ULTRASONIC MEASUREMENTS OF SUSPENDED SEDIMENT CONCENTRATIONS AT HARRIS BAYOU

Wayne Carpenter, Senior R&D Engineer, University of Mississippi, National Center for Physical Acoustics, University, MS, wocarpen@olemiss.edu;
Daniel Wren, Research Hydraulic Engineer, USDA, ARS-NSL, Oxford, MS, daniel.wren@ars.usda.gov;
Bradley Goodwiller, Research and Development Engineer, University of Mississippi, Dept. of Mechanical Engineering, University, MS, btgoodwi@olemiss.edu;
James Chambers, Associate Dean for Research and Graduate Programs and Associate Professor, University of Mississippi, Dept. of Mechanical Engineering, University, MS, chambers@olemiss.edu;
Thomas Kajdan, Graduate Research Assistant, University of Mississippi, Dept. of Civil Engineering, University, MS, alex.kajdan@gmail.com;
Cristiane Surbeck, Associate Professor, University of Mississippi, Dept. of Civil Engineering, University, MS, csurbeck@olemiss.edu;
Roger Kuhnle, Research Hydraulic Engineer, USDA, ARS-NSL, Oxford, MS, roger.kuhnle@ars.usda.gov

Abstract: The use of ultrasonic acoustic technology to measure the concentration of fine suspended sediments has the potential to greatly increase the temporal and spatial resolution of sediment measurements while reducing the need for personnel to be present at gauging stations during storm events. A laboratory investigation by Carpenter et. al (2009, 2014) was undertaken by the National Center for Physical Acoustics in cooperation with the USDA-ARS National Sedimentation Laboratory. In these experiments, two immersion transducers were used to measure attenuation from 20 MHz acoustic signals propagated through suspended clay (smectite and kaolinite) and silt particles (i.e. clays and silts ranging from 0.03–14 micrometer particle size diameter) for a wide range of concentrations (0.3–14 g/L). Attenuation curves for each particle classification were compared to the theoretical attenuation curves developed by Urick (1948) and Sheng and Hay (1988) for scattering as presented by Landers (2010), and a model for estimating concentration was created. Subsequently, a customized field deployable system was developed using the laboratory transducer design parameters and deployed as an acoustic surrogate monitoring fine sediment particles in suspension at Harris Bayou, in cooperation with personnel from the U. S. Geological Survey. Using the laboratory and field systems concurrently, the calibration measurements show good agreement between the laboratory grade equipment and the new prototype system. The results of laboratory calibration and testing of the prototype system at Harris Bayou will be presented.

INTRODUCTION

Growing populations and increased economic development, coupled with the effects of a warming climate, will place an increased strain on water resources. The accurate measurement of sediment transport in rivers and streams, typically associated with upland erosion, is an important and ongoing problem that affects water quality (Holeman, 1968). The use of ultrasonic acoustic technology as a surrogate method to monitor the concentration of fine suspended sediments has the potential to greatly increase the temporal and spatial resolution of sediment measurements.

METHODOLOGY

In order to improve the state of knowledge, laboratory investigations by Carpenter et. al (2009, 2014) were conducted at the National Center for Physical Acoustics with collaboration from the USDA-ARS National Sedimentation Laboratory. In the experimental setup, two immersion transducers were used to measure attenuation from 20 MHz acoustic signals propagated through suspended clay (smectite and kaolinite) and silt particles (i.e. clays and silts ranging from 0.03–14 micrometer particle size diameter) for a wide range of concentrations (0.3–14 g/L). Attenuation curves for each particle classification were compared to the theoretical attenuation curves developed by Urick (1948) and Sheng and Hay (1988) for scattering as presented by Landers (2010), and a model for estimating concentration was created assuming spherical-sized particles. The calibration curve is valid for silt-sized particles (D_{50} = 20 μm).

$$\alpha_s = SSC_v * k(\gamma - 1)^2 * \left(\frac{s}{s^2 + (\gamma + \tau)^2}\right) + \frac{k^4 * a_s^3}{5 * (1 + 1.3\, k^2 a_s^2 + 0.24\, k^4 a_s^4)} * \frac{8.686}{2} \quad (1)$$

where,

α_s is a coefficient of attenuation, measured in $\left({}^{dB}/_{cm}\right)$

SSC_v is the volumetric sediment concentration (*SSC* divided by the sediment density)

k is the wave number, $k = \frac{2\pi}{\lambda}$, where λ is the wavelength in cm

γ is the specific gravity of the sediment

a_s is the sediment radius in cm

$$s = \left[\frac{9}{4\beta a_s}\right] * \left[1 + \frac{1}{\beta a_s}\right]$$

$$\tau = \left[0.5 + \frac{9}{4\beta a_s}\right]$$

$\beta = \left[\frac{\omega}{2\nu}\right]^{0.5}$, $\omega = 2\pi f$ and ν is the kinematic viscosity of the water.

A customized field deployable system was developed using the laboratory transducer design parameters and a digital signal processor (DSP).

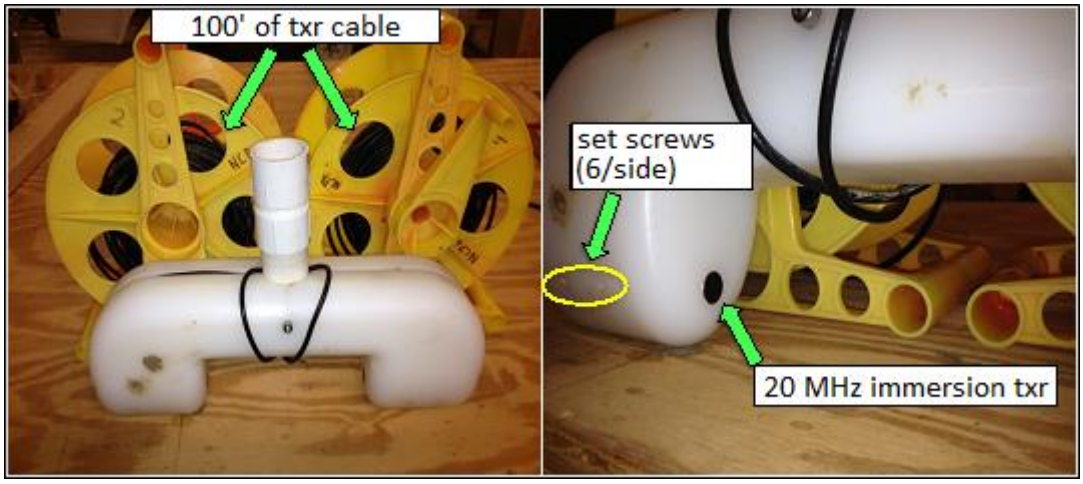

Figure 1 Field-Grade Transducer Casing

RESULTS

Using the laboratory and field systems concurrently, the calibration measurements show good agreement and a high level of reproducibility between the laboratory grade equipment and the new prototype system.

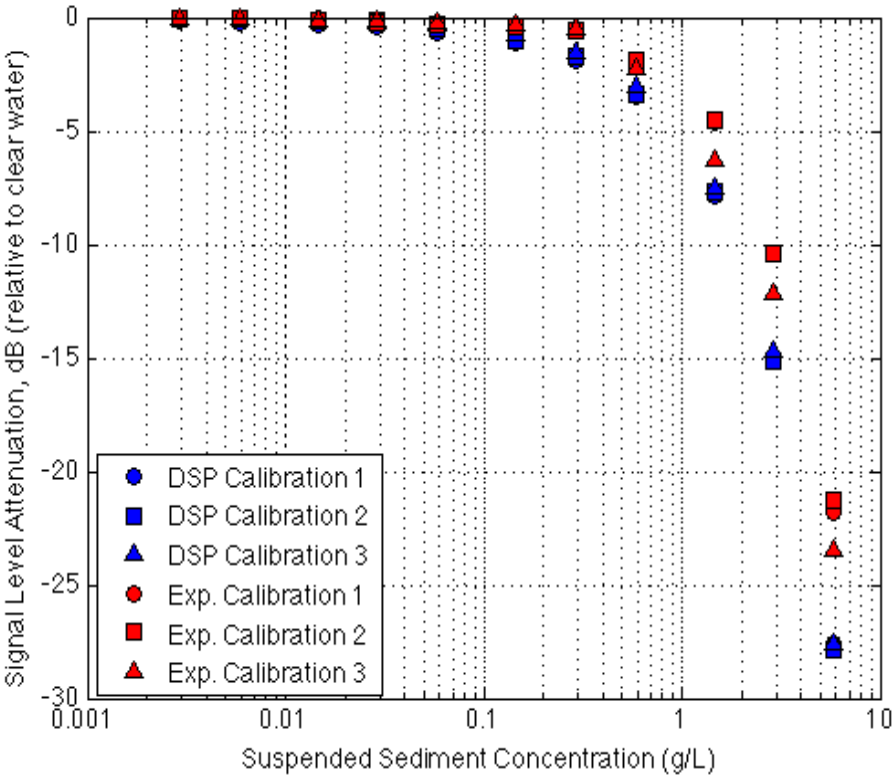

Figure 2 Comparison Plot DSP System vs. Experimental System

The red symbols represent the attenuation values computed by the verified experimental system during the three calibration experiments. The blue symbols represent the attenuation values that were found using the DSP system. Following the comparison, it was concluded the first well-defined signal drop was shown at 0.15 g/L. It is estimated that the upper detection threshold of the DSP system is ≈ 6.0 g/L.

Subsequently, the field system was deployed to monitor suspended fine sediment particles, less than 100 microns in diameter. In cooperation with personnel from the U. S. Geological Survey, the DSP system was deployed at Harris Bayou near Alligator, MS. The Harris Bayou watershed is a 71,592-acre watershed located in Bolivar and Coahoma Counties, Mississippi. The transducers were submerged in the bayou, and continuous in-situ measurements of fine suspended sediments were conducted. The acoustically measured suspended sediment concentration (SSC) data were compared with grab samples taken in predetermined intervals throughout the data collection period. Statistical methods were used to validate the accuracy of the acoustic prediction. However, field results were inconclusive, and the acoustic predictive model did not agree with the grab samples. Therefore, current studies are underway to examine the effect of water temperature on the acoustic prediction.

CONCLUSION

Multiple field trials were conducted at Harris Bayou to validate the prototype DSP system. A conversion scheme was successfully developed to convert the binary data from the field. The conversion routine can be used for future field trials. The acoustic SSC results were compared with the SSC found in the grab samples. It was shown that additional parameters, such as water temperature at near surface may be affecting the acoustic response of the system. Additional variation could result from the variation of pH, conductivity, and nutrient concentrations. This hypothesis should be evaluated in future work. It is recommended that an independent evaluation be conducted to determine if these factors have any effect on the acoustic response of the DSP system. Work is proceeding to calibrate the system with respect to temperature.

REFERENCES

Carpenter, W.O., Chambers, J.P., Wren, D.G., Kuhnle, R.A., Diers, J.A. (2009). "Acoustic Measurements of Clay-Size Particles," Journal of the Acoustical. Society of America Express Letters, 126(6).

Carpenter, W.O., Goodwiller, B.T., Wren, D.G., Kuhnle, R.A., Chambers J.P. (2014). "Acoustic measurement of suspensions of clay and silt particles using single frequency attenuation and backscatter," Applied Acoustics, Volume 85, pp 123-129.

Holeman, J.N. (1968). "The Sediment Yield of Major Rivers of the World," Water Resources Research, 4(4), pp 737-747.

Landers, M.N. (2010). "Review of methods to estimate fluvial suspended sediment characteristics from acoustic surrogate metrics," Joint Federal Interagency Conf. (2), pp 1-2.

Sheng, J., Hay, A.E. (1988). "An examination of the spherical scatterer approximation in aqueous suspensions of sand," Journal of the Acoustical Society of America, 83(2), pp 598610.

Urick, R.J. (1948). "The absorption of sound in suspensions of irregular particles," Journal of the Acoustical Society of America, 20(1), pp 283-289.