impacts is expected to provide a greater insight into bed load transport specifics using the frequency information

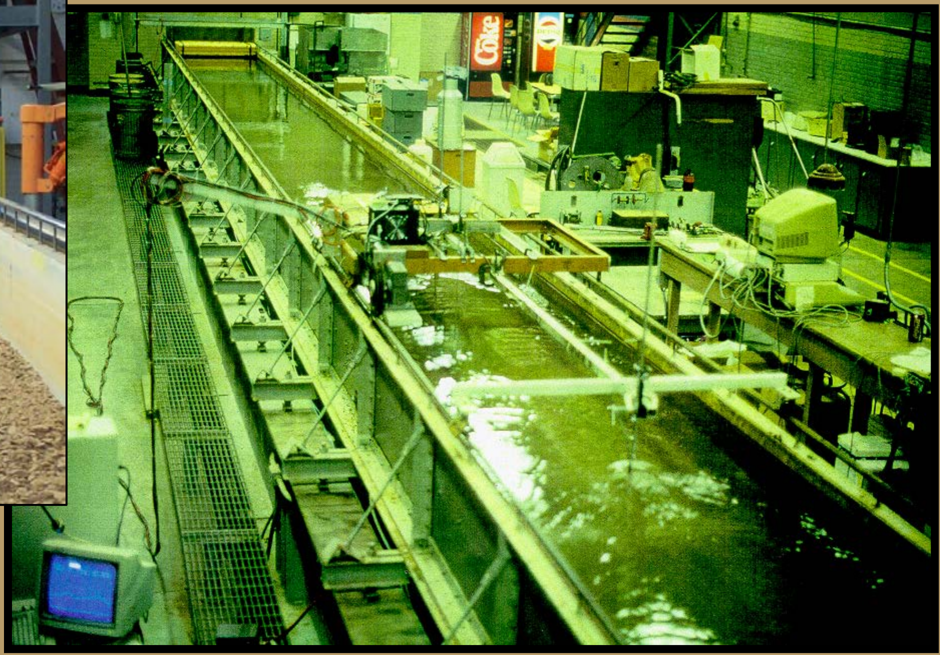
Future Work

- Recirculating flume at the National Sediment Lab
  - The two-plate system, equipped with accelerometers, will be placed at the downstream end of the flume immediately upstream of the sediment measurement system

Downstream End

Upstream End

Channel: 30 m x 1.2 m x 0.6 m
Continuous measurement sediment transport
Recirculation of sediment up to 100 mm



Photos courtesy of Dr. Roger Kuhnle

Future Work

- Will need to examine the opportunities for replacing inoperable sensors
  - 2 accelerometers
  - 6 geophones
- Difficulties are presented by sensors installed on a perennial stream
  - Permit to perform in-stream work
  - Difficult to divert flow during repair
  - Anticipated cost of in-stream work is significant

Future Work

- Automation of post-processing impulse data to obtain bed load information
  - Seamless process between the first stage of post-processing provided by the on-site computers and a final value of bed load transport
  - Re-format LabView output and use MatLab to provide bed load data
- Remote access from my desktop at work
  - Current access is through channels unauthorized by DOI computer policy
  - Have been trying to get IT support to accomplish this for more than 1 year with no progress

Future Work

- Will explore all opportunities to collaborate with researchers investigating surrogate bed load measurement technologies
  - Hydrophone measurement of bed load transport (current research project (# 4864) with Dr. James Chambers, NCPA)
- Other potential collaborators researching surrogate technologies
  - Dr. Colin Rennie (U. Ottawa)
    - Researching bed load measurement with down-looking ADCP using apparent bed load velocity
  - Dr. Brandon Schmandt (U. New Mexico)
    - Researching bed load measurement using seismic methods on the stream bank using energy imparted to the bed by moving particles

Future Work

- Potential Collaborators (cont'd.)
  - Dr. Dieter Rickenmann (Swiss Federal Institute)
    - Using maximum voltage to determine particle size with geophone plates
    - Determination of the influence of particle shape and mode of transport on impact plate registration
    - What additional information can be gained using accelerometers vs. geophones
  - Dr. Thanos Papanicolaou (U. of Tennessee)
    - Assistance with flume measurements using impact plates

Conclusions

- The Elwha impact plate system is proving successful for obtaining continuous bed load measurements
- In the near future, following a complete system calibration, data from the Elwha impact plate system will prove valuable towards:
  - A better understanding of coarse bed load transport during and after dam removal
  - A better understanding of bed load transport on a moderately sized and sloped gravel bed river
  - Application toward possible installation at other sites where bed load measurement is needed

Conclusions

- Resulting publications
  - Installation of Impact Plates to Continuously Measure Bed Load: Elwha River, WA, USA
    - Submitted to the *Journal of Hydraulic Engineering*, March 2014
      - R.C. Hilldale, W.O. Carpenter, B. Goodwiller, J.P. Chambers, and T.J. Randle
  - Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load
    - Submitted to *Geomorphology*, July 2014
      - C.S. Magirl, R.C. Hilldale, C.A. Curran, J.J. Duda, T.D. Straub, M. Damanski, and J.R. Foreman
  - Calibration of bed load impact plates on the Elwha River, USA
    - Presented at the International Workshop of Acoustic and Seismic Monitoring of Bedload and Mass Movements, Zürich/Birmensdorf, Switzerland, September 4-7, 2013

Collaborators During Research

- Dr. James Chambers, Brian Carpenter, Bradley Goodwiller, *National Center for Physical Acoustics, Univ. of Mississippi*
- Dr. Roger Kuhnle, Dr. Daniel Wren, Dr. J.R. Rigby, *USDA-ARS*
- Dr. Chris Magirl, Dr. Chris Curran, *USGS, Washington Water Science Center*
- Dr. Andy Ritchie, *National Park Service, Olympic National Park*
- Dr. Colin Rennie, *University of Ottawa*
- Dr. Dieter Rickenmann, *Swiss Federal Research Institute, Birmensdorf, Switzerland*
- Dr. Jonathan Laronne, *Ben-Gurion University of the Negev, Beer Sheva, Israel*
- Dr. Helmut Habersack, *University of Natural Resources and Life Sciences, Vienna, Austria*
- Dr. Knut Möen, *VP Group Risk and Capital Allocation, Oslo, Norway*
- Jeff Marr, *St. Anthony Falls Laboratory, Univ. of Minnesota*
- The Federal Interagency Sedimentation Project, *USACE, USGS, Reclamation, USDA-ARS, USDA-FS, US EPA, BLM, NMFS*

References Cited

- Banziger, R. and Burch, H. (1990). “Acoustic sensors (hydrophones) as indicators for bed load transport in a Mountain Torrent”, In, *Hydrology in Mountain Streams. I - Hydrological Measurements; the Water Cycle*, H. Lang and A. Musy, (eds.), IAHS Publ. no. 193, Wallingford, UK, pp. 207-214.
- Rickenmann, D. and McArdell, B.W. (2007). “Continuous measurement of sediment transport in the Erlenbach stream using piezoelectric bedload impact sensors”, *Earth Surface Processes and Landforms*, 32, 1362 – 1378.
- Rickenmann, D., Turowski, J.M., Fritschi, B. Wyss, C., Laronne, J., Barzilai, R., Reid, I., Kreisler, A., Aigner, J., Seitz, H., and Habersack, H. (2013). “Bedload transport measurements with impact plate geophones: comparison of sensor calibration in different gravel-bed streams”, *Earth Surface Processes and Landforms*, DOI: 10.1002/esp.3499.
- Turowski, J.M. and Rickenmann, D. (2009). “Tools and cover effects in bedload transport observations in the Pitzbach, Austria”, *Earth Surface Processes and Landforms”*, 34, 26-37 DOI: 10.1002/esp.1686

Appendix A

submitted to the *Journal of Hydraulic Engineering* March 2014

Installation of impact plates to continuously measure bed load: Elwha River, WA, USA

Robert C. Hilldale, Wayne O. Carpenter, Bradley Goodwiller, James P. Chambers, Timothy J. Randle

Abstract

In 2008 and 2009 a series of bed load impact plates was installed across a channel spanning weir on the Elwha River, Washington, USA. This is the first permanent installation of its kind in North America and one of the largest anywhere. The purpose of this system is to measure coarse bed load during and after the removal of Elwha and Glines Canyon Dams. It is estimated that 2.1 x 107m3 of sediment have accumulated behind both dams, with 45 to 50% of the total accumulated volume expected to be eroded through natural processes. The impact plate system consists of 72 plates installed at a diversion weir downstream from both dams and 5 kilometers upstream from the river mouth. Of the 72 plates, 46 are instrumented with a geophone and 26 with an accelerometer. Collection of physical bed load data for calibration of the geophone plates has begun, with additional measurements to be collected in the near future. This note describes the specifics of the Elwha impact plate system and the ongoing process to collect bed load measurements for system calibration.

Appendix B

submitted to *Geomorphology*, July 2014

Large-scale dam removal on the Elwha River, Washington, USA: Fluvial sediment load

Christopher S. Magirl, Ph.D.; Robert C Hilldale; Christopher A Curran; Jeffrey J Duda; Timothy D Straub, Ph.D.; Marian Domanski; James R Foreman

Abstract

The Elwha River restoration project, in Washington State, includes the largest dam-removal project in United States history to date. Starting September 2011, two nearly century-old dams were removed over three years with a top-down deconstruction strategy designed to meter the release of 21 ± 3 million m3 of dam-trapped sediment. Sediment gauging using sediment-surrogate technologies during the first two years of the project, from September 2011 to September 2013, indicated 8,200,000 ± 3,400,000 t of sediment transported from the dam-removal project, with 1,100,000 and 7,100,000 t moving in year 1 and 2, respectively. During the study period, the discharge in the Elwha River was greater than normal (107% in year 1 and 108% in year 2); however, the magnitudes of the peak-flow events during the study period were relatively benign with the largest discharge of 292 m3/s (73% the size of the 2-year peak-flow event) occurring 23 November 2011 when both extant dams were retaining sediment. Despite the muted peak-flow hydrology, sediment transport was significant, with measured suspended-sediment concentration during the study period ranging from 44 to 16,300 mg/L and gauged bedload transport as large as 24,700 t/day. Five distinct sediment-release periods were identified when sediment loads were notably smaller (when reservoir retention or seasonal low flows reduced sediment transport) or larger (when sediment transport from the former reservoirs was active). Total suspended-sediment load was 930,000 t in year 1 and 5,400,000 t in year 2. Of the total 6,300,000 ± 3,200,000 t of suspended-sediment load, 3,400,000 t was fine grained (silt- and clay-sized particles) and 2,900,000 t was sand sized. Gauged bedload in year 2 of the project in the lower Elwha River was 450,000 ± 360,000 t. Bedload was not quantified in year 1, but qualitative observations using the bedload-surrogate technology indicated detectable bedload starting just after full removal of the downstream dam. Using comparative studies from other sediment-laden rivers, the total ungauged fraction of < 2-mm bedload was estimated to be 1,500,000 ± 1,400,000 t.

Data Sets that support the final report

Share Drive folder name and path where data are stored:

This location is a shared network drive in the Sedimentation and River Hydraulics Group
Z:\DO\Sediment\Data\Elwha\research\BedloadImpactSensors

Point of Contact name, email and phone:

Robert C. Hilldale
Ph: (303)445-3135
e-mail: rhilldale@usbr.gov

Short description of the data: (types of information, principal locations collected, general time period of collection, predominant files types, unusual file types.)

All data for the design, construction, and calibration of the Elwha bed load impact system is contained in the back-up directory. Data collected by contractor Graham Matthews and Associates is included, along with 3 years of surrogate impact data along with information provided by the NCPA (reports, etc.). Spreadsheets and other documentation are also included, along with photographs.

Keywords:

Continuous bed load measurement, surrogate sediment measurement, impact plate, Elwha

Approximate total size of all files:

16 GB