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Proposal for Implementation of an Acoustic Beam Calibration – Phase 2

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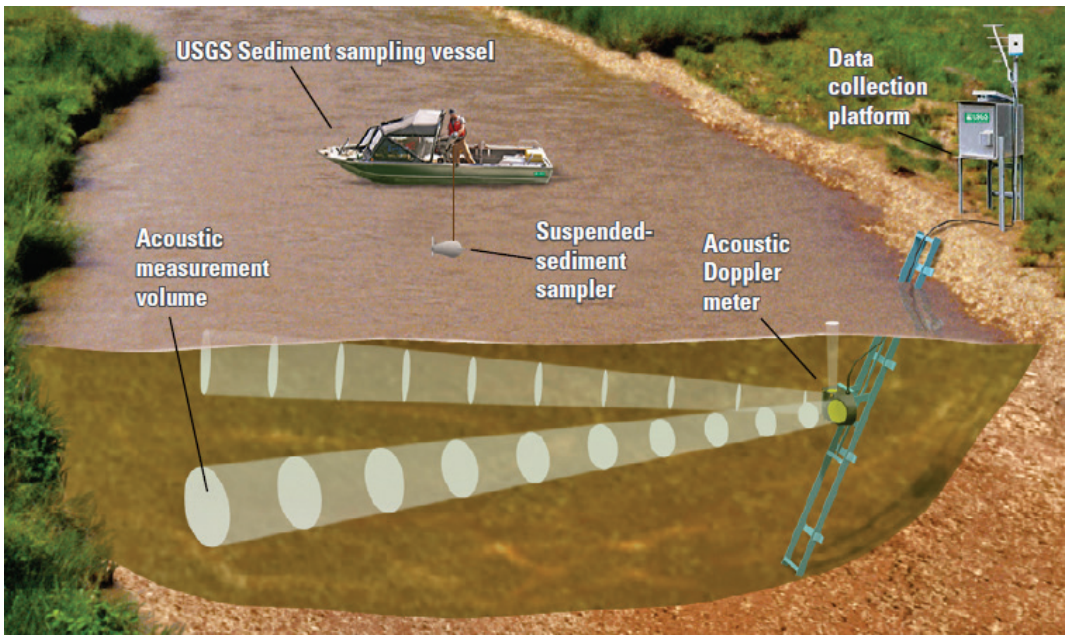

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Proposal Title

Implementation of an Acoustic Beam Calibration – Phase 2

Principal Investigator (PI)

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Introduction and Background

Acoustic Doppler velocity meters (ADVMs) can be used for monitoring of suspended sediment concentration (SSC) through the development of a site-specific sediment acoustic index rating. This can provide cost-effective time series data that cannot be readily collected by other methods; the data is essential for addressing many environmental, engineering and agricultural concerns. However, if the ADVM needs to be replaced, the rating for that site may not be able to be used with a new system – even for the same make, model and frequency. Generating a new rating for the replacement instrument is an expensive and time consuming process.

As part of the Federal Interagency Sediment Project (FISP), in 2019 the U.S. Geological Survey (USGS) hired OneFish Engineering, LLC (OneFish) to recommend an acoustic beam calibration procedure that will allow a calibrated ADVM to be replaced by another of the same frequency without re-generating the sediment acoustic rating.

An effective calibration technique should accomplish the following.

- It should estimate the offset in measured backscatter between different ADVMs; sources of the offset include the transmit signal intensity and overall receiver sensitivity.
- It should estimate the linearity and slope of the measured backscatter over the dynamic range of the system. This is primarily driven by the intensity scale factor (K) of the ADVM receiver, but may be influenced by other factors.
- Ideally the calibration would provide the following, although these are not essential.
    - Transmit and receive beam patterns
    - Near-field response
    - Offset between measured and absolute backscatter
- The procedure should have an overall accuracy similar to the resolution of ADVM measured backscatter data (0.2-0.6 dB).

That project (phase 1) was completed in November 2019. It recommended the use of a reference acoustic hydrophone; details of the calibration procedure are described later in this proposal. The USGS has asked OneFish to provide a proposal for phase 2 of this project to implement the recommended calibration procedure.

Phase 2 Goals

The purpose of phase 2 is to assist the USGS in implementing the acoustic beam calibration procedure. This phase of the project will include the following tasks.

- Assist in the specification and procurement of a reference acoustic hydrophone
- Design and assist with procurement of all required mechanical, electrical, and ADVM data acquisition systems
- Develop data processing software to calculate acoustic beam calibration parameters that can be applied within existing sediment acoustic rating software
- Work with USGS personnel to perform initial calibrations, while providing training and documentation for future ADVM calibrations

The calibration equipment and procedures should be applicable to all side-looking ADVMs that are currently in use by the USGS.

The USGS is also interesting in pursuing additions and improvements to the software used to generate sediment acoustic ratings, called the Surrogate Analysis and Index Developer (SAID). Phase 2 of the project will investigate the scope of these changes, and provide a proposal to perform the software development work in the future.

Hydrophone Calibration Procedure

The reference hydrophone calibration procedure is outlined below.

- The ADVM and hydrophone would be mounted in a large tank of water.
    - The ADVM beam to be calibrated would be aimed along the axis of the tank.
    - Other ADVM beams would have dampening devices installed to prevent additional energy in the water that could affect measurements.
    - The distance between the hydrophone and ADVM would be outside the transducer near-field but within its normal profiling range.
        - The near field distance depends on the ADVM frequencies and transducer size. It varies from less than 0.5 m for high frequency systems (i.e. 3000 kHz), to more than 2 m for lower frequency systems (i.e. 500 kHz).
        - The mounting distance might be 1-4 m depending on frequency.
- The instruments would be carefully aligned in the center of their beams.
    - The ADVM and hydrophone would need to be rotated about both their horizontal and vertical axes to achieve the best alignment. The alignment would be done with the hydrophone in both transmit and receive modes.
- Data collection with the ADVM would be use the same operating parameters normally used in the field.
- In receive mode, the hydrophone would measure the intensity of the transmit pulse.
    - Its calibration relates the measured voltage to pressure in the water.
- In transmit mode, the hydrophone would output a continuous signal at the ADVM frequency.
    - Based on the amplitude of the driving voltage, the pressure in the water can be calculated. After accounting for distance, measured backscatter can then be directly related to pressure in the water.

    - The measurements would be repeated over a range of driving voltage / pressure levels. This would allow precise calculation of the intensity scale factor (K).
- Transmit and receive pressures, along with other system parameters and corrections, would be used to calculate absolute backscattering. The resulting data should be consistent for any instrument operating at the same frequency.
- This calibration procedure is applicable to any ADVM, whether side-looking or vertically profiling. Phase 2 of the project will specifically address side-looking systems. Relatively minor efforts would be required to apply it to other ADVMs.

When developing the test procedures, additional parameters will be measured to assist in data analysis and to evaluate some of the assumptions inherent with using acoustics to monitor suspended sediment.

- The transmit and receive beam patterns of the ADVM transducer
- Non-linearities in the ADVM receive sensitivity
- Variations in transmit/receive data with distance, particularly the near-field response

The most appropriate reference hydrophone would be supplied by the U.S. Navy Underwater Sound Reference Division (USRD). OneFish will assist the USGS in final specification and procurement of a hydrophone from the USRD.

- The USRD acts as the equivalent of the National Institute of Standards and Testing (NIST) for underwater sound applications.
- Two USRD hydrophones operate at the range of frequencies required by ADVMs: the E8 (200 to 2000 kHz) and E37 (100 to 2000 kHz).
    - These hydrophones are calibrated to a maximum frequency of 2000 kHz, whereas some ADVMs operate at frequencies up to 3000 kHz. Based on discussions with the USRD, the hydrophone may provide reliable performance up to 3000 kHz.
    - Performance of the hydrophone at these higher frequencies will need to be tested to verify they can provide a reliable calibration.
- USRD hydrophones are leased on an annual basis; the price includes annual calibration.
    - Current prices are $2,875/year for the E8 and $4,025/year for the E37.

The preferred facility for the beam calibration is the USGS Hydrologic Instrumentation Facility (HIF) in Mississippi. OneFish has participated in preliminary discussions of the calibration with the HIF; they have agreed the calibration is within the capabilities of their personnel and facilities, and they are willing to add it to the services they provide.

The table below lists all side-looking ADVM types currently used by the USGS at sediment monitoring stations, as understood by OneFish. The calibration equipment developed in this project will be applicable to all of these system types. Additional system types can be added, although this may impact the scope and cost of the project.

Manufacturer	Model	Frequencies (kHz)
SonTek	SL	500, 1500, 3000
	SL (3G)	1500, 3000
TRDI	Channel Master	300, 600, 1200
	Workhorse H-ADCP	300, 600, 1200
NorTek / OTT	AquaDopp	600, 1000, 2000
	Easy-Q / OTT SLD	600, 1000, 2000

Phase 2 Scope and Deliverables

Phase 2 of this project would consist of the following tasks and deliverables.

- Task 1: Facility evaluation
  - OneFish will travel to the HIF for 2 days to meet with USGS personnel to discuss the details of the project and to finalize a plan moving forward.
  - The team will review HIF facilities and collect information required for design of mechanical, electrical, and data acquisition systems.
  - A final specification for the reference hydrophone will be agreed upon so that the USGS can place an order with the USRD.
- Task 2: Mechanical systems
  - OneFish will design a mounting system for the reference hydrophone.
  - OneFish will design mounting systems suitable for all ADVM types listed earlier.
  - OneFish will design transducer damping systems suitable for all ADVM types.
  - OneFish will support USGS personnel for the procurement of these mechanical systems; procurement costs will be paid directly by the USGS.
- Task 3: Electrical systems
  - OneFish will design an electrical system to sample and measure the signal received by the hydrophone for the ADVM transmit calibration.
  - OneFish will design an electrical system to drive the hydrophone at a known frequency and a range of voltages to perform the ADVM receive calibration.
  - OneFish will support USGS personnel for the procurement of these electrical systems; procurement costs will be paid directly by the USGS.
  - OneFish will assemble and perform preliminary tests of the electrical systems at our offices in Colorado. The USGS will supply one or more ADVMs to assist with this process.
- Task 4: ADVM data acquisition
  - OneFish will design a data acquisition system to control and collect data from the ADVM during the calibration procedure.
  - OneFish will support USGS personnel for the procurement of this system; procurement costs will be paid directly by the USGS.
  - OneFish will assemble and perform preliminary tests of the data acquisition system at our offices in Colorado. The USGS will supply one or more ADVMs to assist with this process.
- Task 5: Sediment processing software proposal
  - Sediment acoustic ratings are commonly developed using a software called SAID. The existing version performs only single frequency calibrations and was written by the USGS in Matlab.
  - The USGS is interested in improving the SAID software in two ways.
    - The software should process both single and dual frequency ratings.
    - The software should be written on the open source Python software platform, avoiding the need for users to purchase a Matlab license.
  - OneFish will investigate the scope of these software modifications by speaking with the developers of the existing code, current software users, as well as sediment processing specialists. OneFish will also review the existing code to better understand its complexity and the degree of effort that would be required.

    - OneFish will write a proposal for the work required to make these changes and improvements to the SAID software.
- Task 6: Calibration processing software
    - OneFish will develop data processing software for the calibration procedure.
        - This will written in the open source software platform Python; no license will be required to operate the software.
    - The software output will be calibration parameters in a format suitable for use in the SAID software written by the USGS.
        - SAID will likely require modifications to apply the beam calibration.
        - These modifications are not part of this Phase 2 proposal.
- Task 7: Initial calibrations
    - OneFish will make two separate trips to the HIF to work with USGS personnel on implementation of the beam calibration procedure.
    - The first trip will include five (5) days of work at HIF facilities.
        - All mechanical systems will be installed, tested, and modified as needed.
        - All electrical systems will be installed, tested, and modified as needed.
        - The ADVM data acquisition system will be installed, tested, and modified as needed.
        - Complete calibration of one ADVM system type will be performed. This will include evaluation of beam patterns and the near-field response.
    - Between trips, results will be evaluated in detail and the calibration procedures will be improved / modified as needed.
    - The second trip will include five (5) days of work at HIF facilities.
        - Complete calibration of two ADVM system types will be performed. This will include evaluation of beam patterns and the near-field response.
    - OneFish will provide written documentation of the calibration procedure.
        - USGS personnel should be able to continue future calibrations without OneFish personnel present.
- Task 8: Ongoing support
    - OneFish will continue to provide support for ongoing calibrations as needed.

Budget

We propose to conduct this work on a time and materials basis.

- All labor would be billed at a standard rate of $150.00 per hour.
- Travel expenses will be billed as follows.
  - Airfare and car rental will be billed as actual costs without overhead.
  - Lodging will be billed as actual costs or standard GSA rates, whichever is less.
  - Meals and incidentals will be billed at standard GSA per diem rates.
  - Any mileage on OneFish vehicles will be billed at the standard GSA mileage rate.
- Direct expenses will be billed as actual costs plus 10% overhead.
  - This may include materials required in developing, assembling, and testing the mechanical, electrical, and data acquisition systems.
  - It is anticipated that large expenditures will be procured by the USGS, and only smaller items would be purchased directly by OneFish.

The total budget is estimated as $79,400 (details in the table below). This would be established as a not-to-exceed limit, beyond which no charges would be made without the client's approval. Travel and material expenses are estimated, and will be billed as described above.

Task	Sub-Task Hours	Task Hours	Travel	Direct Expenses	Cost
Task 1: Facility evaluation		24	$ 1,700		$ 5,300
Preparation / planning	8				
HIF visit	16				
Task 2: Mechnical systems		64		$ 500	$ 10,100
Hydrophone mounting design	16				
ADVM mounting design	32				
Transducer damping design	8				
Procurement support	8				
Task 3: Electrical systems		96		$ 500	$ 14,900
Hydrophone receive design	32				
Hydrophone transmit design	32				
Procurement support	8				
Assembly and testing	24				
Task 4: ADVM data acquisition		40		$ 500	$ 6,500
System design	24				
Procurement support	8				
Assembly and testing	8				
Task 5: Sediment processing software proposal		20			$ 3,000
Research and scoping	16				
Proposal preparation	4				
Task 6: Calibration processing software		64	$ 2,400		$ 12,000
Code development (Python)	56				
Integration with SAID	8				
Task 7: Initial calibrations		128	$ 2,400		$ 21,600
Preparation / planning	16				
Calibration trip 1	40				
Data analysis	16				
Calibration trip 1	40				
Final analysis and documentation	16				
Task 8: Ongoing support		40			$ 6,000
Project Total		**476**	**$ 6,500**	**$ 1,500**	**$ 79,400**

Timeline

The timeline for this project will depend a variety of factors including the availability of USGS personnel and facilities, as well as lead times for procurement of mechanical / electrical / data acquisition systems. An estimate of the time required for each task is given below.

It is anticipated that the tasks 1-7 will be completed by the end of 2021; ongoing support (task 8) may continue into 2022. The exact timeline and associated deadlines can refined as the project moves forward.

Task	Estimated Duration
Task 1: Facility evaluation	1 month
Task 2: Mechanical systems	3-6 months Tasks 2-4 will be done concurrently
Task 3: Electrical systems	
Task 4: ADVM data acquisition	
Task 5: Sediment processing software proposal	1 month
Task 6: Calibration processing software (Python)	2 months
Task 7: Initial calibrations	2-3 months
Task 8: Ongoing support	6-12 months

PI Qualifications

The Principal Investigator, Craig Huhta, has spent his 25+ year career designing and operating specialized instrumentation for the measurement of water. He has designed some of the most successful hydrology instruments on the market including the FlowTracker, the Argonaut-SW, the SonTek-IQ, and portions of the RiverSurveyor ADCP. He has made measurements at sites from 3 cm to 5 km deep, and in locations around the world.

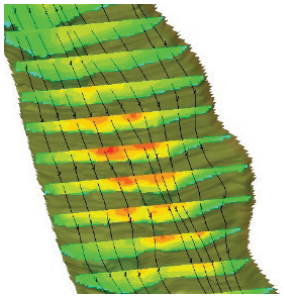
Craig understands how to operate these sophisticated instruments, and the technology behind the data. He works closely with hydrologists, scientists, engineers, and other water resource professionals. Craig takes the time to understand the goals of each application to be sure the data delivers what is needed.

The use of acoustic backscatter data for suspended sediment monitoring has been a regular and recurring application throughout his career. He has worked with universities, the U.S. Geological Survey, the U.S. Army Corps of Engineers, and other agencies to understand and evaluate this application on a variety of projects. Coupled with his intimate knowledge of the design of these instruments, he is uniquely qualified to successfully complete this project.

Professional Experience

OneFish Engineering, LLC, Co-Owner, Senior Engineer, 2013 to Present

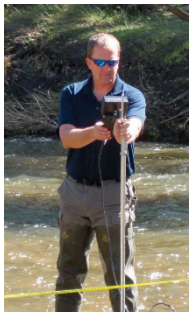





Craig provides engineering expertise in the fields of hydraulic measurement, data analysis, and modeling. Some of his projects include:

- Development of the WaterCube data analysis software which utilizes ADCP data in an entirely new fashion to provide detailed, 3D maps of topography and water velocity over large bodies of water
- Design and implementation of hydraulic and hydrological studies including instream flow and irrigation efficiency studies
- Design and installation of monitoring systems for hydraulic data and other parameters, including real time telemetry and remote data access
- Hydraulic modeling and data analysis

SonTek/YSI, Inc., Senior R&D Engineer, 1994 to 1998, 2001 to 2012



Craig led the design of acoustic instruments for the measurement of water depth, velocity and flow. His responsibilities included:

- New product development and support: acoustic systems, hydraulic measurement, modeling, firmware/software coding, user interface, data analysis, documentation, and field testing
- Direct responsibility for the design of new measurement firmware and data analysis techniques optimized for each application
    - Instruments included the FlowTracker, Argonaut-SL, Argonaut-SW, SonTek IQ, and the SmartPulseHD® measurement technology that provides un-matched velocity data quality from the RiverSurveyor ADCP
- Coordination of all aspects of product development including supervision of mechanical, electrical, and software engineers
- Extensive field data collection to evaluate and document instrument operation

United States Antarctic Program, 1999 to 2000

Craig managed and operated a variety of instruments in support of scientific experiments conducted from two research vessels operated in the waters around Antarctica. Measurements included water velocity, salinity, temperature, multi-beam sonar, and geomorphic bed profiling.

University of Hawaii, 1992 to 1994

Craig performed field work, developed data processing software, and managed data collection for ADCPs operating from research vessels working throughout the Pacific Ocean. The data collection includes measurements from vessel mounted ADCPs, and deployed ADCPs providing current profiles over the full depth of the ocean up to 5 km.