Sound Science -- Continuous Suspended-Sediment Monitoring Using Acoustic Surrogates

OSW Hydroacoustics Webinar
September 2, 2014

Office of Surface Water,
Sediment Acoustic Leadership Team
http://water.usgs.gov/osw/SALT/

U.S. Department of the Interior
U.S. Geological Survey

SEDIMENT ACOUSTIC LEADERSHIP TEAM (SALT)

- **Research:** Promote and conduct to address next issues
- **Methods**: Training and Guidance on Best Practices
- **Tools**: Surrogate Analysis & Index Developer Tool (SAID); Real Time processing tools (for NWIS & NRTWQ); Stationary Time-Series Analysis
- **Demonstration Sites**: Continuous real-time acoustic-SSC.
- **Representatives**: OSW, WSCs [IL, ID, TX, CO, CA], OFAs

Best Practices for continuous suspended-sediment monitoring using acoustic surrogates

- **Relevance and applications of continuous suspended sediment monitoring (Landers)**
- **Principles and Methods to Adjust measured acoustic backscatter to obtain sediment surrogates (Landers)**
- **Overview of data, metadata, monitoring requirements and data-compilation measures (Wood)**
- **Use of Surrogate Analysis and Index Developer tool (SAID) to evaluate and develop rating curve. (Straub)**
- **Real-time continuous Suspended Sediment. (Wood)**
- **Documentation and Review (Landers).**
- **Questions. (All)**

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Increasing Need for Sediment Information

Sediment and associated pollutants are lead causes of impairments and TMDLs

Causes of Impairment for 303(d) Listed Waters

Description of this table

NOTE: Click on a cause of impairment (e.g. pathogens) to see the specific state-reported causes that are grouped to make up this category. Click on th
Reported" to see a list of waters with that cause of impairment.

Cause of Impairment Group Name	Number of Causes of Impairment
Pathogens	10,951
Nutrients	7,697
Metals (other than Mercury)	7,143
Organic Enrichment/Oxygen Depletion	6,713
Sediment	6,626
Polychlorinated Biphenyls (PCBs)	5,760
Mercury	4,896
pH/Acidity/Caustic Conditions	4,326
Cause Unknown - Impaired Biota	3,704
Temperature	3,241
Turbidity	2,914

Accessed Aug o4, 2014

National Cumulative TMDLs by Pollutant

Pollutant Group	Number of TMDLs	Number of Causes of Impairment Addressed
Pathogens	12,331	12,625
Metals (other than Mercury)	9,395	9,584
Mercury	7,153	7,181
Nutrients	5,766	6,922
Sediment	3,881	4,511

motivation

Fluvial Sediment Data are essential to understand and solve critical needs in:

- Engineering
- Ecology
- Water Quality
- Agriculture

Suspended Sediment:

Concentration

Grain Size

Load

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Increasing Need for Sediment Information

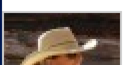
Dam Removal & Reservoir Sediment Management

Patapsco River dam removal will restore miles of fish passage

Va. removing dam on Appomattox River

News Watch

Rebirth on the River: Washington's Elwha Flourishing After Big Dam Removals

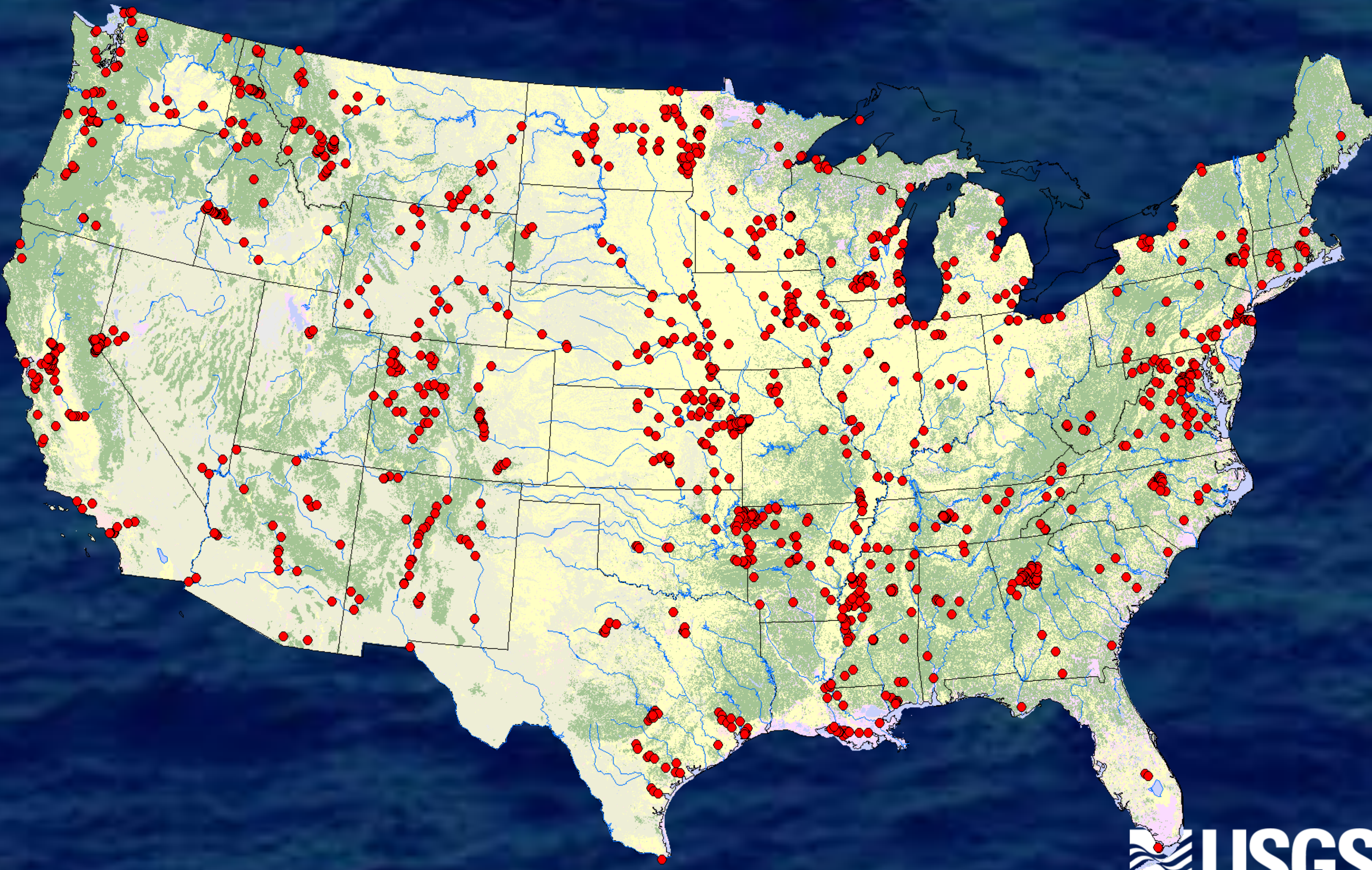


51 Dams Removed to Restore Rivers in 2013

Remove all four dams on the Klamath River, environmental analysis recommends

[Condit Dam Removal on White Salmon R, WA 10/28/2011]

1390 Sites with at least 10 SSC *and* streamflow values 2010-Present



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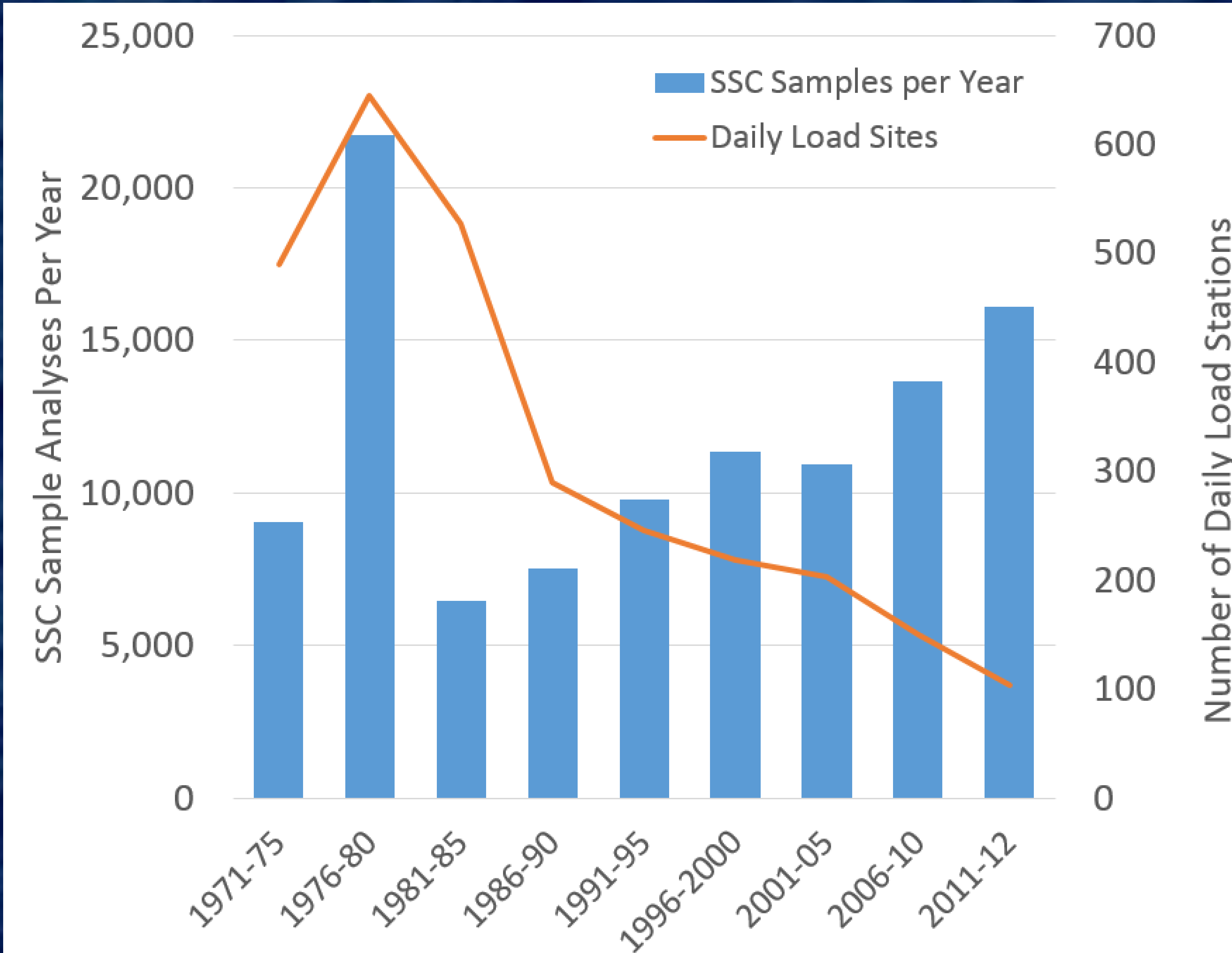
SSC Samples per Year
Daily Load Sites
SSC Sample Analyses Per Year
Number of Daily Load Stations
25,000
20,000
15,000
10,000
5,000
0
700
600
500
400
300
200
100
0
1971-75
1976-80
1981-85
1986-90
1991-95
1996-2000
2001-05
2006-10
2011-12

USGS Sediment Program Elements

- Physical Sampling
- Lab Analyses
- Sediment Surrogates
- Load Computation
- Geomorphology
- RESSED
- Interpretive Studies
  - Dam Removal / Ecosystems / Urban / Estuarine / Ag / Reservoir / Dredging / Coastal Erosion / Sediment Fingerprinting

OSW Sediment Program Development and QA

- FISP & HIF
- Training
  - Field Techniques, Computation Techniques, Geomorphology, Sediment-Acoutic Methods
- SALT
- HAWG
- Software Support
  - GCLAS, SLEDS, SedLogin, SAID, RASDAT, RESSED, ...
- SLQA
- Technical Reviews
- Representation (SOS, ASTM, ISO, ...)

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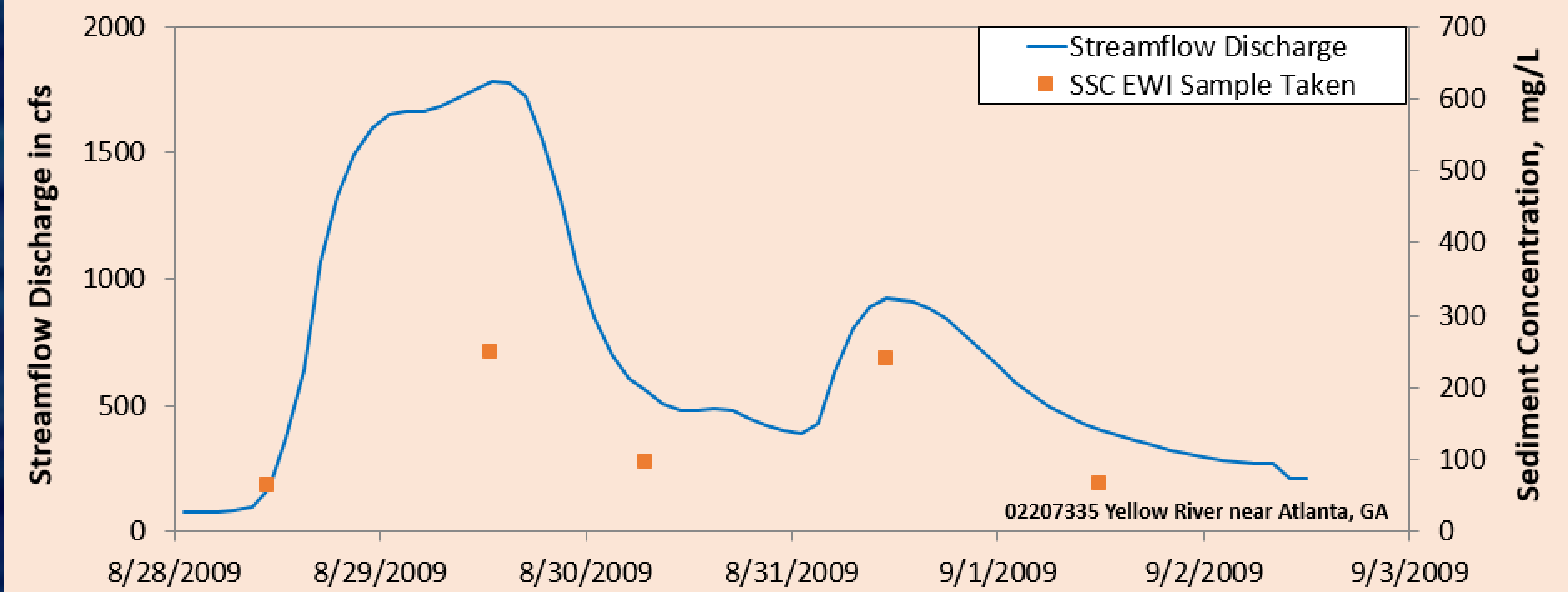
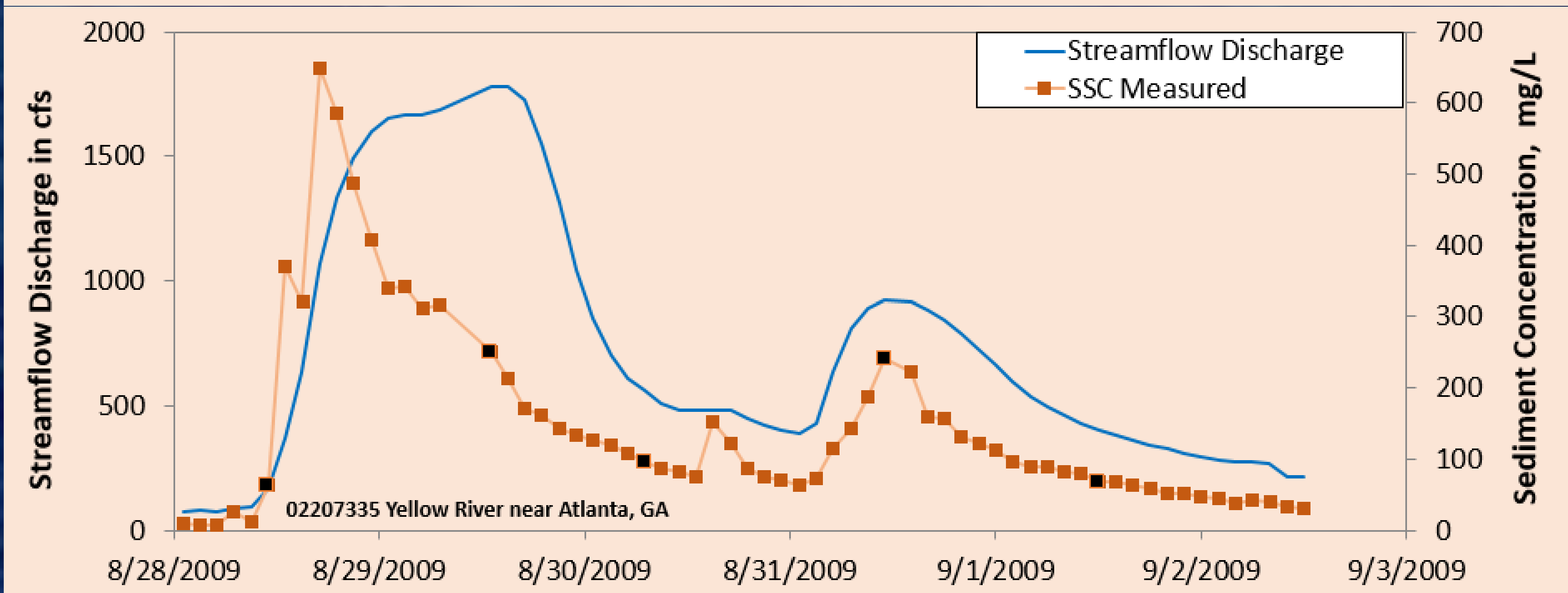
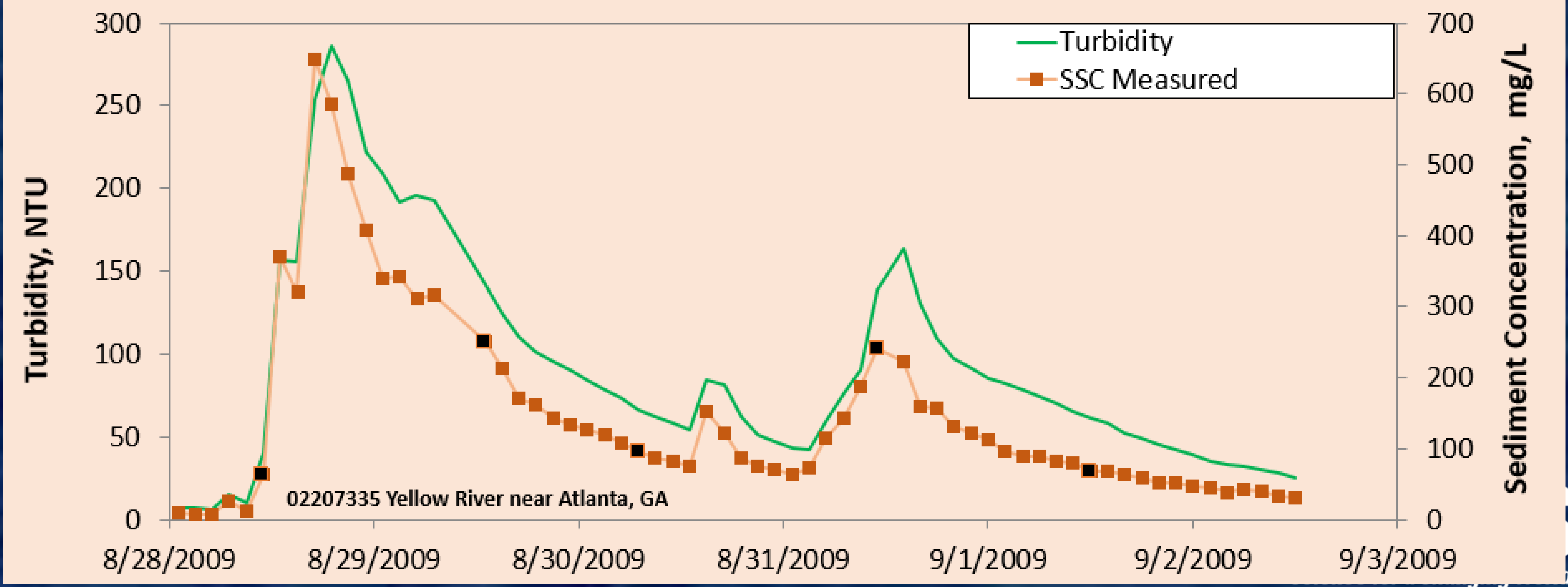
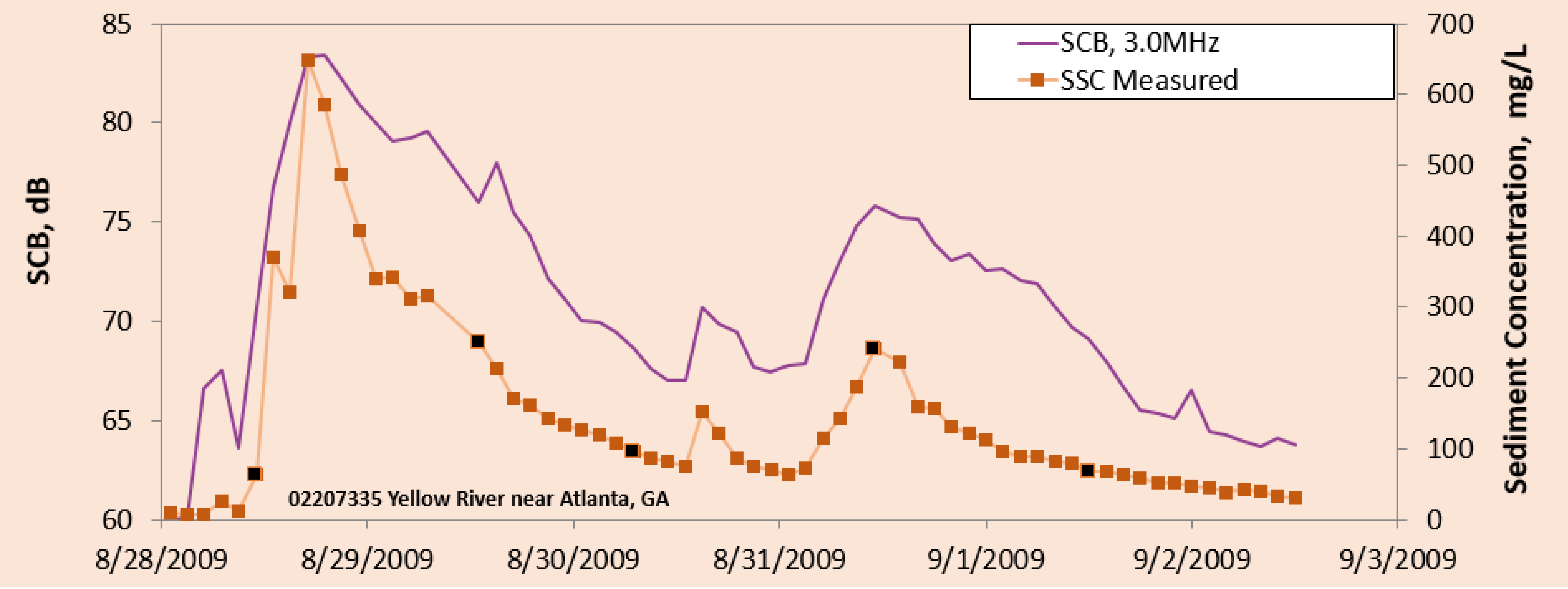

Streamflow Discharge
SSC EWI Sample Taken
Streamflow Discharge in cfs
Sediment Concentration, mg/L
02207335 Yellow River near Atlanta, GA
2000
1500
1000
500
0
700
600
500
400
300
200
100
0
8/28/2009
8/29/2009
8/30/2009
8/31/2009
9/1/2009
9/2/2009
9/3/2009

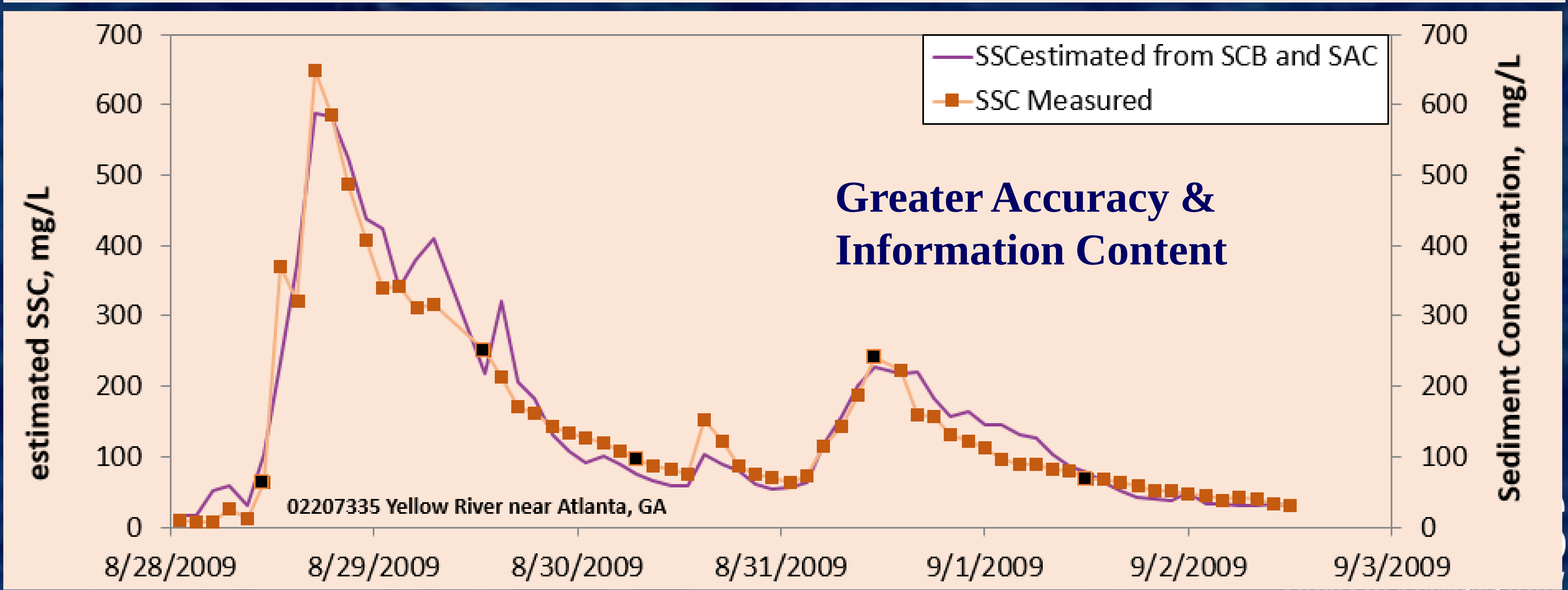

Streamflow Discharge
SSC Measured
Streamflow Discharge in cfs
Sediment Concentration, mg/L
02207335 Yellow River near Atlanta, GA
2000
1500
1000
500
0
700
600
500
400
300
200
100
0
8/28/2009
8/29/2009
8/30/2009
8/31/2009
9/1/2009
9/2/2009
9/3/2009

Potential continuous surrogate measures for SSC:

- Streamflow
- Turbidity
- Acoustics
- Laser-Diffraction
- Density Difference







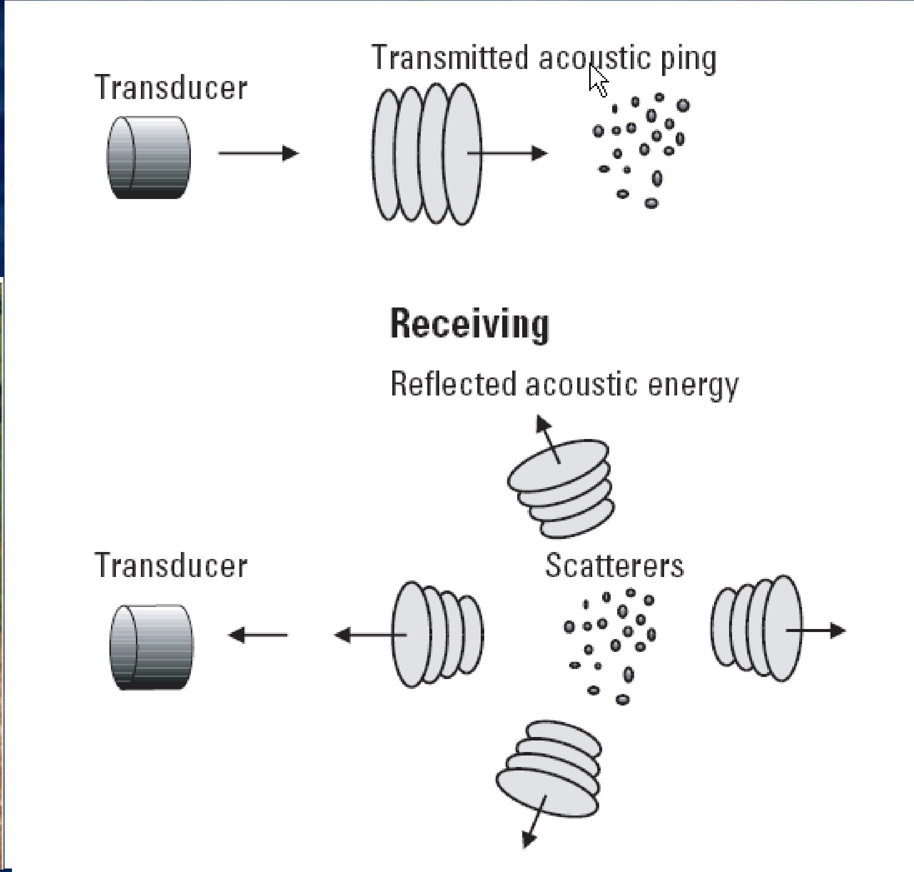
Greater Accuracy & Information Content

Acoustic Surrogates

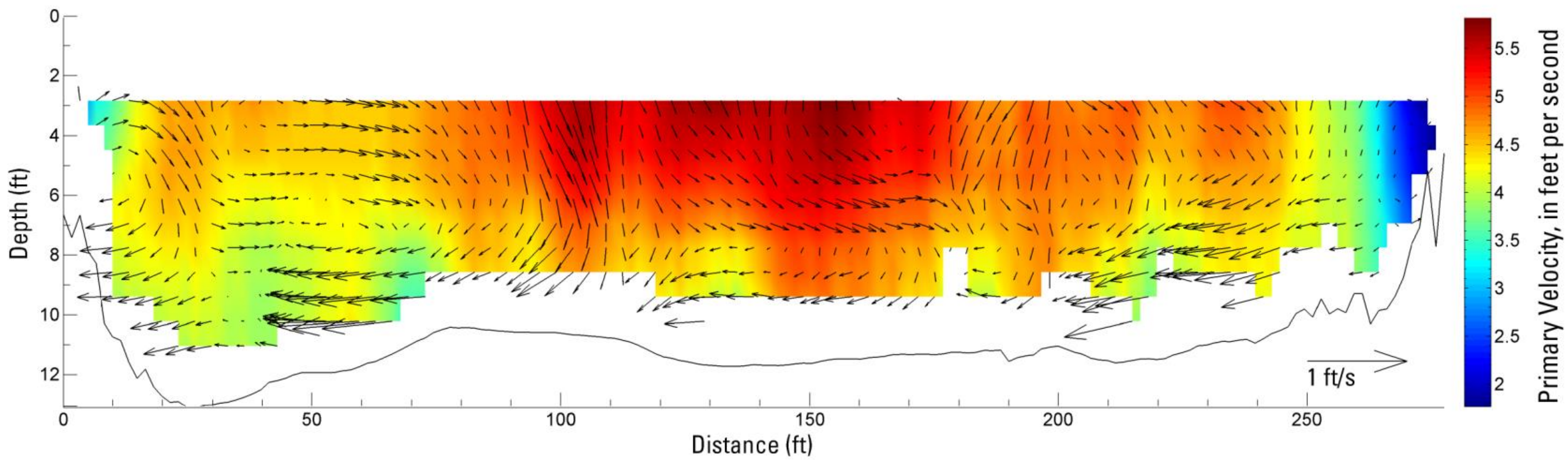
- Instrument Technology
  - Transmit Acoustic Energy of Known f
  - Measure shift in f from energy scattered
  - Compute Velocity

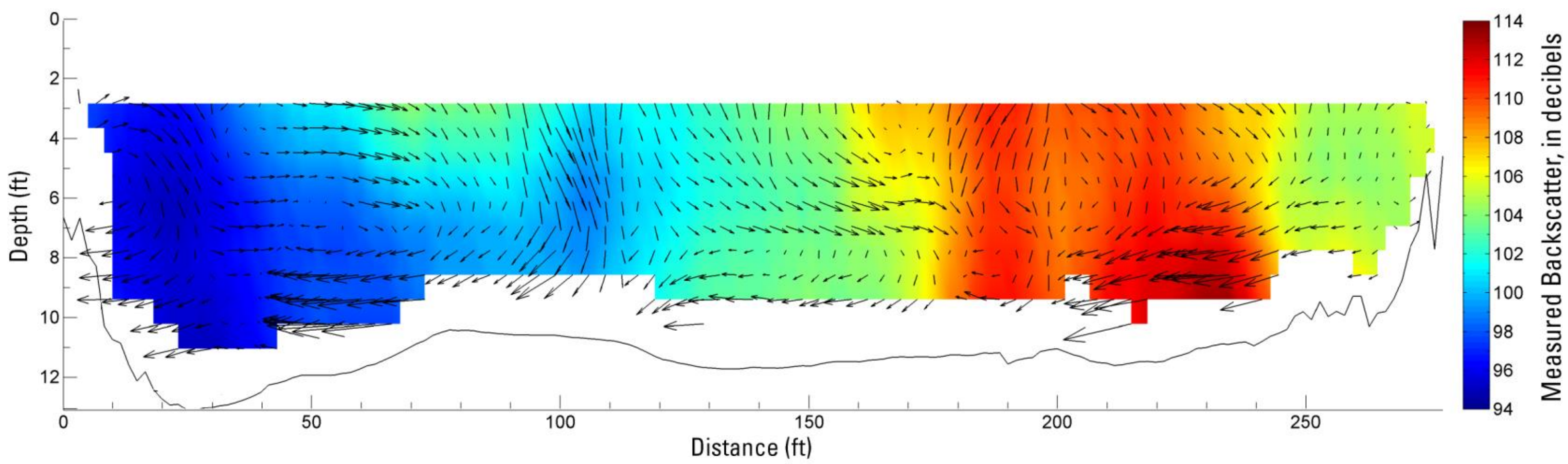
$$u = \frac{c\, f_D}{2\, f_0}$$

- Properties Measured:
  - Frequency Shift → Velocity
  - Hydroacoustic backscatter



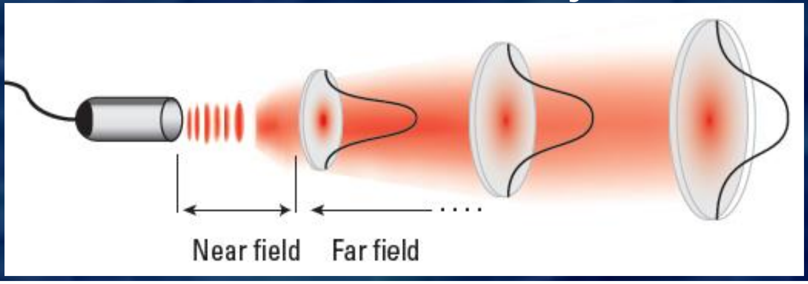
ADCP Primary and Secondary Velocities and Backscatter

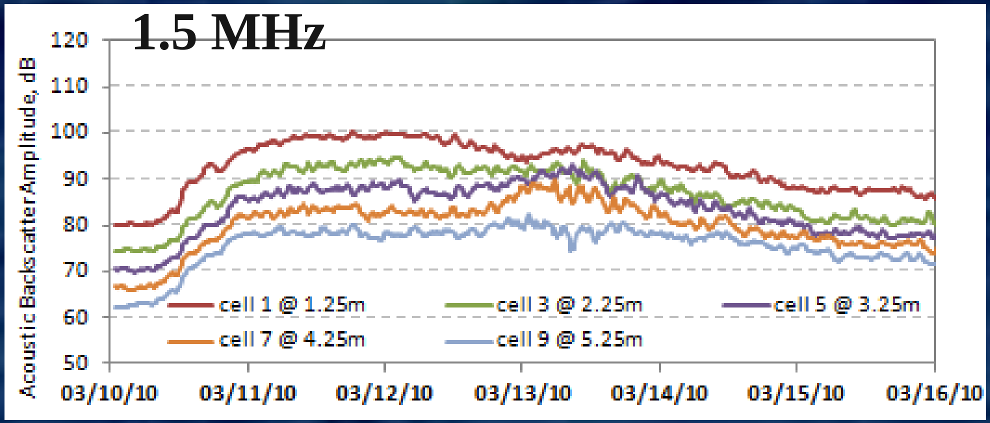


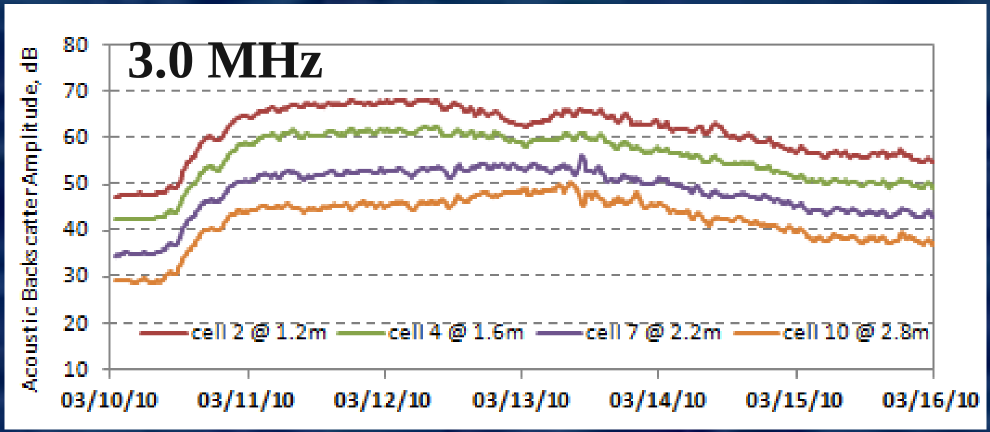


Acoustic Surrogates of SSC

Backscatter Intensity = function of:







Range from transducer (signal spreading)

Near Field Effects

Acoustic Frequency

Transducer Properties

Power Supply Amplitude

Water Temperature (viscosity)

Dissolved Solids (sound velocity)

Pressure (Depth, if >100ft)

Sediment Properties

Size, Shape, Density

Sediment Concentration (SSC)

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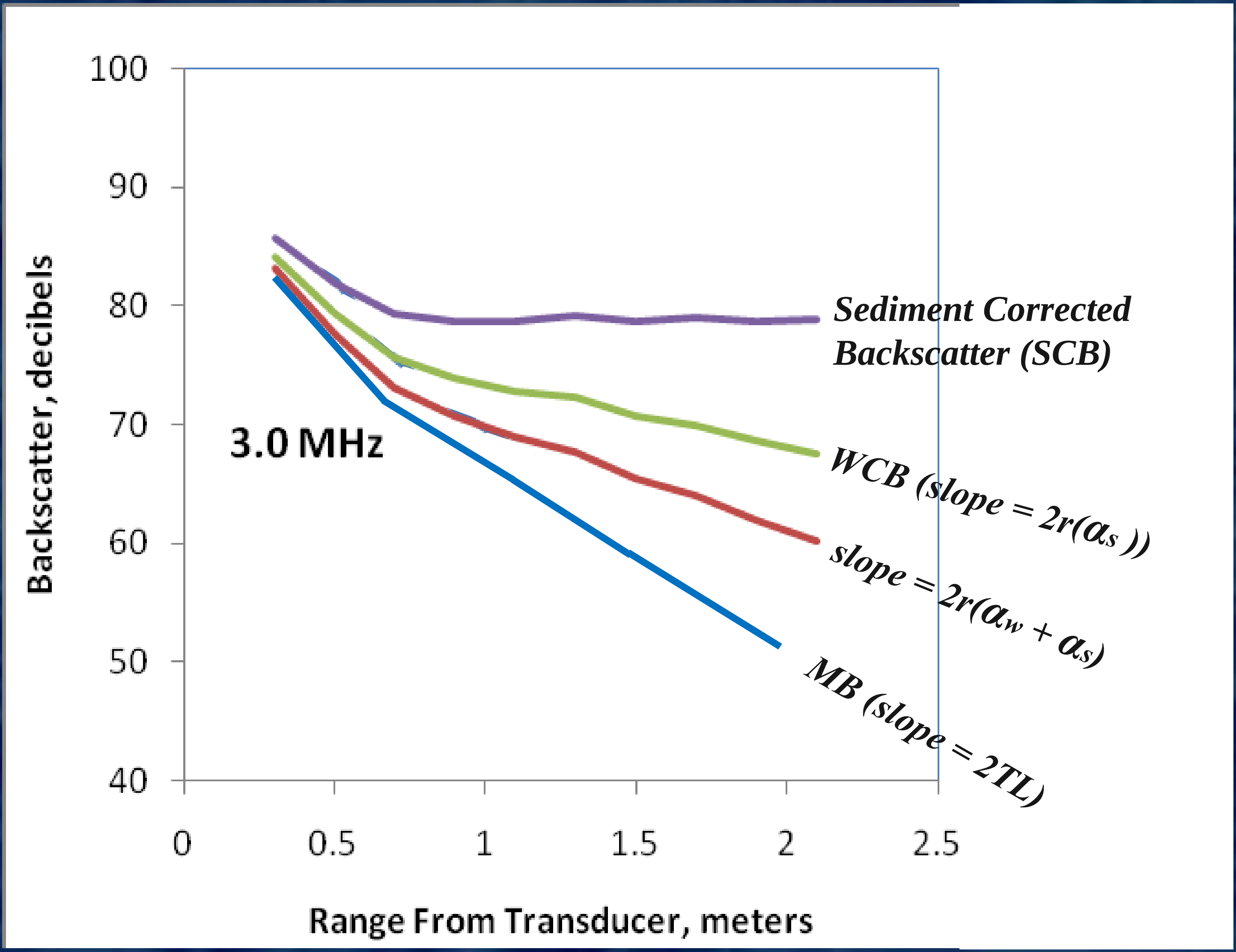
Acoustic Attenuation by Sediment:

- Backcatter Amplitude Profiles: Measured & Normalized



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Acoustic Surrogates: Principles

$$WCB = MB + 20\log_{10}(\psi r) + 2r(\alpha_w)$$

$$SCB = WCB + 2r\alpha_s$$

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

Measured Backscatter

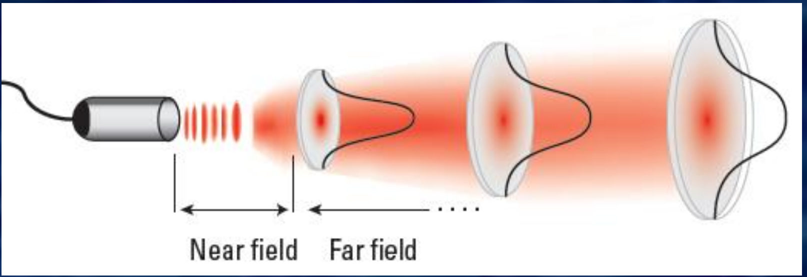
Beam Spreading

Water Absorption

Sediment Attenuation
α_s =SAC

$$\underbrace{\text{Beam Spreading} \quad \text{Water Absorption} \quad \text{Sediment Attenuation}}_{\text{2-Way Transmission Losses}}$$

2-Way Transmission Losses



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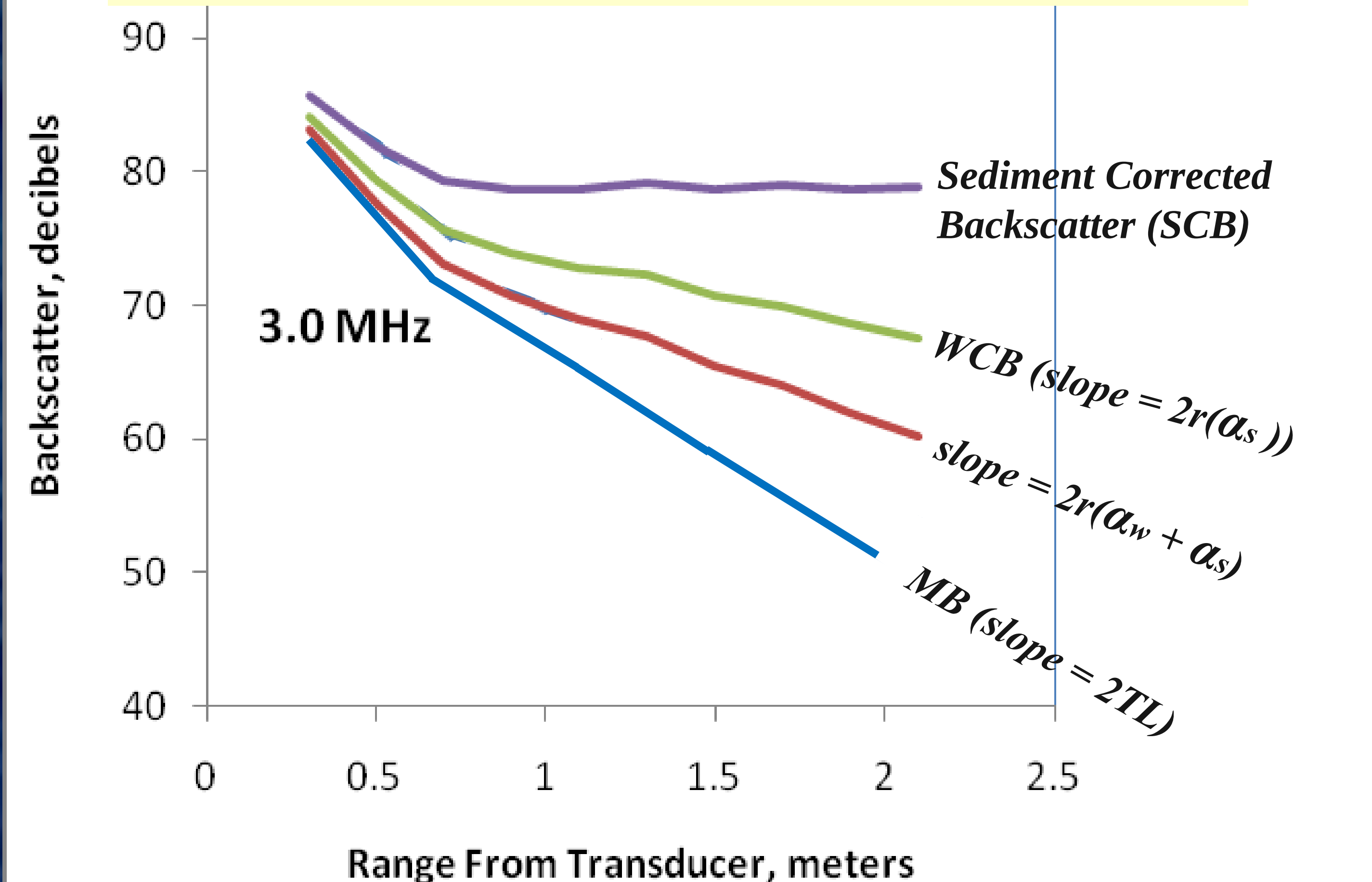
Acoustic Attenuation by Sediment:

- Backcatter Amplitude Profiles: Measured & Normalized

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



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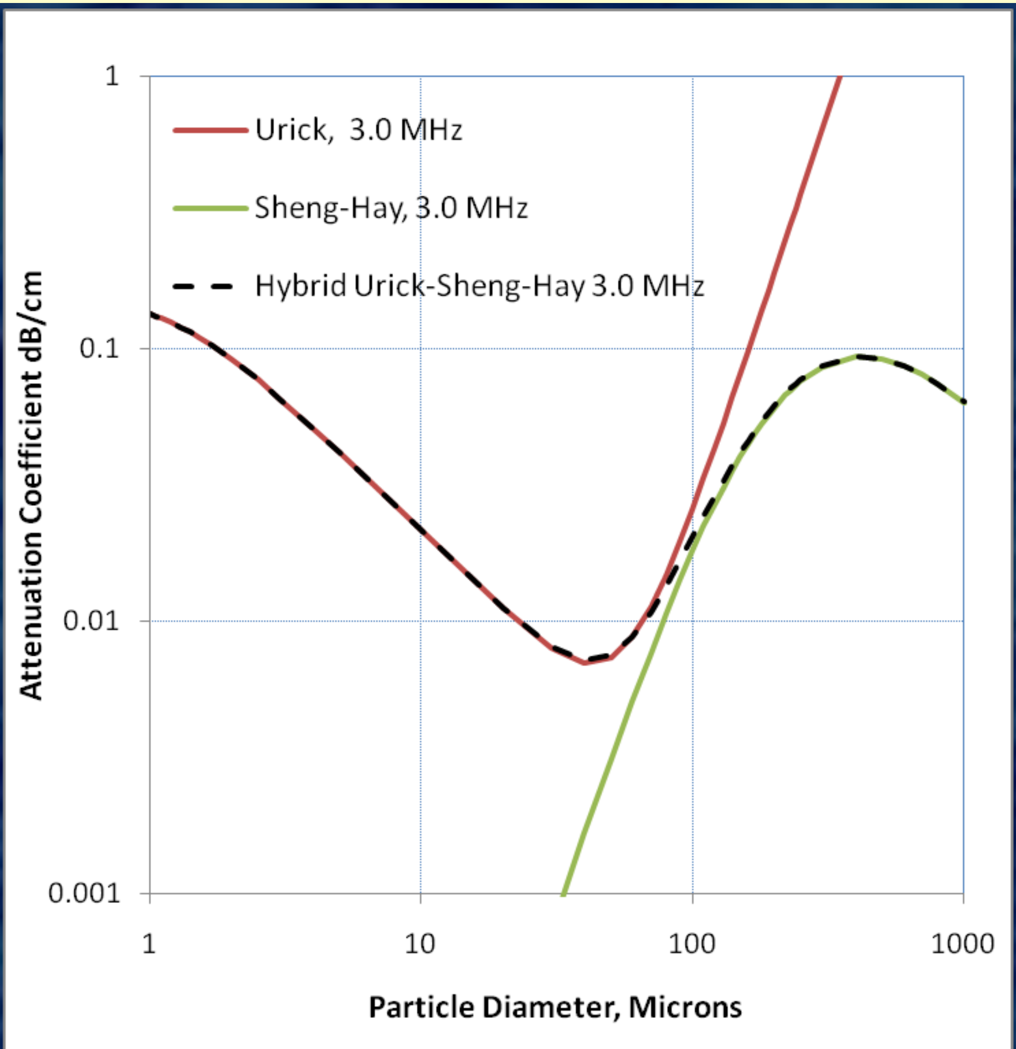
Acoustic Attenuation by Sediment:

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

- Hybrid Urick-Sheng-Hay Method:



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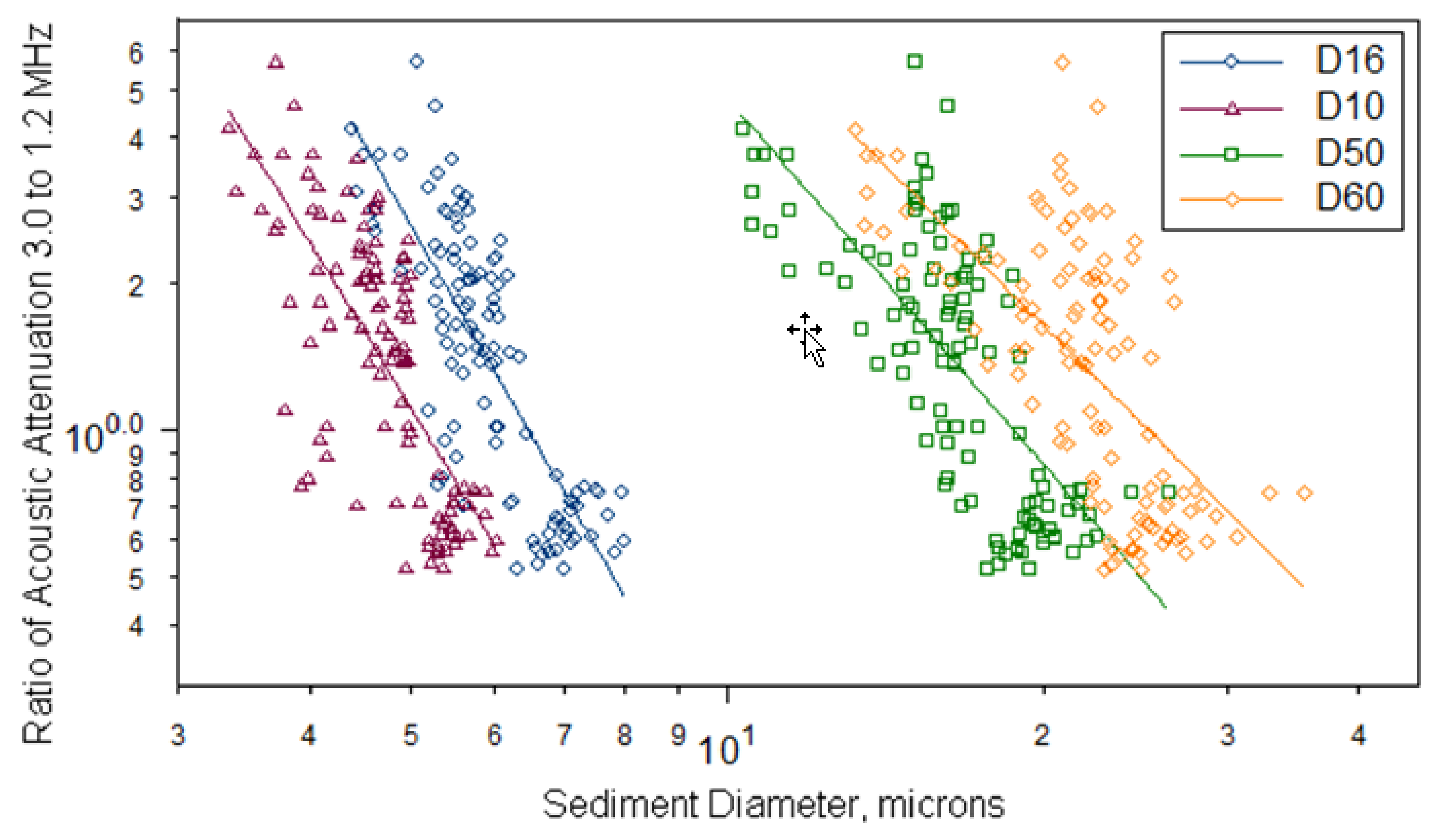
Sediment Size from Acoustic Attenuation



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Traditional Suspended-Sediment Monitoring

Physical Samples and Gravimetric Analyses

- Difficult
- Expensive
- Labor intensive
- <u>Essential</u>

Limited samples often provide inadequate resolution of variability and require large interpolations

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Sediment Data

- Sediment Data
  - EWI or EDI composite samples
  - Wide range of sediment and flow conditions
  - Recommended analyses:
    - Suspended sediment concentration
    - Sand/silt break
    - Full grain size analysis
    - Organic matter (loss on ignition)

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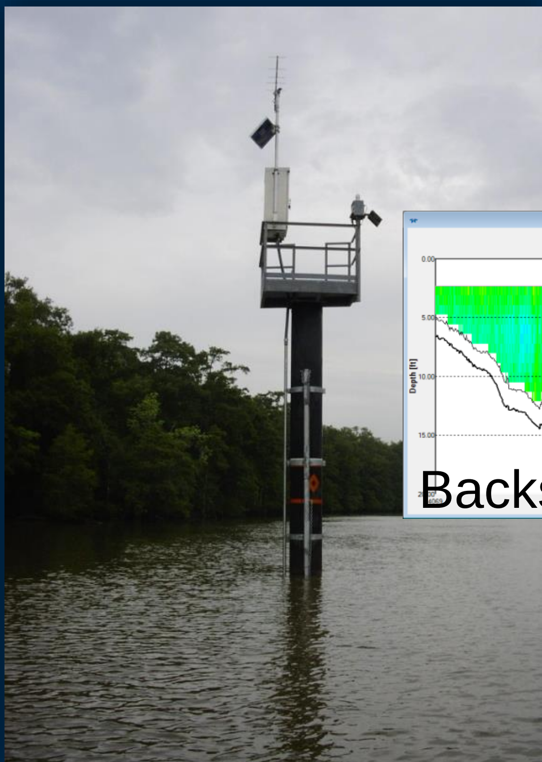
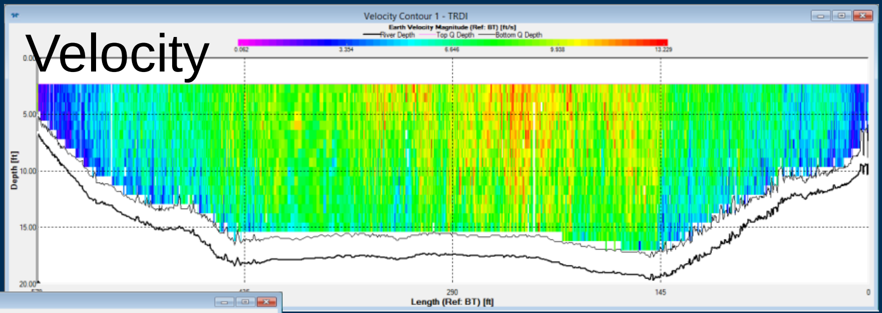
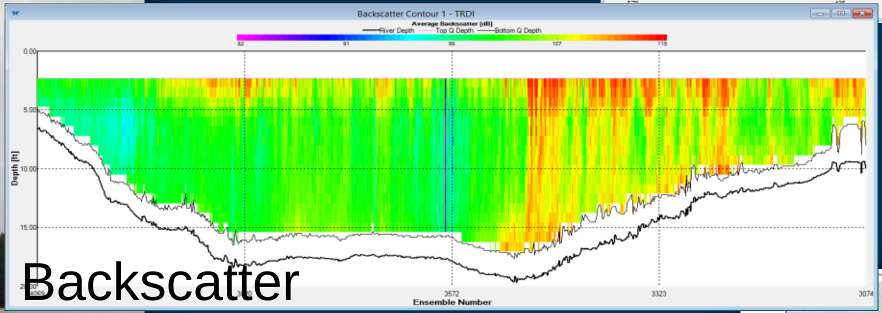
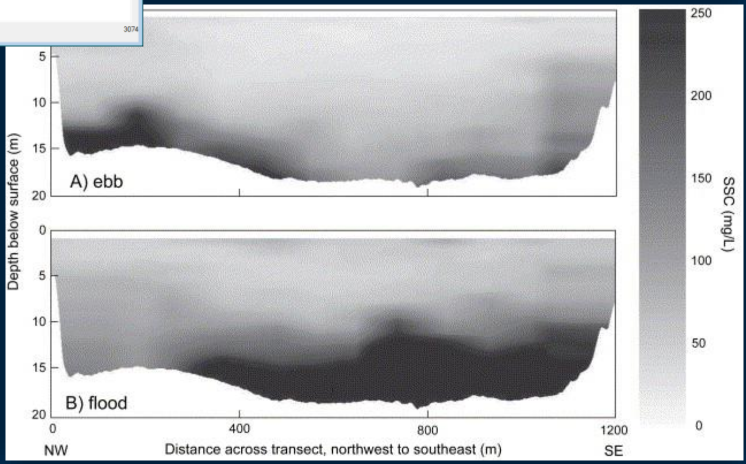
Site Reconnaissance & Selection is Essential to a Successful Gage





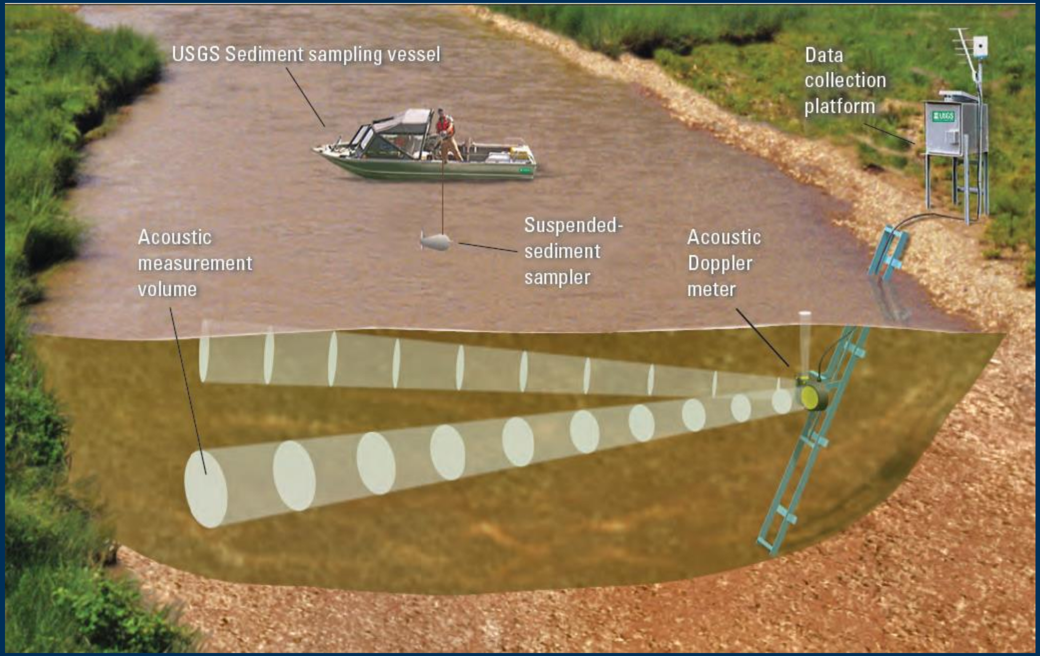




Don’t make it an after-thought!!!

Site Selection

The goal is to "index" acoustic readings in the volume measured by the ADVM to the overall mean channel sediment concentration, represented by an EWI/EDI sample



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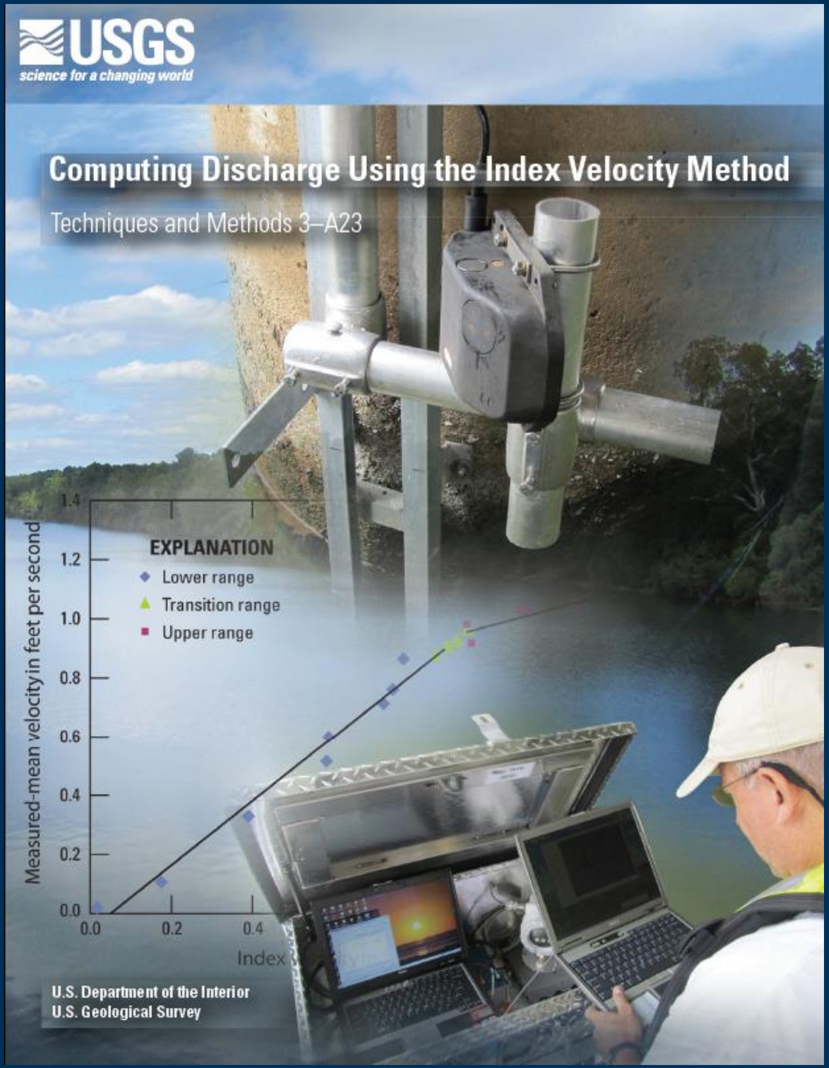
Index-Velocity T&M Report

- Many of the same site selection criteria apply as for index-velocity streamgages!
- http://pubs.usgs.gov/tm/3a23/



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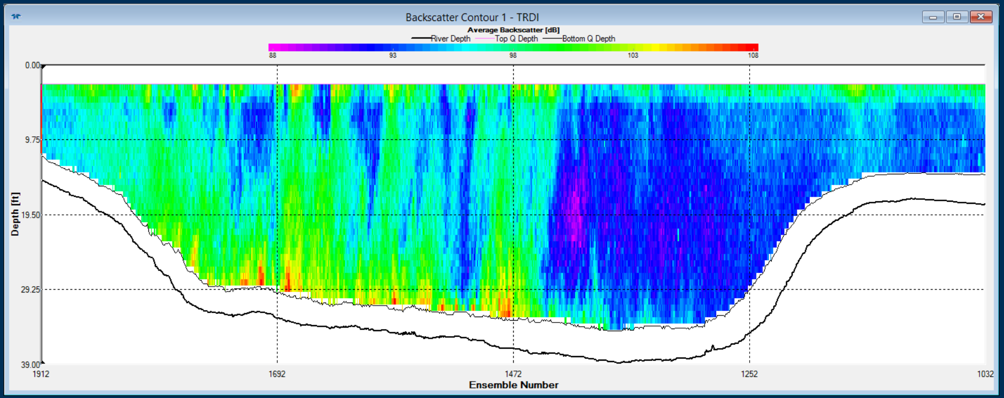
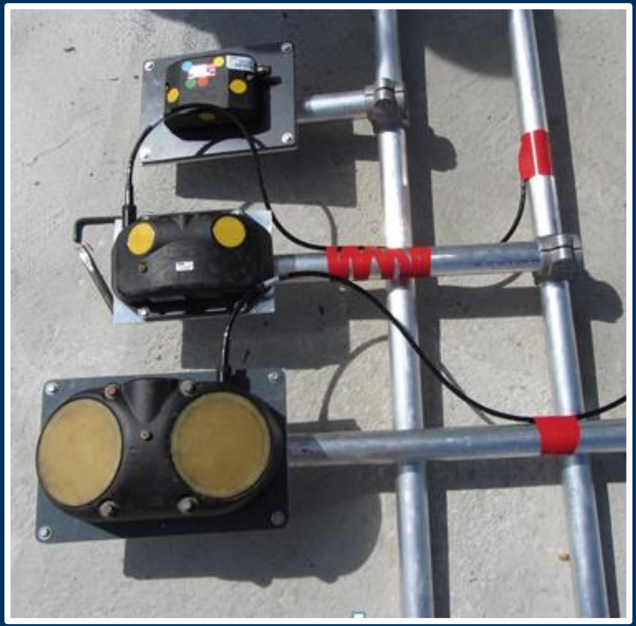
Site Selection Guidelines

1. Sediment should be well-mixed
2. Relatively consistent flow and sediment distribution
3. Sampling reasonably close to ADVM
4. Easy access to ADVM over range of flows
5. Reasonable protection from debris
6. Relatively straight reach for the greater of about 300 ft or 5 to 10 channel widths upstream and downstream from the gage site
7. Located a minimum of 5 to 10 channel widths upstream or downstream from any tributary inflows or flow control structure



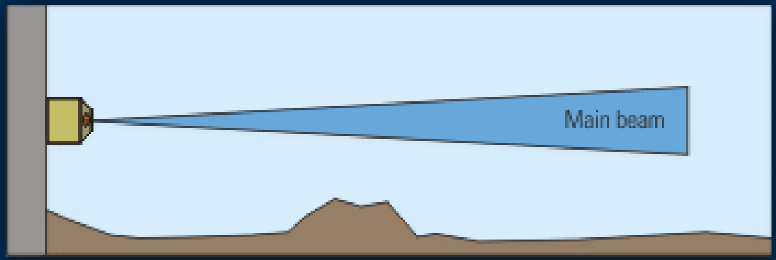
Instrument Selection

- Typical frequencies range 0.5 – 3 MHz
- Common models:
  - SonTek SL
  - TRDI Channelmaster
  - Nortek EasyQ (now Ott SLD)



Instrument Configuration

- Want to measure zone of uniform, well-mixed sediment
- Avoid obstructions and boundaries which can cause a “false” high backscatter
  - Boundaries can be fixed (streambed, tree branch) or moving (water surface)



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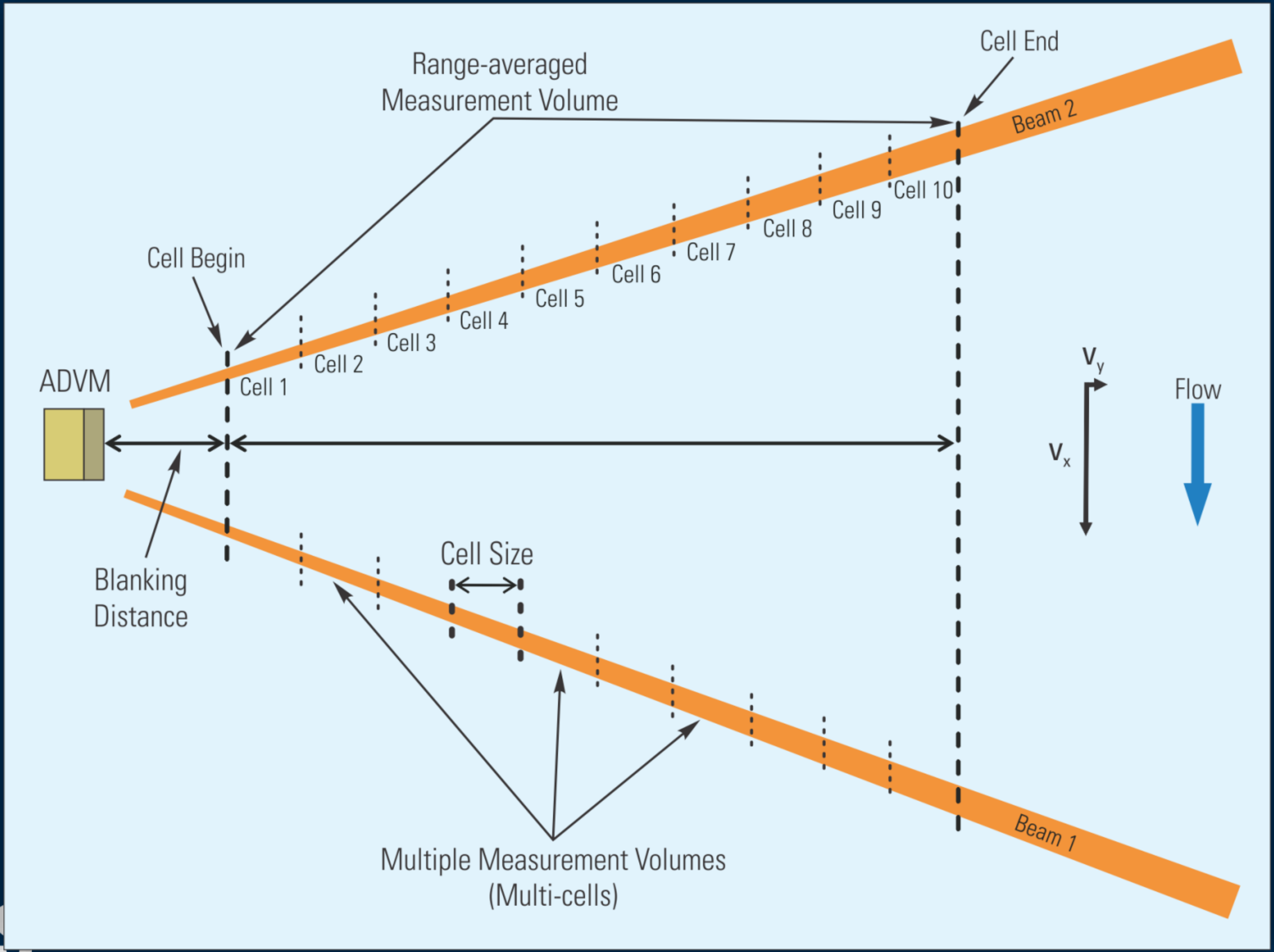
Measurement Volume and Multi-Cell



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Additional Considerations, cont.

- Ideally integrate with gagehouse and DCP
  - Data storage
  - Cable and power protection
  - Real-time transmission
- AC power best, but can do DC/solar

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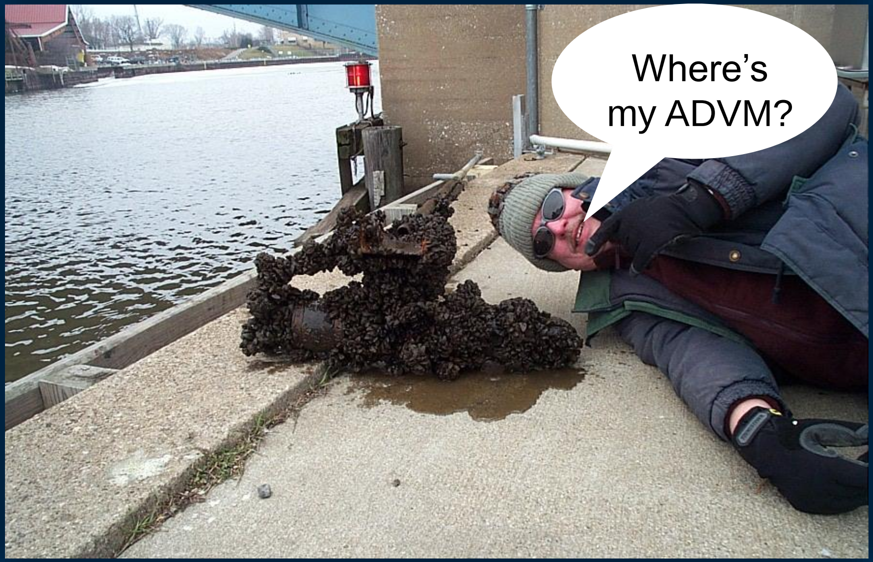
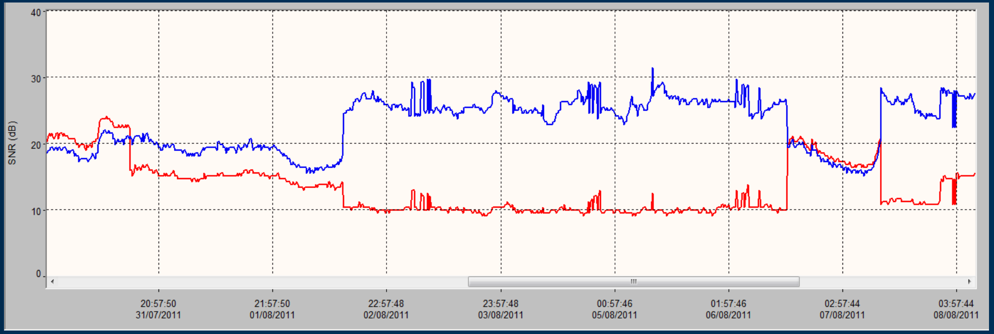
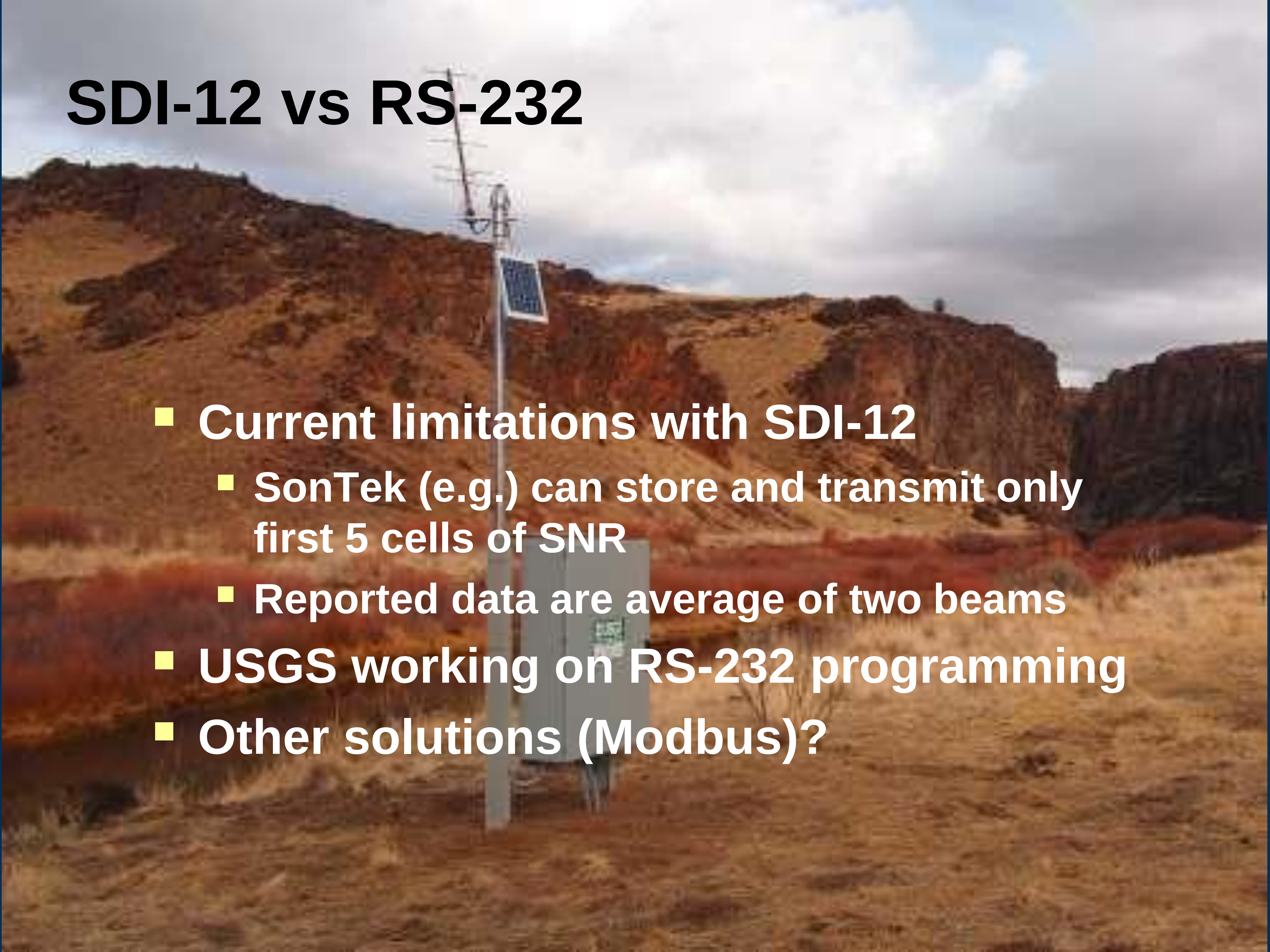
Mounts

- Want easy access at all flows for cleaning and servicing
- Redeploy to same location every time



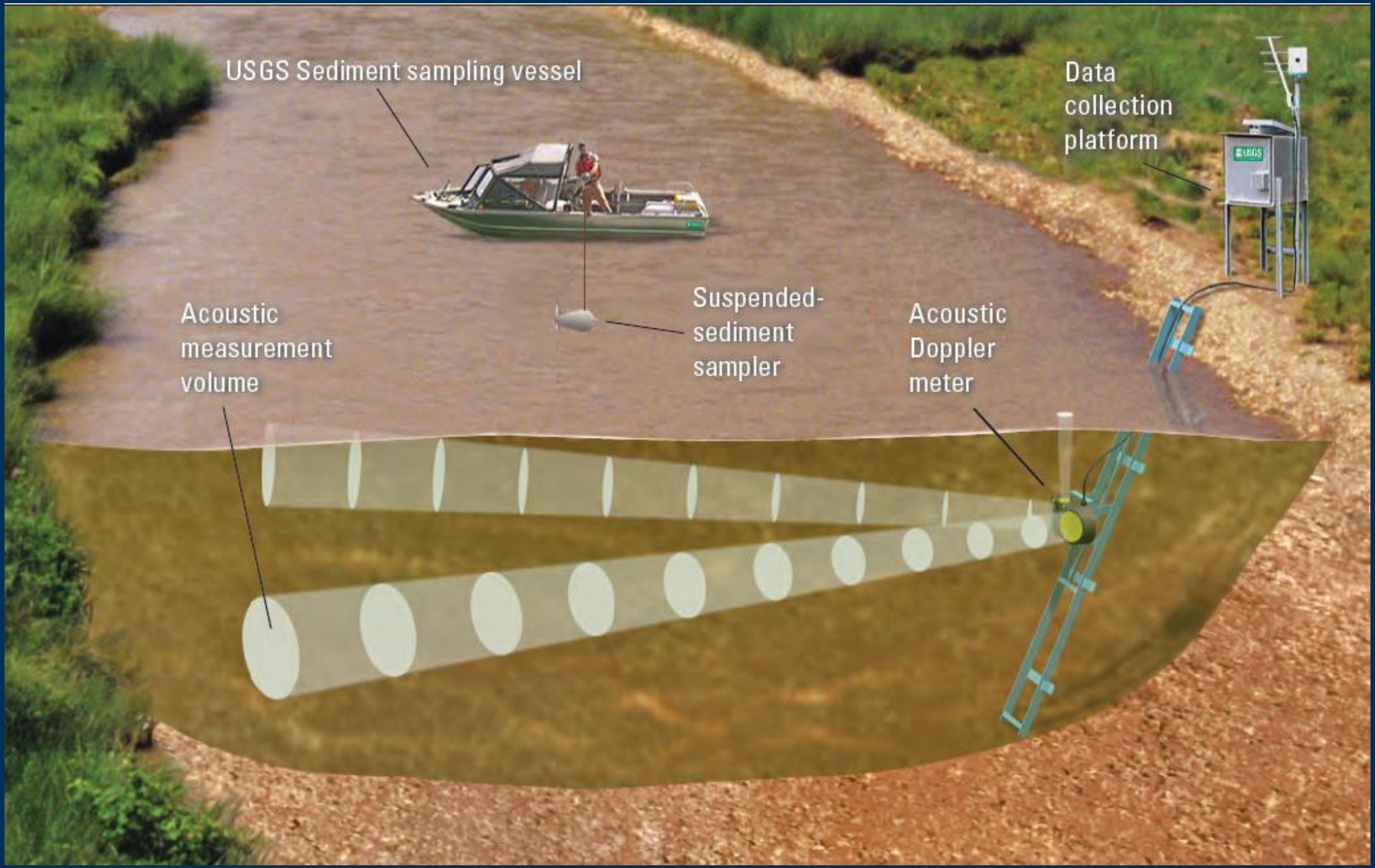




SDI-12 vs RS-232

- Current limitations with SDI-12
  - SonTek (e.g.) can store and transmit only first 5 cells of SNR
  - Reported data are average of two beams
- USGS working on RS-232 programming
- Other solutions (Modbus)?

Example Sediment Acoustic Site



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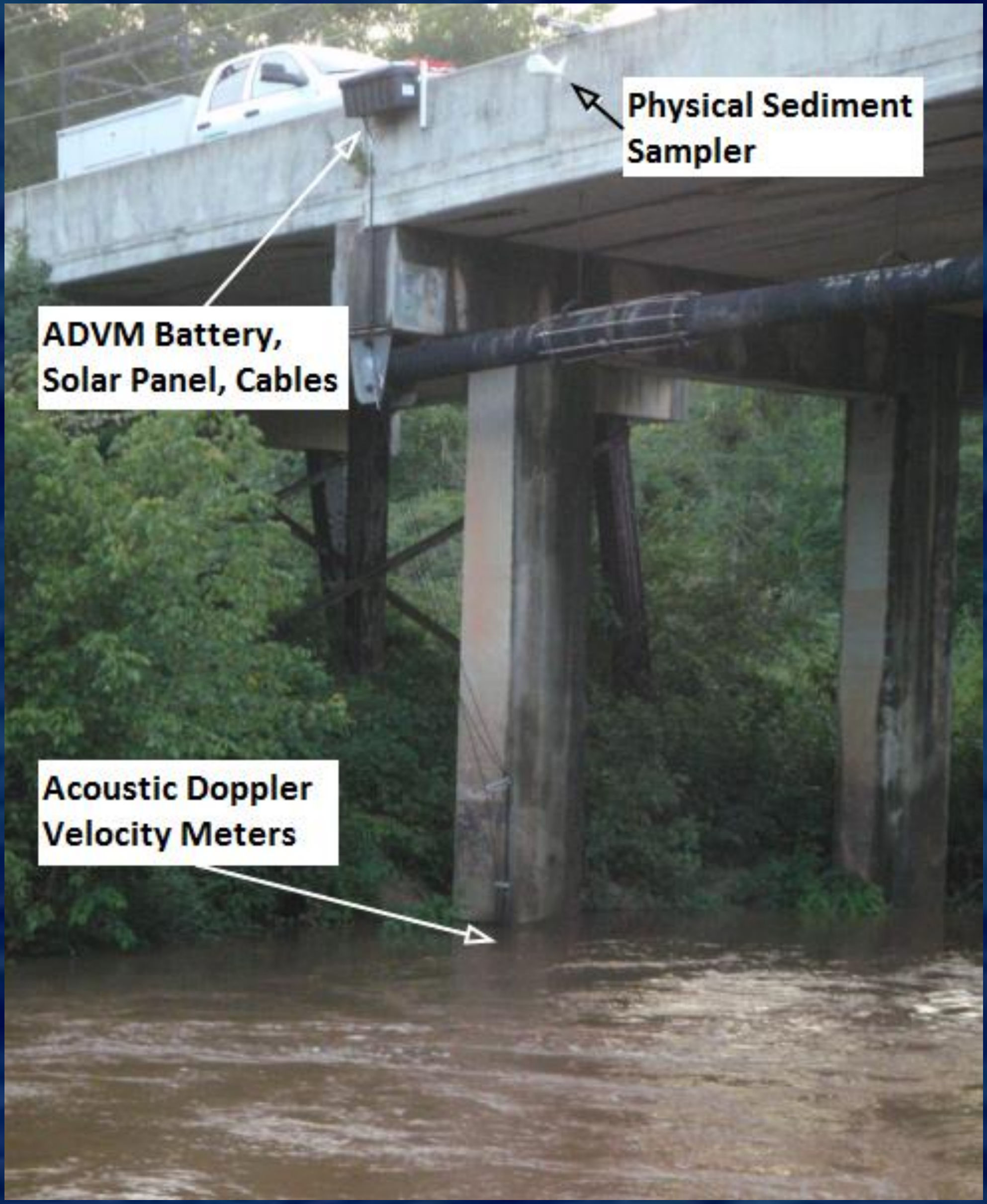
Yellow River at Gees Mill Road near Metro Atlanta, GA, 02207335



Acoustic Doppler Current Profilers
(A) 1.2MHz (B) 1.5MHz (C) 3.0MHz

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Laboratory analysis for mass concentration and percent finer than 63μm (251+ samples)

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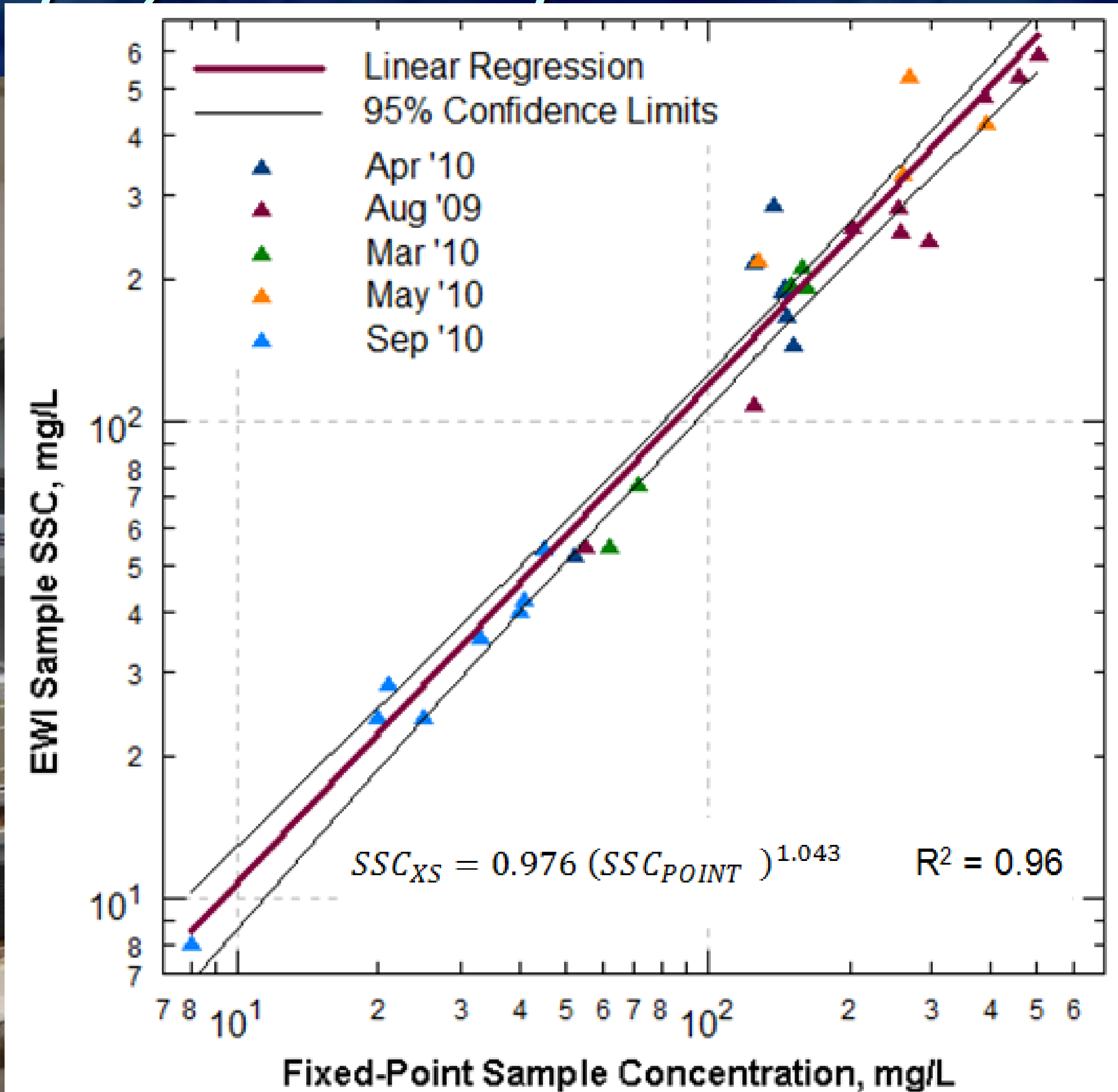
Calibration of fixed-point to cross section physical samples of SSC



Federal Interagency Sedimentation Project

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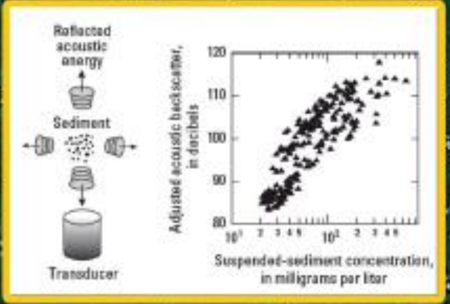
Sediment and Water-Quality Samplers and Research

water.usgs.gov/fisp

Federal Interagency Sedimentation Project
3039 Amwiler Road, Suite 130
Atlanta, GA 30360-2824

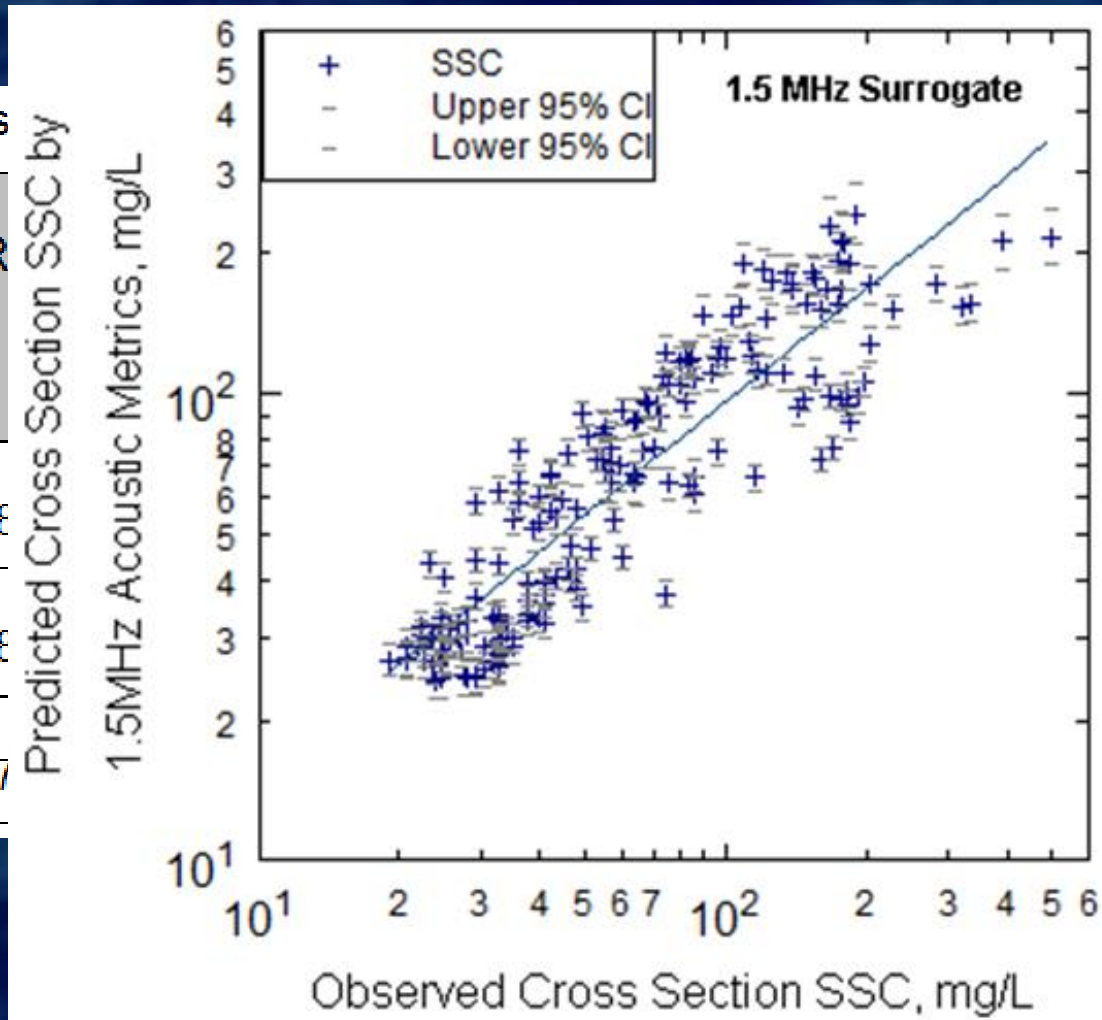
(770) 903-9152
(770) 903-9199 (Fax)



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 $\alpha s_{1.2MHz}$



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Discrete Measurements of SSC by Acoustics

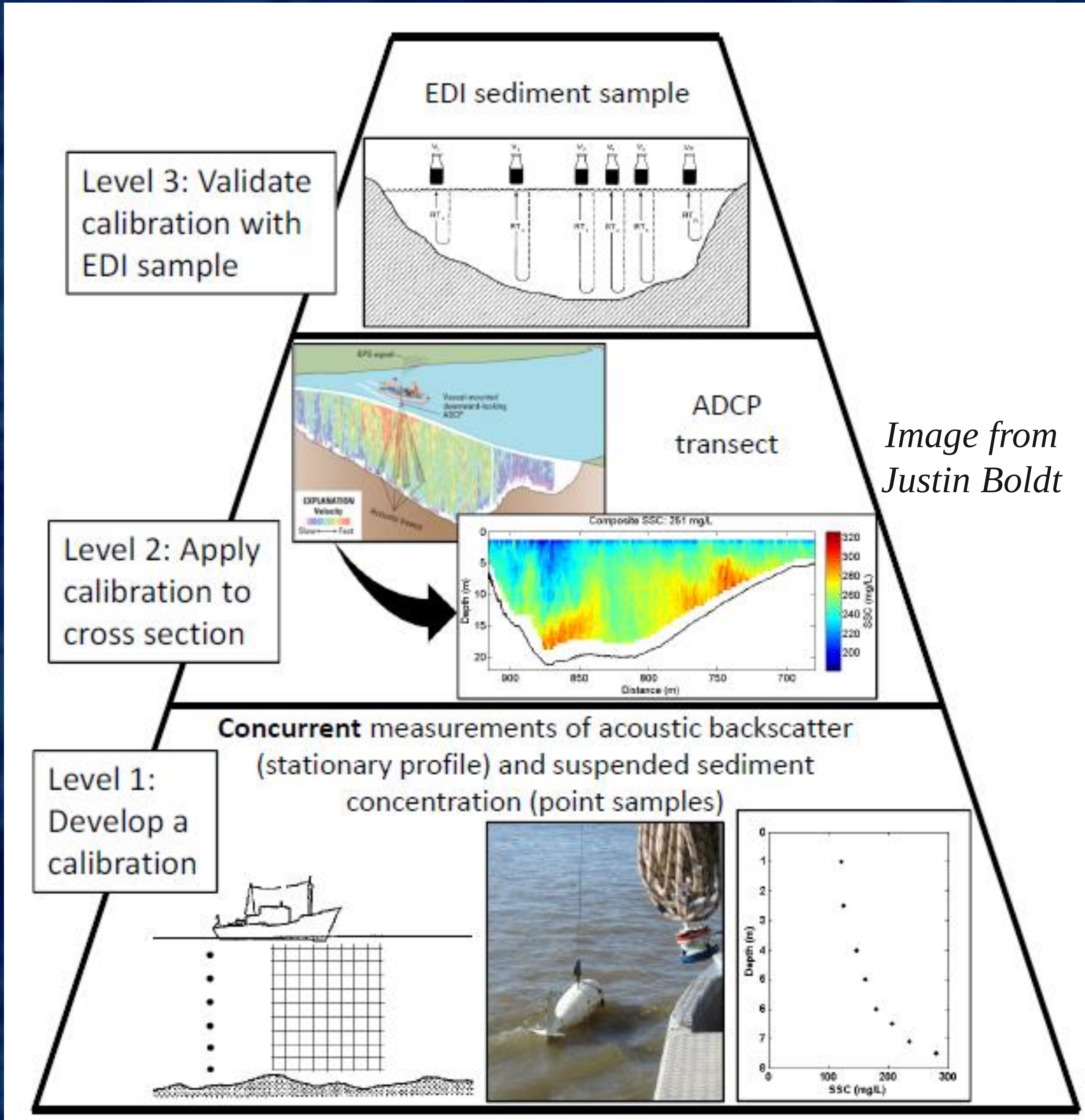

Image from Justin Boldt

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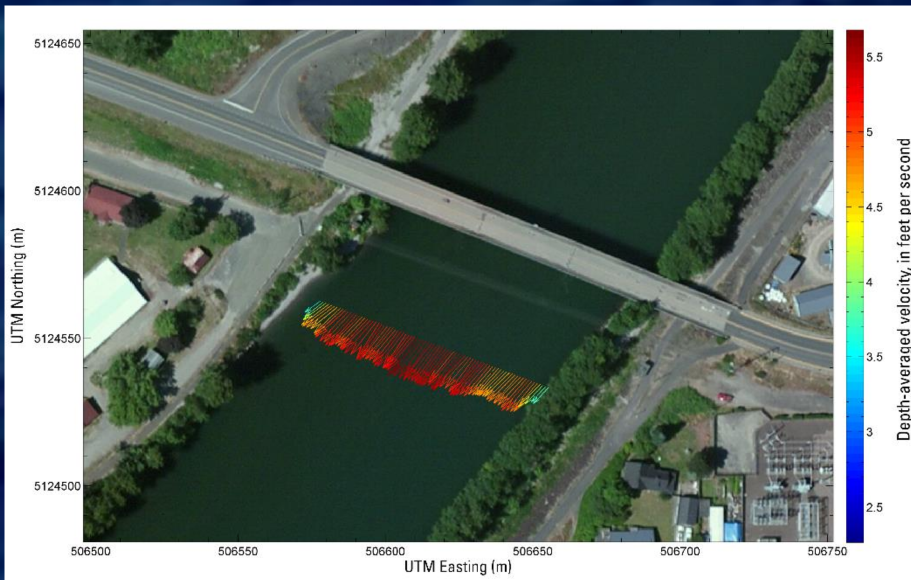
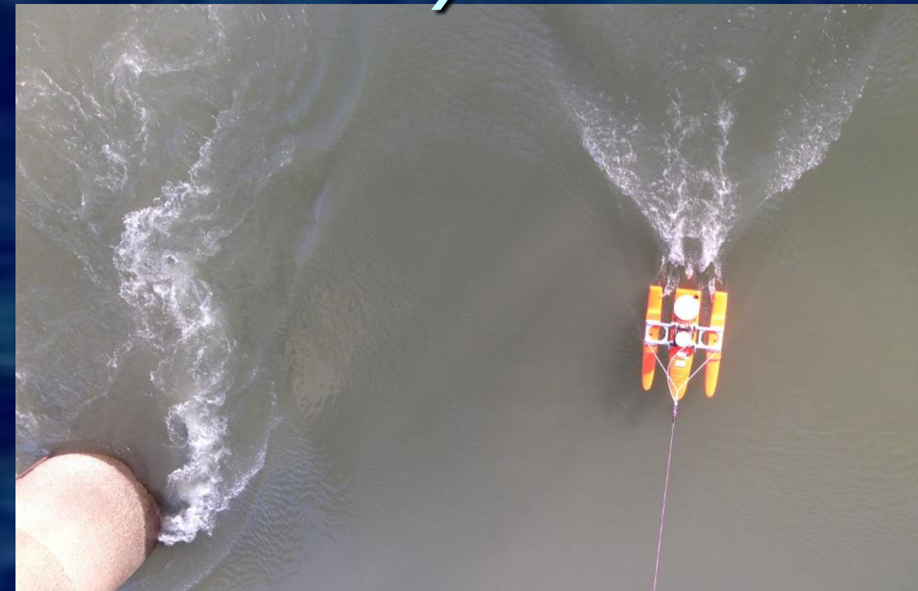
Discrete Measurements of SSC by Acoustics





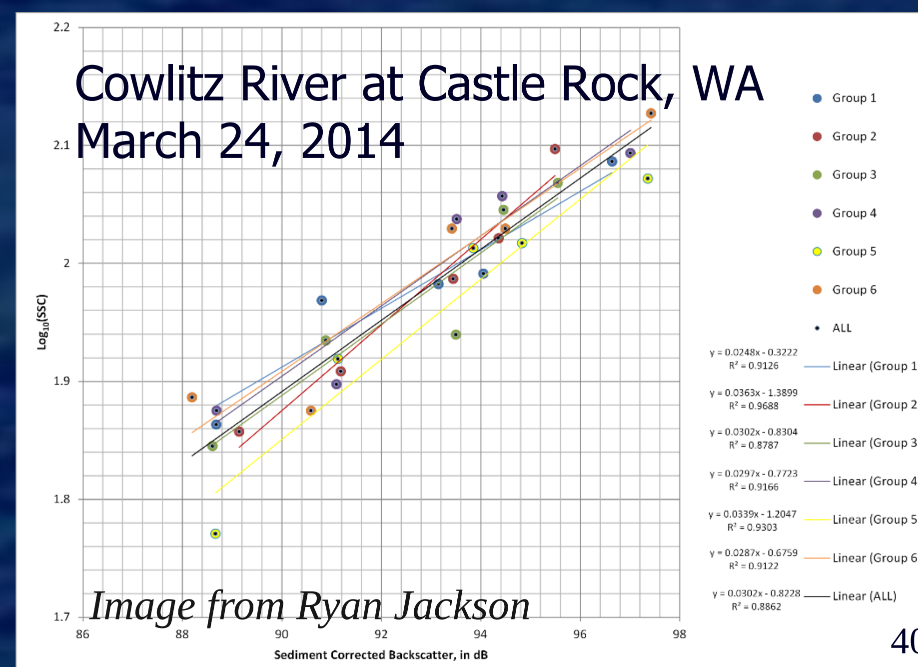
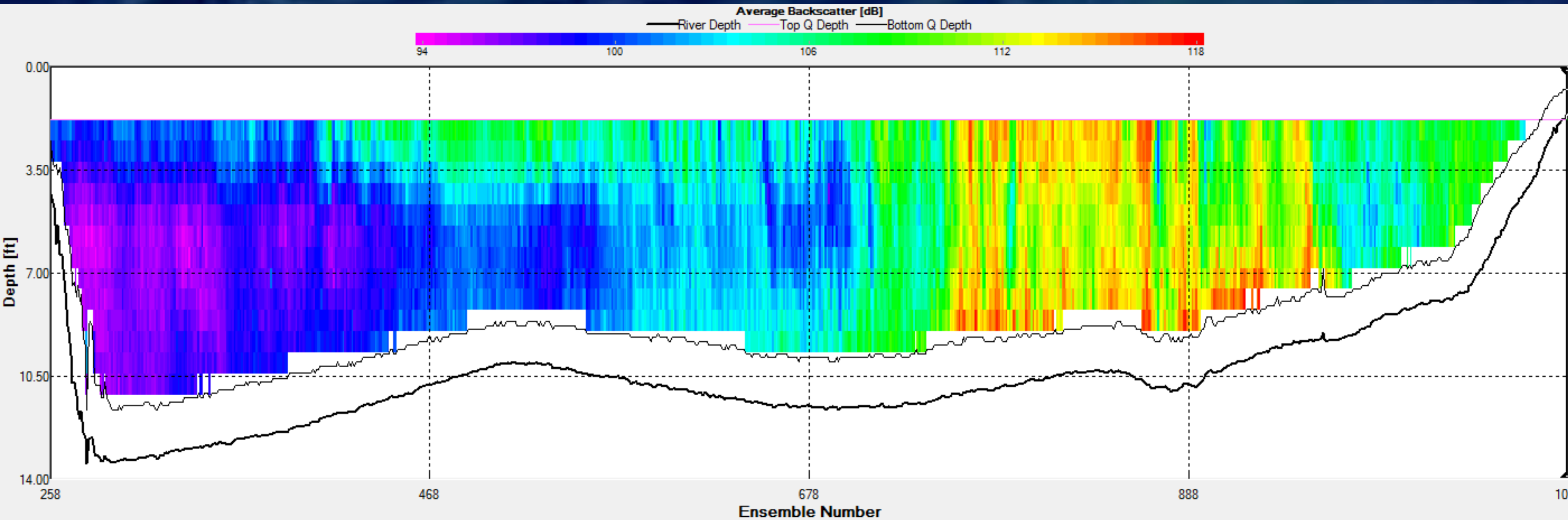


Image from Ryan Jackson

Measured Backscatter (dB)



Suspended Sediment Concentration (mg/L)

EDI = 71.4 mg/L

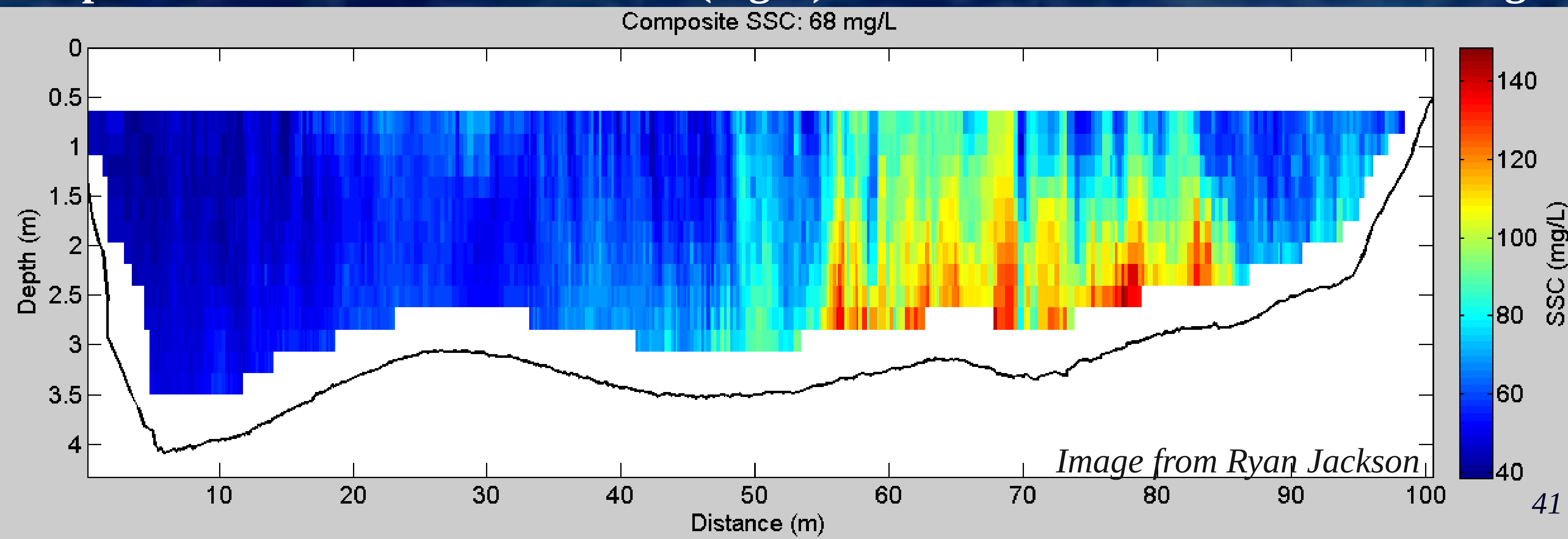


Image from Ryan Jackson

Summary: Acoustic Surrogates of Sediment

- Sound Science
- Continuous, High Temporal Resolution & Real Time
- Discrete, High Spatial Resolution
- Greater Accuracy & Information Content
- High Potential to Leverage Existing Instrumentation & Practices
- Work under way to build tools (software), policies, and documented procedures
- **Strong potential to substantially benefit fluvial sediment data collection science**

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