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

**Sediment Acoustics**

[water.usgs.gov/osw/SALT/](water.usgs.gov/osw/SALT/)
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)
Increasing Need for Sediment Information

Sediment and associated pollutants are lead causes of impairments and TMDLs.

### Causes of Impairment for 303(d) Listed Waters

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

Accessed Aug 04, 2014

### National Cumulative TMDLs by Pollutant

<table>
<thead>
<tr>
<th>Pollutant Group</th>
<th>Number of TMDLs</th>
<th>Number of Causes of Impairment Addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pathogens</td>
<td>12,331</td>
<td>12,625</td>
</tr>
<tr>
<td>Metals (other than Mercury)</td>
<td>9,395</td>
<td>9,584</td>
</tr>
<tr>
<td>Mercury</td>
<td>7,153</td>
<td>7,181</td>
</tr>
<tr>
<td>Nutrients</td>
<td>5,766</td>
<td>6,922</td>
</tr>
<tr>
<td>Sediment</td>
<td>3,881</td>
<td>4,511</td>
</tr>
</tbody>
</table>
**motivation**

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

- Engineering
- Ecology
- Water Quality
- Agriculture

**Suspended Sediment:**
- Concentration
- Grain Size
- Load
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

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

Elwha R, Nov 2010

Elwha R, Apr 2014

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
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-Acoustic Methods
- SALT
- HAWG
- Software Support
  - GCLAS, SLEDS, SedLogin, SAID, RASDAT, RESSED, ...
- SLQA
- Technical Reviews
- Representation (SOS, ASTM, ISO, ...)
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

- **Properties Measured:**
  - Frequency Shift $\rightarrow$ Velocity
  - Hydroacoustic backscatter

\[ u = \frac{c f_D}{2 f_0} \]
ADCP Primary and Secondary Velocities and Backscatter

![Graph of ADCP Primary and Secondary Velocities and Backscatter](image)

- **Depth (ft)**
- **Distance (ft)**
- **Primary Velocity in feet per second**
- **Measured Backscatter in decibels**

USGS

*science for a changing world*
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)
Acoustic Attenuation by Sediment:

- Backscatter Amplitude Profiles: Measured & Normalized

![Graph showing acoustic attenuation profiles](image-url)
**Acoustic Surrogates: Principles**

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

\[ SCB = WCB + 2r\alpha_s \]

- **Measured Backscatter**
- **Beam Spreading**
- **Water Absorption**
- **Sediment Attenuation** \( \alpha_s = SAC \)

**2-Way Transmission Losses**
Acoustic Attenuation by Sediment:

- Backcatter Amplitude Profiles: Measured & Normalized

\[
SAC \text{ or } \alpha_s = -\frac{1}{2} \frac{d}{dr} \left( RL + 20 \log_{10}(y r) + 2r \alpha_w \right)
\]
Acoustic Attenuation by Sediment:

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

- Hybrid Urick-Sheng-Hay Method:
Sediment Size from Acoustic Attenuation

Ratio of Acoustic Attenuation 3.0 to 1.2 MHz vs. Sediment Diameter, microns
Traditional Suspended-Sediment Monitoring

Physical Samples and Gravimetric Analyses

- Difficult
- Expensive
- Labor intensive
- Essential

Limited samples often provide inadequate resolution of variability and require large interpolations
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)
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.
Index-Velocity T&M Report

- Many of the same site selection criteria apply as for index-velocity streamgages!
- http://pubs.usgs.gov/tm/3a23/
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)
Measurement Volume and Multi-Cell
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
Mounts

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

Where's my ADVM?
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

- USGS Sediment sampling vessel
- Acoustic measurement volume
- Suspended-sediment sampler
- Acoustic Doppler meter
- Data collection platform
Yellow River at Gees Mill Road near Metro Atlanta, GA, 02207335

Acoustic Doppler Current Profilers
(A) 1.2MHz  (B) 1.5MHz  (C) 3.0MHz
Laboratory analysis for mass concentration and percent finer than 63 µm (251+ samples)
Calibration of fixed-point to cross section physical samples of SSC

\[ SSC_{XS} = 0.976 \left( SSC_{POINT} \right)^{1.043} \]

\[ R^2 = 0.96 \]
Federal Interagency Sedimentation Project

Sediment and Water-Quality Samplers and Research

water.usgs.gov/fisp

Federal Interagency Sedimentation Project
3038 Amwiler Road, Suite 130
Atlanta, GA 30360-2824
(770) 903-9152
(770) 903-9199 (Fax)
Acoustic Surrogates of SSC

Table 9.2—Regressions of Predicted Cross Section SSC by 1.5 MHz Acoustic Metrics, mg/L

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>R squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>RB_{1.5MHz}</td>
<td>0.8</td>
</tr>
<tr>
<td>\alpha_s_{1.5MHz}</td>
<td>0.8</td>
</tr>
<tr>
<td>RB_{3.0MHz}</td>
<td>0.7</td>
</tr>
<tr>
<td>\alpha_s_{3.0MHz}</td>
<td></td>
</tr>
<tr>
<td>RB_{1.2MHz}</td>
<td></td>
</tr>
<tr>
<td>\alpha_s_{1.2MHz}</td>
<td></td>
</tr>
</tbody>
</table>

1.5 MHz Surrogate

Surrogate metrics

Model

- \alpha_s_{1.5MHz} = 0.0543
- \alpha_s_{3.0MHz} = 0.0611
- \alpha_s_{1.2MHz} = 0.0476

Observed Cross Section SSC, mg/L
Discrete Measurements of SSC by Acoustics

Image from Justin Boldt

Level 1: Develop a calibration

Level 2: Apply calibration to cross section

Level 3: Validate calibration with EDI sample

Concurrent measurements of acoustic backscatter (stationary profile) and suspended sediment concentration (point samples)
Discrete Measurements of SSC by Acoustics

Cowlitz River at Castle Rock, WA
March 24, 2014

Image from Ryan Jackson
Measured Backscatter (dB)

Suspended Sediment Concentration (mg/L)

EDI = 71.4 mg/L
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