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Evolving Geophysical Tools for Tracking Fate and Transport at Groundwater / Surface Water Interfaces

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Outline

- Transient electromagnetics (TEM)
- Passive seismic horizontal to vertical spectral ratio (HVSR)
- Borehole nuclear magnetic resonance (bNMR)
- Frequency domain electromagnetics (FEM)
- Summary

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Transient electromagnetics (TEM)

- Strengths
  - Some systems provide rapid spatial coverage;
  - Shallow and deep investigations (30 to 100+ meters)
  - Rapid deployment, not labor intensive (tTEM setup)
  - Field inversion available
  - Real-time inversions allow for focused surveys
- WalkTEM
  - Two operators
  - Deep investigations with conductor at depth
  - Typical DOI 30 to 200+ meters
- sTEM-profiler
  - Two to three operators
  - Better for near surface lithological distinction
  - Typical DOI 30 to 100+ meters
- tTEM/FloaTEM
  - » Two operators
  - » Best for leveraging agricultural fields for rapid coverage
  - » Typical DOI 30 to 80+ meters

WalkTEM

sTEM-profiler

tTEM

FloaTEM

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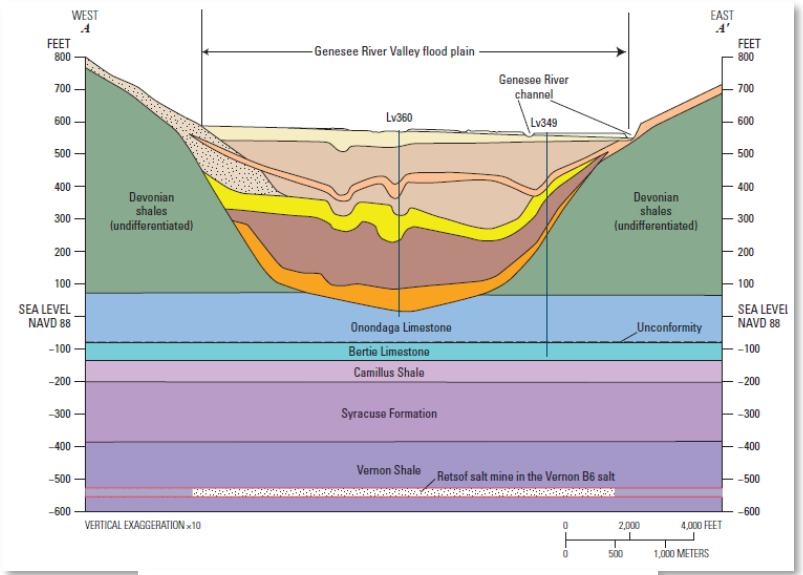
WalkTEM – Retsof, NY
1D inversion result



EXPLANATION

Unconsolidated deposit

- Alluvial-fan and flood-plain deposit—Silt, sand, and gravel
- Lacustrine sand, silt, and clay
- Deltaic deposit—Pebbly sand
- Till—Dense silt and clay embedded with pebbles
- Supraglacial debris—Silty sand and gravel
- Englacial meltout material and subaqueous deposit—Mix of clay, silt, sand, and gravel
- Subglacial meltwater deposit—Sand and gravel

Lv349 **Well and U.S. Geological Survey (USGS) well number**—Number and Lv prefix (Livingston County) assigned by the USGS

Extent of the Vernon B6 salt

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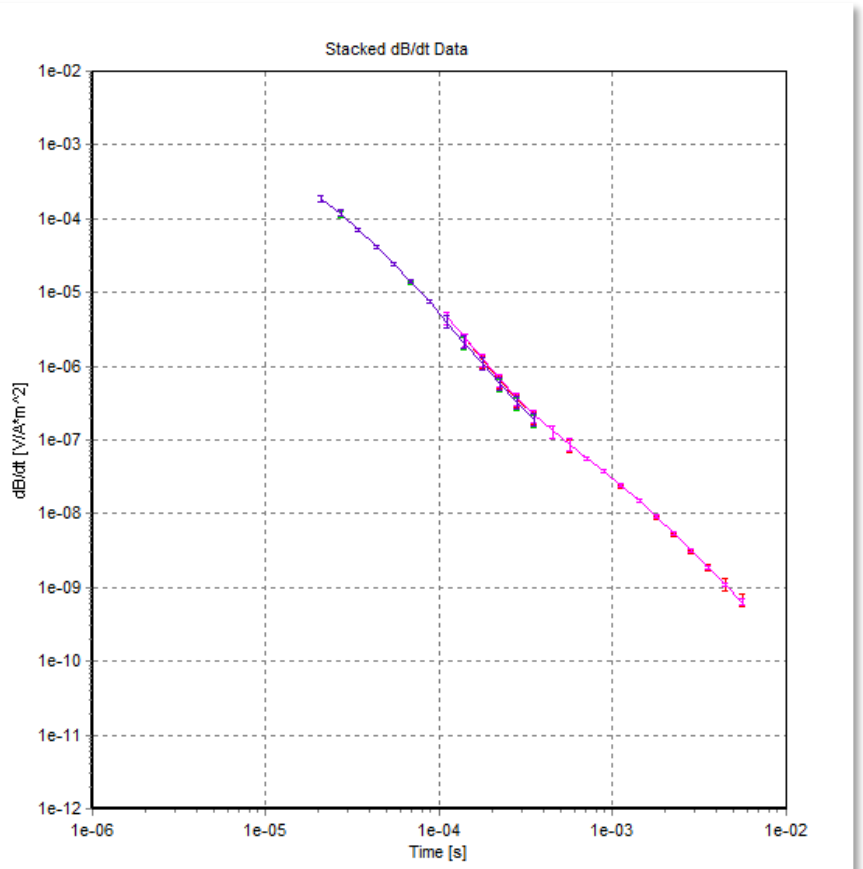
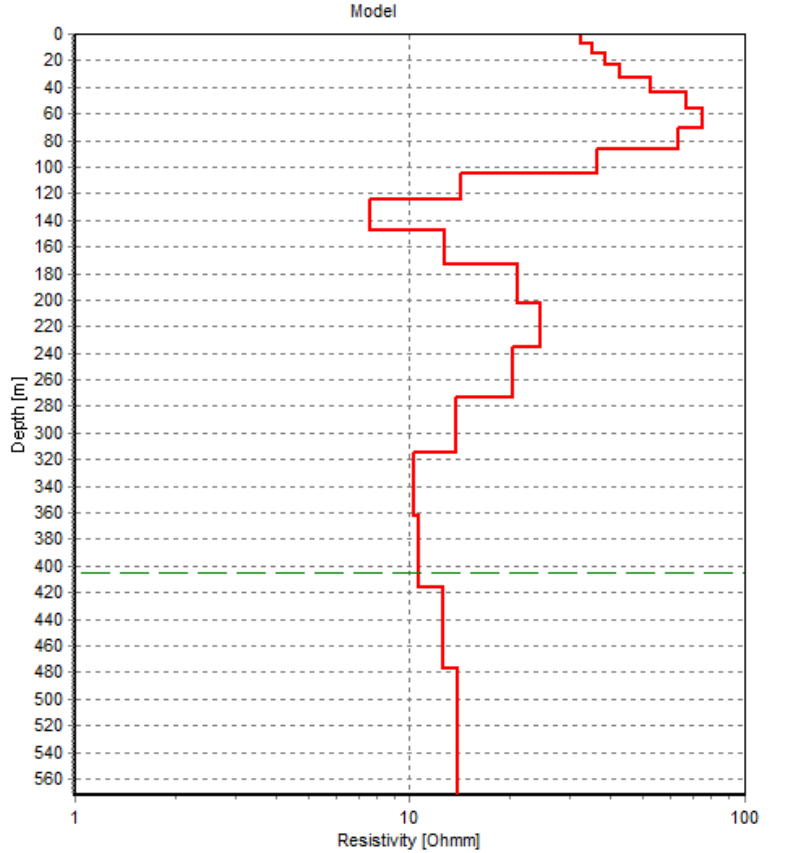




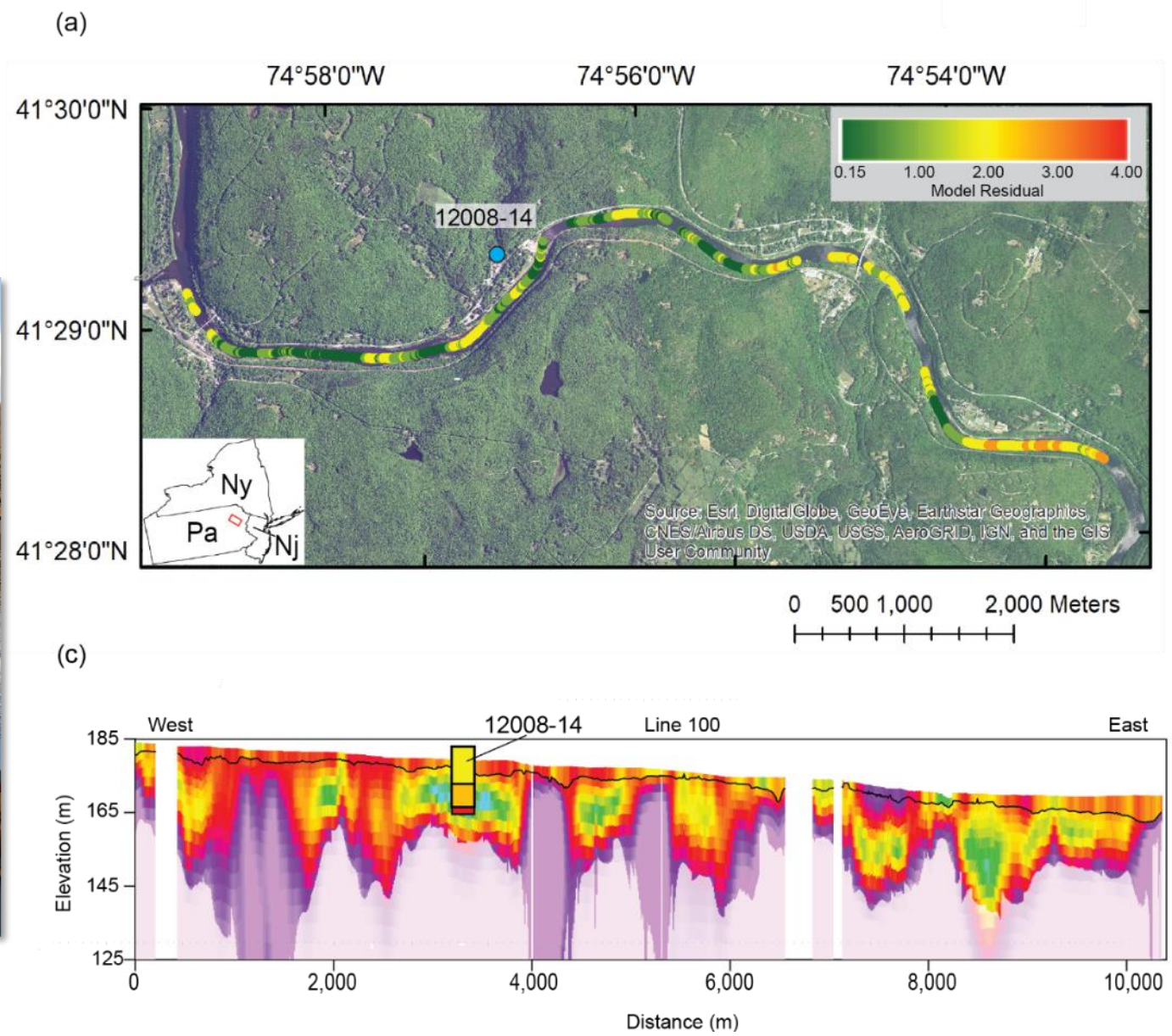
Collapsed salt mine - groundwater inflow from the valley-fill aquifer system and bedrock fracture zones go into the mine through two bedrock-rubble chimneys and the subsequent dissolution and filling of the mine with saturated brine.

WalkTEM results helped reveal:

- Saline water in the confined, lower part of the valley-fill aquifer system. The delineated saline-water zone extends more than 4km north from the mine collapse area. Saline water flowing upward through the bedrock-rubble chimneys and mixing with northward groundwater flow in the lower confined aquifer is believed to be a major source of chlorides.

Williams et al., 2021

FloaTEM – NGWOS Delaware River Basin



FloaTEM results helped reveal:

- Low-resistivity zones in the streambed that extend 100's of meters and may indicate sediments with higher silt content that would inhibit GW/SW exchange.

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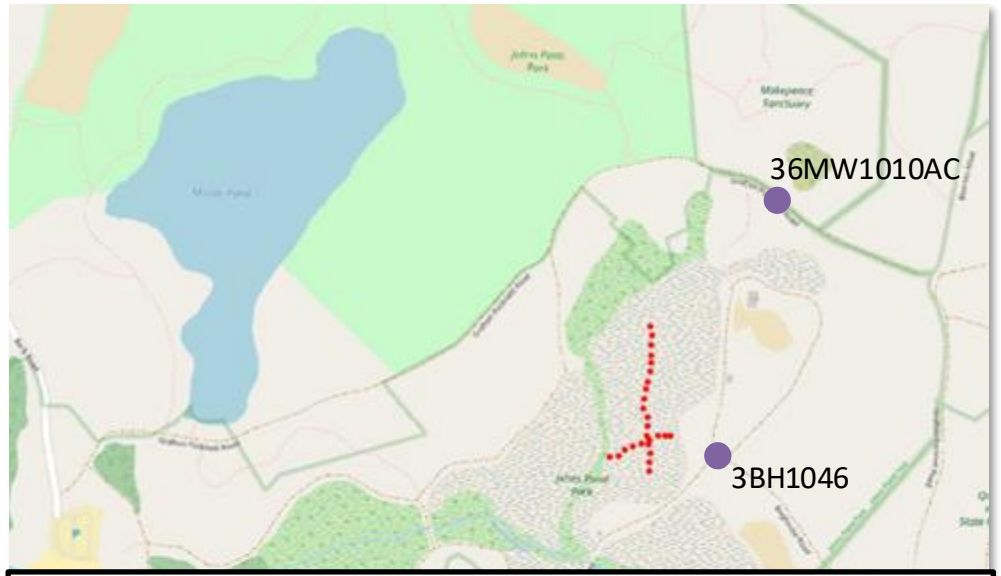
Lane et al., 2020

Cape Cod, MA sTEM-profiling

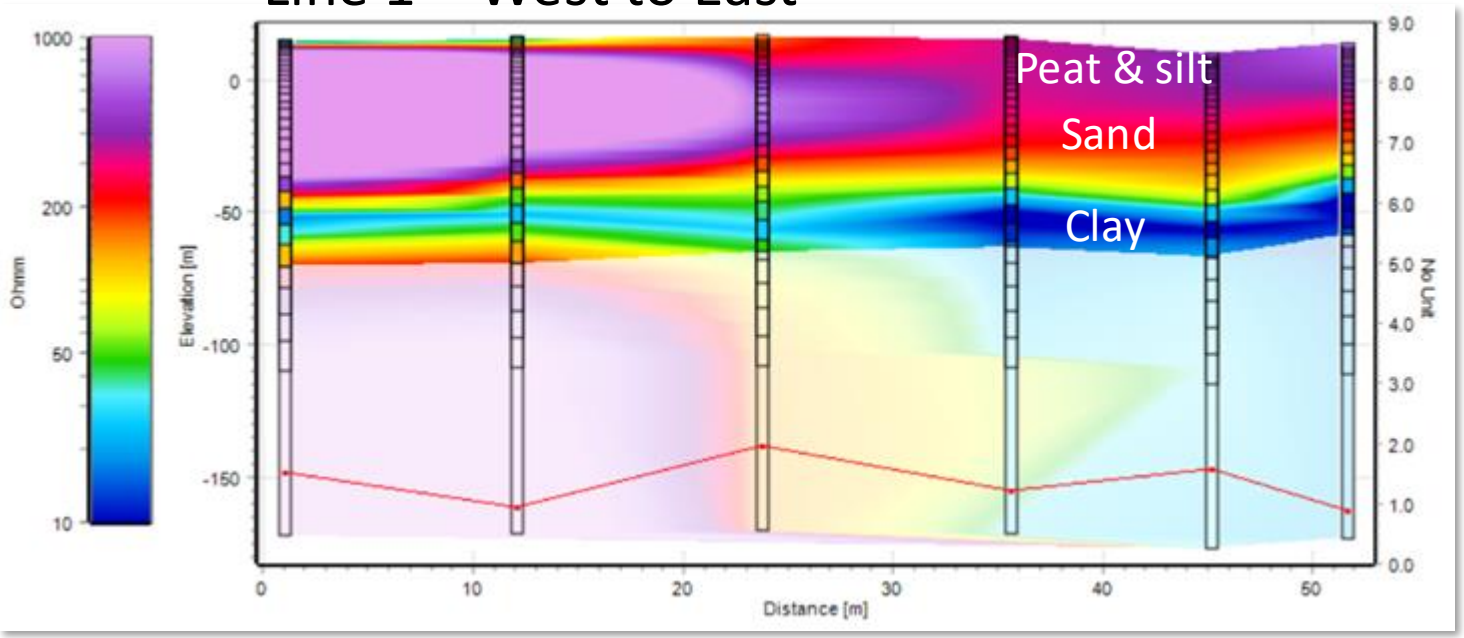
Model residual



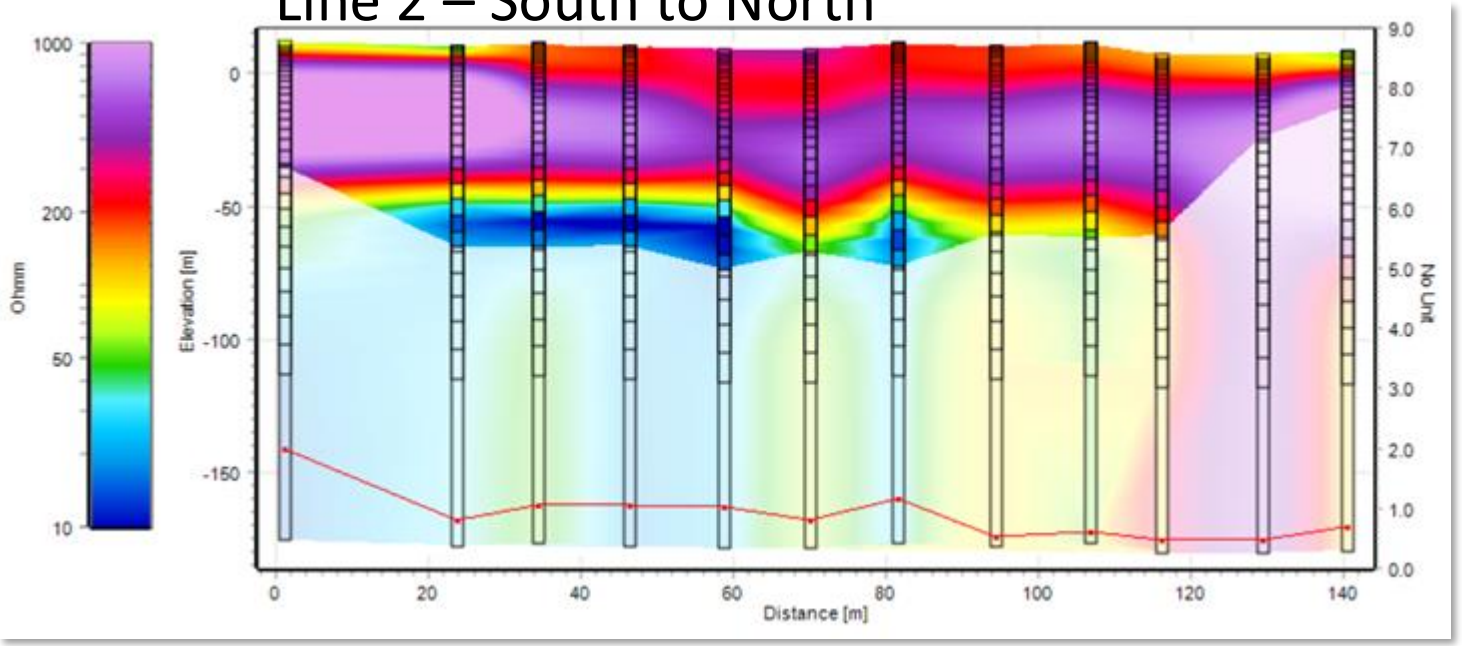
Aquifer characterization in peat bogs.

sTEM-profiler results helped confirm:
• Logs from the two closest boreholes along the eastern/northeastern edge of the bogs, 36BH1046 and 36MW1010AC, show a clay layer at ~42 and 46 meters.

Line 1 – West to East



Line 2 – South to North



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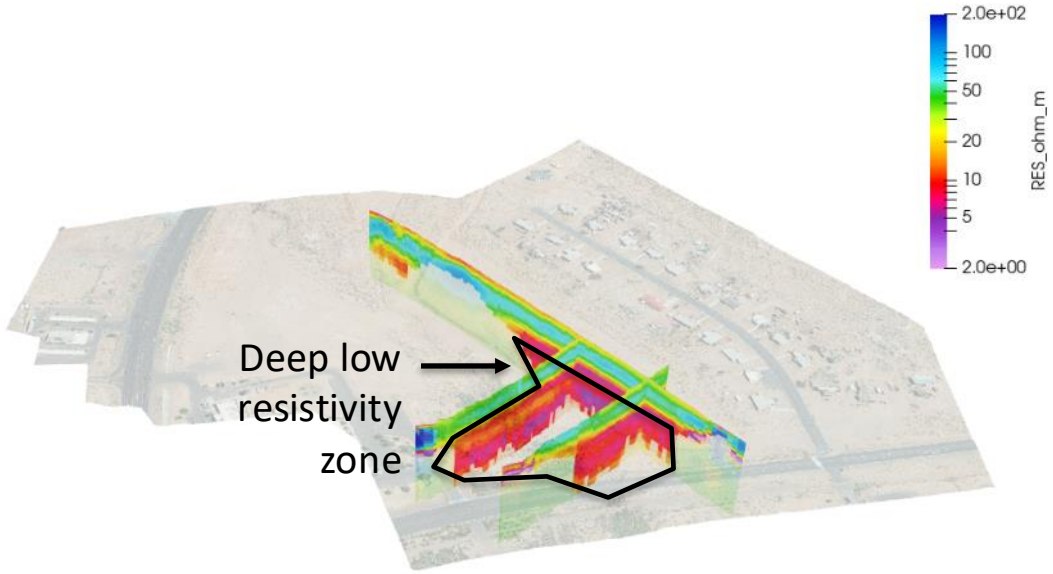
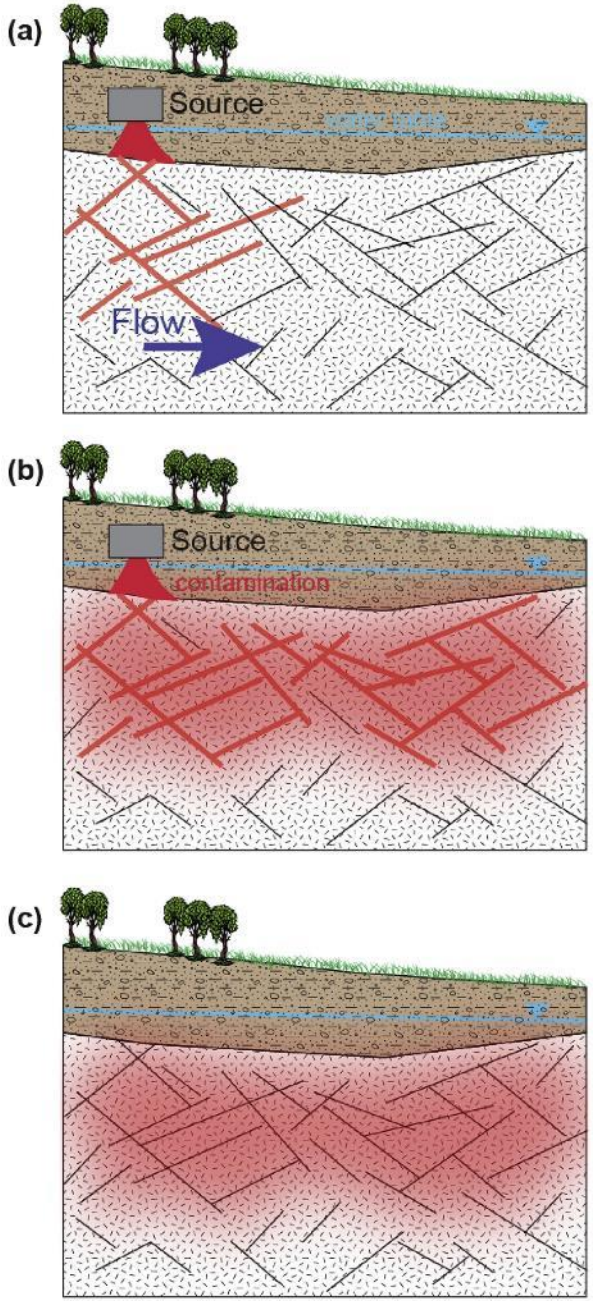
Preliminary Information-Subject to Revision. Not for Citation or Distribution.

Tuba City AZ DC resistivity and sTEM-profiling

- LNAPL contamination at site potentially **threatens downgradient springs** (local sources of drinking water)
- DC Resistivity and TEM data confirmed a low resistivity zone at depth **not captured by monitoring wells** (below the screened interval)
- Results support conceptual model of LNAPL degradation at site – **high specific conductance plume that persists in the fractured sandstone at the site**





Conceptual representation of contamination of fractured rock aquifers
From Day-Lewis et al. (2017)

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EPA

Horizontal-over-Vertical Spectral Ratio (HVSR)

- Strengths
  - Deep investigations
  - Rapidly deployed, fast, and lightweight
  - Low-cost reconnaissance tool
  - Operational simplicity
  - No active source required
  - Non-invasive
  - Useful in difficult terrain (dense forest, active urban areas)
- Tromino
  - Single operator
  - All-in-one seismometer (passive & active)
  - Internal GPS
  - SD card → USB download
  - GRILLA processing software

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Haddam Meadows, CT
HVSR to map depth to bedrock

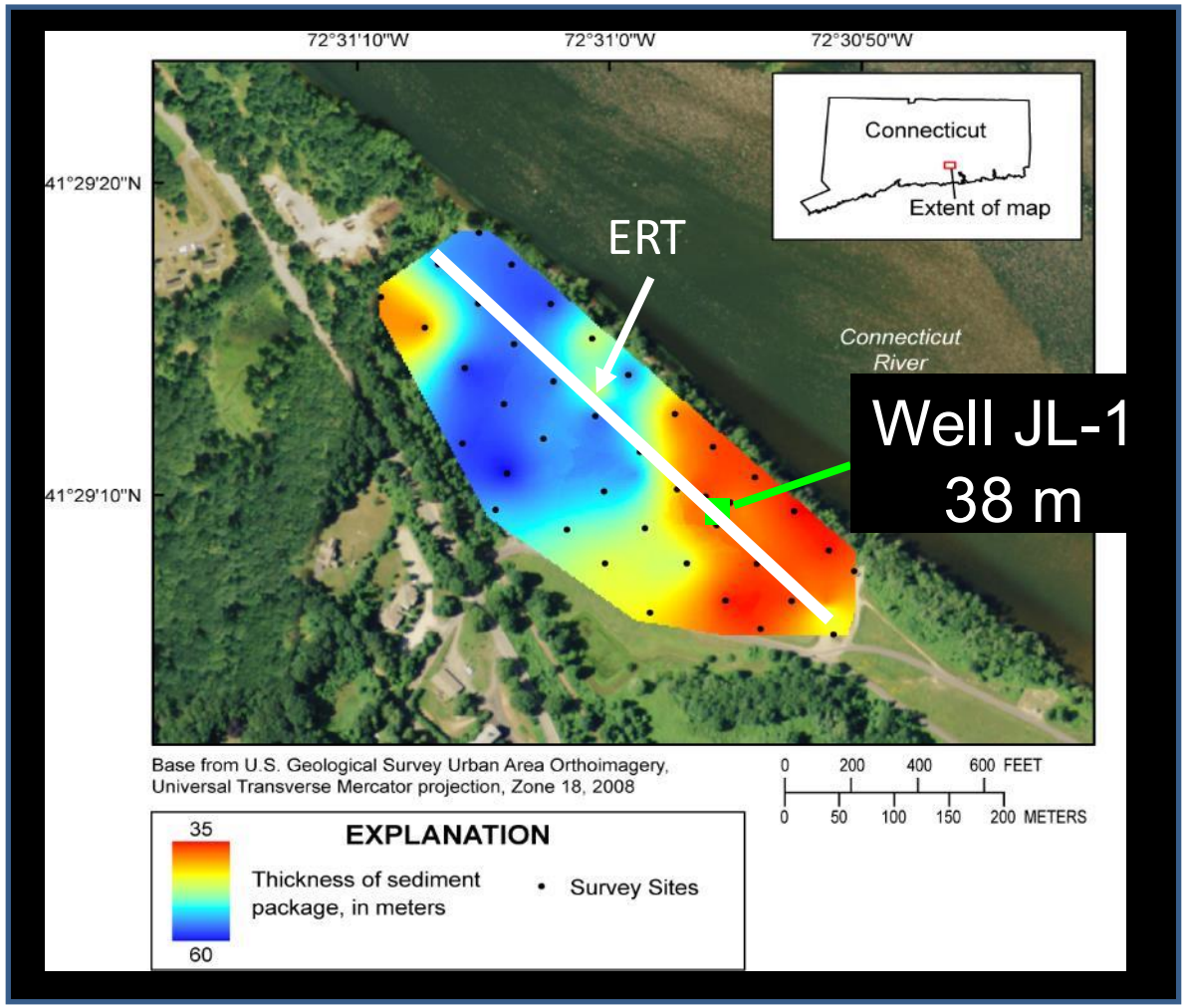
HVSR 40+ points

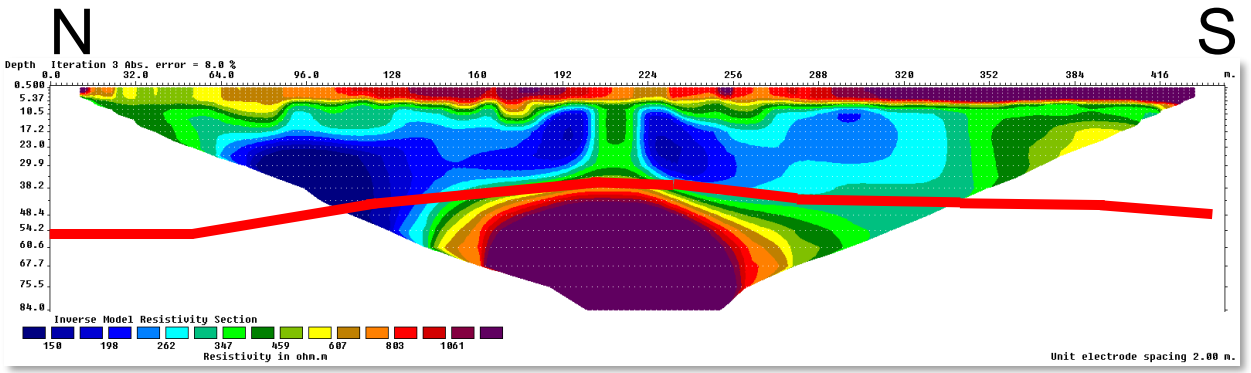
Contoured and color shaded

Comparison to wells e.g.: JL-1

Mapping of bedrock surface.

HVSR results were in good agreement with drilled depth and ERT profile.





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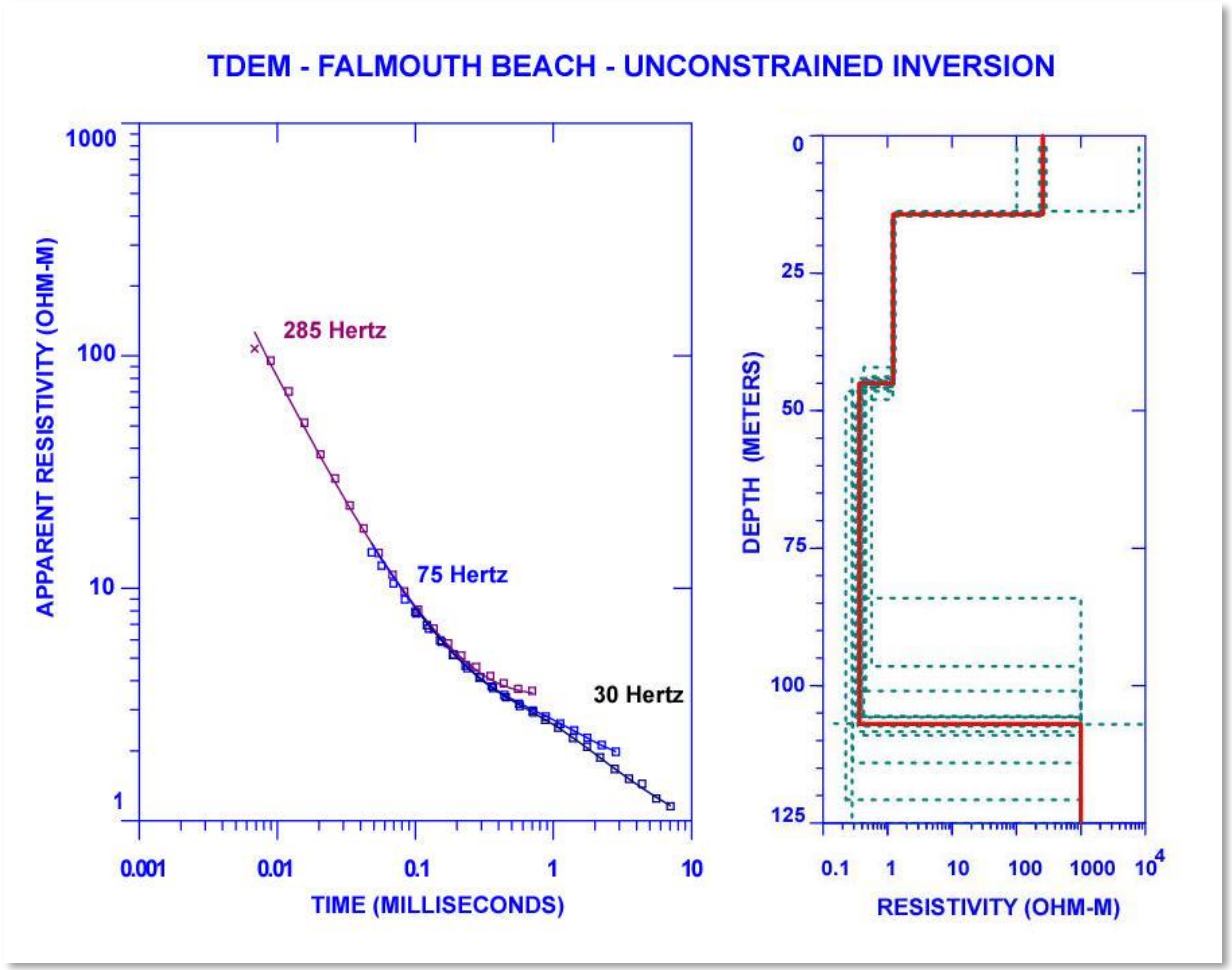
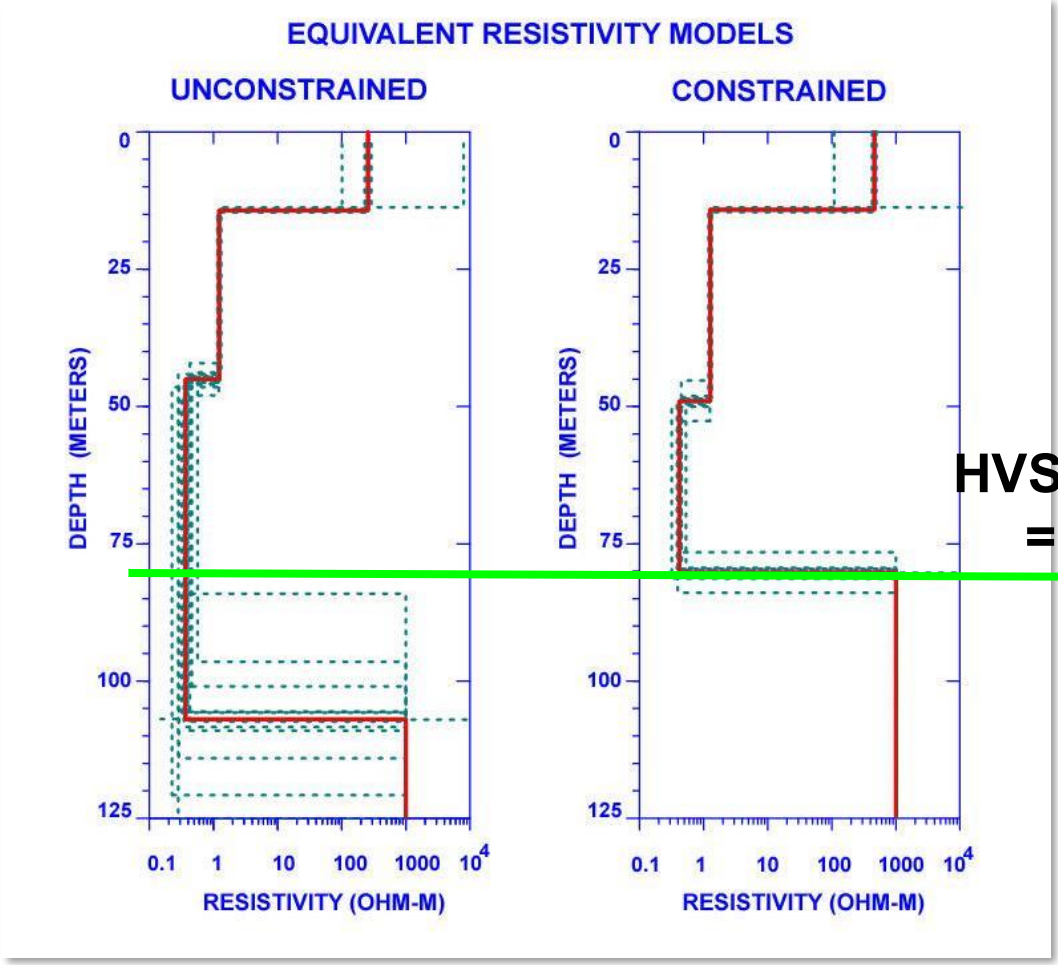
Cape Cod, MA
HVSR to constrain TEM

HVSR used in combination with other geophysical techniques:
TEM is sensitive to conductive targets and inversion of TEM data produces non-unique models. HVSR used to constrain the depth to bedrock focusing the interpretation.





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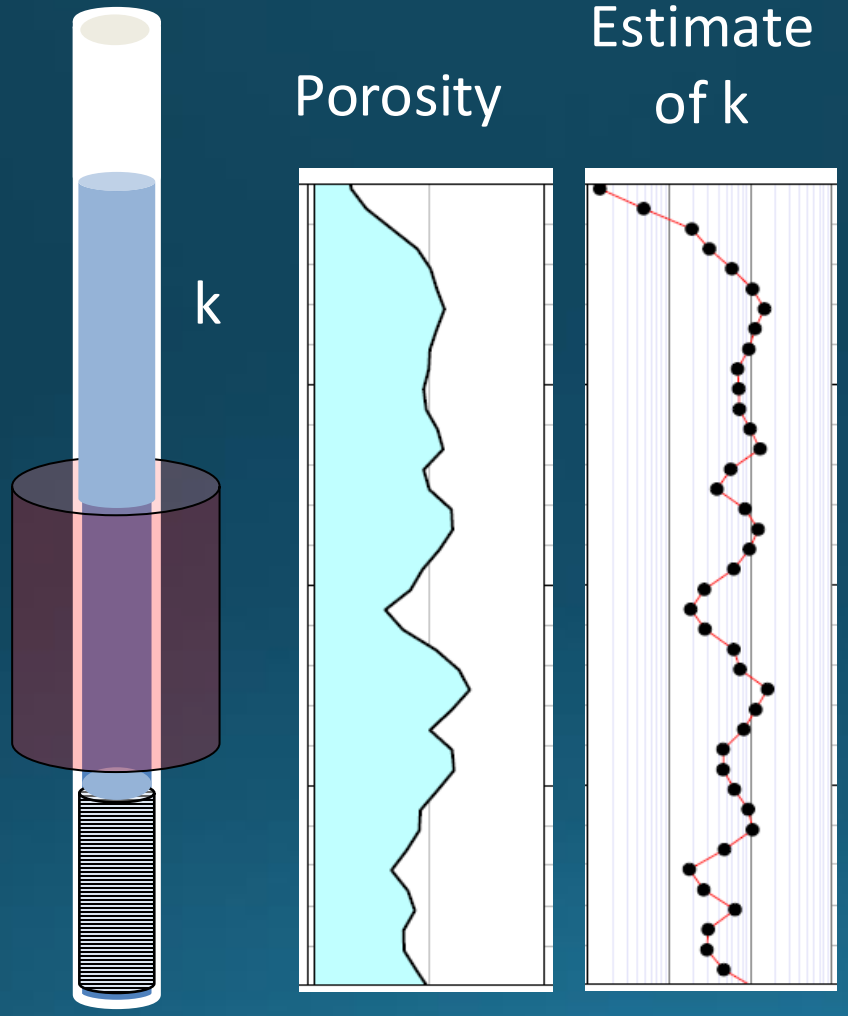
Johnson et al., 2019

Borehole NMR – why do it?

Typical PVC cased borehole with short screened interval

Single measurement of hydraulic conductivity (k)



Direct, depth dependent, continuous measurements of water content

and estimates of hydraulic conductivity

No use of nuclear sources

No need for pumping or contact with the formation

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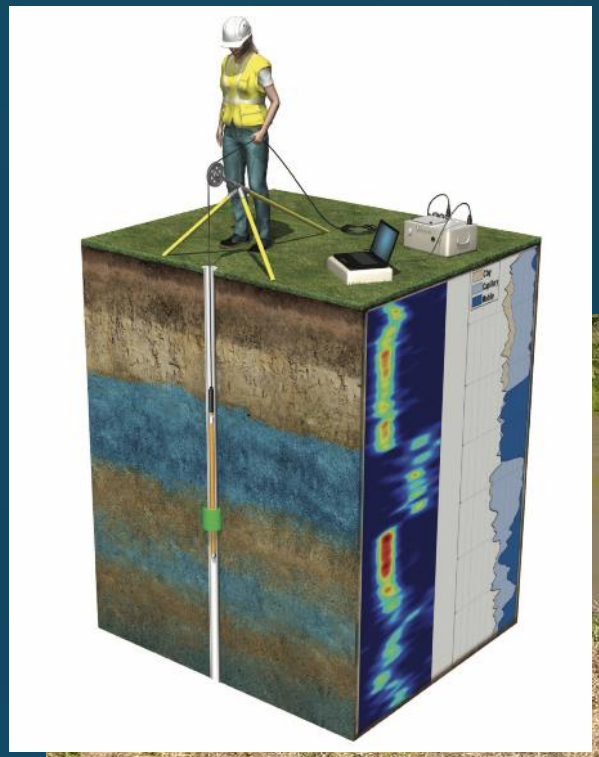
Dart NMR

- Lite system – “portable”
- Requires boreholes drilled < 6” and >=2” casing
- Good for Geoprobe wells and small diameter core holes
- Shallow (<= 20 m/30 m)
- Soil moisture/ saturation



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NMR Dart tool example: WI Glacial Aquifers Well G5

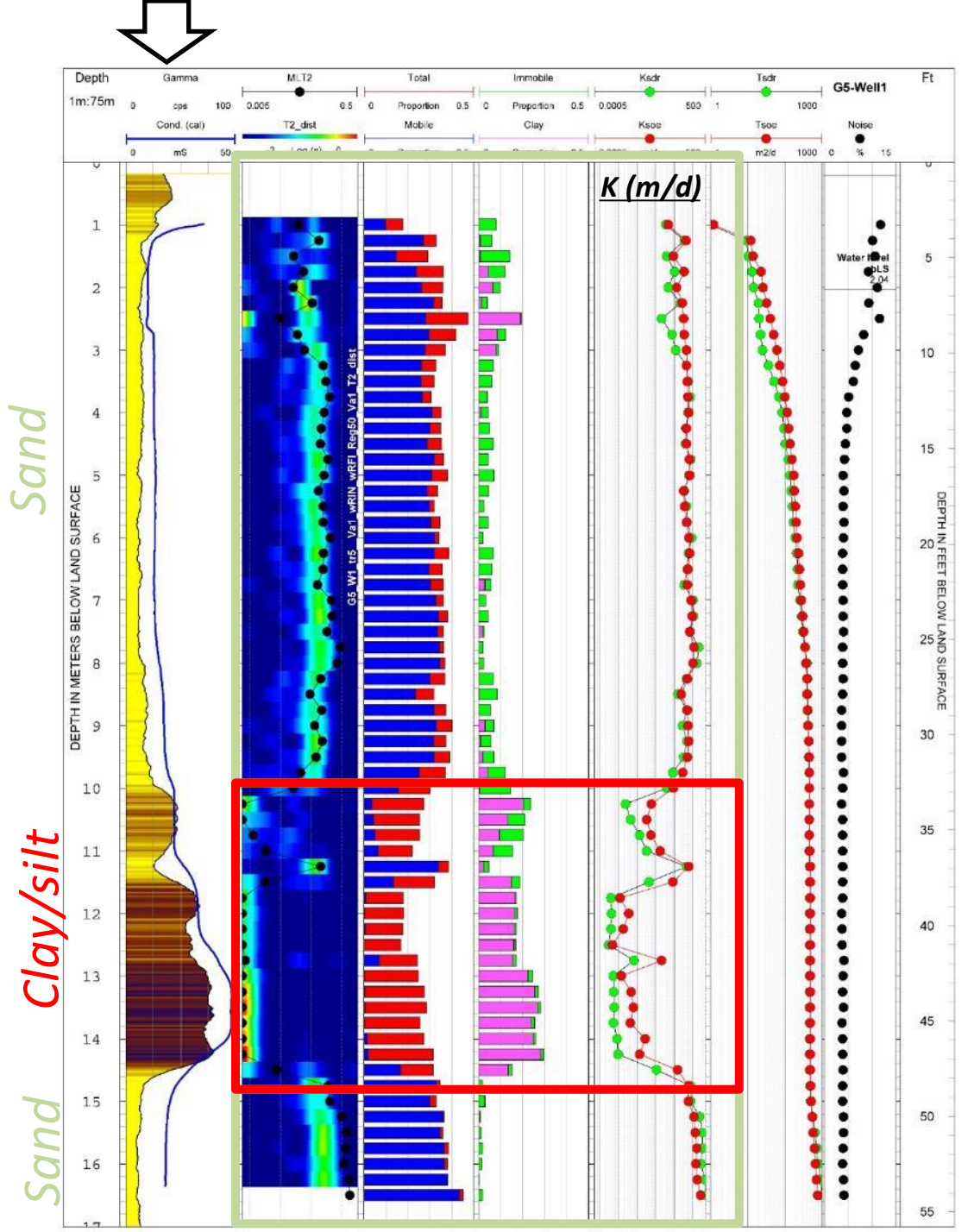
Dual frequency Dart used to depth of 16.5 m below LS

Results show clay and silt unit (depth of 10-14 m) characterized by early-time decay, immobile water, and low permeability

Sand above and below is characterized with late-time decay, mobile water and high hydraulic conductivity

Results consistent with gamma and electromagnetic induction logs

Kendrick et al., 2020



Frequency domain electromagnetics (FEM)

- Strengths
  - Rapid spatial coverage;
  - Shallow resolution (< 10 meters)
  - Difficult areas
  - Rapid results (raw data plots informative)
  - Adapting to non-motorized watercraft

- GEM-2
  - Single operator
  - Good for saline groundwater mapping; buried metallic infrastructure detection
  - Typical DOI ~3 to 10 meters

- DualEM-421
  - Two operators
  - Better for near surface lithological distinction
  - Typical DOI ~5 to 20 meters

DualEM-421

GEM-2

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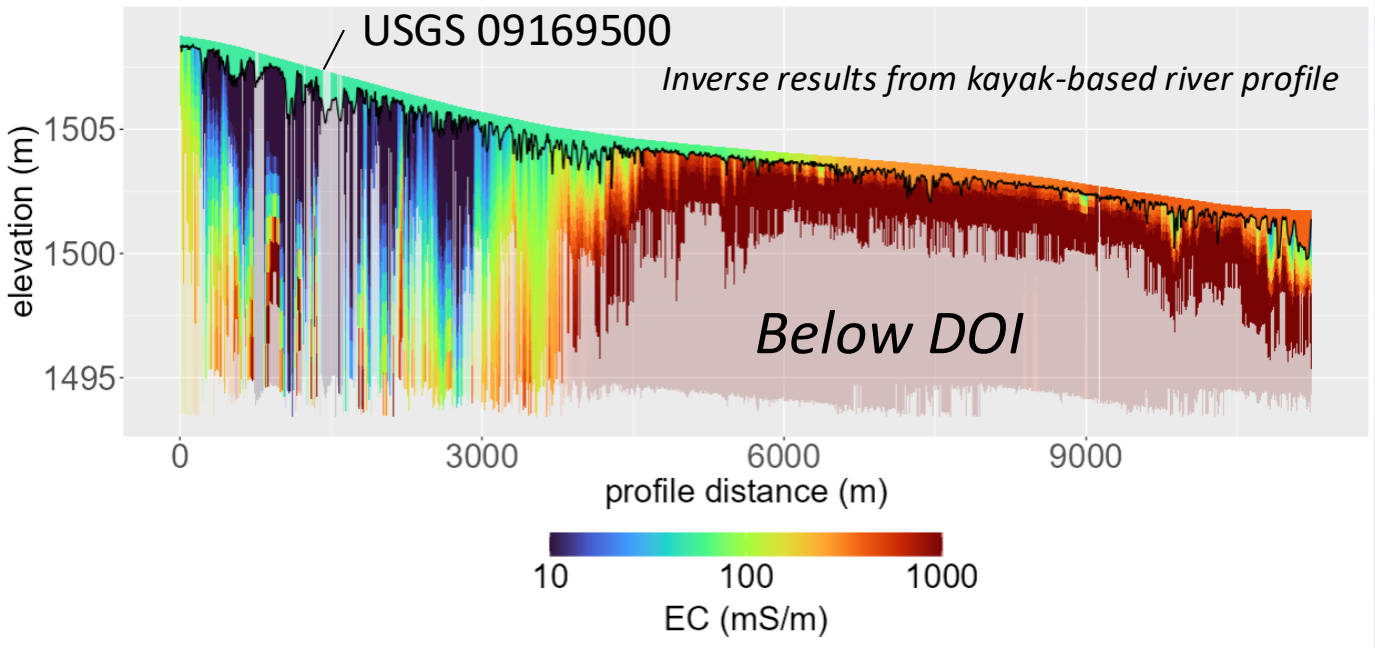
Paradox Valley, CO brine discharge GEM-2 surveys

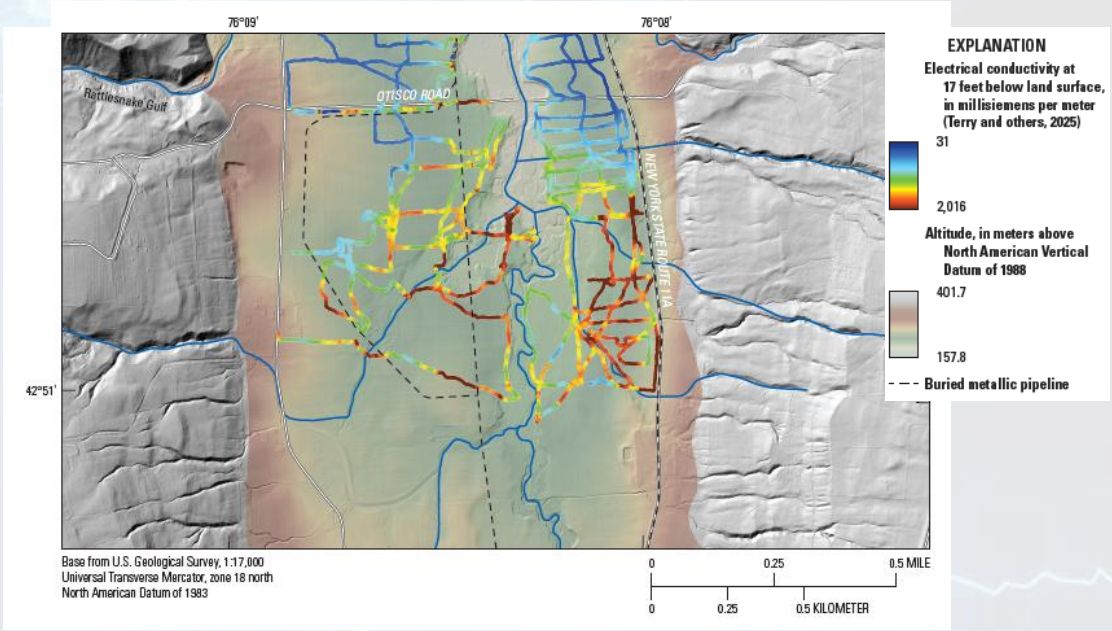


Collapsed salt dome sources brine to Dolores River through alluvial aquifer; additional brine interception wells considered to improve water quality

GEM-2 results revealed:

- Depth to the brine layer in the area surrounding the river channel, down to 15+ meters*
- Over 100 km of data collected in under 1 week

Tully Valley, NY mudboils DualEM-421 surveys



Mudboils discharge turbid, salty water to Onondaga Creek; stream relocation paths considered

DualEM results revealed:

- "Danger" areas with high near surface electrical conductivity
- Near surface soil texture and moisture variations
- Buried metallic pipelines
- Over 30 km of data collected in 3 days

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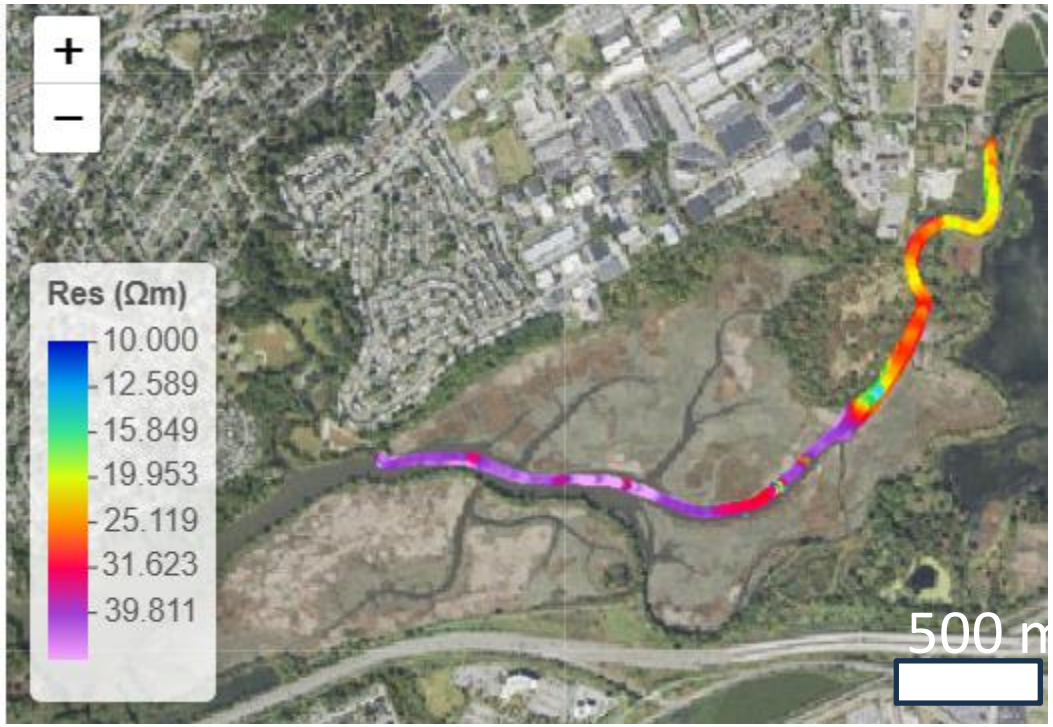
Terry et al., 2025

Williams et al., 2026

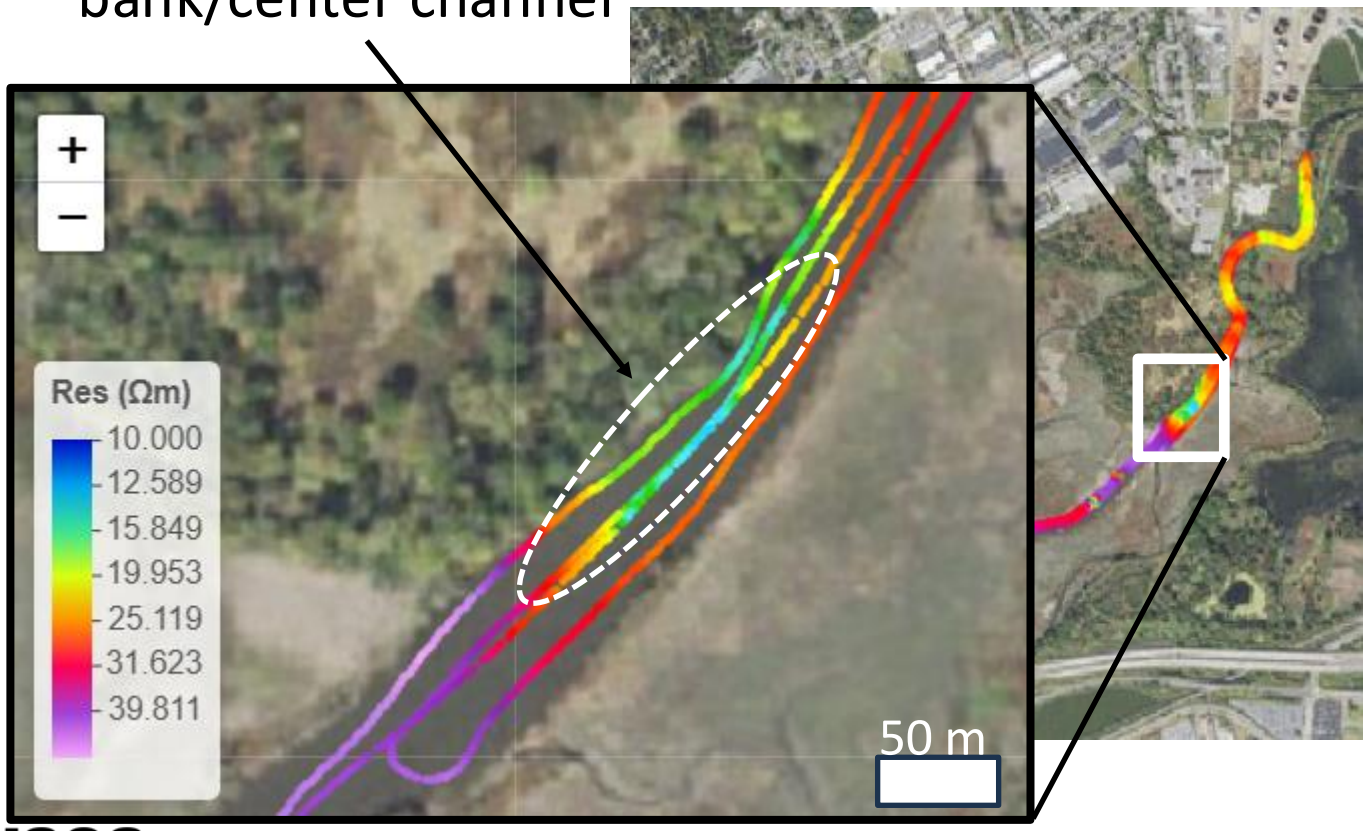
Darby Creek, PA FEM surveys

- DualEM-421 instrument towed from jon boat
- 3 km of creek surveyed
- Goal to identify seeps for sensor placement
- Only seeps with specific conductance signatures can be identified

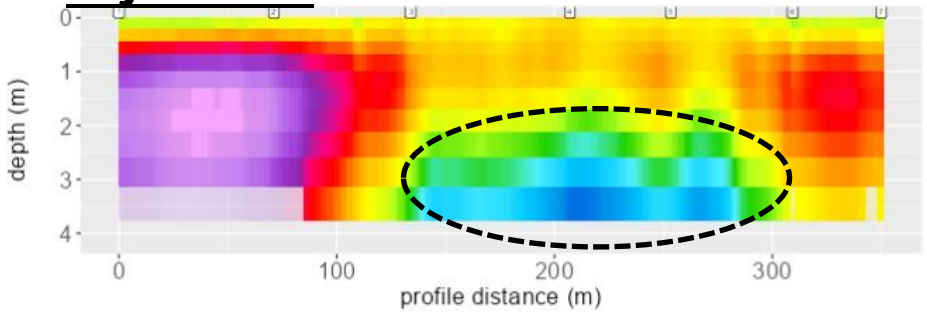


Darby Creek, PA FEM surveys

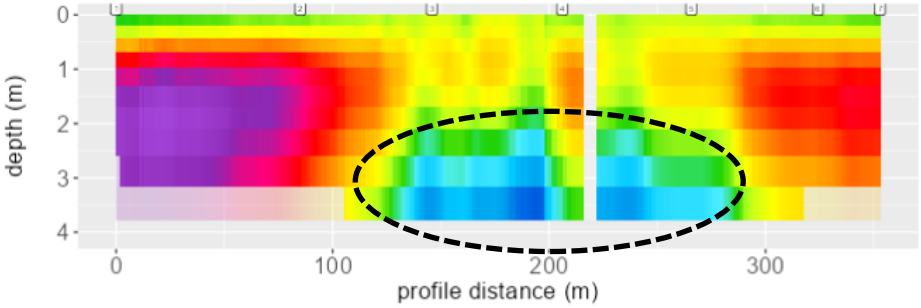
- Multiple smaller seeps located
- Large 150-m apparent seep identified along left bank/center channel



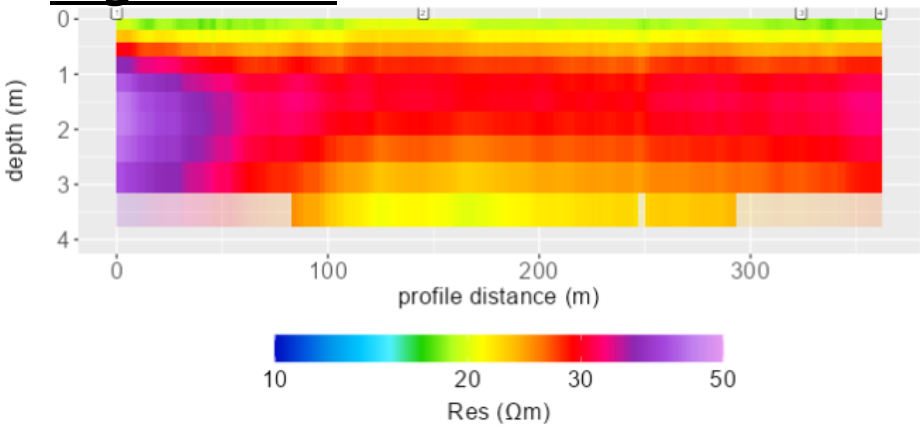
Left bank



Center channel



Right bank



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Summary

- Electromagnetic tools
  - TEM
    - Deeper/aquifer scale characterization (10 – 100+ m depth)
    - Conductive plume mapping, Unconsolidated sediment texture mapping,
  - FEM
    - Shallower/soils scale characterization (0 – 10 m depth)
    - Conductive seep mapping, soil moisture variations, soil texture variations
- Borehole NMR and HVSR
  - 1D water content, estimated hydraulic conductivity, and depth to bedrock
  - Valuable constraints for site-scale 2D-3D electromagnetic interpretations
- Other tools available include
  - Active seismic refraction and MASW, waterborne seismic reflection, DC resistivity, GPR, magnetometer, and several borehole logging instruments

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