Acoustic Measurements of Clays and Silts. Brian Carpenter (Research & Development Engineer II, National Center for Physical Acoustics, University of Mississippi, 1 Coliseum Drive, University, MS 38677, wocarpen@olemiss.edu), Daniel Wren (USDA-ARS-NSL, P.O. Box 1157, Oxford, MS 38655), Roger Kuhnle (USDA-ARS-NSL, P.O. Box 1157, Oxford, MS 38655), Jeffrey Diers (USDA-ARS-NSL, P.O. Box 1157, Oxford, MS 38655), and James Chambers (National Center for Physical Acoustics, University of Mississippi, 1 Coliseum Drive, University, MS 38677).

ABSTRACT:

Measuring the concentration of particles smaller than 100 microns in water has implications for river engineering, reservoir management, and environmental stewardship. The use of a single frequency system to measure these fine particles is attractive, since it avoids the complication and cost of multi-frequency electronics. Using two 20 MHz immersion transducers, attenuation and backscatter measurements were obtained for acoustic signals propagated through mixtures of clay (bentonite, illite, and kaolinite) and silt particles suspended in water. The resulting data set has allowed for relationships between backscatter and attenuation to be used for estimating both the concentration and clay/silt ratio in water. Detailed experimental results based on data collected in a test-tank at the National Center for Physical Acoustics will be presented, including estimates of measurement error across a broad range of concentrations (0.01 – 14 g/L) and particle sizes (0.1 – 64 micron diameter particles).

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OBJECTIVE:

Ultrasonic measurement systems can detect particles with a high degree of both spatial and temporal resolution, making them ideal for addressing the needs those who rely on sediment data. The research objective is to develop a technique for using a single acoustic frequency system to measure fine sediment particle concentrations suspended in water. Recalling attenuation measurements from Carpenter et. al (2009), it was determined that two 20 MHz immersion transducers in a pitch-catch configuration with 18 cm spacing provided a range of concentration measurements ranging roughly 0.01-14 g/L for clays and 0.01-5.5 g/L for silts. Using the aforementioned setup, the intention of this research is to create a compilation of attenuation and backscatter data with the goal of using acoustic techniques to measure the concentration of fine sediment particles (0.1 – 64 micron diameter) in water. Attenuation and backscatter data will be analyzed and presented for known concentrations of bentonite (0.2 – 1 mm), illite (0.2 – 2 mm), kaolinite (2 – 5 mm), and silt (45 – 60 mm) as well as clay/silt mixtures.

SETUP:

The 110 gallon calibration tank recirculated the known concentrations and particles sizes in water for fixed distance measurements between transducers. From the experimental setup, we can also obtain physical samples in-situ with a pump to verify our acoustic concentration measurements. This setup is shown in Figure 1.

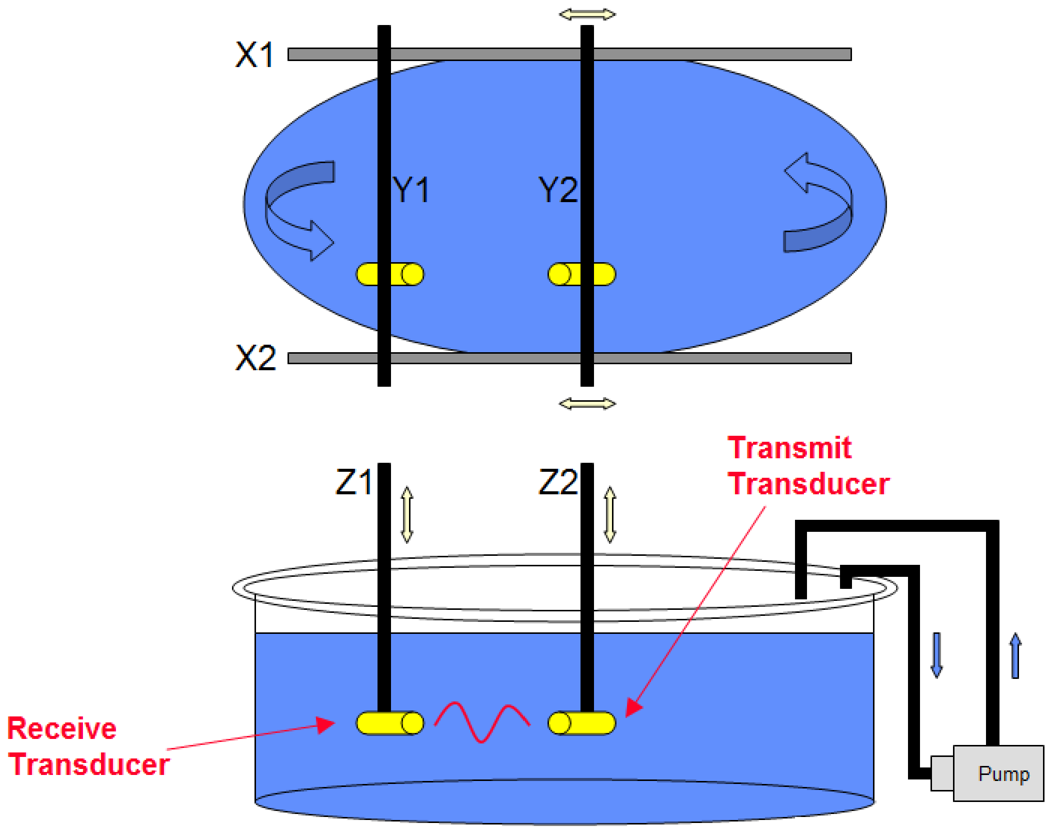

Figure 1: Recirculation Tank

Using two 20 MHz immersion transducers, data were acquired by a computer equipped with a National Instruments 1GS/s oscilloscope operating LabVIEW software written by Carpenter and a preamp. The input Signal was 20 Mhz, 300 V_{p-p}, 100 cycle, 10 ms wait between bursts, and 1000 pings/data set (3 data sets total).

SUMMARY OF ATTENUATION DATA:

In Figure 2, the signal level difference relative to clear water (dBV) is measured over a range of clays and silts concentrations. As expected, the larger particles produce consistently more attenuation and consequently, lower signal levels. The same relationship exists as concentration increases and attenuation increases, thereby, producing lower signal levels.

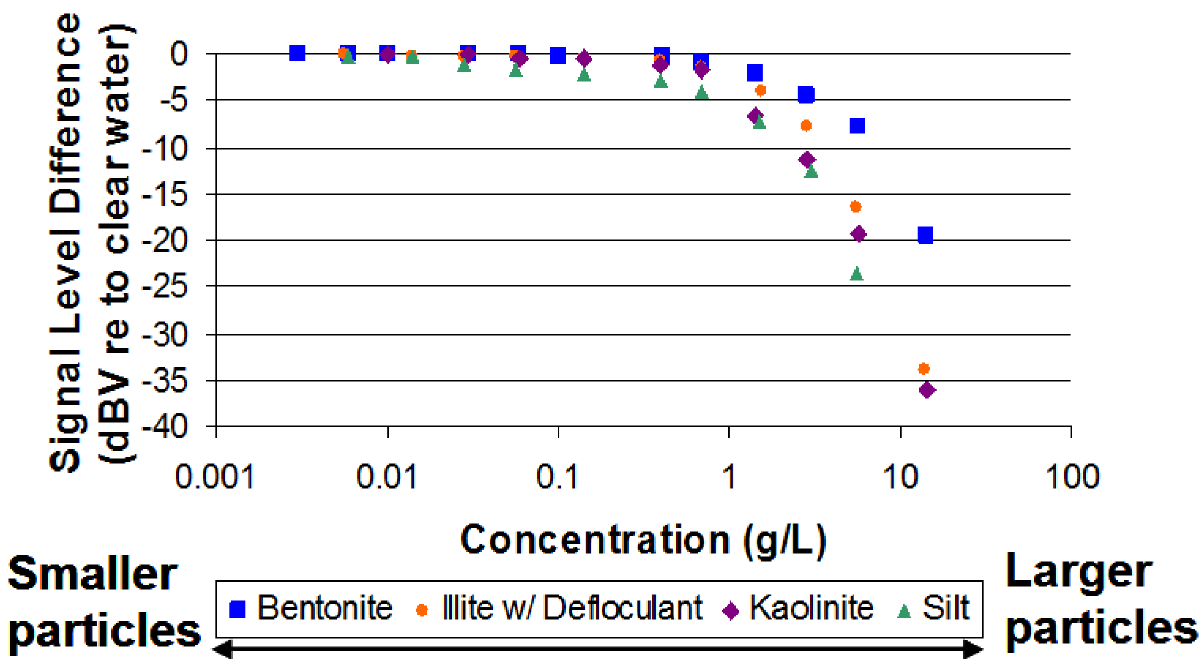

Figure 2: Summary of Attenuation Data

Under closer inspection, the relationship can also be identified for concentrations smaller than 1 g/L. In Figure 3, one can still see a prominent signal level differentiation between each of the particle sizes (0.5 dBV at 0.4 g/L). Additionally, it is noted that illite with added sodium hexametaphosphate, a deflocculant, is distinguishable from illite without deflocculant. This result illustrates the importance of proper mixing to insure all particles in the water column are suspended and evenly distributed.

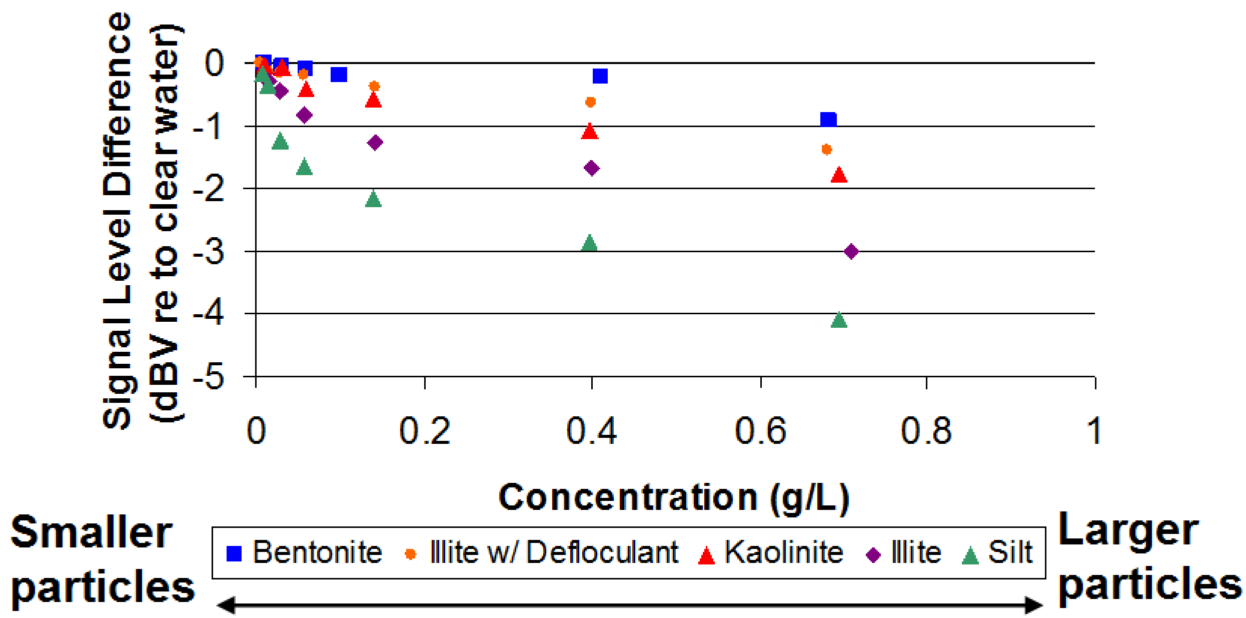

Figure 3: Close-up of Low Concentration Data

CLAY/SILT MIXTURES:

The previous work has provided a framework for expected signal level differences using attenuation between clay and silt particles in suspensions. However, much of the samples collected in-situ will be mixtures. To better understand the association of multiple particle sizes, a comparison between kaolinite clay and silt in Figure 4 shows that various ratios of kaolinite and silt lie between the individual constituents.

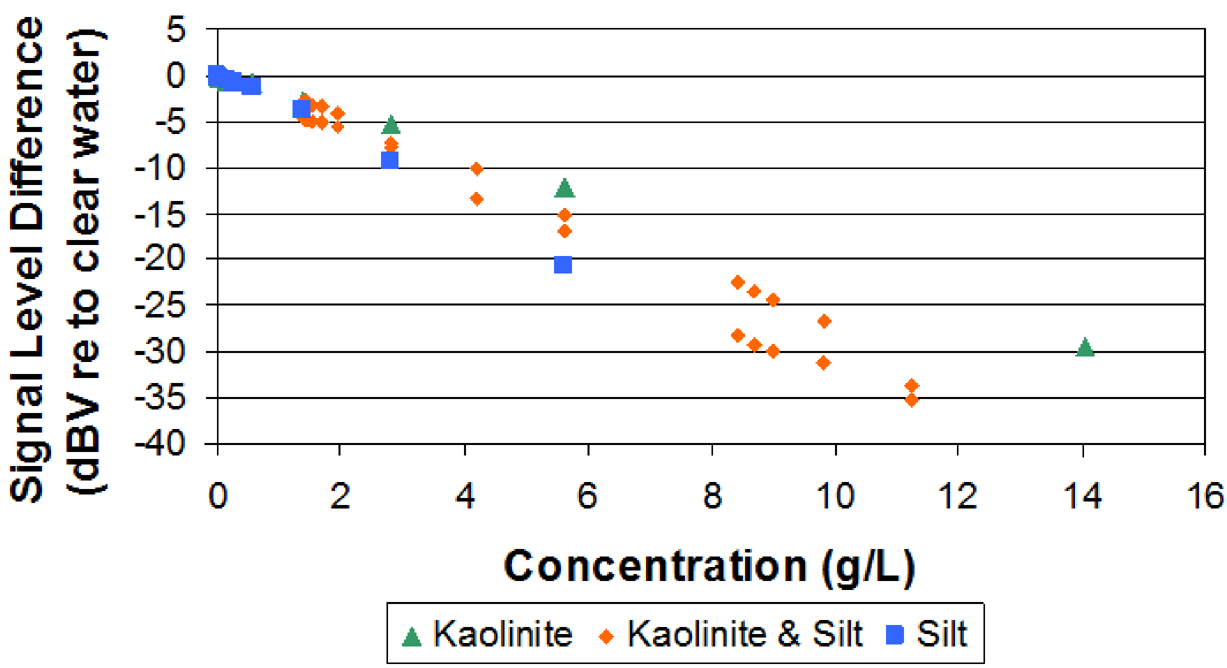

Figure 4: Comparison between Clay/Silt Mixtures vs. Kaolinite Clay and Silt

In Figure 5, analysis of the mixtures shows a differentiation between the sizes of the particle added to the overall concentration. In this plot, the x-axis is the concentration added while keeping the initial concentrations as constants. Initially, the concentration with larger concentrations of silt particles relative to kaolinite has more attenuation, but as the ratio of kaolinite to silt becomes near 1:1, one can see the two signal level difference values converge. The two studies on this plot show a repeatability of the measurement.

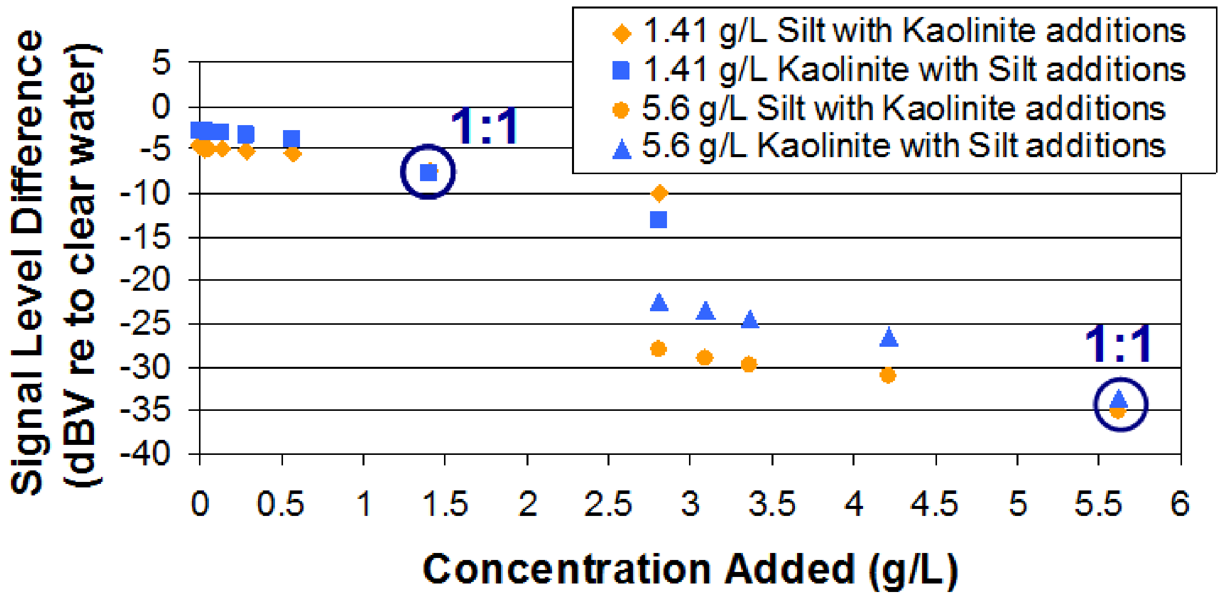

Figure 5: Attenuation for Varied Clay/Silt Mixtures

BACKSCATTER AND ATTENUATION:

Recall the summary of the attenuation data for all particle sizes and concentrations. In the field, an acoustic system measuring attenuation in a water column with suspended sediment concentrations will provide only a signal level difference. Without prior knowledge of the sediment transport or active pump sampling, a distinction between particle size and concentration cannot be made with this configuration. In Figure 6, one can note that a signal level difference can provide wide range of concentrations and particle size possibilities. Therefore, it is necessary to supplement the attenuation measurement with a backscatter measurement to identify the particle size and the concentration.

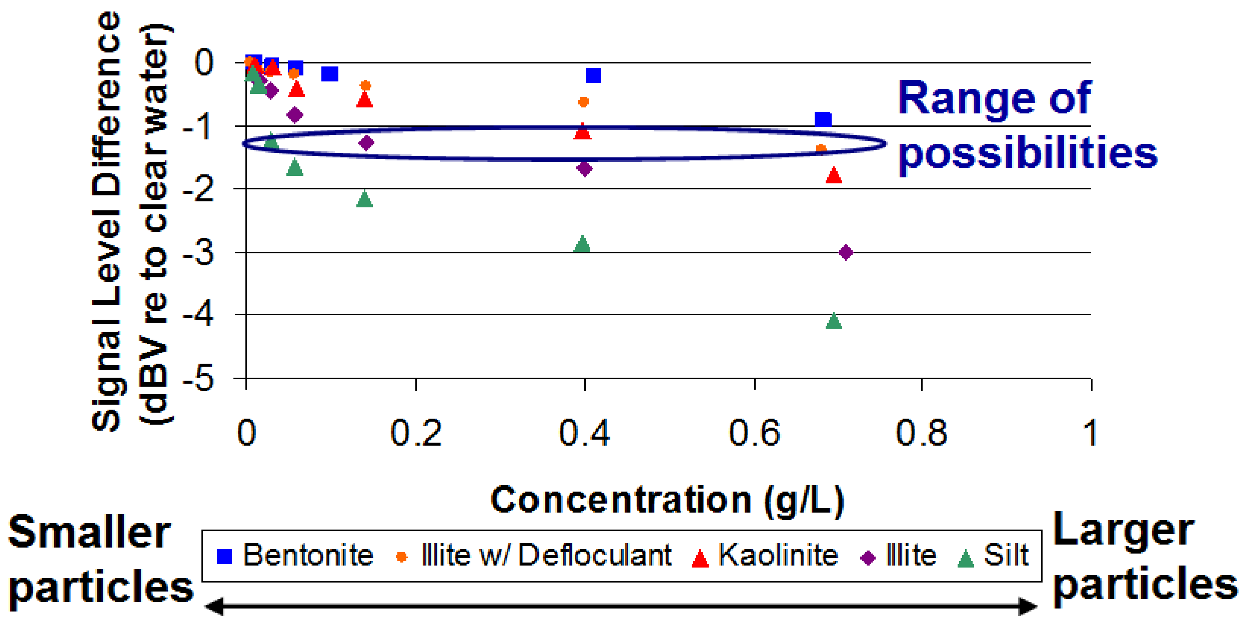

Figure 6: Close-up of Low Concentration Data (Revisited)

In Figure 7, backscatter and attenuation measurements were made for suspended bentonite particles in water. At the lowest concentrations, there is some increase in acoustic backscatter (approximately 1 dBV) with an increase in concentration. However, as the concentration increases, the individual particle scatterers are limiting the amount of backscattered signal. For concentrations larger than 0.5 g/L, it is likely added particles were flocculating and thereby decreasing the measured backscatter.

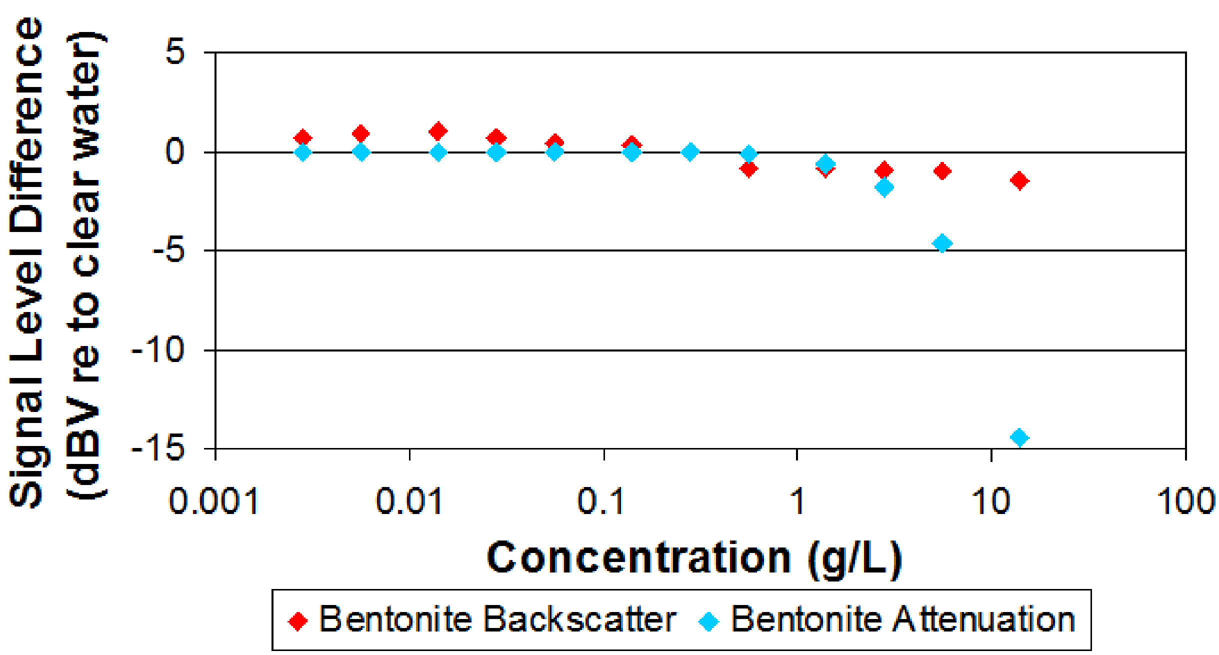

Figure 7: Backscatter and Attenuation for Bentonite (0.2 – 1 mm)

From Figure 8, a 2-3 dBV rise can be noted for the backscattered signal in suspended kaolinite particles.

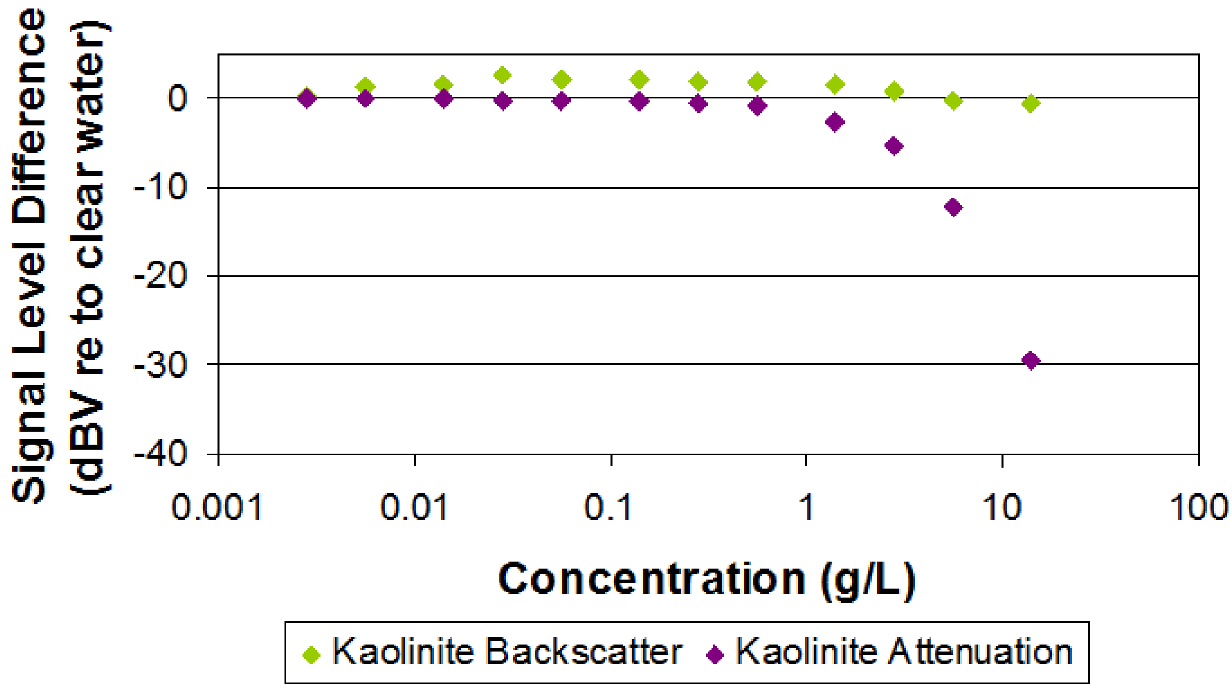

Figure 8: Backscatter and Attenuation for Kaolinite (0.2 – 2 mm)

Lastly, backscatter and attenuation results are compiled in Figure 9. In this plot, we see a net backscatter signal level change of 5 dBV in suspended silt.

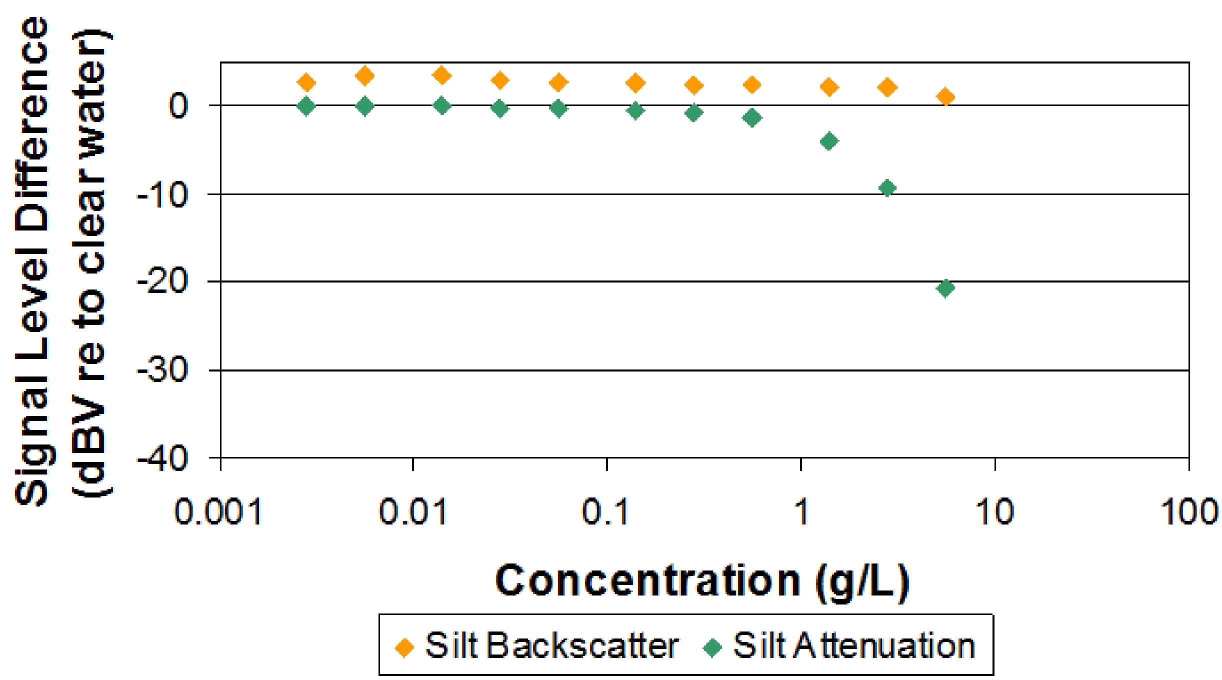

Figure 9: Backscatter and Attenuation

DATA SUMMARY:

Figures 10 and 11 show the backscatter and attenuation data compiled for bentonite, kaolinite, illite, and silt. The backscattered results are hard to distinguish each particle size. For example in Figure 10, it is difficult to discern the illite and silt backscatter results. It is also curious that kaolinite backscatter measurements for concentrations smaller than 0.01 g/L are within 0.5 dBV of bentonite and less than 2 dBV of illite.

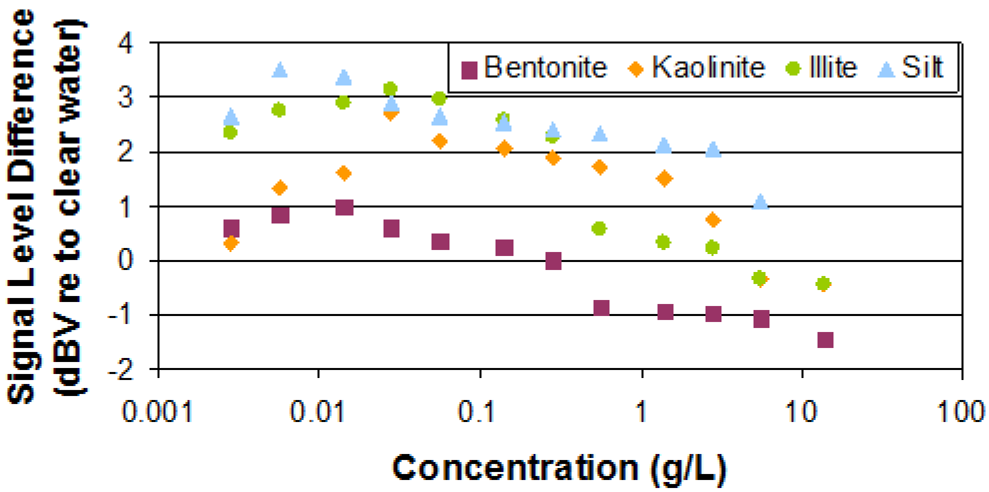

Figure 10: Summary of Backscatter Data

As previously noted, the attenuation data in Figure 11 shows a clear distinction between each of the clays and silt.

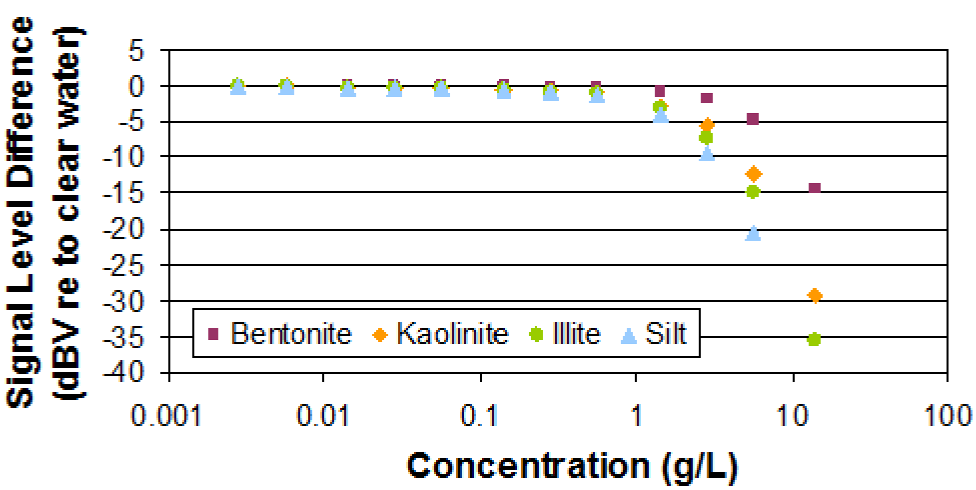

Figure 11: Summary of Attenuation Data

However, the backscatter measurements appear to have the most distinction when evaluating the presence of bentonite in concentrations of 0.01 g/L or higher. There is also a 2 dBV difference between illite and silt for concentrations larger than 0.5 g/L. Figure 12 shows the backscatter data for concentrations less than 0.6 g/L. Under these considerations, estimations of concentration can be more predictable.

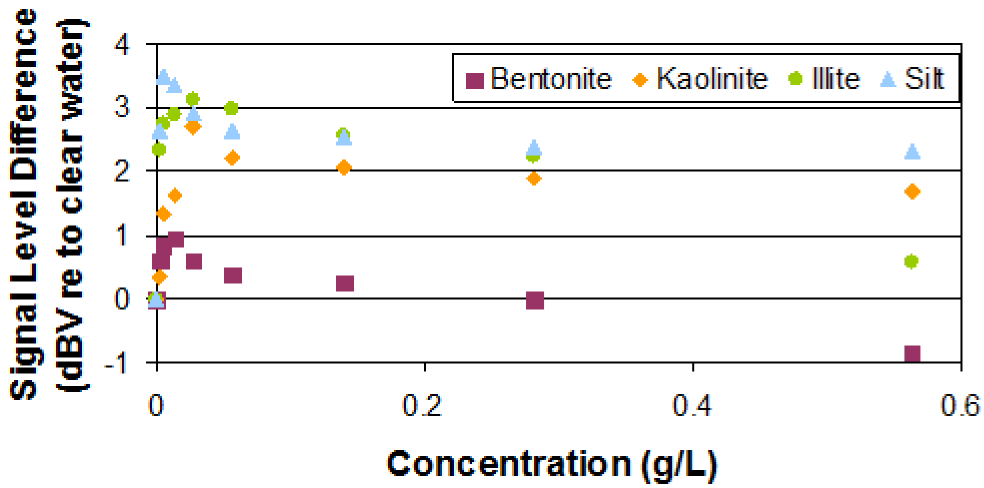

Figure 12: Summary of Backscatter Data (< 0.6 g/L)

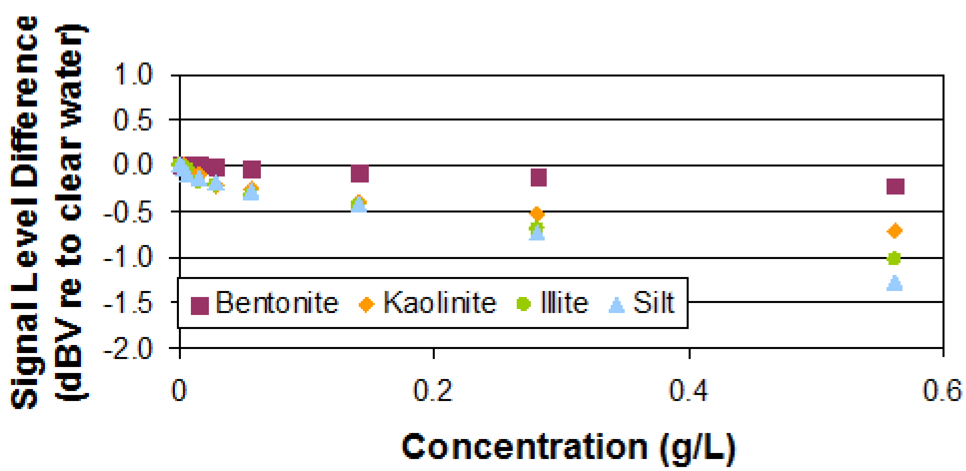

Figure 13: Summary of Attenuation Data (< 0.6 g/L)

SUMMARY:

In this research, new attenuation and backscatter data were collected for a wide range of concentrations for clays, silts, and clay/silt mixtures. The attenuation levels for the clay/silt mixtures fell between levels for individual constituents as suspected. The backscatter levels were less responsive to particle size than expected. Despite careful procedure, an explanation for this result could be flocculation of the particles. For this reason, we must continue to measure in-situ particle size. Based on the data, it is likely that the combination of backscatter and attenuation will allow for rough (clay vs. silt) particle size discrimination with 20 MHz signal.

FUTURE WORK:

In-situ effective particle-size measurements will be obtained for clays, silt, and clay/silt mixtures using LISST-100X from Sequoia Scientific. During these experiments, more rigorous measurements of the detection threshold will be investigated as well as the resolution of the measurements. Based on the results presented and those obtained in future experiments, a technique for using a single acoustic frequency to measure fine particle concentration in water will be developed. Upon development of hardware, a prototype instrument will be constructed and installed on a floating instrument platform in the ARS Goodwin Creek Experimental Watershed for use to monitor fine sediment concentrations during storm events.