Hydroacoustic Sediment Surrogates and Methods —test results for a small urban river—

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Federal Interagency Sedimentation Project Chief

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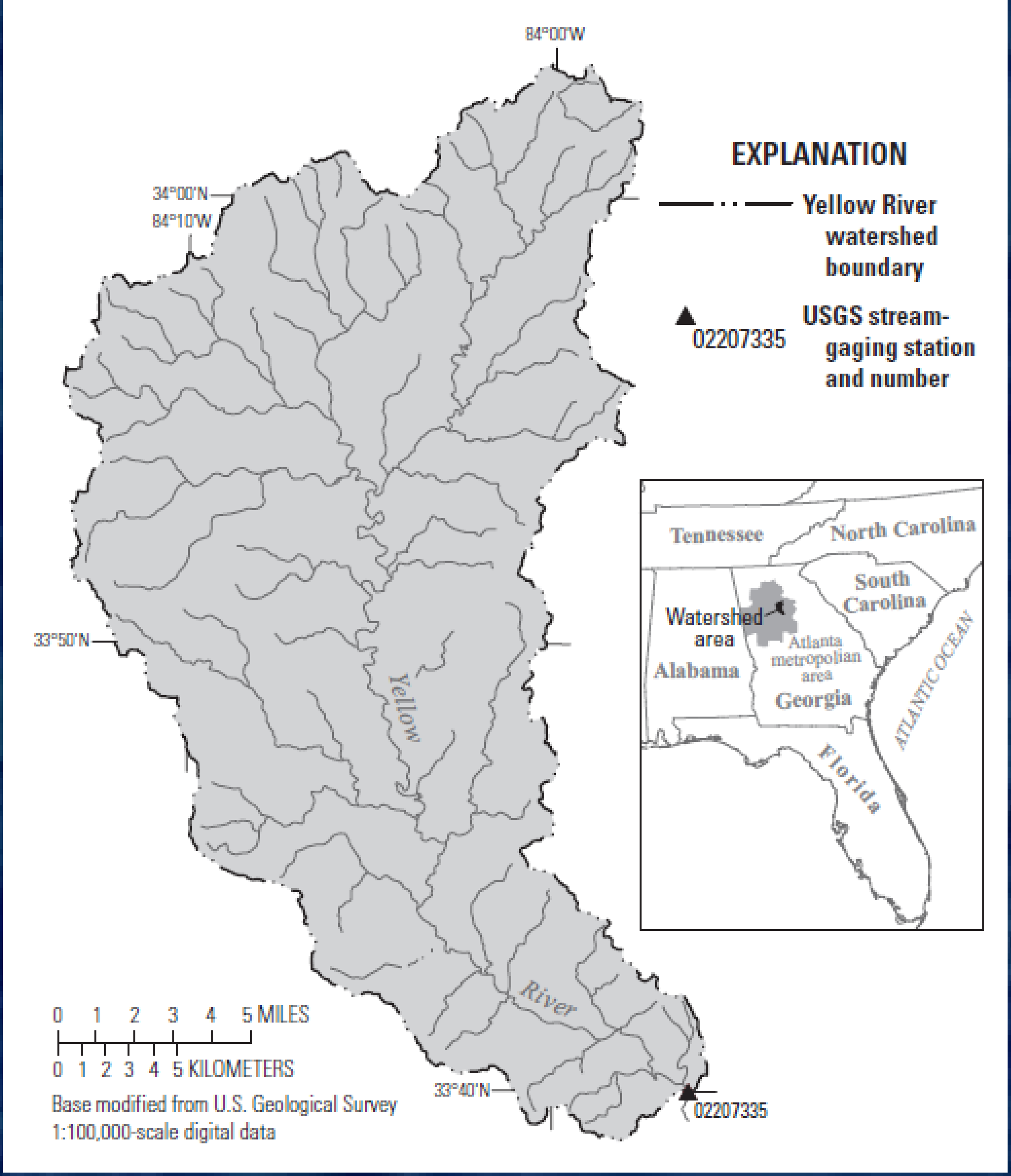
USGS, Reston, VA, and WEB-EX

water.usgs.gov/fisp

Yellow River at Gees Mill Road near Metro Atlanta, GA, 02207335



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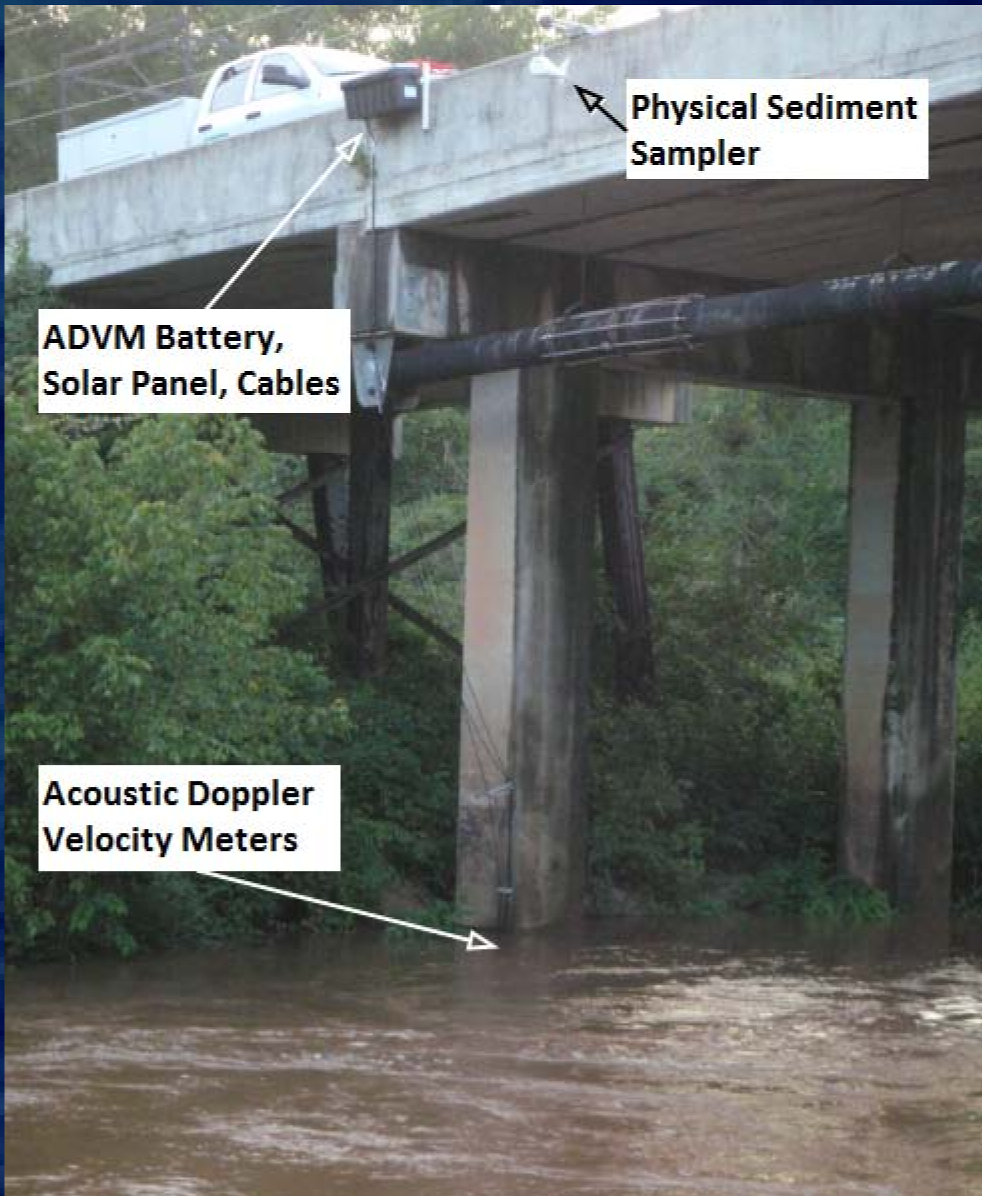
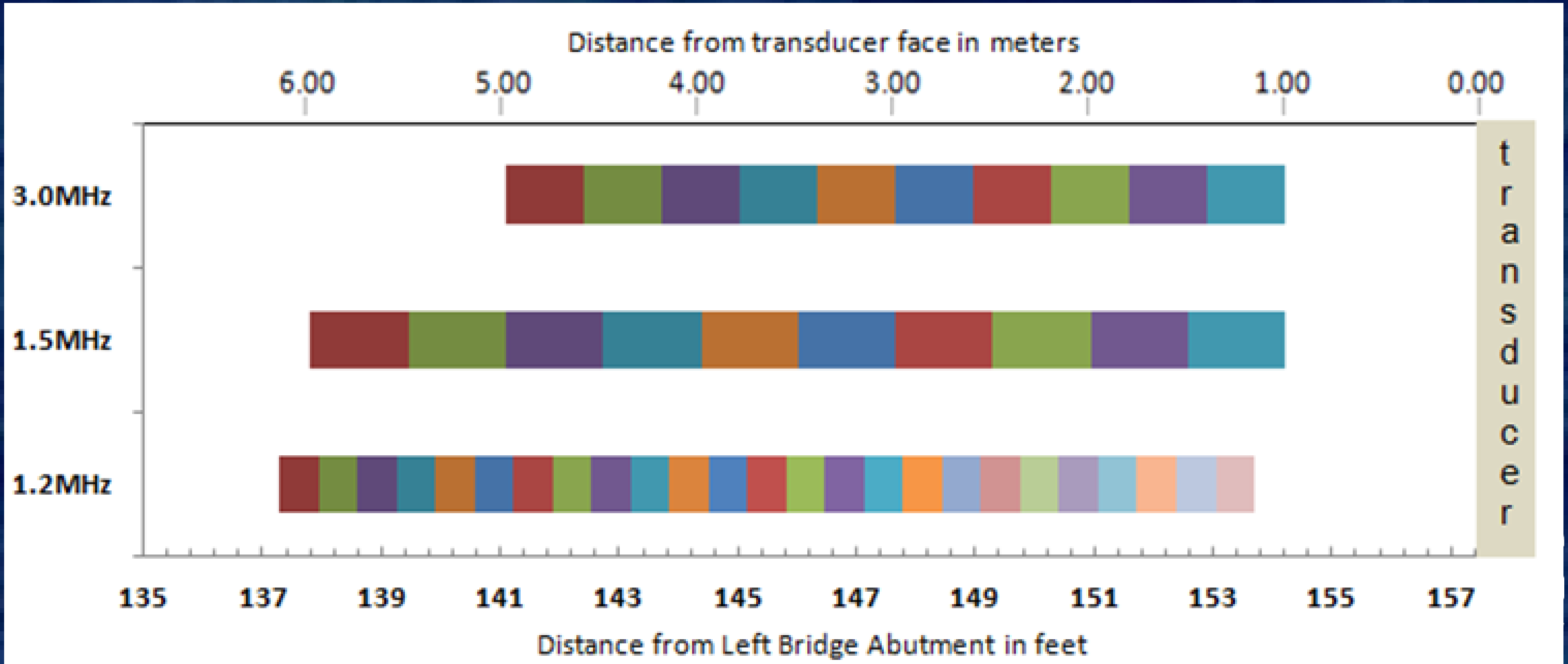


Acoustic Doppler Current Profilers

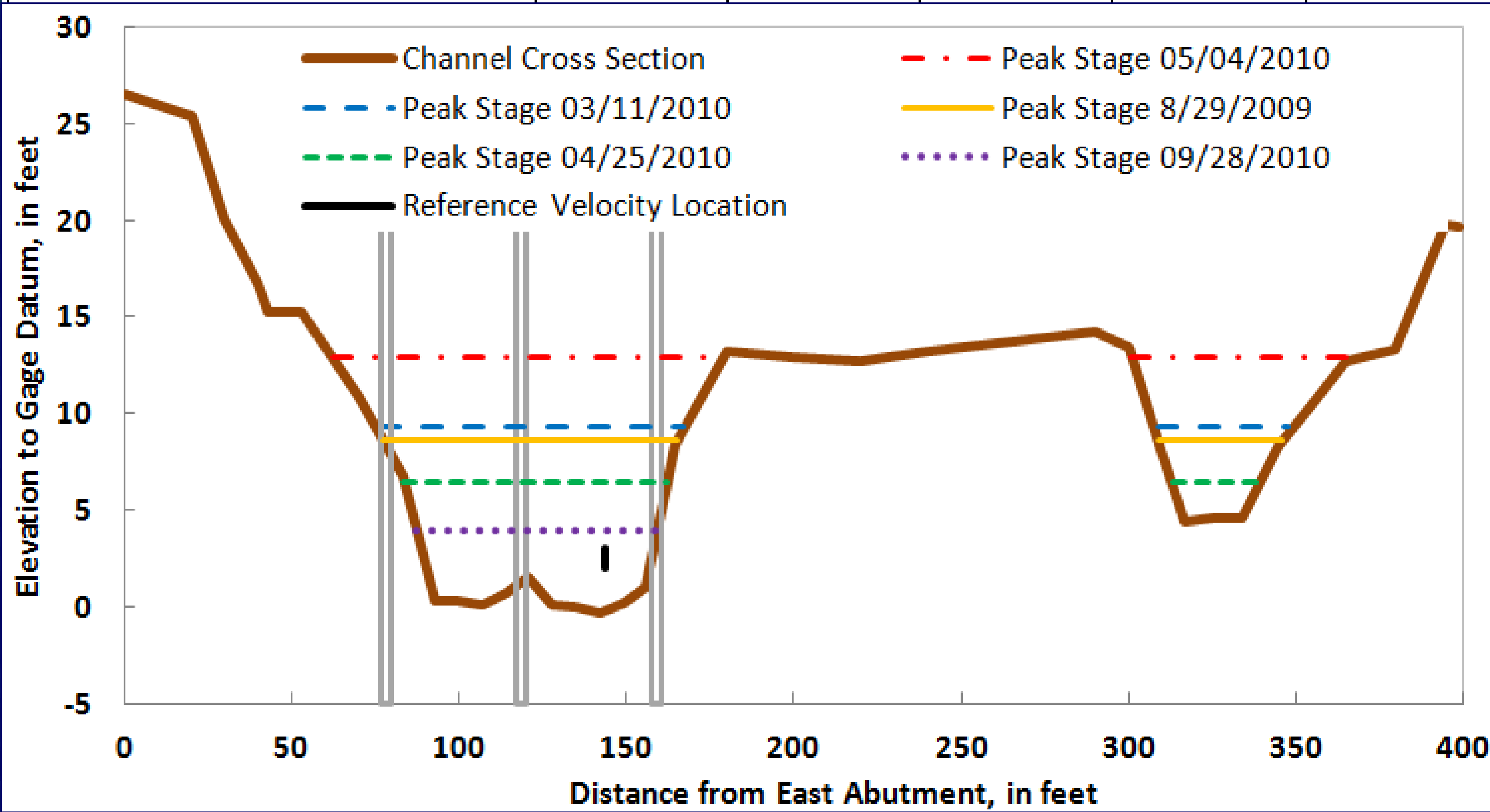
(A) 1.2MHz (B) 1.5MHz (C) 3.0MHz

Acoustic Doppler Current Profiler Configuration

	1.2MHz RDI	1.5MHz Sontek	3.0 MHz Sontek
Blank (m)	1.16	1.0	1.0
Cell Size (m)	0.2	0.5	0.4
No. of Cells	25	10	10
End Last Cell	6.16	6.0	5.0



Event Begin Date	8/28/2009	3/10/2010	4/24/2010	5/3/2010	9/27/2010
Start and End Time, Month/Day	01:00 08/28 12:00 09/02	13:00 03/10 13:00 03/15	14:00 04/24 04:00 04/27	04:00 05/03 00:00 05/06	14:00 09/27 12:00 10/01
Peak Flow, cfs	1800	2640	1270	5070	368
Peak Stage, feet	8.56	9.36	6.43	12.85	3.89
Total Precipitation, inches	2.67	2.33	1.49	2.23	2.18
Total Runoff, inches	0.58	0.86	0.26	1.16	0.15
Event Duration, days	5.5	4.0	2.6	2.8	3.9



Acoustic Surrogates of SSC

- Urick's Method:

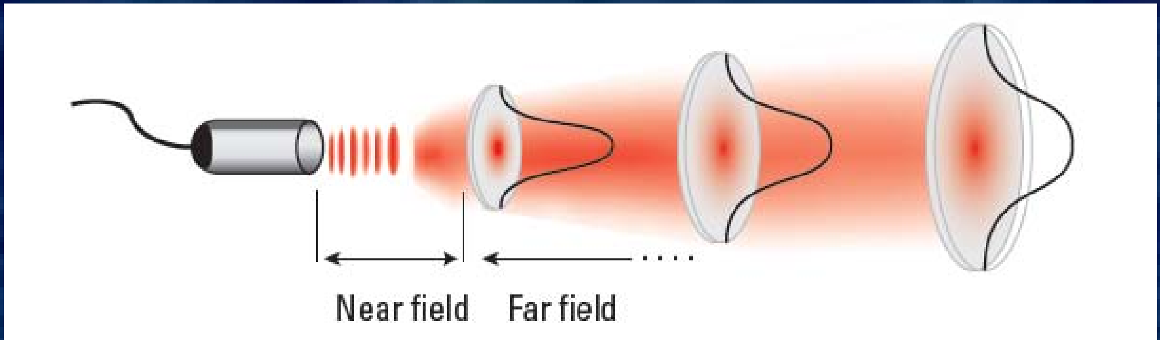
$$SSC = 10^{(A+B\,(RL + 2TL))}$$

Measured Backscatter

$$2TL = 20\log_{10}(\psi r) + 2r(\alpha_s + \alpha_w)$$

Computed WaterAttenuation

$$\alpha_w = 8.686\, f^2\,(55.9 - 2.37T + 0.0477T^2 - 0.000348T^3)\,10^{-15}$$



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Acoustic Surrogates of SSC

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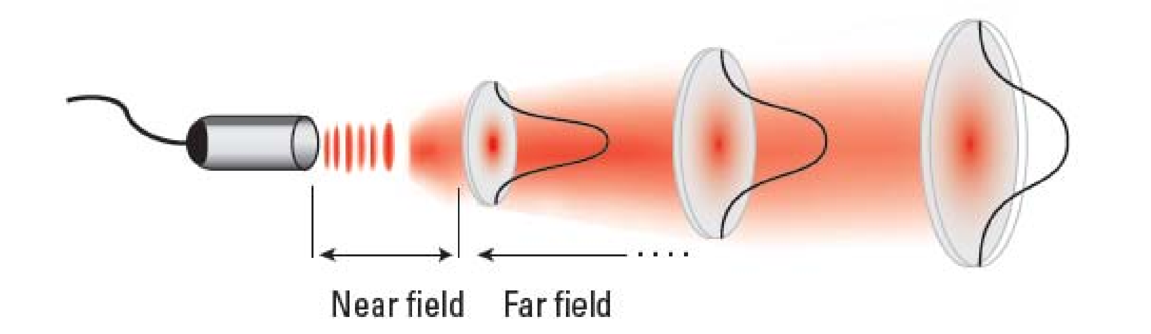
Computed WaterAttenuation

$$\psi(r) = 1 + \frac{1}{(1.35r/r_n) + (2.5r/r_n)^{3.2}}$$

Near Field for 3.0 MHz SW (27mm dia) is 1.16m; for 1.5MHz SL (50mm dia) is 1.98m; for 1.2MH RDI ChanMaster (70mm dia) is 3.11.
Correction at 1m for each is about 4%, 20%, and 70%, respectively.



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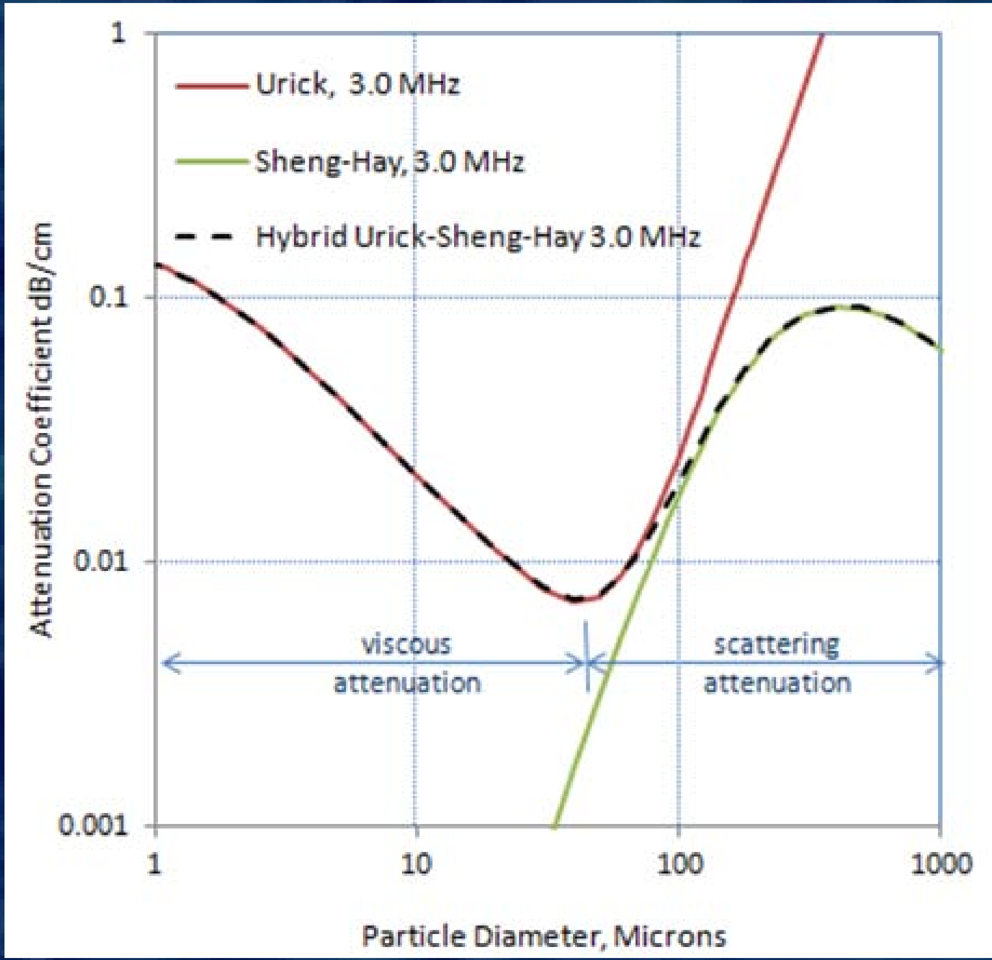
Acoustic Attenuation by Sediment:

$$\alpha_S = SSC_V \left[k(\gamma - 1)^2 \left\{ \frac{s}{s^2 + (\gamma + \tau)^2} \right\} + \left\{ \frac{k^4 a^3}{5(1 + 1.3k^2a^2 + 0.24k^4a^4)} \right\} \right] 4.34$$

Hybrid Urick-Sheng-Hay Method:



$$s = \left(\frac{9}{4\beta a} \right) \left(1 + \frac{1}{\beta a} \right)$$

$$\tau = \left(0.5 + \frac{9}{4\beta a} \right)$$

$$\beta = \sqrt{\frac{\omega}{2\nu}}$$

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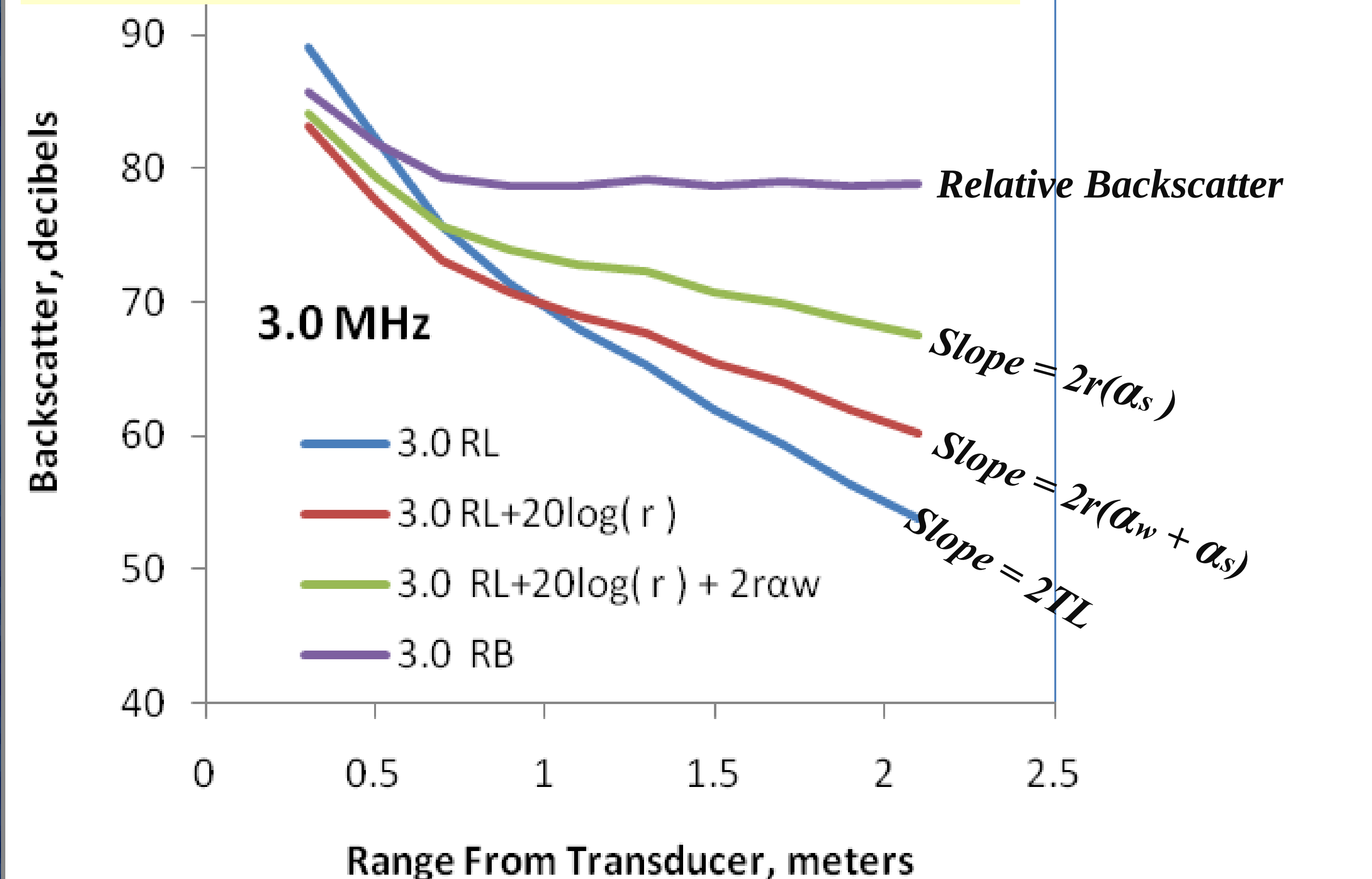
Acoustic Attenuation by Sediment:

- Backcatter Amplitude Profiles: Measured & Normalized

$$\alpha_s = -\frac{1}{2}\frac{d}{dr}\left(RL + 20\log_{10}(\psi r) + 2r\alpha_w\right)$$



Acoustic Surrogates of SSC

- Urick's Method:

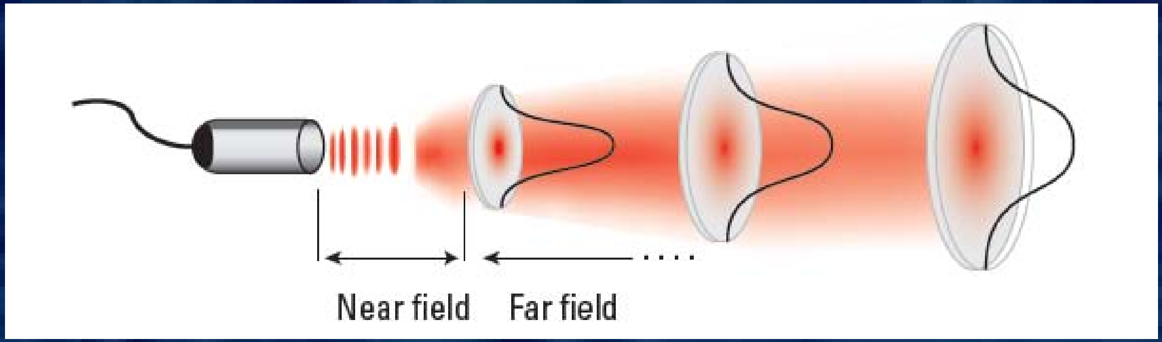
$$SSC = 10^{(A+B\,(RL + 2TL))}$$

Measured Backscatter

$$2TL = 20\log_{10}(\psi r) + 2r(\alpha_s + \alpha_w)$$

Measured Sediment Attenuation

Computed WaterAttenuation



Acoustic Surrogates of SSC

Dependent ~ Independent Parameters	R^2	Residual Standard Error	Slope	p< 0.001	Degrees of Freedom
$log(SSC_{xs})$ ~ $RB_{1.5MHz}$	0.76	0.159	0.032	Y	182
$log(SSC_{xs})$ ~ full $\alpha_{s\ 1.5MHz}$	0.57	0.211	0.298	Y	182
$log(SSC_{xs})$ ~ sub $\alpha_{s\ 1.5MHz}$	0.38	0.256	0.151	Y	181
$log(SSC_{xs})$ ~ $RB_{3.0MHz}$	0.77	0.157	0.032	Y	183
$log(SSC_{xs})$ ~ full $\alpha_{s\ 3.0MHz}$	0.61	0.204	0.244	Y	183
$log(SSC_{xs})$ ~ sub $\alpha_{s\ 3.0MHz}$	0.43	0.244	0.175	Y	183
$log(SSC_{xs})$ ~ $RB_{1.2MHz}$	0.75	0.140	0.022	Y	150
$log(SSC_{xs})$ ~ full $\alpha_{s\ 1.2MHz}$	0.47	0.204	0.210	Y	150
$log(SSC_{xs})$ ~ sub $\alpha_{s\ 1.2MHz}$	0.31	0.232	0.115	Y	150
$log(SSC_{xs})$ ~ log(velocity)	0.60	0.207	2.036	Y	184

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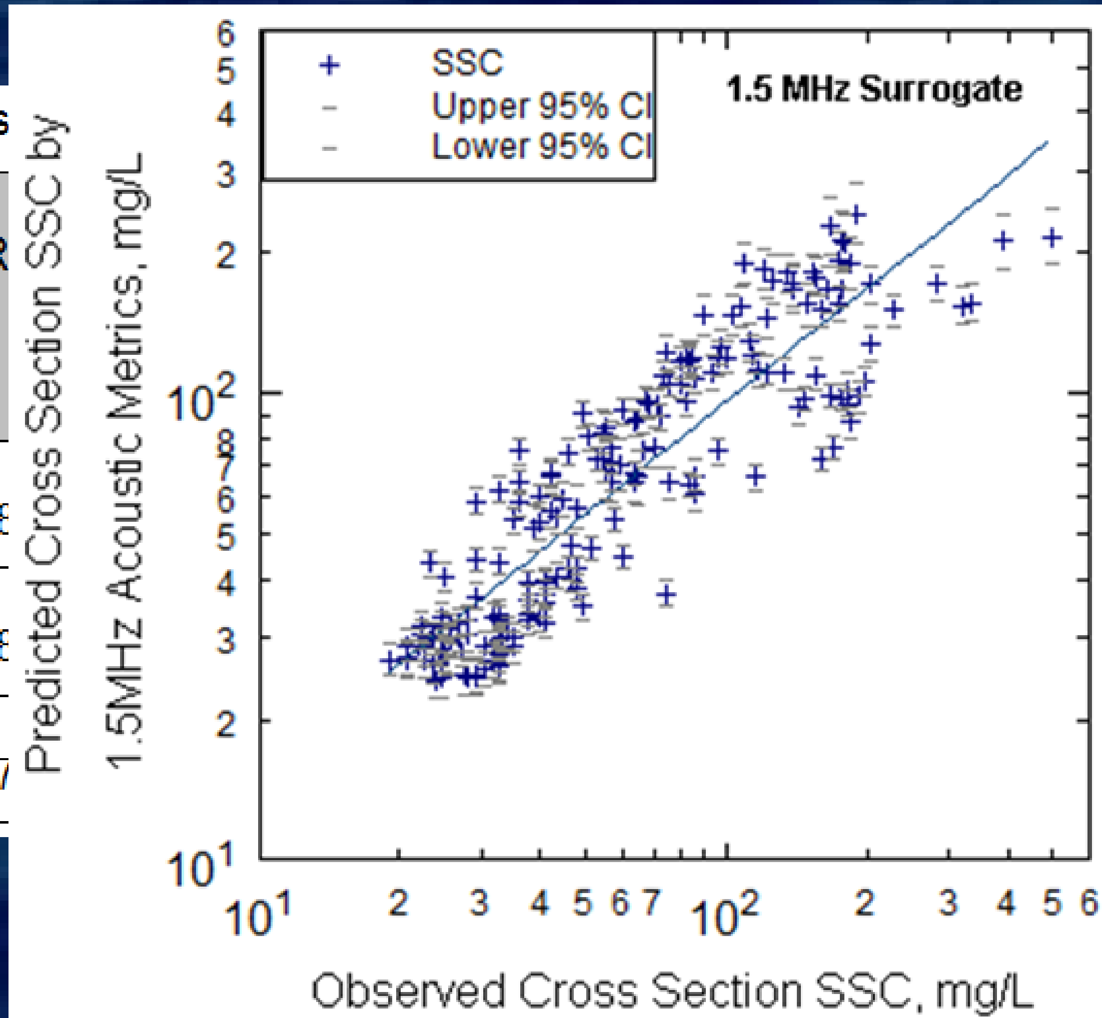
Acoustic Surrogates of SSC

Table 9.2—Res ... surrogate metrics

Explan-atory Variables	R ...	Model
$RB_{1.5MHz}$ $\alpha_{s\ 1.5MHz}$	0.8	.0543 $\alpha s_{1.5MHz}$
$RB_{3.0MHz}$ $\alpha_{s\ 3.0MHz}$	0.8	0.0611 $\alpha s_{3.0MHz}$
$RB_{1.2MHz}$ $\alpha_{s\ 1.2MHz}$	0.7	0.0476 $\alpha s_{1.2MHz}$



Conclusions re: Acoustic Backscatter and Attenuation as Surrogates of Suspended Sediment Concentration

- The methods proposed by Topping et al. (2007) to empirically measure acoustic attenuation from profiling ADCP measurements do apply for a stream in the southeastern USA.

- Using both relative acoustic backscatter (*RB*) and acoustic attenuation as explanatory variables results in a significantly improved model of SSC_{XS}, compared with traditional sonar equations using only *RB*.

- Fluvial suspended sediment concentration can be determined by high-resolution acoustic measurements with much greater accuracy than using traditional SSC ~ streamflow discharge ratings. R^2 improved from 0.57 to (0.79 to 0.80); and model residual standard error improved from 73% to (34% to 40%).

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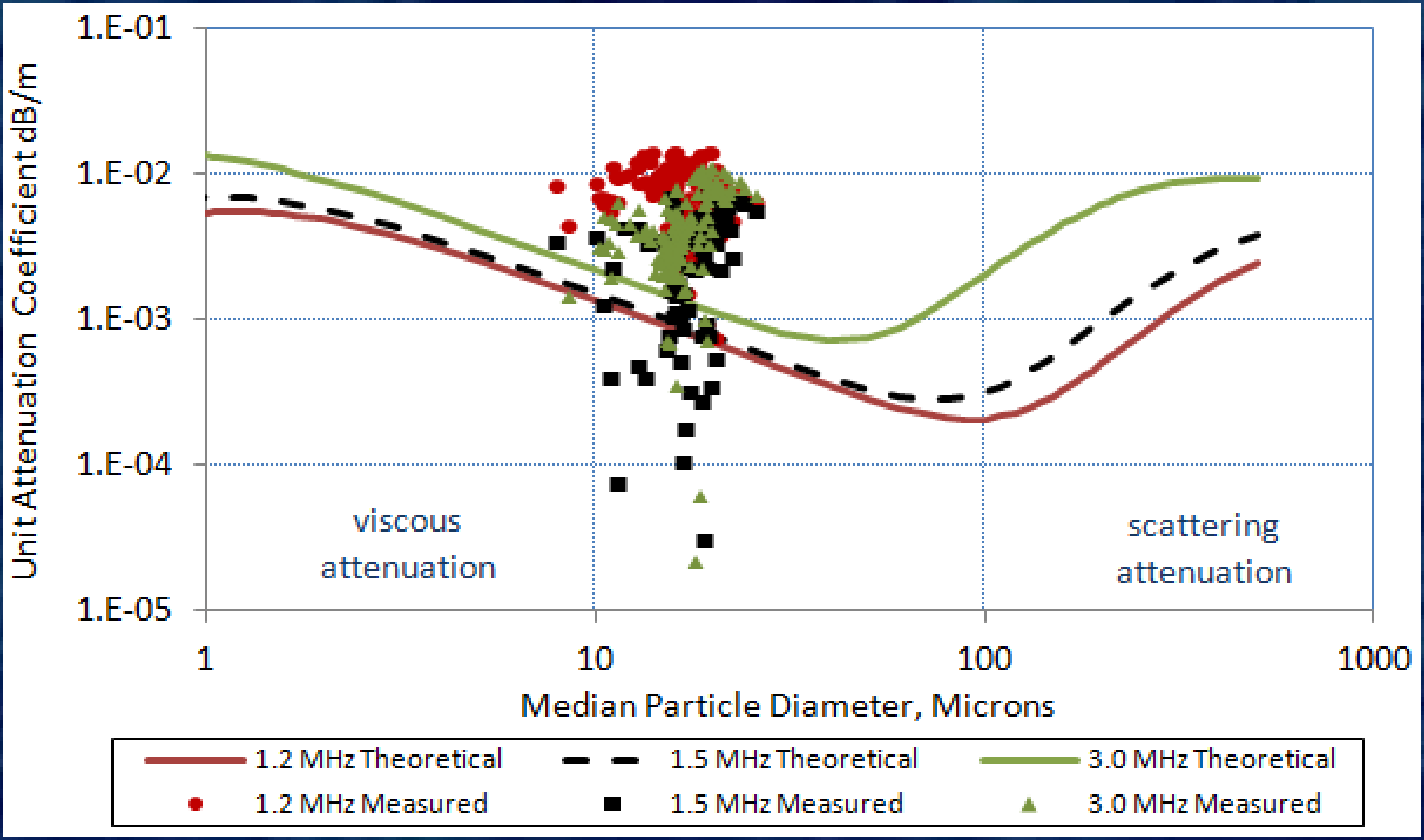
Sediment Size from Acoustic Attenuation



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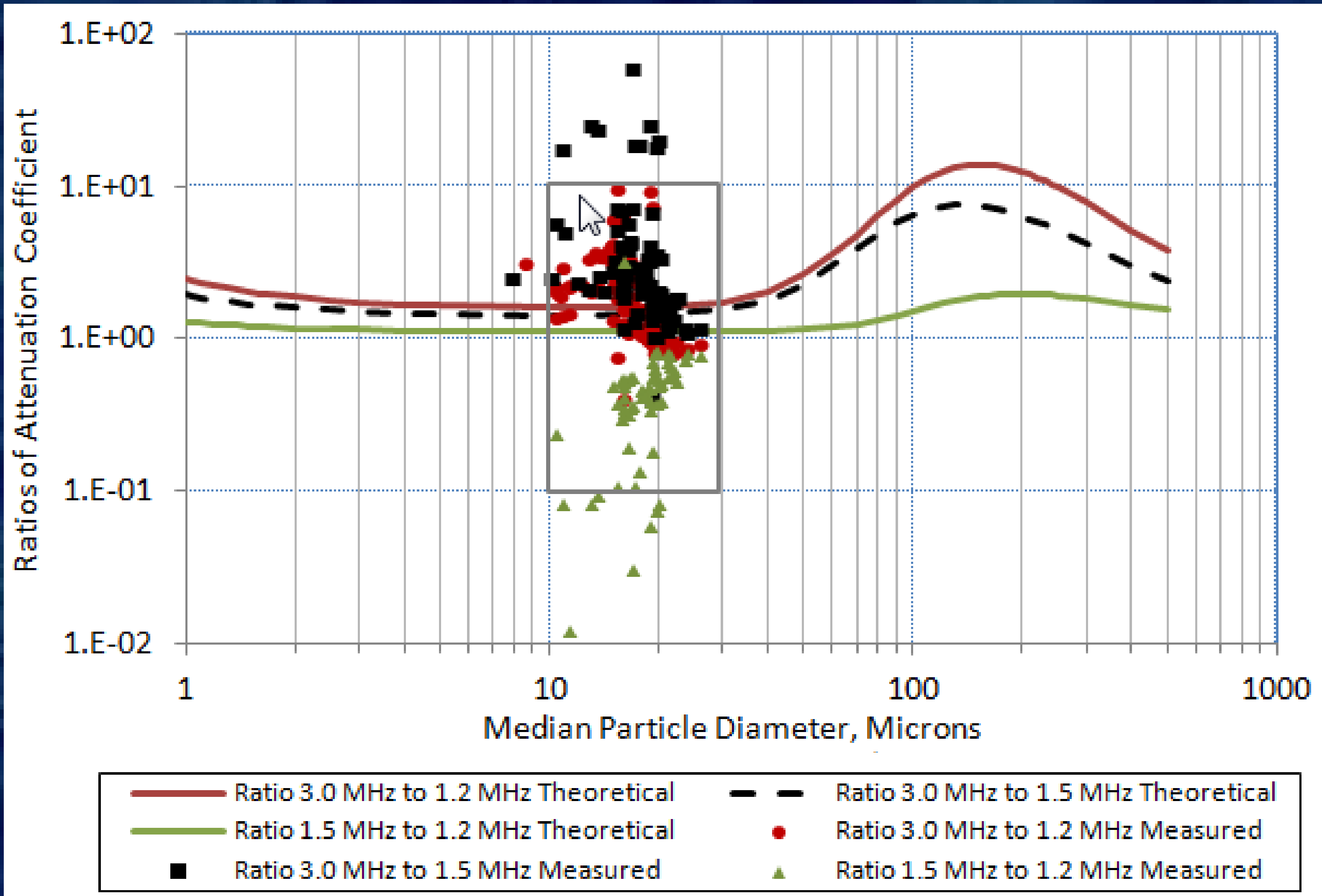
Sediment Size from Acoustic Attenuation



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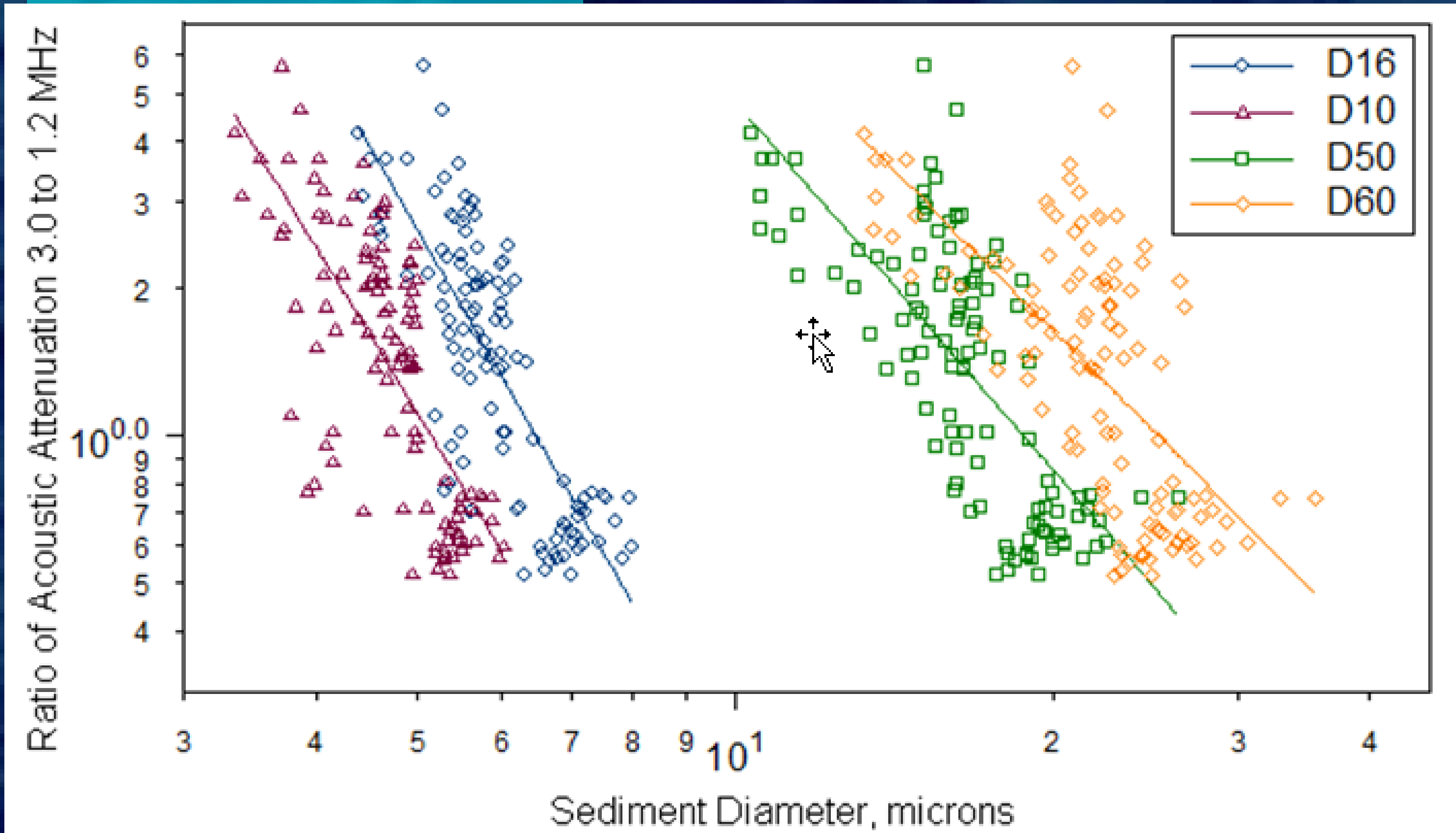
Sediment Size from Acoustic Attenuation



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Conclusions re: Acoustic Attenuation Surrogates of Sediment Size

- Representative particle sizes cannot be determined from these data by optimizing the theoretical acoustic attenuation equation using measured acoustic attenuation for single acoustic frequencies nor for ratios of multiple acoustic frequencies.

- Suspended sediment PSD is significantly correlated with ratios of measured acoustic attenuation at different frequencies.

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Recommendations for Further Research

This study has identified the following needs for further research:

- Evaluate measured and theoretical acoustic attenuation for characterization of suspended sediment size. The data needed for this research includes concurrent measurements of SSC, full PSD, and multi-frequency profiles of acoustic backscatter and attenuation on different streams having diverse sediment characteristics.
- Test, validate, and develop generalized methods for use of acoustic backscatter and attenuation for estimation of suspended sediment concentration and load.

Sediment Size from Acoustic Attenuation

Dependent ~ Independent Variable (logarithmic space)	R^2	Residual Std Err	Std Err %	Slope	$p<0.001$
D10 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.2}$	0.54	.0389	9	-0.15	Y
D16 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.2}$	0.64	.0352	8	-0.17	Y
D50 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.2}$	0.53	.0549	13	-0.21	Y
D60 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.2}$	0.33	.0734	18	-0.20	Y
D84 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.2}$	0.02	.1466			N
D10 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.5}$	0.38	.0782	28	-0.14	Y
D16 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.5}$	0.39	.0679	17	-0.12	Y
D50 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.5}$	0.32	.0710	18	-0.11	Y
D60 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.5}$	0.23	.0736	18	-0.09	Y
D84 ~ Ratio $\alpha_{s3.0} / \alpha_{s1.5}$	0.0	.115			N
D10 ~ Ratio $\alpha_{s1.5} / \alpha_{s1.2}$	0.35	.0464	11	0.09	Y
D16 ~ Ratio $\alpha_{s1.5} / \alpha_{s1.2}$	0.40	.0438	11	0.10	Y
D50 ~ Ratio $\alpha_{s1.5} / \alpha_{s1.2}$	0.39	.0457	11	0.10	Y
D60 ~ Ratio $\alpha_{s1.5} / \alpha_{s1.2}$	0.32	.0470	11	0.09	Y
D84 ~ Ratio $\alpha_{s1.5} / \alpha_{s1.2}$	0.04	.0638			N