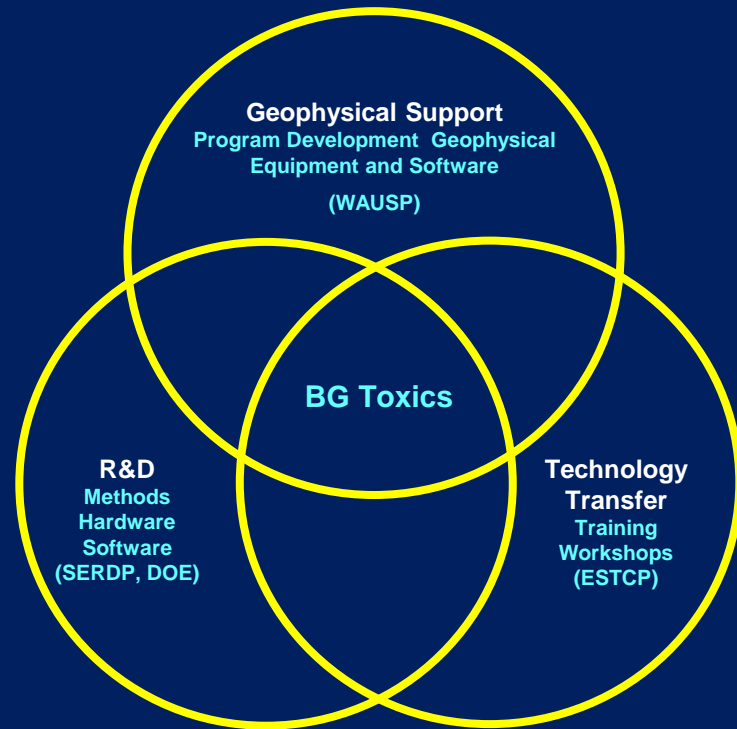




A Hydrogeophysical Toolkit for Understanding Groundwater/Surface-Water Exchange in Support of Restoration Efforts

Martin Briggs,
John Lane, Fred Day-Lewis
mbriggs@usgs.gov
U.S. Geological Survey
Hydrogeophysics Branch

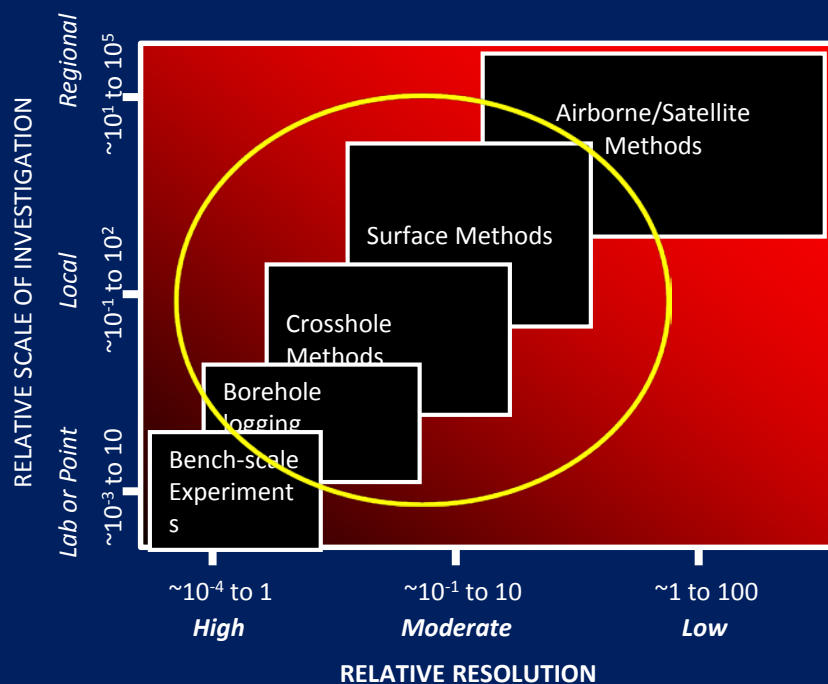
Hydrogeophysics Branch Mission



Hydrogeophysics Branch Toxics (CTT)

- John Lane, Ph.D., Branch Chief – surface geophysics, airborne geophysics, sUAS, GPR
- Fred Day-Lewis, Ph.D. – geophysical inverse problems, fractured rock, software development, aquifer hydraulics, gw/sw interaction
- Martin Briggs, Ph.D. – gw/sw interaction, hydro-ecology, temperature methods, stream tracer experiments
- Carole Johnson – borehole geophysics, fractured rock, NMR, marine methods
- Neil Terry, Ph.D. (postdoc) – electrical methods, EM methods, inverse problems, software development
- John Williams (NYWSC) – borehole geophysics, fractured rock, flowmeter logging
- Eric White – diverse field methods, equipment pool management
- + students, collaborators, WSC staff

The Hydrogeophysical Toolbox



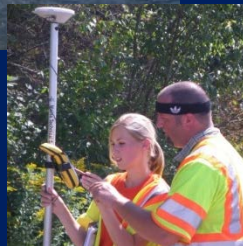
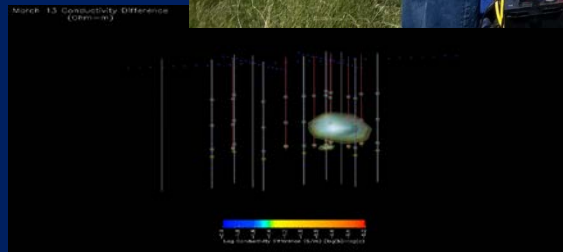
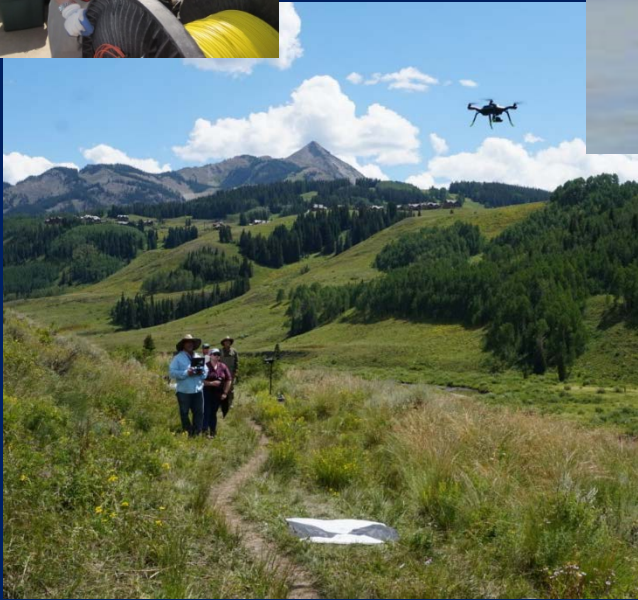
[Modified from Hubbard and Rubin, 2005]

- Reconnaissance
- Characterization
- Monitoring
- Filling gaps in space & time
- Covering large areas rapidly
- Cost effective

The Hydrogeophysical Toolbox

- Electrical - resistivity, induced polarization, self potential
- Seismic – MASW, refraction, reflection, passive seismic/microtremor
- Radar – borehole reflection & transmission, surface reflection
- EM – TDEM, FD inductive EM
- Gravity – relative, absolute
- Temperature: Fiber-optic distributed temperature sensing, FLIR camera
- Marine: resistivity, chirp seismic, GPR
- Airborne: sUAS, FLIR, AEM, etc.

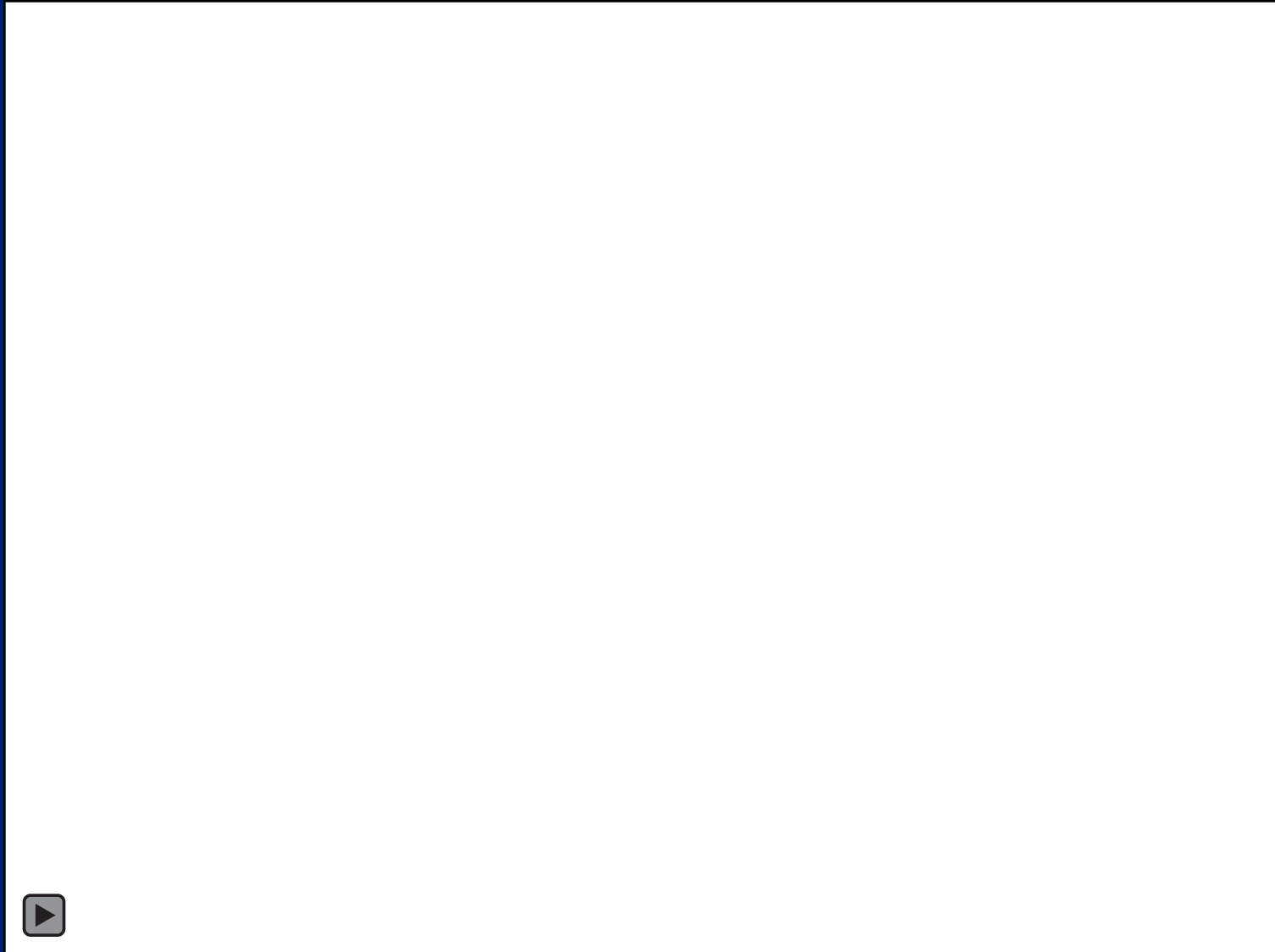




Remote sensing of useful water and sediment properties



“Process-based” wetland restoration



Physical Methods: seepage meters and piezometers



No point data

**Distributed direct measurements are time consuming,
and difficult/impossible in armored streambeds**

Efficient, multi-scale characterization



Multiple geophysical methods can be used together to connect scales of information, but efforts should be refined from the “shotgun” approach.

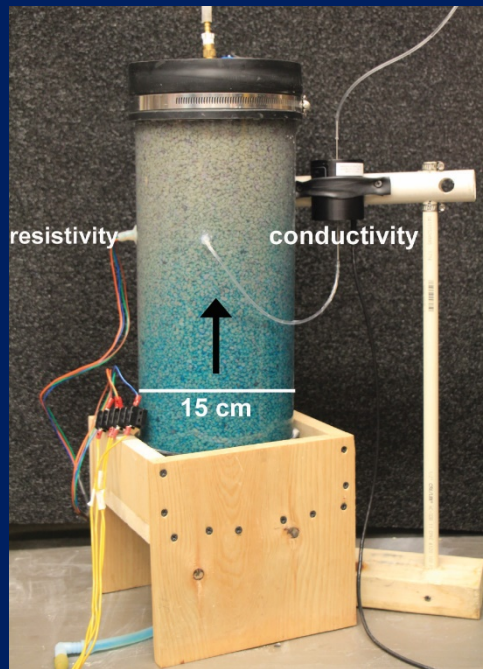
pore

bedform

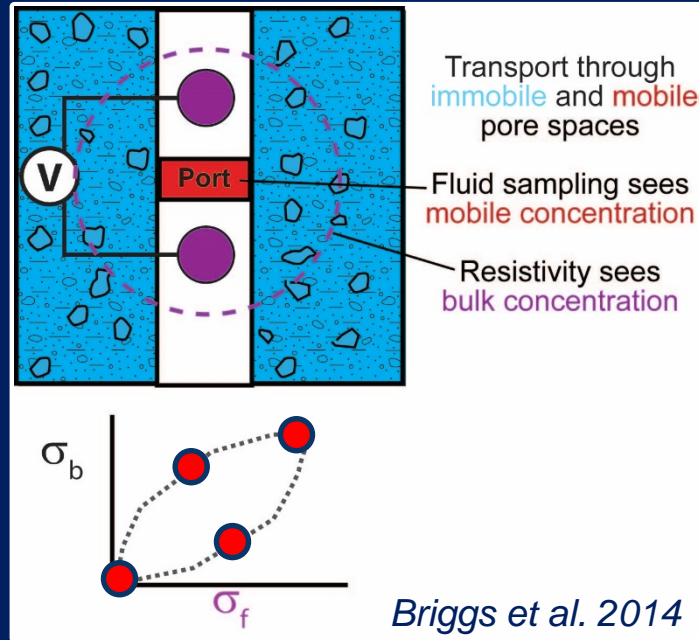
reach/lake

basin

Fine-scale electrical resistivity



local exchange with less-mobile porosity



pore

bedform

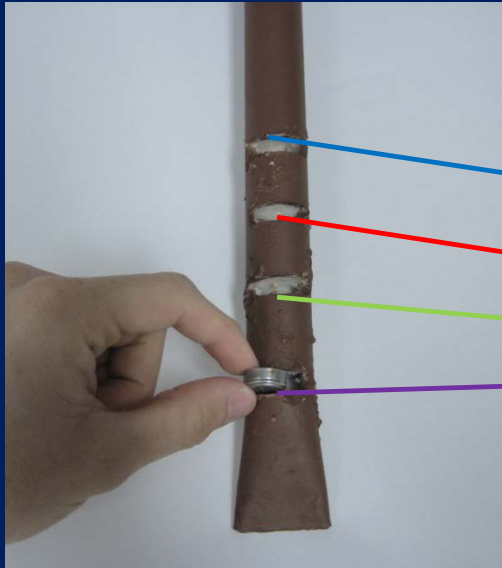
reach/lake

basin

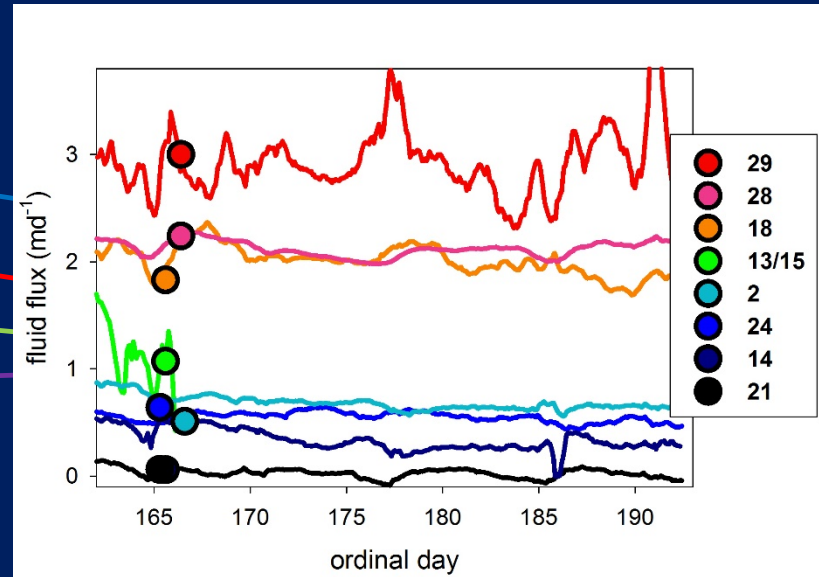
Less-mobile porosity may control long term contaminant storage and release in streambed sediments....

Vertical streambed temperature > flux

convert vertical temperature time-series to 1D fluid flux



custom thermal profiler



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bedform

reach/lake

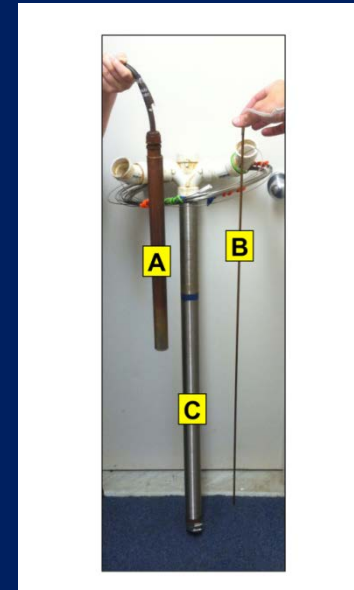
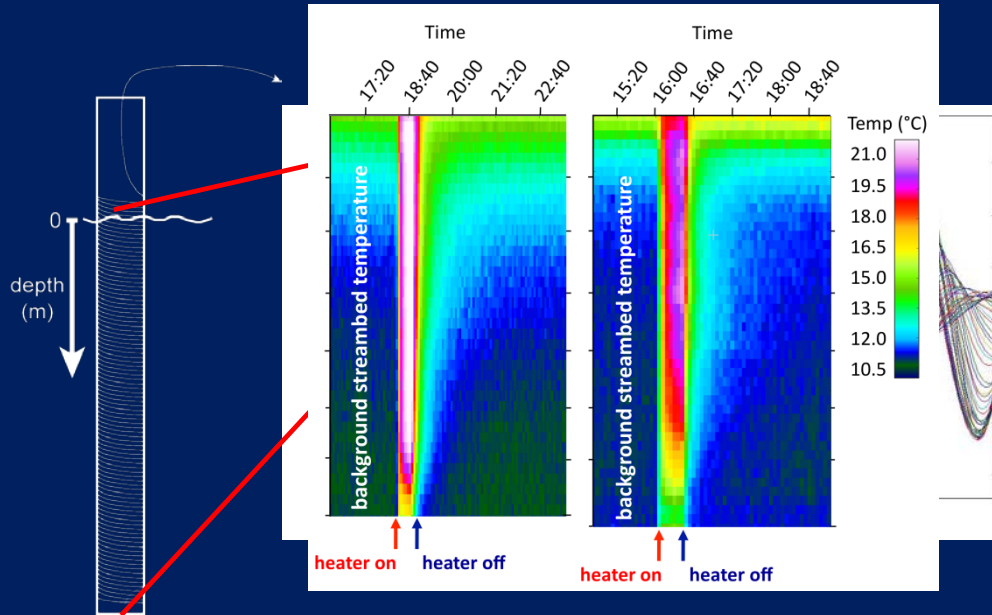
basin

Automated modeling programs such as 1DTempPro and VFLUX allow efficient analysis of vertical fluid flux rates.

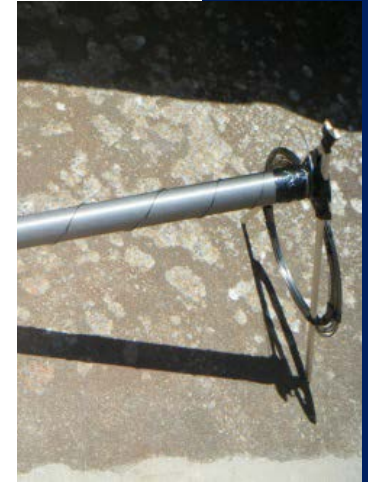
High-resolution vertical temperature

High-resolution temperature profiles in water-column and bed

FO-HRTS



daily heat pulses



Briggs et al. 2012b

pore

bedform

reach/lake

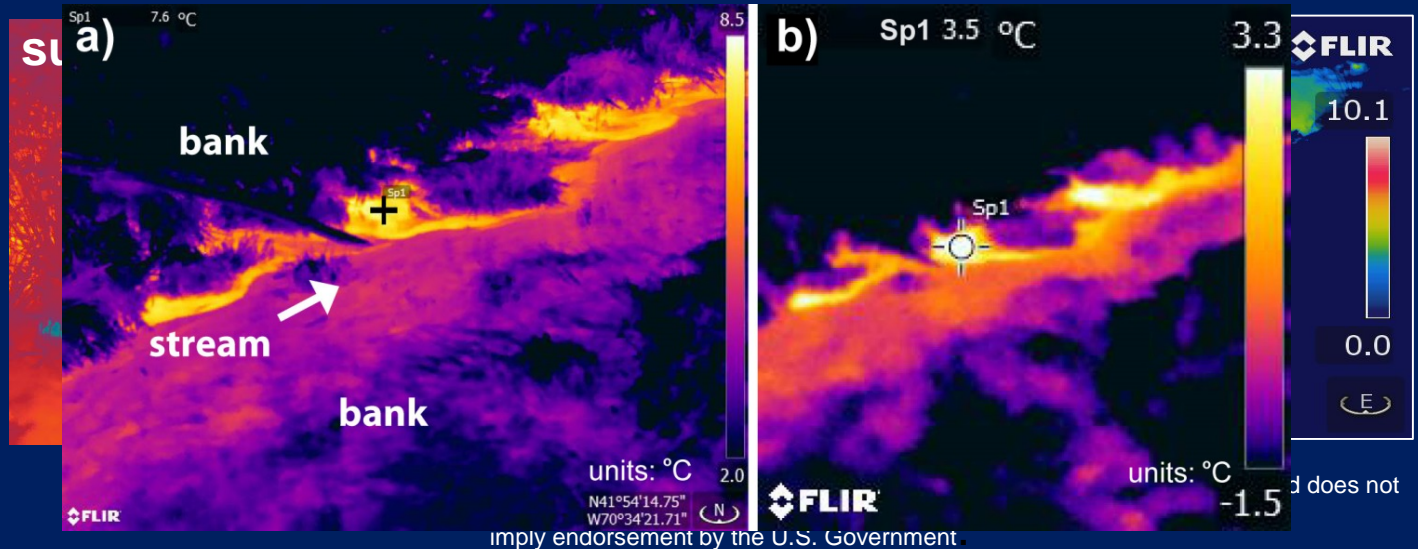
basin

High-resolution temperature records allow quantification of streambed structure and complicated flow dynamics (water residence time).

Infrared imaging of discharge

Thermal infrared images capture contrast in GW/SW temperatures (GW seepage)

TIR imagery



Hare et al. 2015

pore

bedform

reach/lake

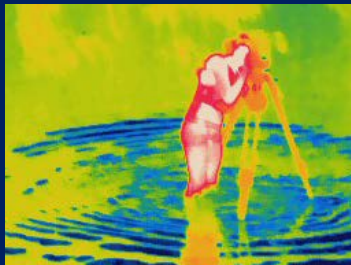
basin

TIR can be an extremely efficient reconnaissance method, under the right conditions...

Bed temperature mapping

Precise, georeferenced measurements of streambed temperature

“point in time”
bed temperature



Streambed

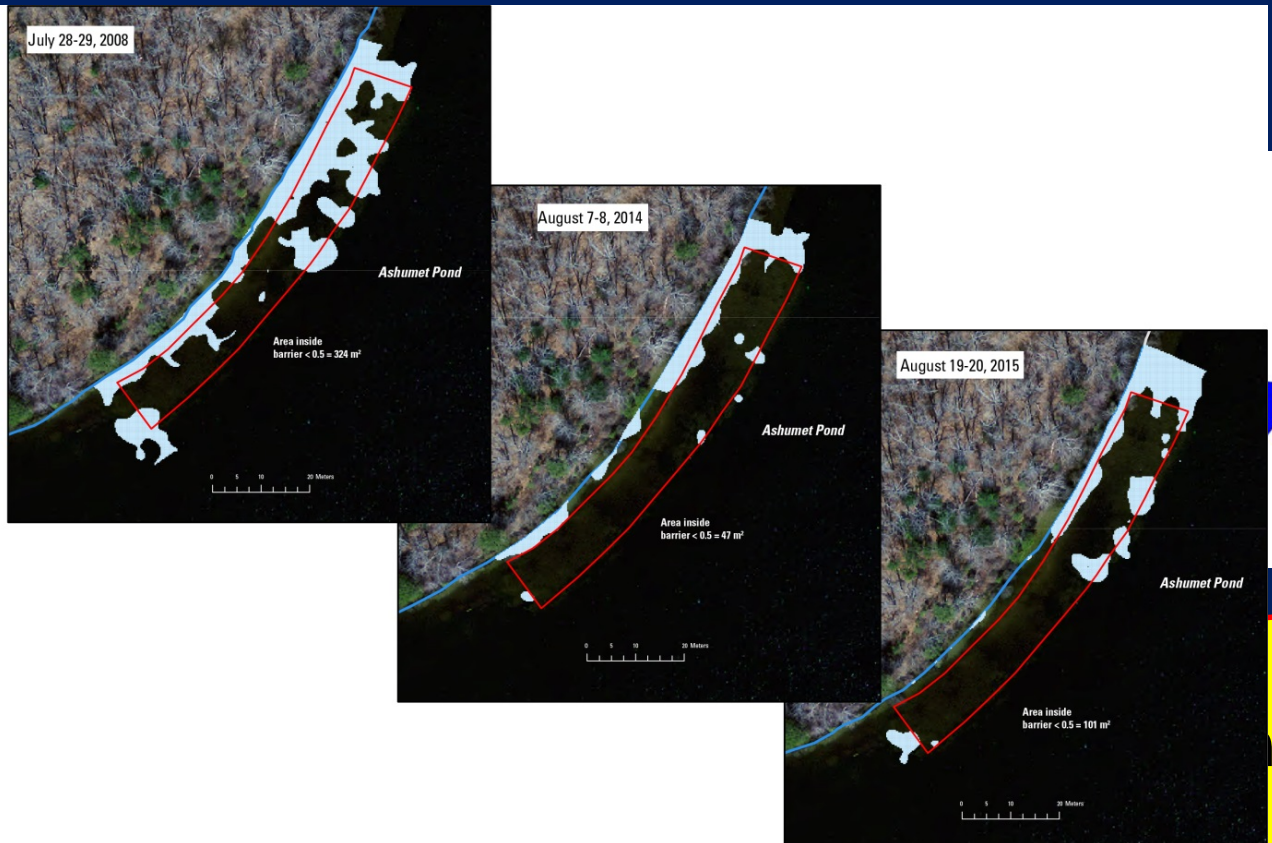


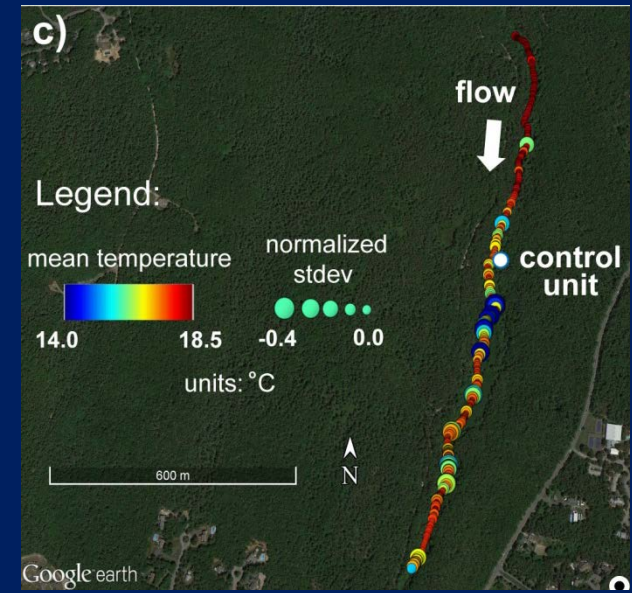
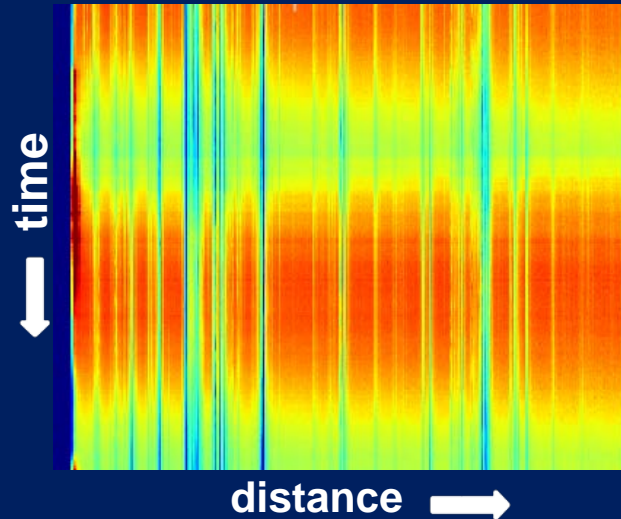
Figure 5. Maps showing areas of lake-bottom groundwater with normalized temperature less than 0.5 (strong groundwater upwelling) in the area of a permeable reactive barrier.

Originally
can be a surrogate for fluid flux and contaminant dynamics

Fiber-optic distributed temperature sensing

Meter-scale temperature measurements over km through time indicate seepage patterns and processes

FO-DTS



pore

bedform

reach/lake

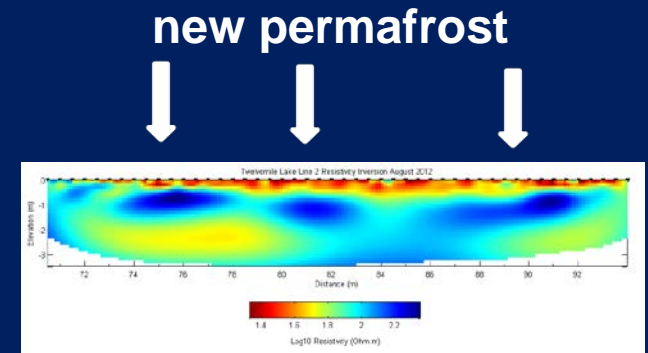
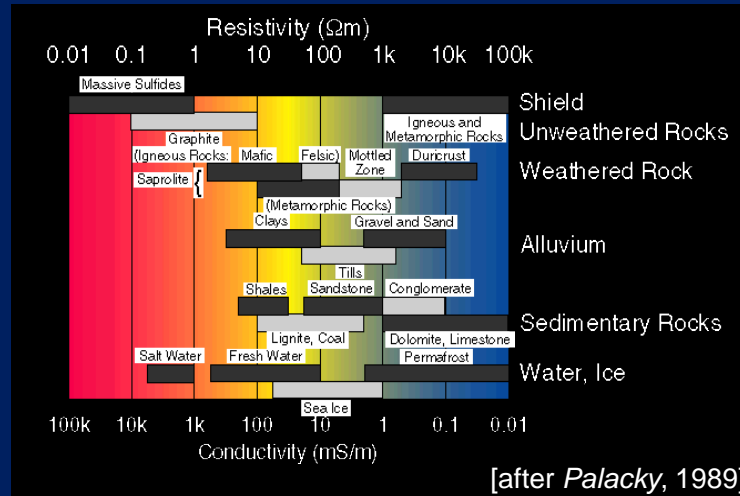
basin

Fiber-optic distributed temperature sensing can pinpoint seepage zones using thermal contrasts and variance (temporal data).

Larger-scale electrical resistivity

Resistivity indicates subsurface geology/water phase/water quality

Electrical resistivity



pore

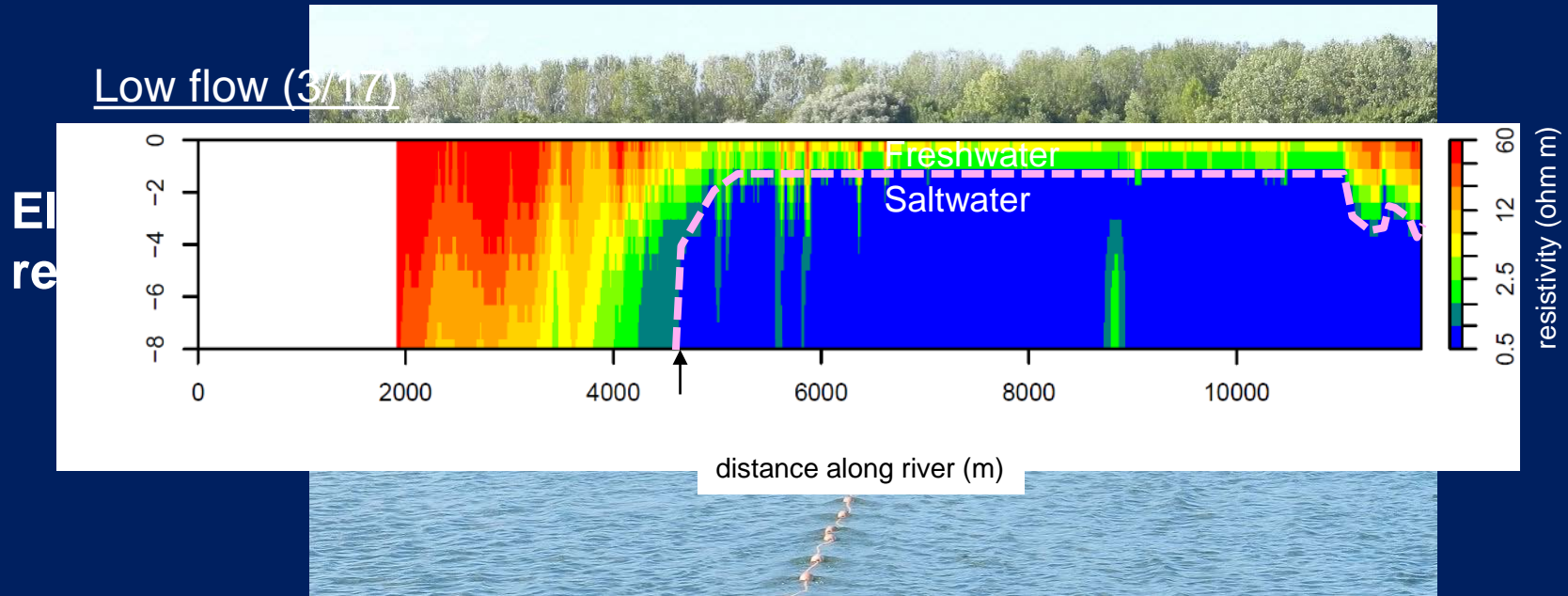
bedform

reach/lake

basin

Bulk electrical resistivity of the subsurface can indicate structure (geology) that controls flow, and groundwater flow itself, when there is an electrical signature (contamination).

Towed electrical resistivity



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reach/lake

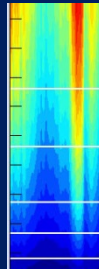
basin

The mobile form of ERT that can be applied over water to indicate bed geology and water salinity.

Mobile electromagnetic induction

Similar info to shallow ER

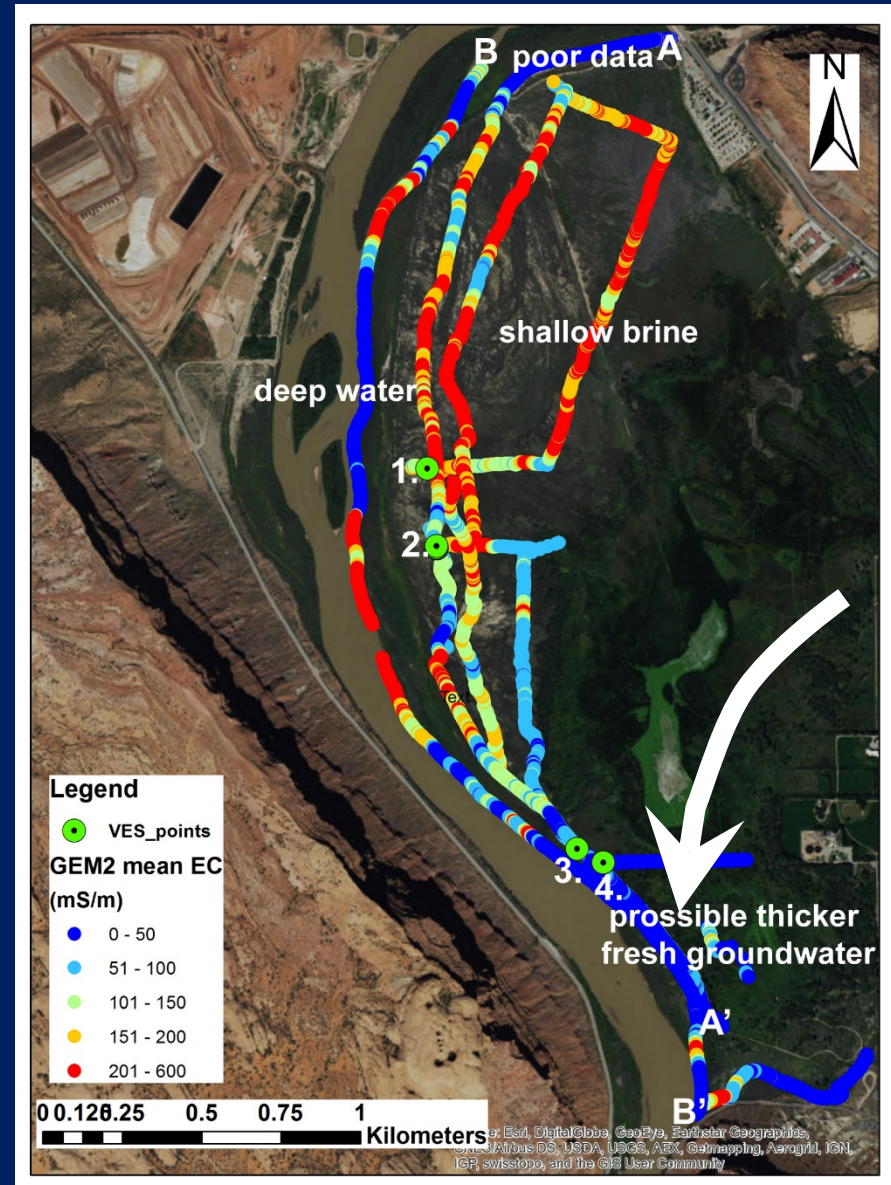
Electromagnetic induction



pore

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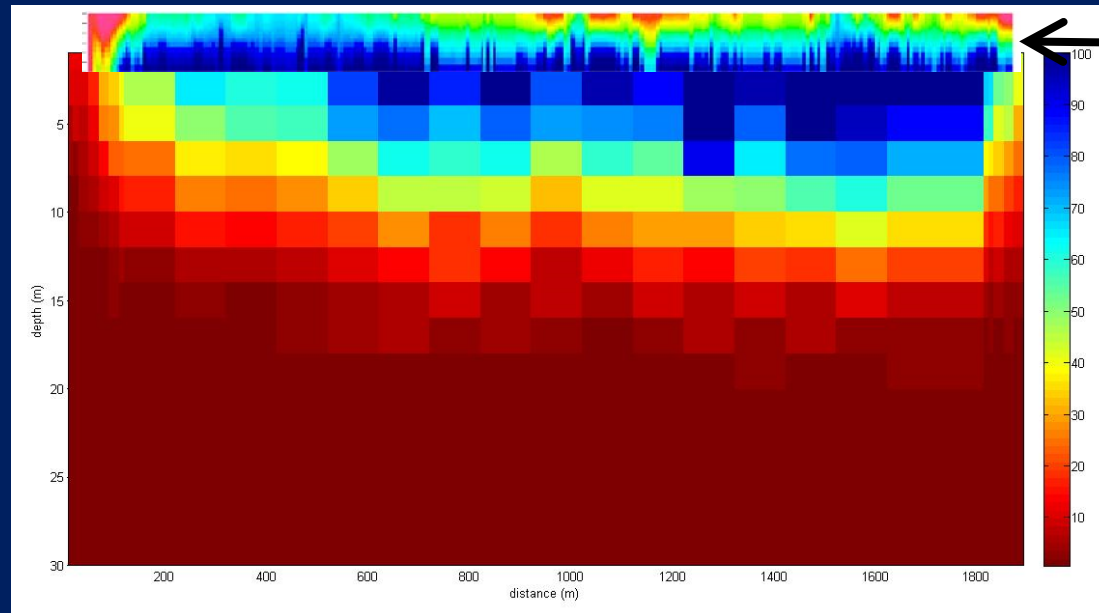
“Hand-held” EMI allows data collection over land and shallow water, but not as deep as ERI.



Time-domain EMI

Much deeper penetration than the mobile GEM2 tool, point in space data

TEM



GEM2

*prelim data,
not reviewed*

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reach/lake

basin

Capability of imaging bulk conductivity to depths >300 m, but typically less-mobile, unless airborne (\$\$)

Radar and seismic (active/passive)

Subsurface structure, gas and water content

Ground Penetrating Radar



passive seismic



pore

bedform

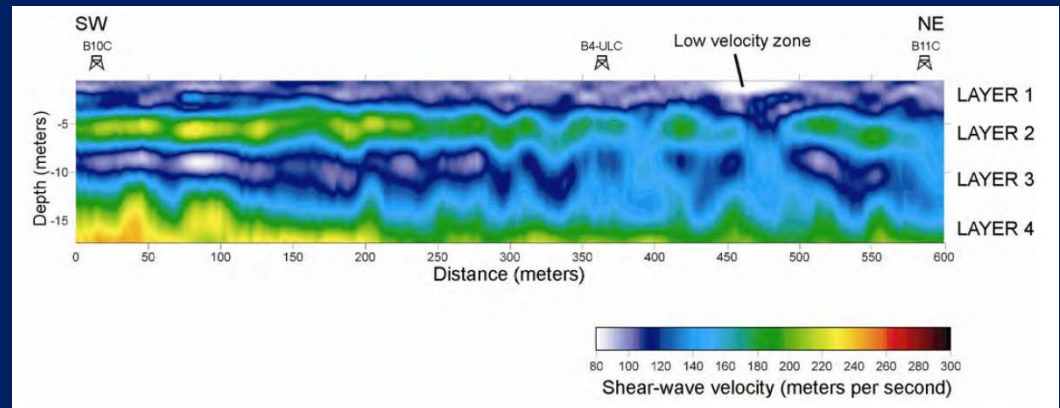
reach/lake

basin

Rapid, multi-scale site characterization examples

New Orleans Levee Evaluations post-Katrina

- Rapid response to Army Corps request
- Combination of towed land-streamer seismic and electromagnetic methods
- Goals:
 - Method testing/demonstration
 - Provide timely, actionable information to USACE



Lane et al., SAGEEP, 2008

Rapid, multi-scale site characterization examples



Bemidji, MN

National Crude Oil Research Site



1979: Pipeline rupture releases 10,000 barrels of oil



1983: Study site established by USGS Toxics Program

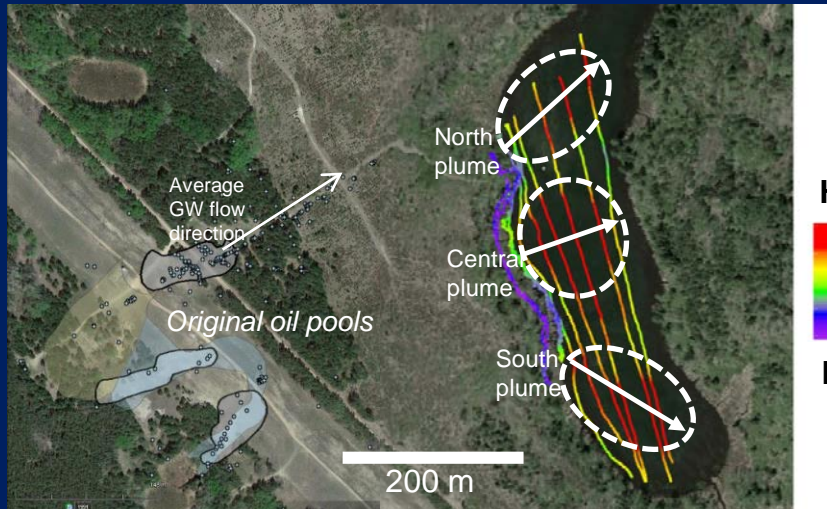


2008-2009: Site formally recognized as National Crude Oil Research Site, facilitating cooperative research between academia, industry, and government

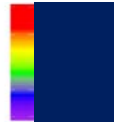
Rapid, multi-scale site characterization examples



Bemidji,
MN



High EC



Low EC

Do we observe discharge of plume into a nearby water body?

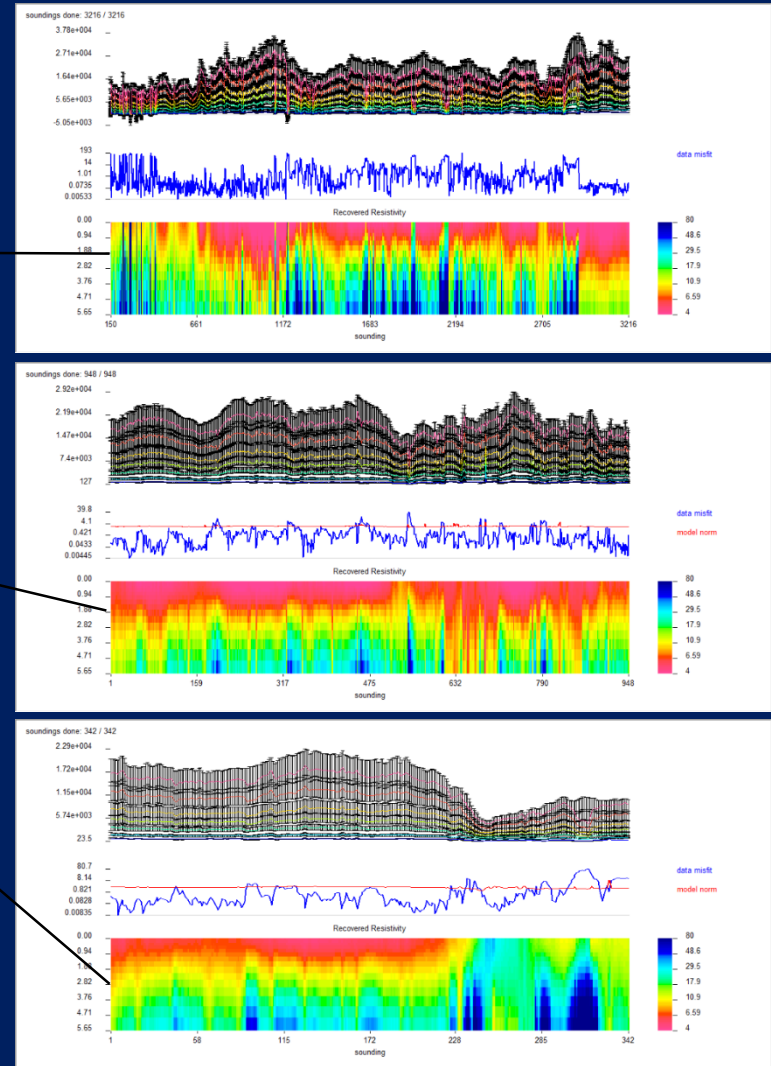
Geophysical data indicated three elevated electrical conductivity anomalies that may reflect discharge of the three main plumes into the lake

Further research in summer 2018 planned to confirm these findings

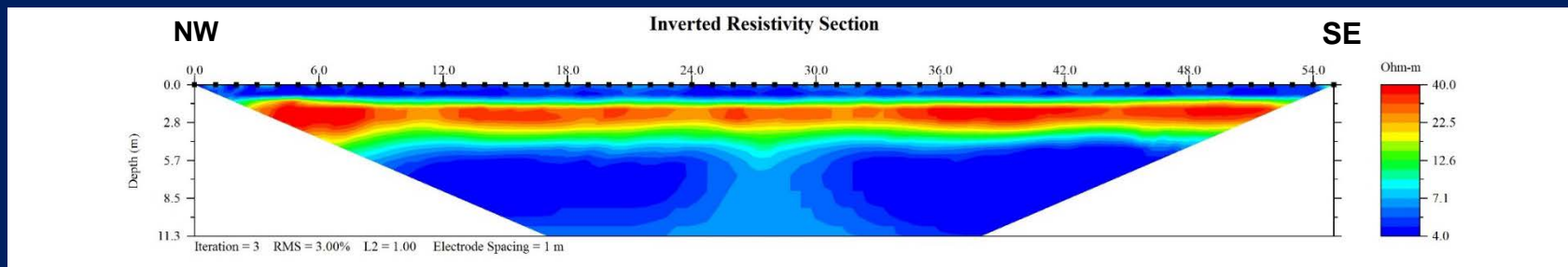
Rapid, multi-scale site characterization examples



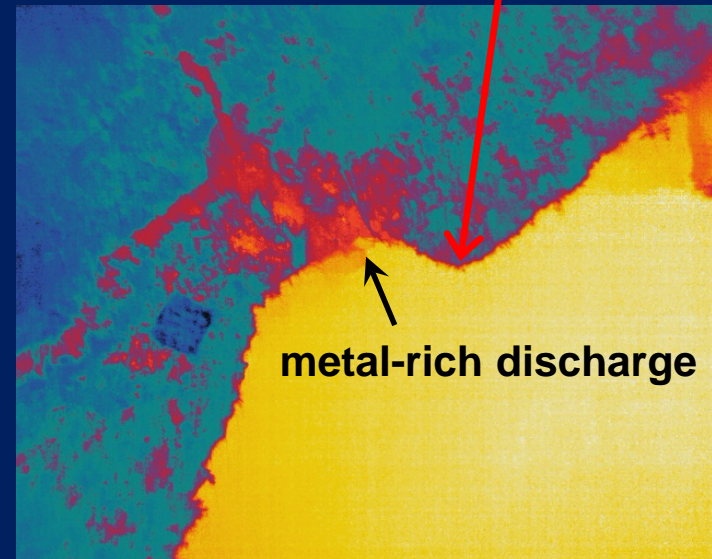
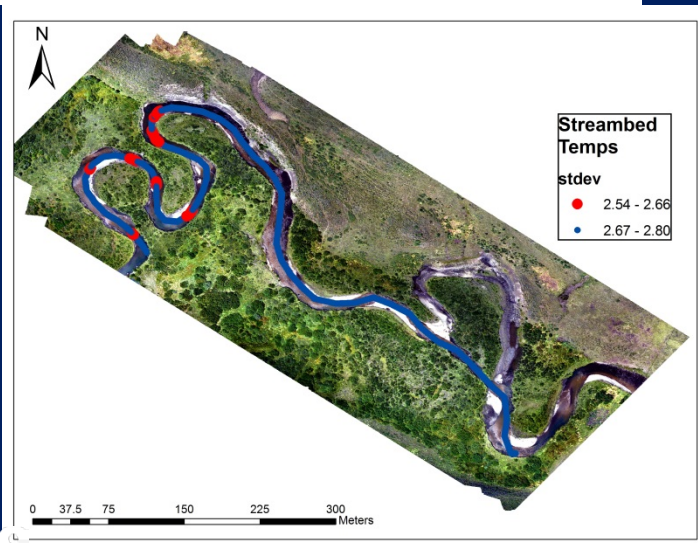
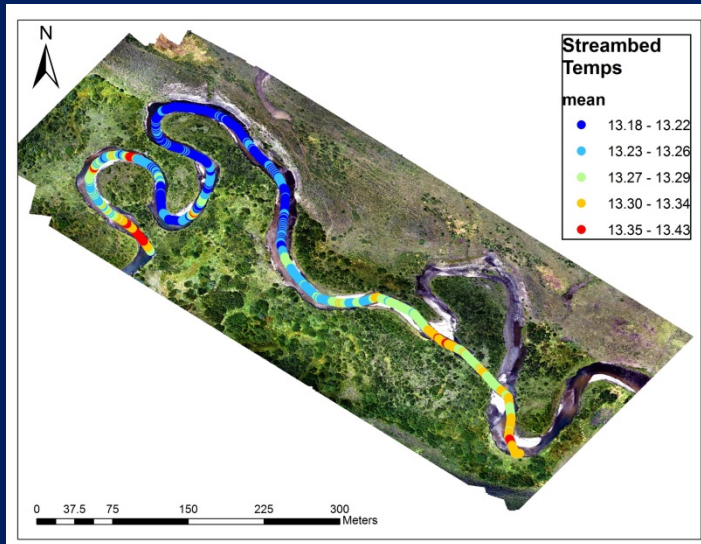
North Dakota UOG produced waters spill into local creek with downstream transport at streambed exchange



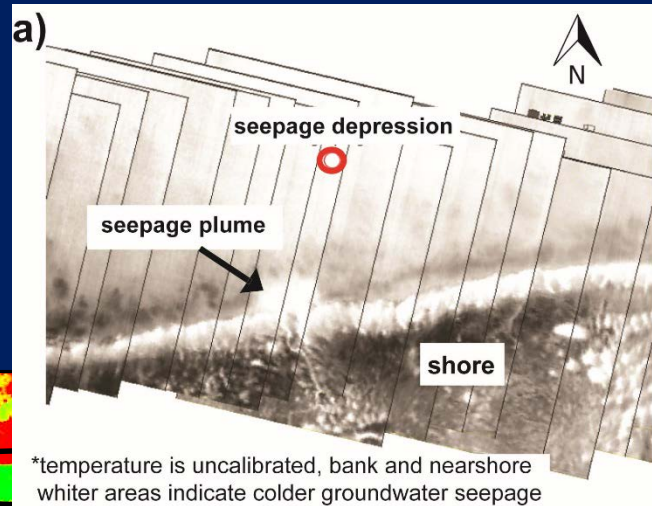
Rapid, multi-scale site characterization examples



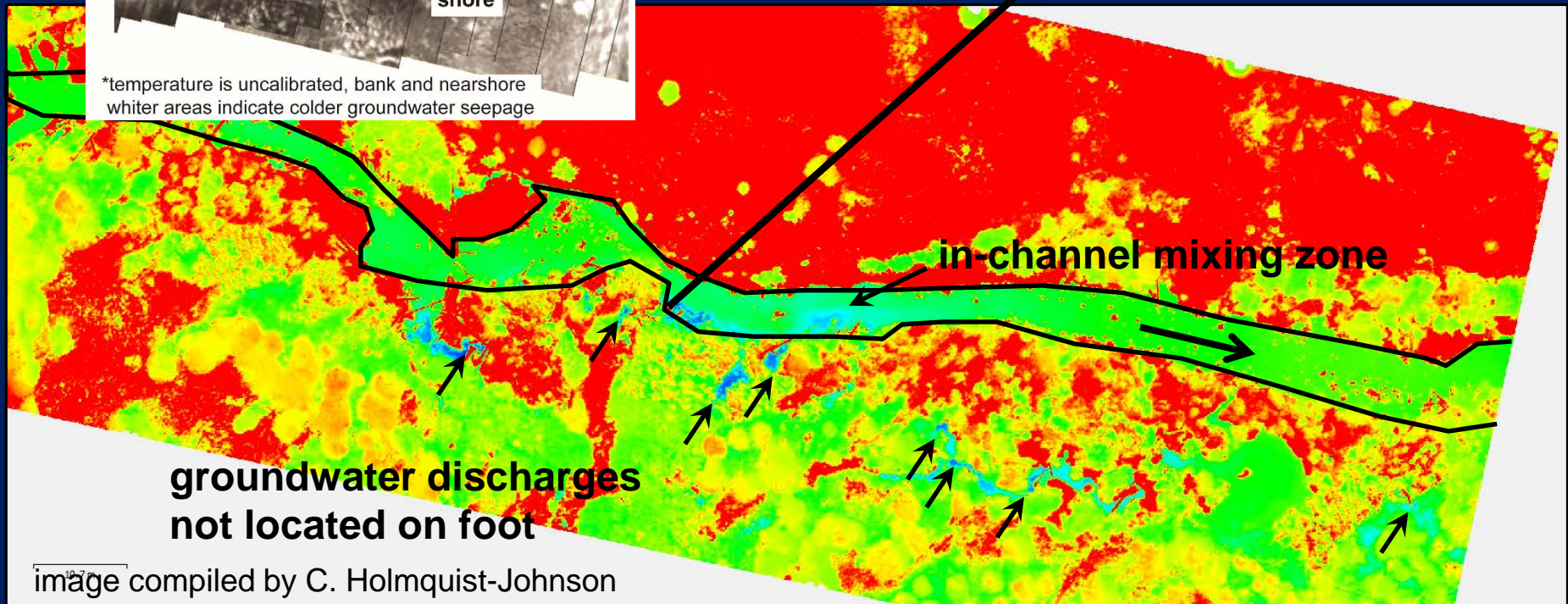
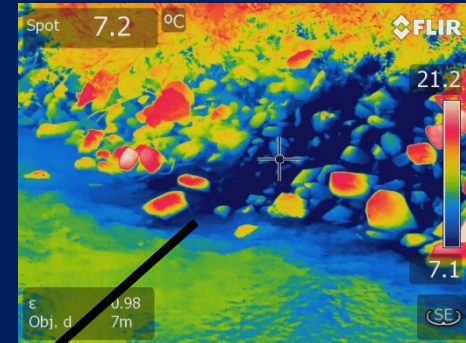
DOE mine-impacted Science Focus Area



DOE mine-impacted Science Focus Area



*UAS TIR
Published
2015*



DOE mine-impacted Science Focus Area



The take-away message:

Geophysical methods (*including heat*) can efficiently guide data collection, put precise point measurements into system-scale context, and build process-based understanding of GW/SW exchange dynamics and contaminant transport.

Please contact us for collaboration, training, and equipment:
mbriggs@usgs.gov