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The Illinois River: Working Locally–Reaching Globally

14TH BIENNIAL GOVERNOR'S CONFERENCE ON THE MANAGEMENT OF THE ILLINOIS RIVER SYSTEM

Current State of Suspended-Sediment Surrogate Technology

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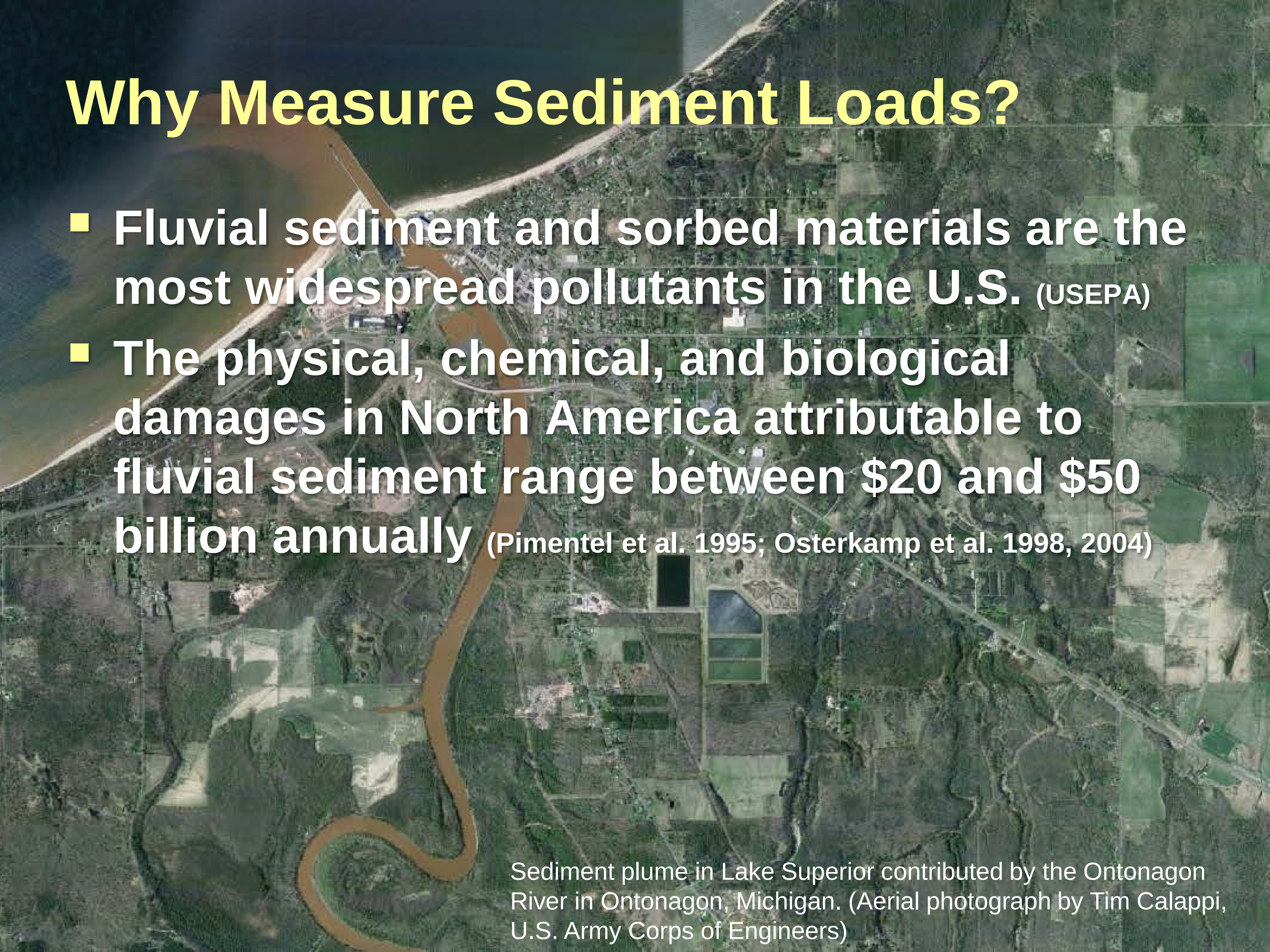
Why Measure Sediment Loads?

- Fluvial sediment and sorbed materials are the most widespread pollutants in the U.S. (USEPA)
- The physical, chemical, and biological damages in North America attributable to fluvial sediment range between $20 and $50 billion annually (Pimentel et al. 1995; Osterkamp et al. 1998, 2004)



Sediment plume in Lake Superior contributed by the Ontonagon River in Ontonagon, Michigan. (Aerial photograph by Tim Calappi, U.S. Army Corps of Engineers)

Greater Demand, Fewer Gages

- **The need for reliable, accurate, and cost-effective sediment data in the U.S. has never been greater**
- **However, between 1981 and 2006 the number of USGS streamgages that collected sediment data decreased by 75% (i.e. 3 of every 4 sediment sites were discontinued)**
- **The principle reason for the decrease in sediment gages is cost**

Matilija Dam Delta (California)

- 5.9 million yd^3 of trapped sediment
- < 500 acre feet capacity remain
- USBR Ecosystem restoration project

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Traditional Suspended Sediment Monitoring

- Gravimetric analyses on samples collected manually or by automatic samplers
- Such methods are:
  - Expensive
  - Difficult
  - Labor intensive
  - Hazardous
- Limited samples may result in inadequate resolution of variability over storm event and require temporal interpolations

Gray and Gartner 2009

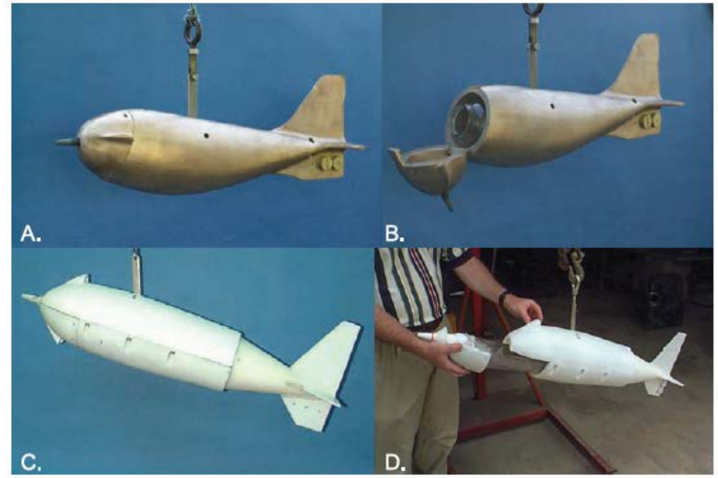
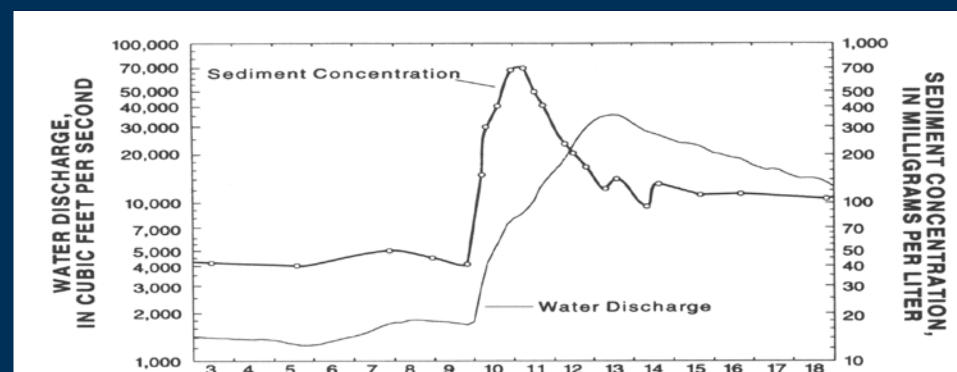
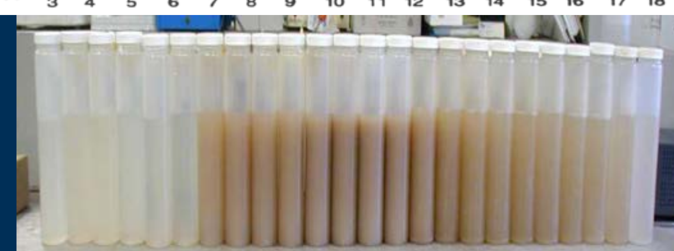


Figure 2. Two Federal Interagency Sedimentation Project suspended-sediment samplers: A U.S. D-74 suspended-sediment rigid bottle sampler (a) closed and (b) open; a U.S. D-96 flexible-bag suspended-sediment sampler (c) closed and (d) with tray containing flexible bag partially open.





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Sediment Surrogate Technologies

Performance Criteria: (Gray and Gartner, 2009)

1. Capital, operational, and analytical costs must be affordable
2. Technology must be able to measure SSC and PSD (in some cases) throughout the range of interest
3. Instrument must be robust, reliable, and not drift
4. Simple to deploy and operate with sufficient training
5. Data processing should be relatively simple or be accompanied by computational routines

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Surrogate Acceptance Criteria
(Gray and Gartner, 2009)

- **Generalized from laser diffraction instrumentation**

Table 1. Acceptance Criteria for Suspended-Sediment Concentrations[a]

Suspended-Sediment Concentration Minimum, g/L	Suspended-Sediment Concentration Maximum, g/L	Acceptable Uncertainty, %
0	<0.01	50
0.01	<0.1	50–25 computed linearly
0.1	<1.0	25–15 computed linearly
1.0	–	15

[a]Suspended-sediment data produced are considered acceptable when they meet these criteria 95 percent of the time [*Gray et al.*, 2002].

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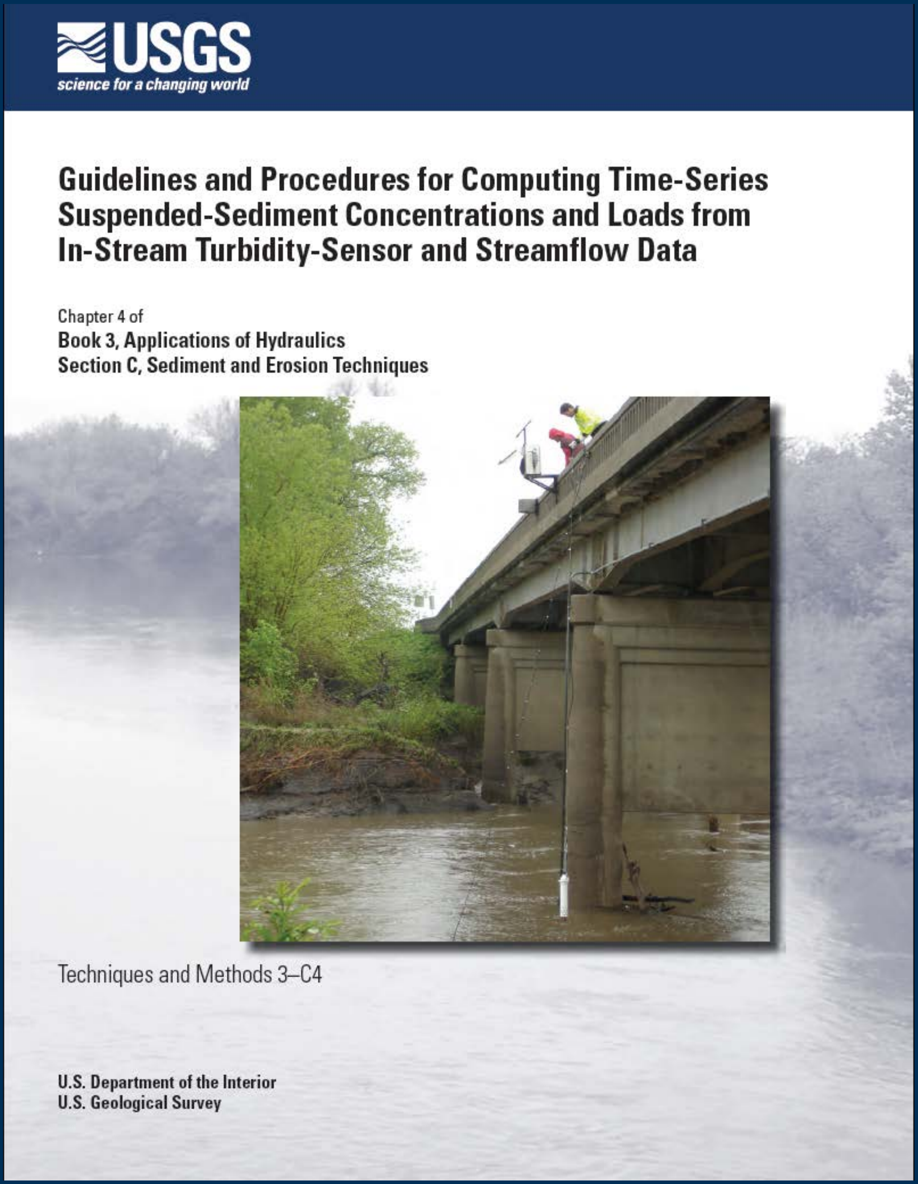
Technological Advances in Suspended Sediment Surrogate Monitoring

Primary Surrogate Technologies

- Bulk optics (Turbidity)
- Laser Diffraction
- Pressure Difference
- Digital Photo-Optics
- Acoustic Backscatter
  - USGS Sediment Acoustic Leadership Team (SALT)

Bulk Optics (Turbidity)

- New chapter in suspended sediment monitoring
- USGS T&M 3-C4
- With an acceptable regression model, suspended-sediment concentration *can be computed beyond the period of record* used in model development
  - Requires ongoing collection and analysis of calibration samples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Guidelines and Procedures for Computing Time-Series Suspended-Sediment Concentrations and Loads from In-Stream Turbidity-Sensor and Streamflow Data

Chapter 4 of
Book 3, Applications of Hydraulics
Section C, Sediment and Erosion Techniques

Techniques and Methods 3–C4

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

Bulk Optics (Turbidity)

- Most common surrogate for SSC in the U.S.
- Can produce reliable results (< 320 g/L OBS)
- First surrogate to be sanctioned by USGS
- Relatively low cost (~$5k)

Figure 1. Three self-cleaning nephelometric turbidity sensors—*A*, YSI Incorporated (Yellow Springs, Ohio) model 6136 turbidity sensor, *B*, Hydrolab (Loveland, Colorado) self-cleaning turbidity sensor, and *C*, Forest Technology Systems (Blaine, Washington) model DTS-12 turbidity sensor.

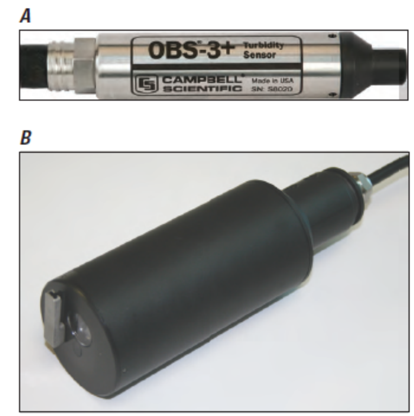

Figure 2. Optical backscatter sensors—*A*, OBS 3+ (Campbell Scientific Inc., Logan, Utah) and *B*, Hach (Loveland, Colorado) Solitax.

USGS T&M 3-C4

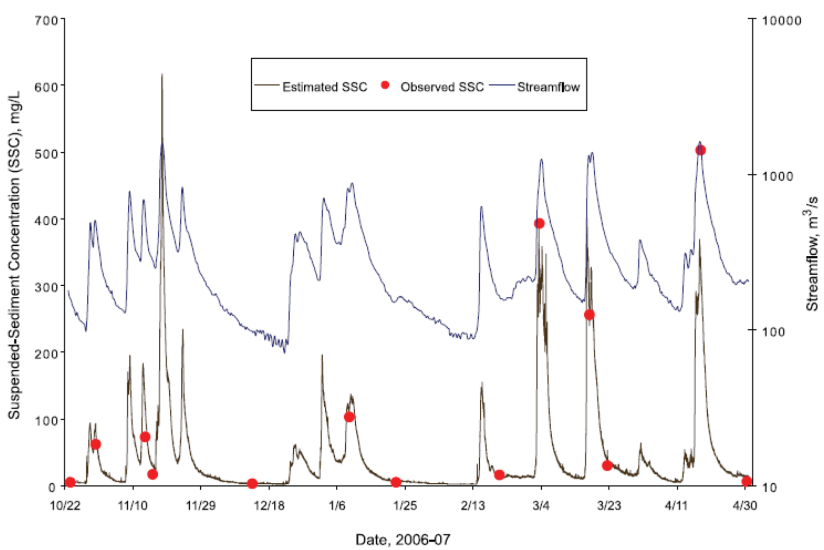

Figure 5. Time series plot of continuous suspended-sediment concentrations (computed by multiple linear regression from square root-transformed time series of turbidity, streamflow, and water temperature data), sampled SSCs in milligrams per liter, and streamflow in cubic meters per second for the James River at Cartersville, Virginia, 22 October 2006 to 30 April 2007. From Jastram et al. (submitted manuscript, 2009).

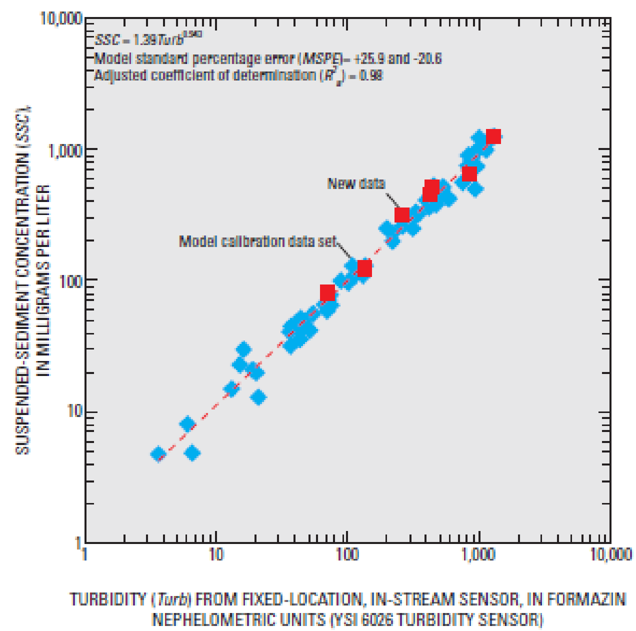

Figure 16. Model-calibration data set (water years 1999–2005) and new (water year 2006) turbidity and suspended-sediment concentration data for U.S. Geological Survey streamgage on Little Arkansas River near Sedgwick, Kansas.

Grey and Gartner, 2009

Bulk Optics (Turbidity)

Advantages

- Large number of data sets and sites are available for evaluation
- Mature and reliable technology
- Calibration techniques documented and straightforward
- Relatively low cost

Limitations

- Point samples (may not represent cross section)
- Can lack consistency amongst sensors
- Variable response to sediment grain size, composition, and shape (best for stable PSD site)
- Subject to saturation
- Biological fouling and damage to optics
- Hysteresis can occur (due to change in PSD, see Landers and Sturm, 2013)

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Laser Diffraction

- **Exploit the Mie scattering theory**
  - **At small forward scattering angles, laser diffraction by spherical particles is identical to diffraction by an aperture of equal size (Agrawal and Pottsmith, 1994)**
- **Originally designed for the lab**
- **Determines the PSD in 32 log-spaced size classes**
- **Computes volumetric SSC from PSD**
- **Insitu and pump-through systems are available**

Sequoia Scientific, Inc.

LISST-100X

LISST-SL

LISST-StreamSide

Laser Diffraction Application

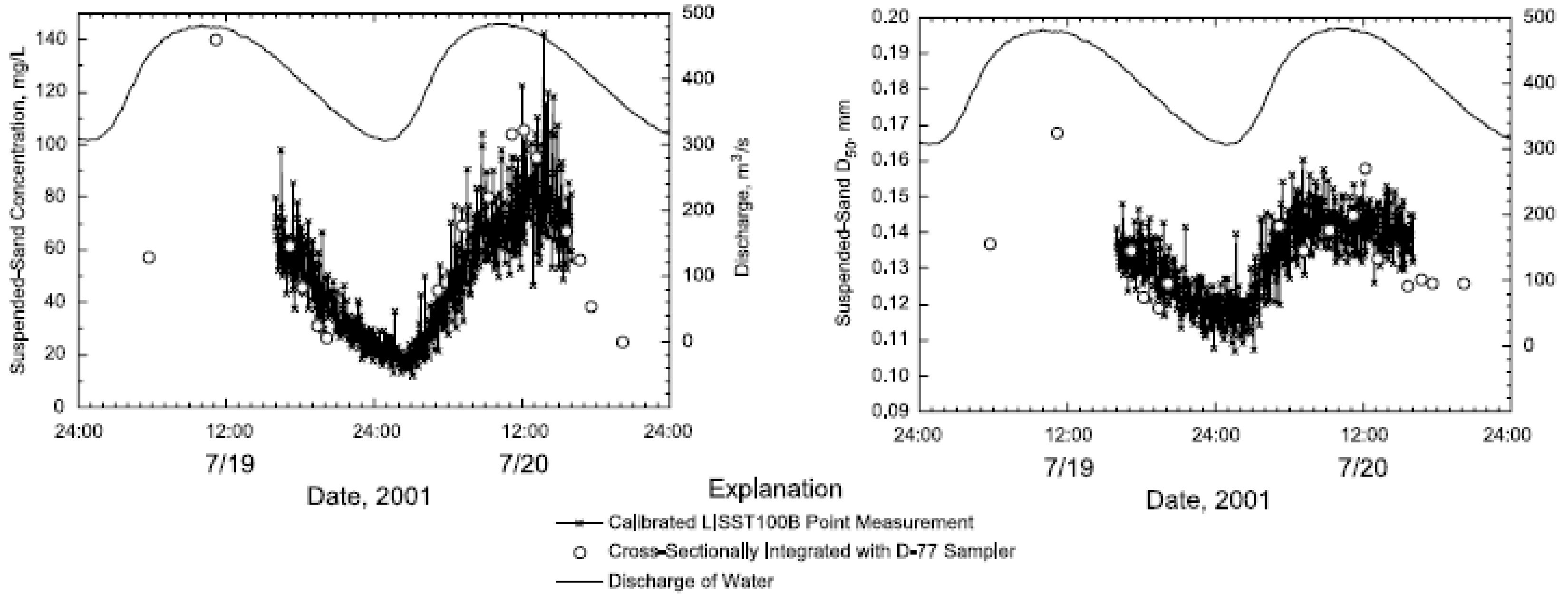

Figure 7. Comparison of sand concentrations in milligrams per liter and median grain sizes in millimeters measured at the USGS streamgage at the Colorado River near Grand Canyon, Arizona, using a LISST-100B and a U.S. D-77 bag sampler. From *Melis et al.* [2003].

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Laser Diffraction

Advantages

- Insitu or real-time PSD in 32 classes
- Calculated volumetric SSC is not affected by changes in PSD
- Isokinetic sampler is available
- Pump-through systems are available

Limitations

- Point measurements may not be representative of cross section
- Deviation of particle shape from spherical may result in bias
- Saturation of the laser sensors occur at about half that of a turbidity sensor
- Biofouling may be an issue
- Costs up to 6 times that of a fully equipped turbidity sensor

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Pressure Difference

- Exploits the pressure difference between to points in the water column to compute water density
- SSC can be inferred after correcting for water temperature and dissolved solids

Assumes:

1. The water surface measured by both sensors is equal
2. The density of the water column above the lowest sensor is constant

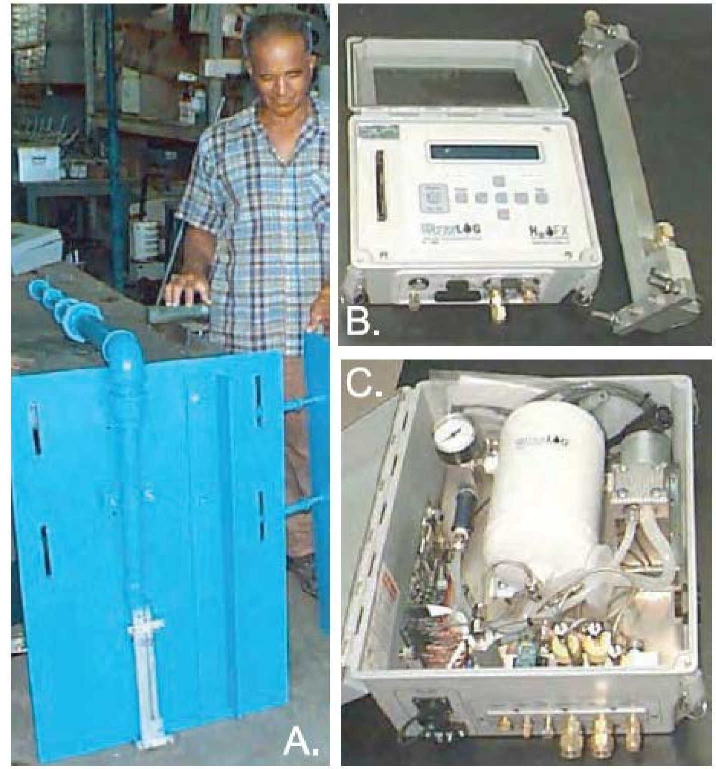

Figure 8. Double Bubbler Pressure Differential Instrument (a) in-stream components before installation, (b) controller and orifice bar, and (c) air compressor and tank assembly. Figures 8b and 8c courtesy of Design Analysis Associates, Inc.

Pressure Difference Application

Paria River, Lees Ferry, Arizona (July 2004)

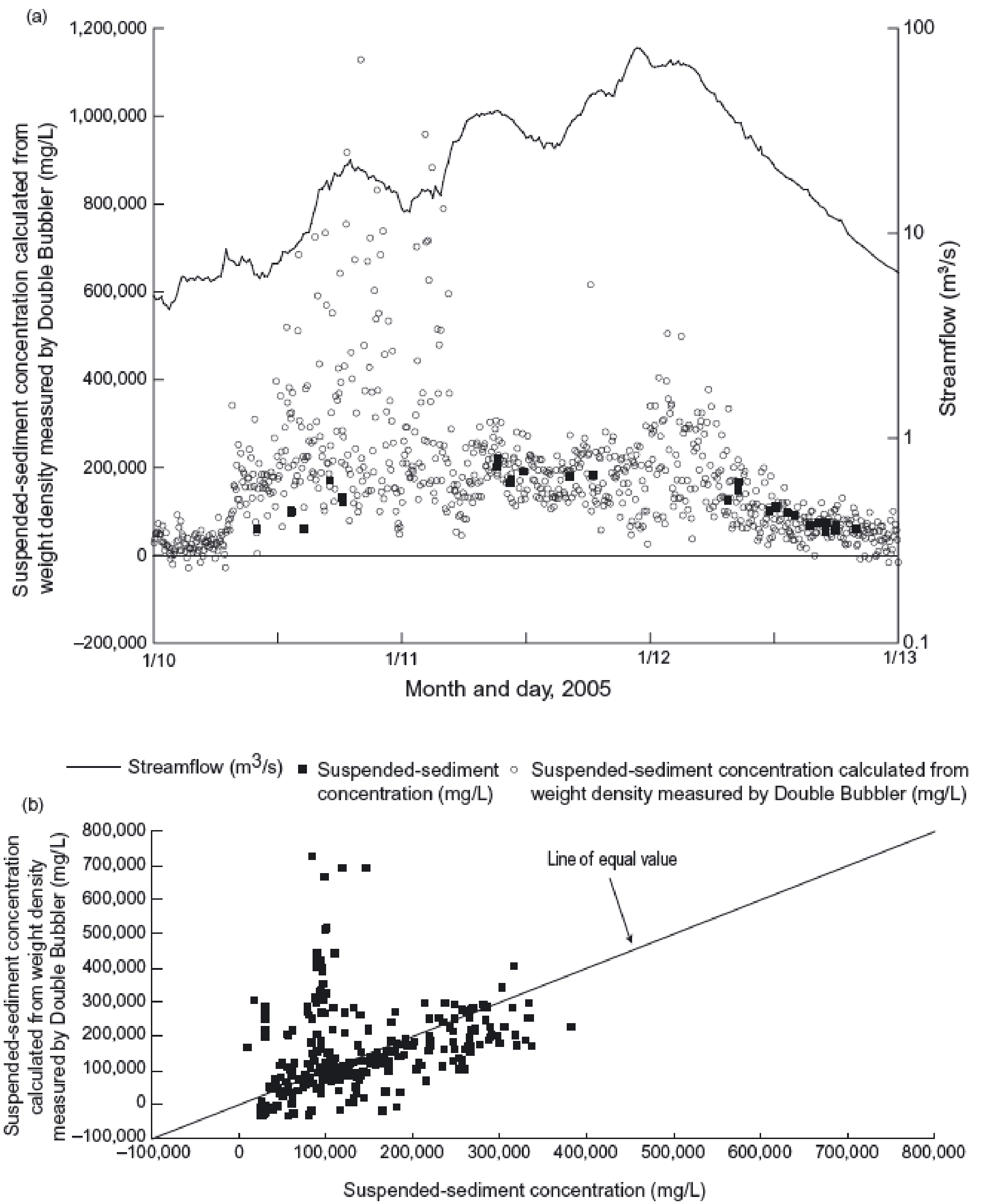

Fig. 1.19 Data for the USGS streamgage on the Paria River at Lees Ferry, Arizona, USA, July 2004 through September 2006. (a) Time series of streamflow, SSCs from samples, and SSCs calculated from weight densities of suspended sediments and dissolved solids measured using the Double Bubbler for a storm in January 2005; (b) scatter plot of measured SSCs from samples and those calculated from the Double Bubbler. Streamflow and sediment data are instantaneous samples, and the Double Bubbler SSC values, calculated from weight densities, are from measurements made at 5-minute intervals.

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Pressure Difference

Advantages

- Infers SSC in a single vertical, rather than point
- Robust technology, resistant to fouling or drift
- Doubles as redundant stage sensor for site
- Accuracy improves with higher SSC (> 10-20 g/L)
- Theory and technology is simple

Limitations

- Assumes constant density above lowest sensor (hard to verify)
- May be incapable of measuring SSC < 10 g/L in turbulent flows (noise) and when bedforms cover one or both orifces
- While lab results are promising, field performance has been poor
- Both orifices must remain in the water and unburied
- Spurious data are numerous (likely turbulence)
- The manufacturer no longer makes this instrument

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Digital Photo-Optics

- Computes size statistics of particles captured in images in a flow-through cell
- Volumetric SSC is inferred from the size statistics
- High-quality, 2-D images are processed at the pixel level
- Primarily lab-based with field testing
- Accurate up to 10 g/L

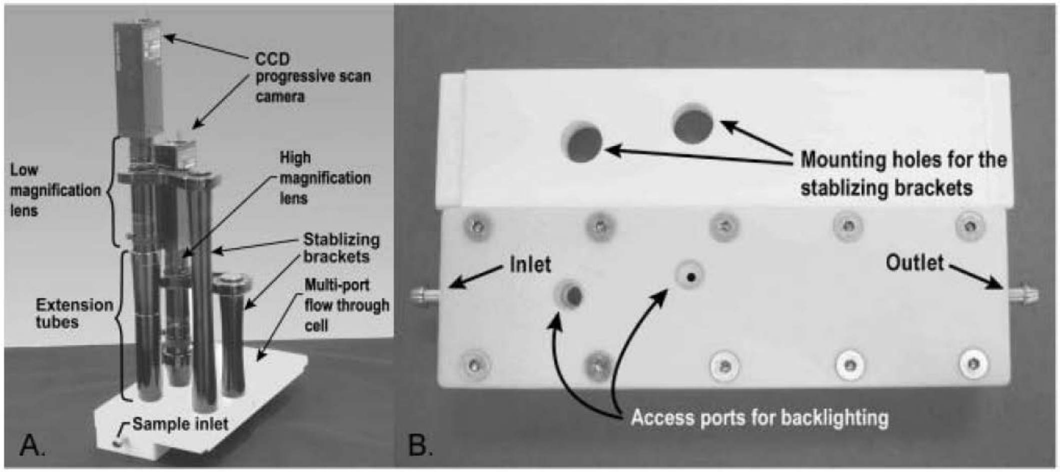

Figure 3 Suspended-sediment digital optic-imaging components: A) Cameras atop encased lenses with extension tubes and encased flow-through cell (fiber optic cable not shown). B) Multi-port flow-through cell (patent pending). From Gooding, 2010.

Digital Photo-Optics

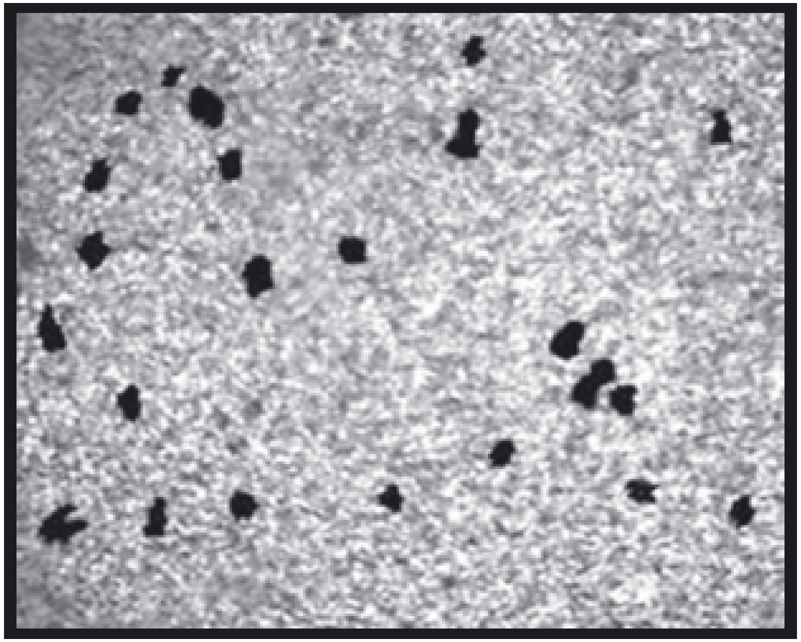

Fig. 1.14 A morphologically transformed image of a water-sediment mixture composed of 10 g/L of material finer than 62 µm, seeded with 125- to 250-µm particles that appear as dark blobs.

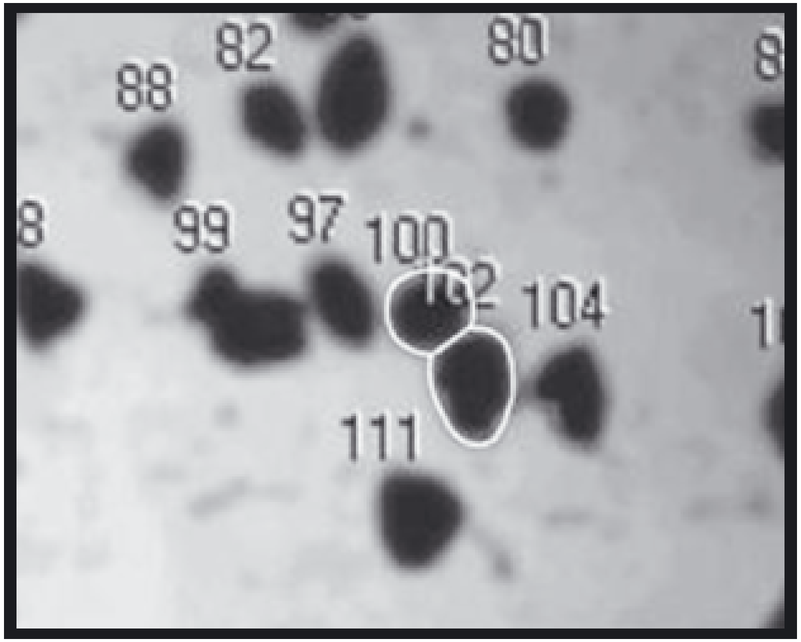

Fig. 1.15 A morphologically transformed image of a water–sediment mixture composed of 62–125 µm particles showing potentially inconsistent interpretation of overlapping or connected particles.

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Digital Photo-Optics

Advantages

- Components cost about the same as a turbidity sensor
- No instrument specific calibrations necessary
- Can be incorporated into isokinetic samplers or stream-side pumped systems

Limitations

- Accuracy can be affected by
  - Partially hidden particles
  - Aggregates
  - High turbidity levels
  - Bubbles
  - Stagnant material in measurement volume
- Results are expressed as volumetric units and not mass per unit volume (requires assumption about particle density or collection of samples)
- Data can be noisy as images are corrupted by factors above

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Acoustic Backscatter

- **Relies on the acoustic returns (backscatter) of particles in the water column as a surrogate for SSC**

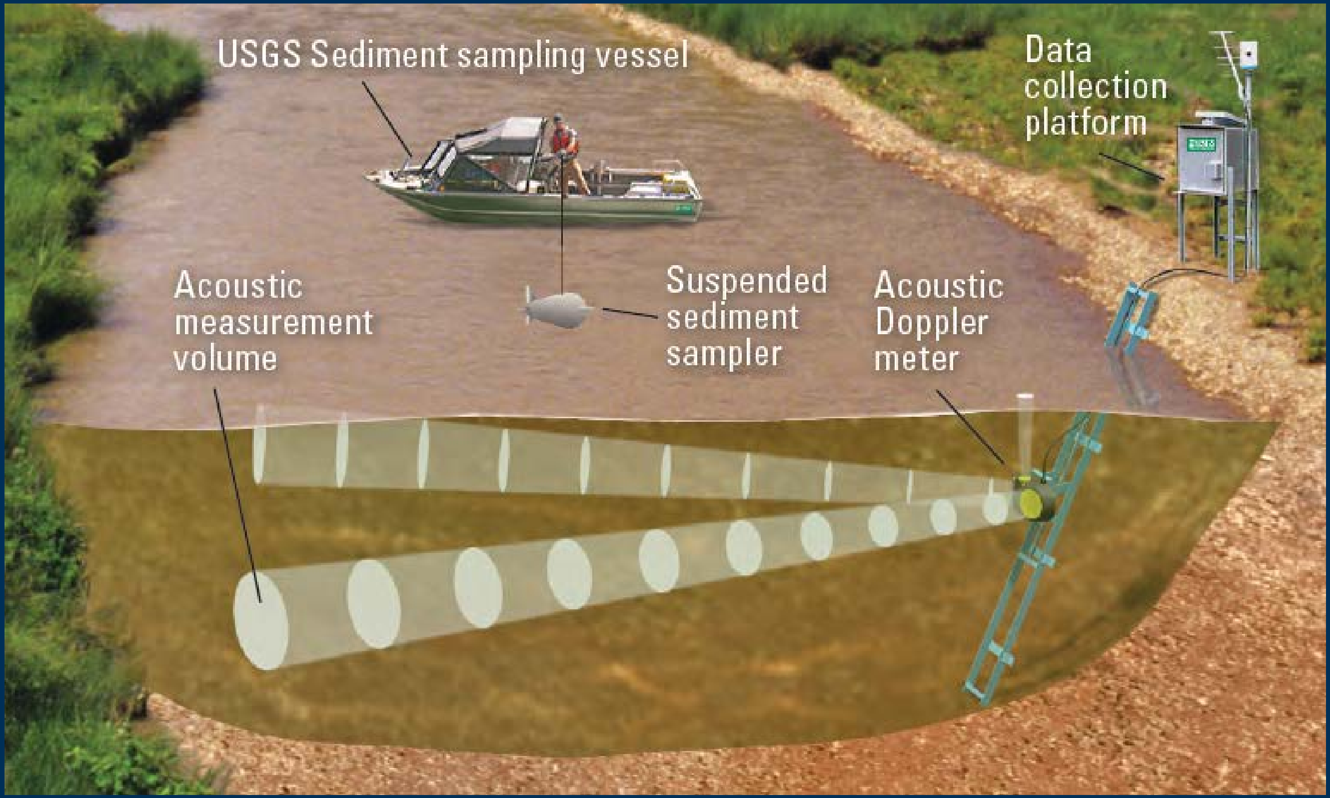

Image from draft Fact Sheet by M. Wood modified from Sontek

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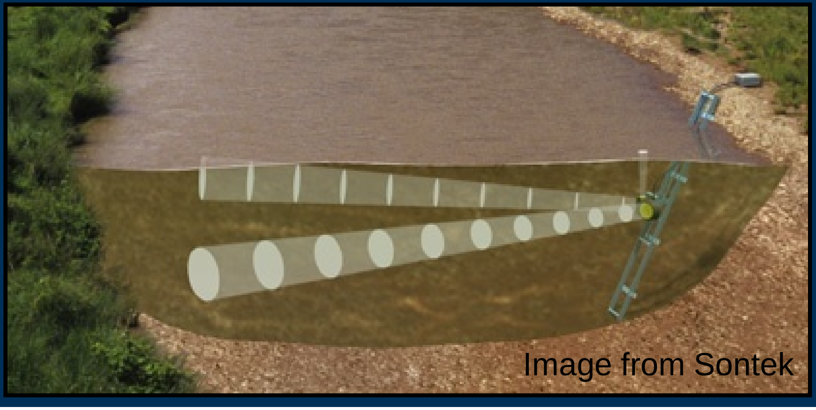
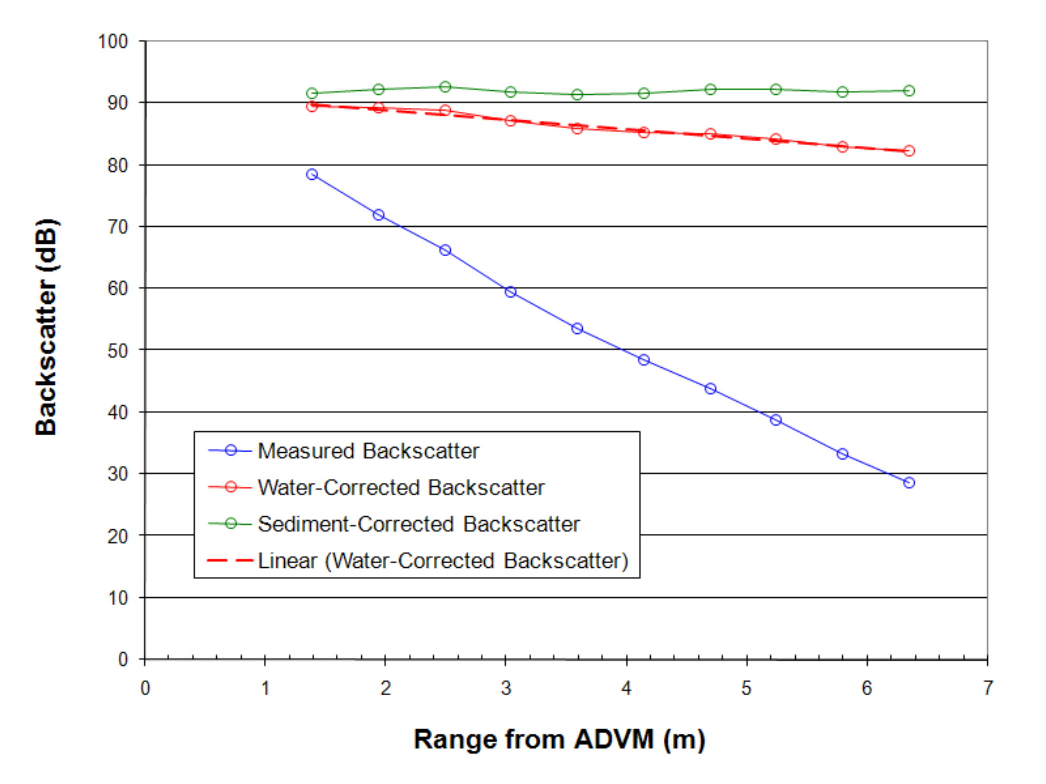
Acoustic Backscatter

- **Assumes a constant concentration along a beam**
- **Uses multiple cells along a beam**
- **Requires multiple steps to formulate a calibration**
  - **Correction for beam spreading and adsorption by water**
  - **Correction for adsorption by sediment**





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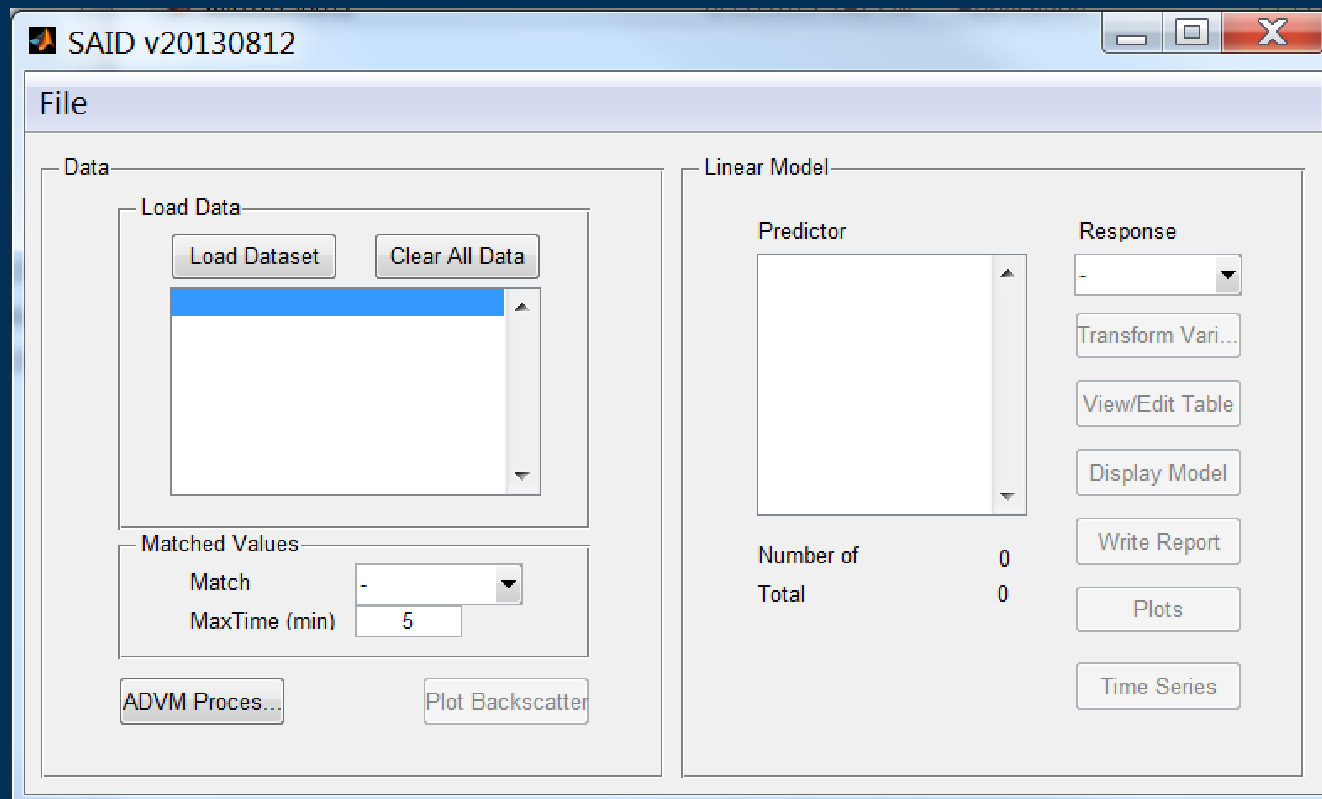
Surrogate Analysis and Index Developer (SAID) Tool

- Processes surrogate data (including sediment acoustic data)
- Initially funded by USGS Midwest Region – RSNI
- Additional 2013 FISP funding



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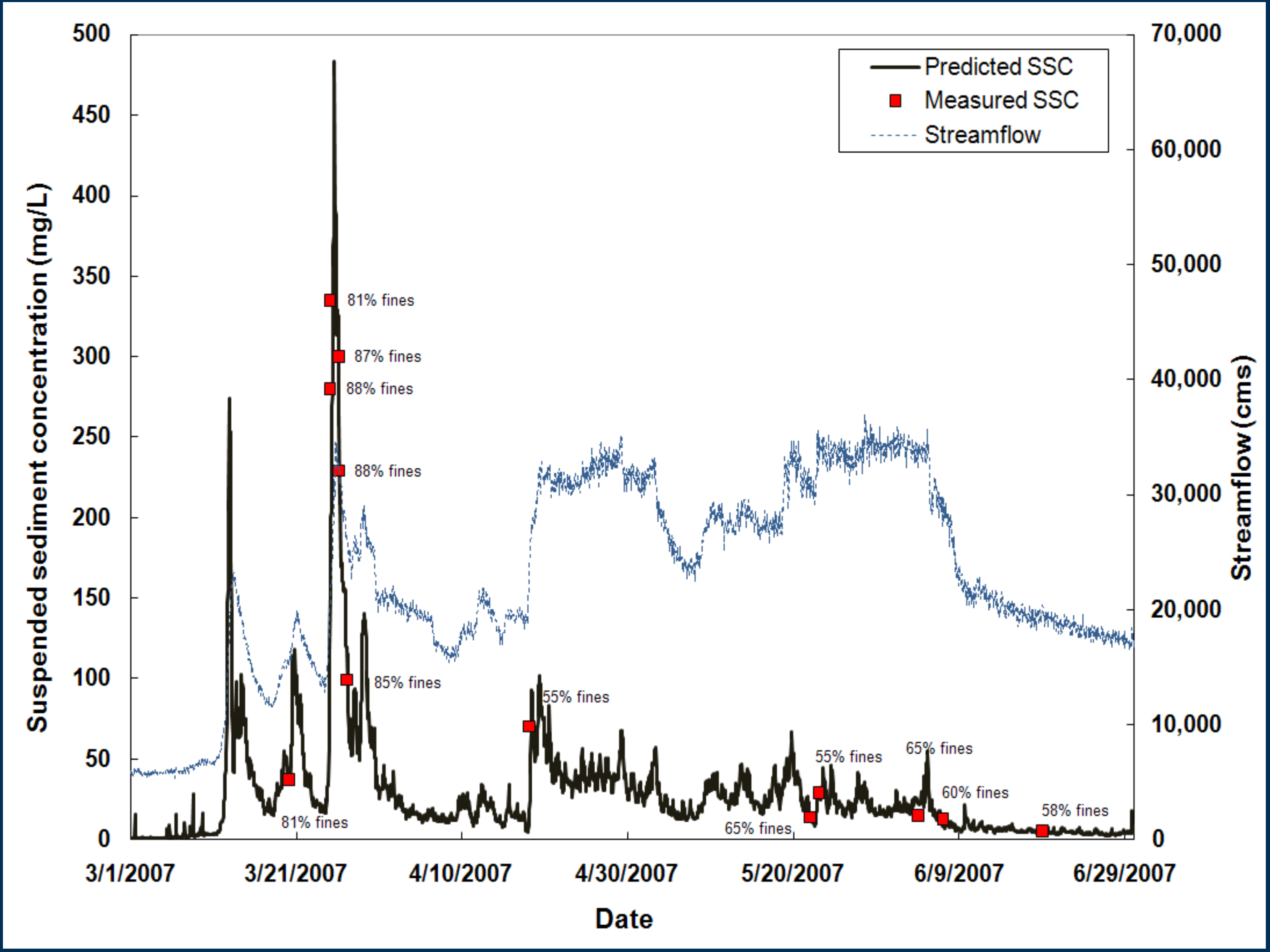
Acoustic Backscatter Application

Kootenai River (ID)
At Tribal Hatchery

Data from M. Wood, USGS ID WSC



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Acoustic Backscatter Applications

Spoon River near Seville, IL

- 1,636 mi^2 drainage area
- Up to 25% sands in suspension

Sontek Argonaut SL

USGS

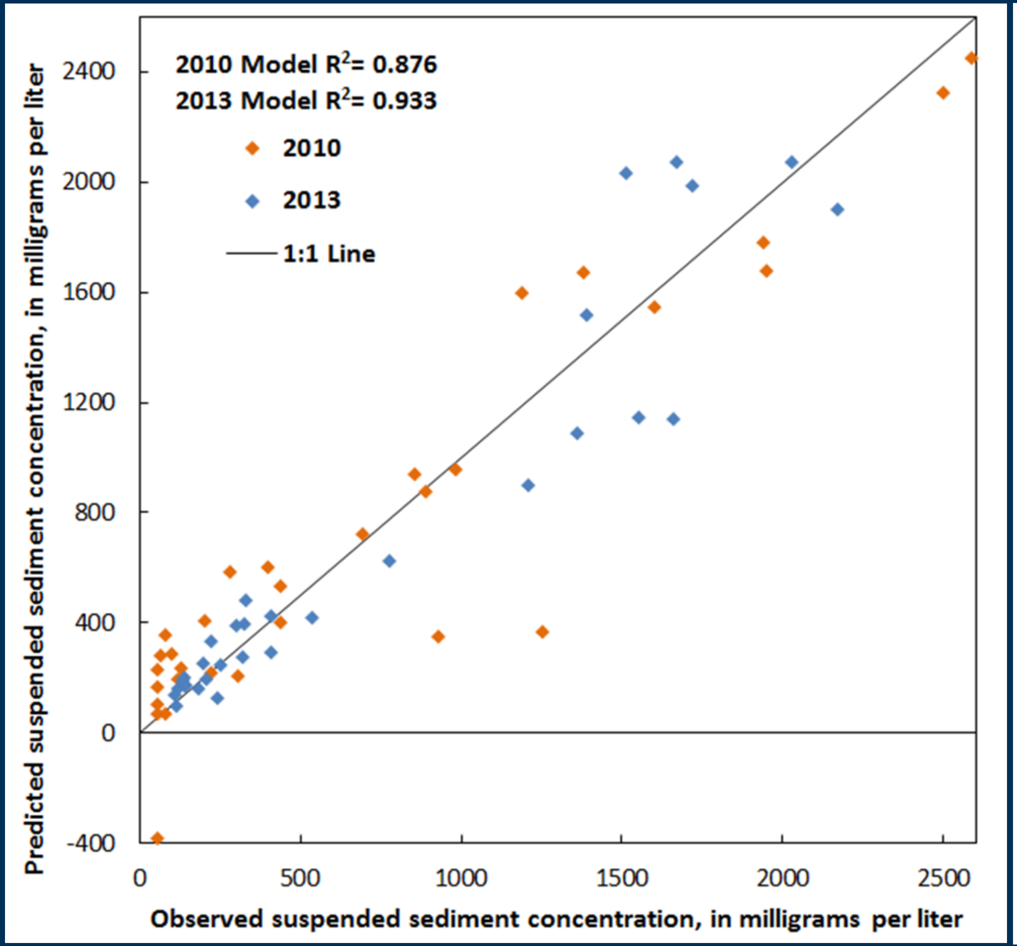
Illinois River at Florence, IL

- 26,870 mi^2 drainage area
- 4 M tons of sediment annually
- USGS sediment and nutrient superstation

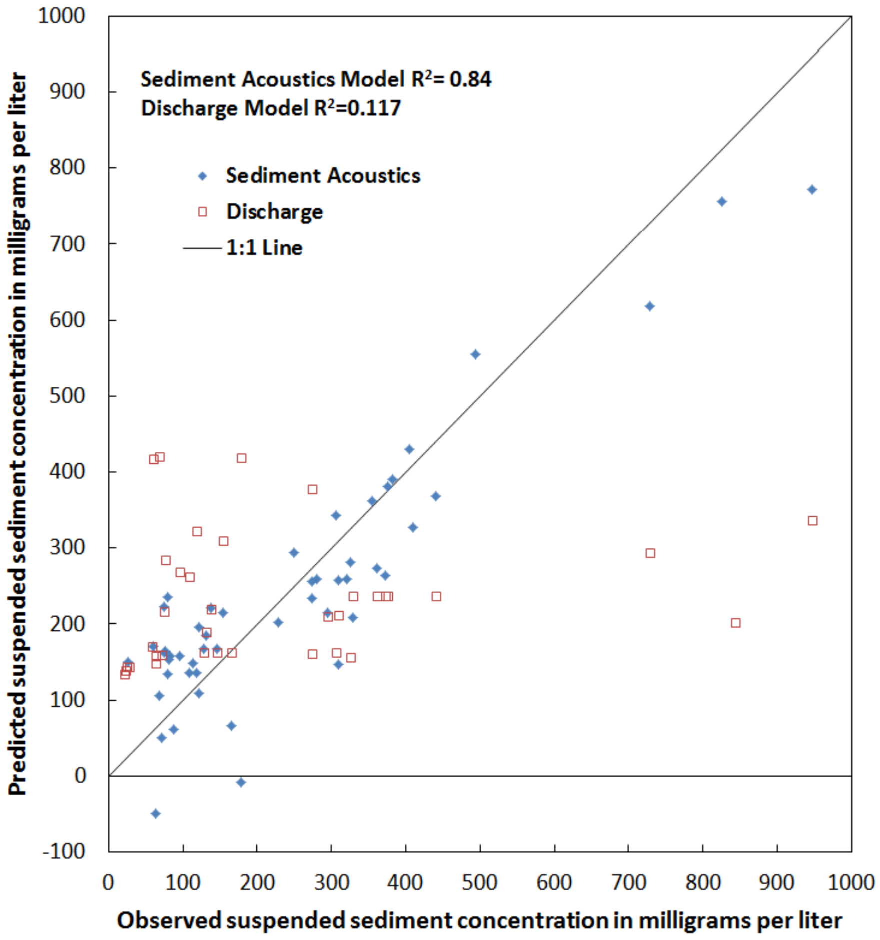
Sontek Argonaut SL500, 1500, 3000

Acoustic Backscatter Applications

Spoon River near Seville, IL



Illinois River at Florence, IL



Acoustic Backscatter

Advantages

- Sample significantly more of the cross section than at-a-point sensors
- Empirically-derived index allows computation of mean cross sectional SSC value. Allows computation of unit and daily value sediment fluxes
- Fouling is not a problem
- Applicable to 0.01-20g/L for silt and clay and 0.01- 3 g/L for sand
- ADVMs also measure velocity data

Limitations

- A single frequency unit cannot differentiate between changes in PSD and SSC without calibration
- There is an optimal frequency for a given particle size and a narrow frequency range for a given PSD
- Complex software is required for reduction and analysis of data and rating development
- Higher cost (about 2-3 times a turbidity sensor)
- Calibrations are instrument specific

Questions?

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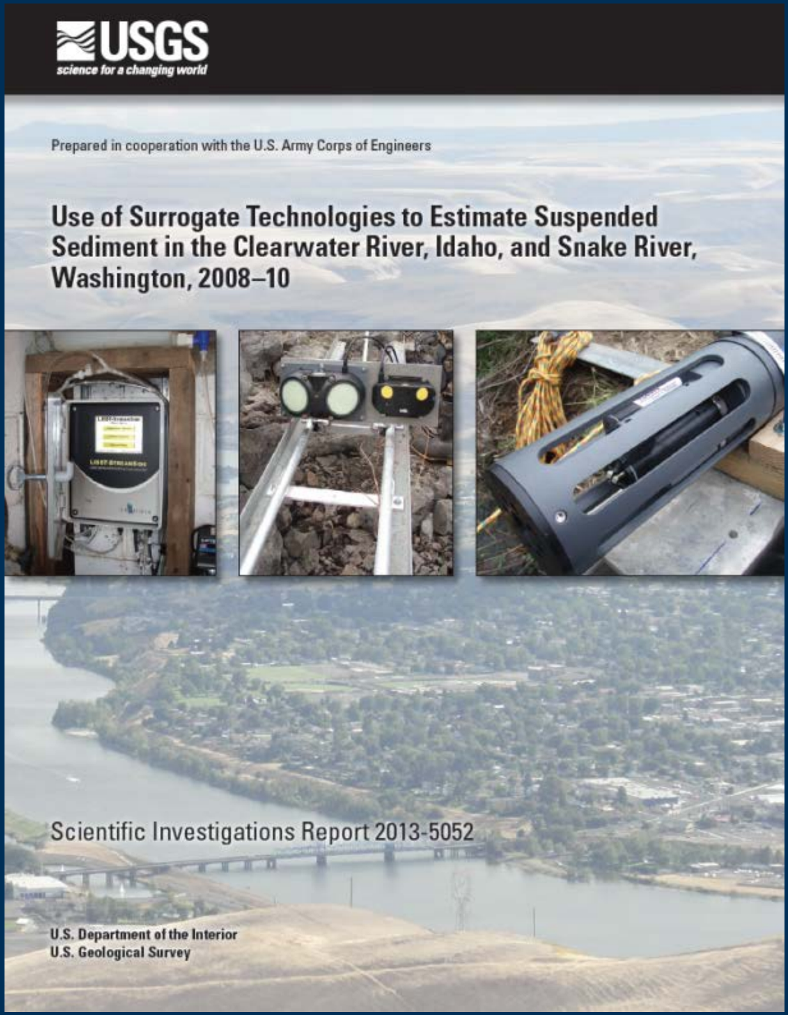
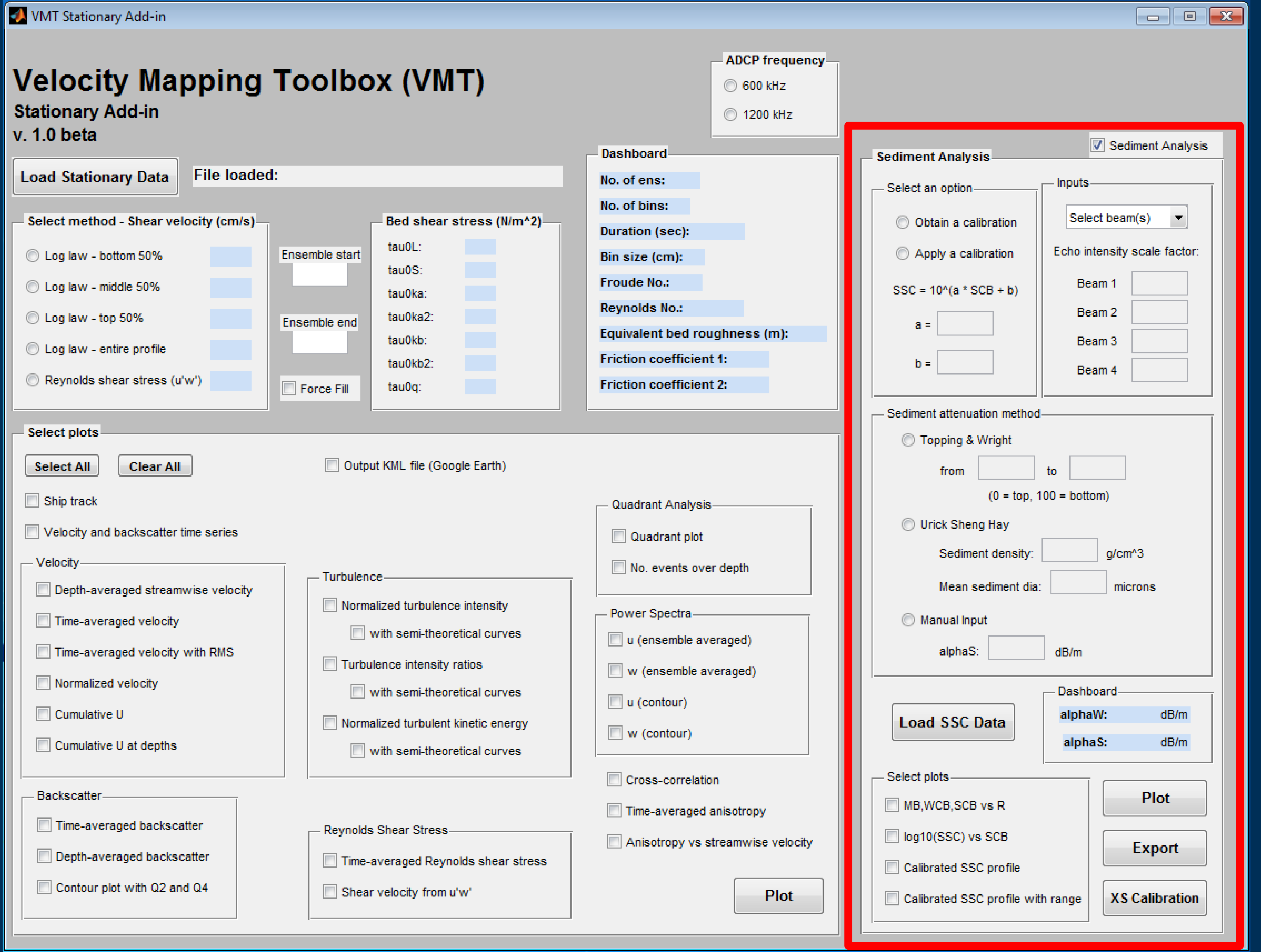


http://pubs.usgs.gov/sir/2013/5052
Molly Wood, P.E.
USGS Idaho Water Science Center


VMT Stationary Add-in
Velocity Mapping Toolbox (VMT)
Stationary Add-in
v. 1.0 beta
Load Stationary Data
File loaded:
ADCP frequency
600 kHz
1200 kHz
Dashboard
No. of ens:
No. of bins:
Duration (sec):
Bin size (cm):
Froude No.:
Reynolds No.:
Equivalent bed roughness (m):
Friction coefficient 1:
Friction coefficient 2:
Select method - Shear velocity (cm/s)
Log law - bottom 50%
Log law - middle 50%
Log law - top 50%
Log law - entire profile
Reynolds shear stress (u'w')
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Ensemble end
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Bed shear stress (N/m^2)
tau0L:
tau0S:
tau0ka:
tau0ka2:
tau0kb:
tau0kb2:
tau0q:
Select plots
Select All
Clear All
Output KML file (Google Earth)
Ship track
Velocity and backscatter time series
Velocity
Depth-averaged streamwise velocity
Time-averaged velocity
Time-averaged velocity with RMS
Normalized velocity
Cumulative U
Cumulative U at depths
Backscatter
Time-averaged backscatter
Depth-averaged backscatter
Contour plot with Q2 and Q4
Turbulence
Normalized turbulence intensity
with semi-theoretical curves
Turbulence intensity ratios
with semi-theoretical curves
Normalized turbulent kinetic energy
with semi-theoretical curves
Reynolds Shear Stress
Time-averaged Reynolds shear stress
Shear velocity from u'w'
Quadrant Analysis
Quadrant plot
No. events over depth
Power Spectra
u (ensemble averaged)
w (ensemble averaged)
u (contour)
w (contour)
Cross-correlation
Time-averaged anisotropy
Anisotropy vs streamwise velocity
Plot
Sediment Analysis
Sediment Analysis
Select an option
Obtain a calibration
Apply a calibration
SSC = 10^(a * SCB + b)
a =
b =
Inputs
Select beam(s)
Echo intensity scale factor:
Beam 1
Beam 2
Beam 3
Beam 4
Sediment attenuation method
Topping & Wright
from
to
(0 = top, 100 = bottom)
Urick Sheng Hay
Sediment density:
g/cm^3
Mean sediment dia:
microns
Manual Input
alphaS:
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Load SSC Data
Dashboard
alphaW:
dB/m
alphaS:
dB/m
Select plots
MB,WCB,SCB vs R
log10(SSC) vs SCB
Calibrated SSC profile
Calibrated SSC profile with range
Plot
Export
XS Calibration

Cross section SSC contour