United States Environmental Protection Agency

Geophysics for LUST sites

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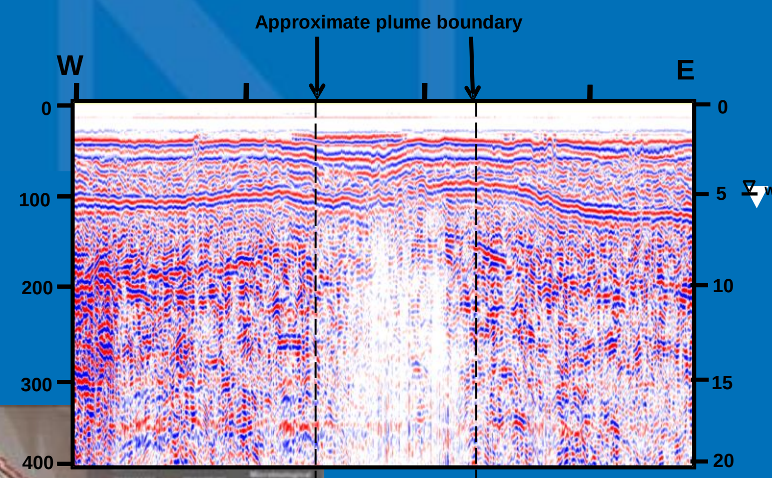
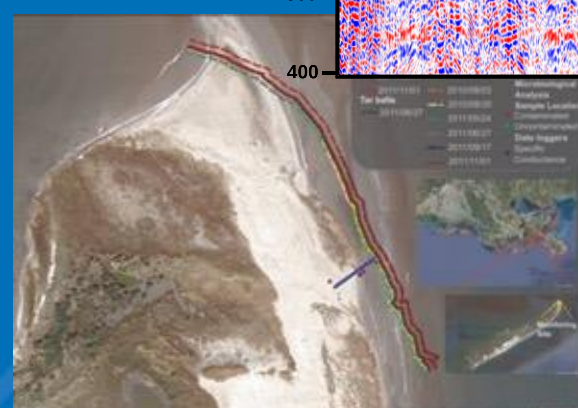
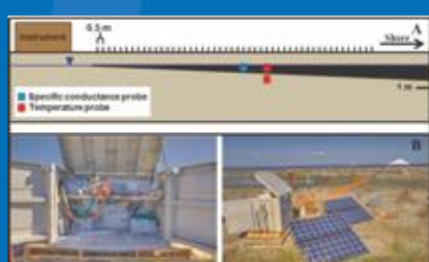


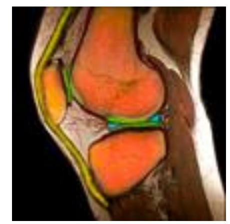




Why geophysics?

- Prior to expensive and invasive surgery we utilize medical imaging.
- Each medical imaging method is used for specific purposes.

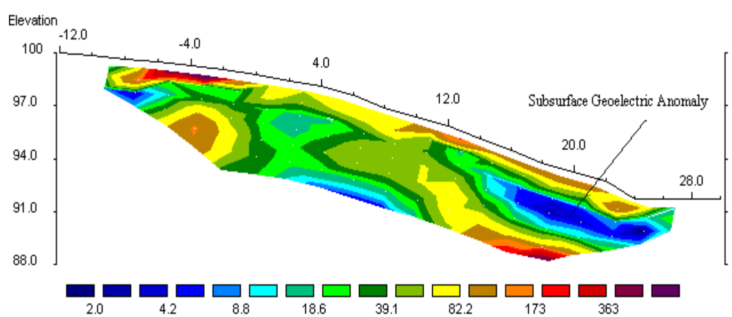
x-ray of knee



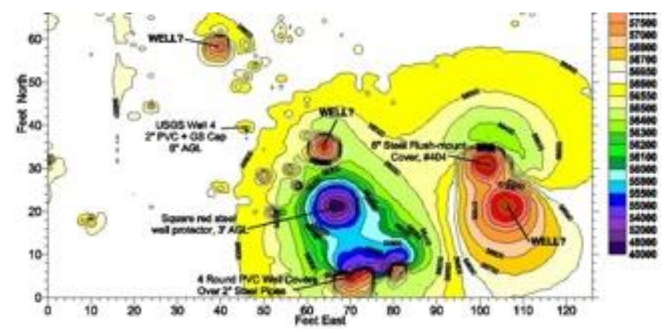
MRI of knee

images credit: Lee Slater

- Prior to expensive earth intrusive investigations (e.g., drilling, excavating, etc.) we can utilize geophysical imaging.
- Each geophysical method is used for specific purposes



Landfill plume mapping



Abandoned well mapping

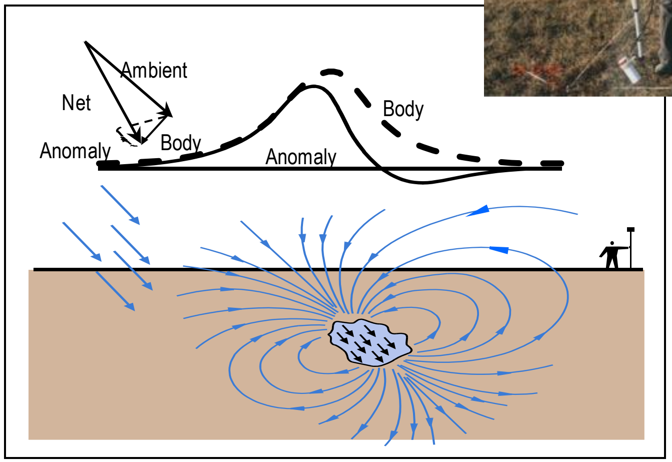
Outline

1. Finding Underground Storage Tanks (USTs) and underground infrastructure
2. Mapping contaminant plumes
3. Monitoring active or passive remediation
4. High resolution characterization and Conceptual Site Model (CSM) development
5. Online resources – under development
   - Online Environmental Geophysics Textbook
   - Decision Support Tools

Geophysical methods include a set of tools in the site investigator's tool box.

1. Finding USTs & subsurface infrastructure

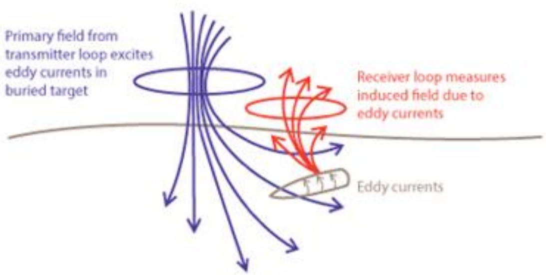
- What are the physical properties of the target, i.e. UST and associated infrastructure?
  - ➢ metal?, ferrous metal? fiberglass?
- Any potential interference?



Geometrics G-858 Cesium vapor magnetometer

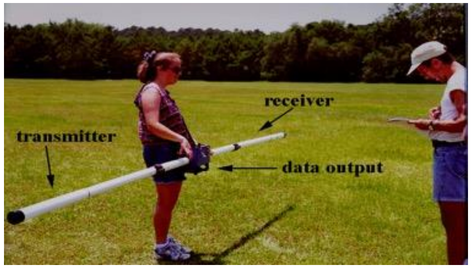
Likely applicable geophysical methods:

1. Magnetic
2. Electromagnetic
3. Ground Penetrating Radar (GPR)



Geophex GEM2

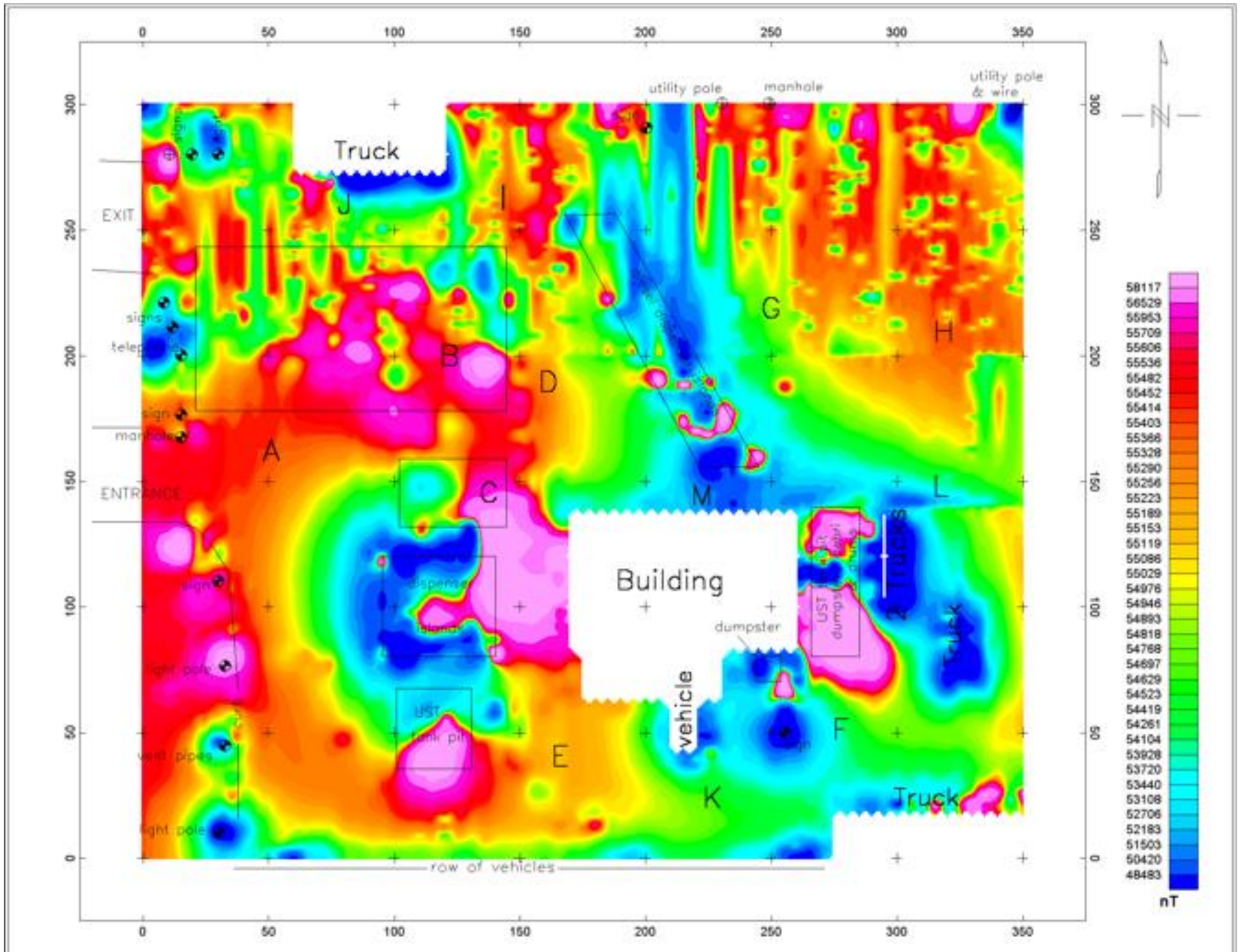
Geonics EM-61



Geonics EM-31

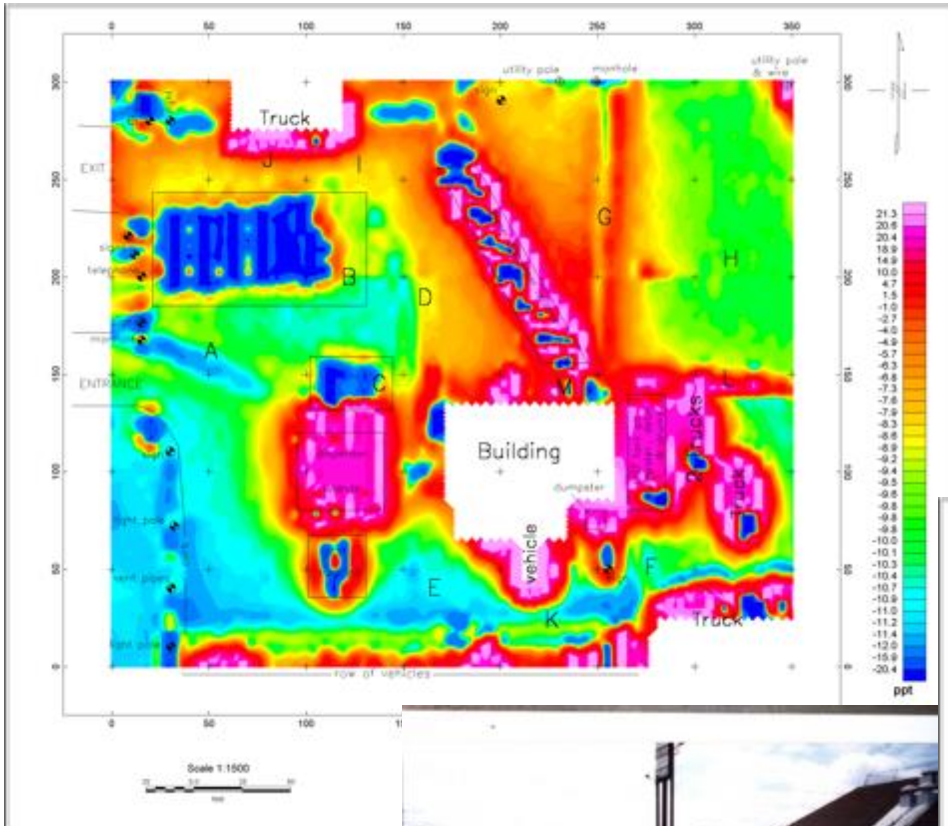
Mala GPR system

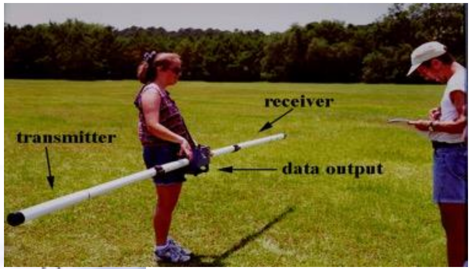
1. Finding USTs & subsurface infrastructure



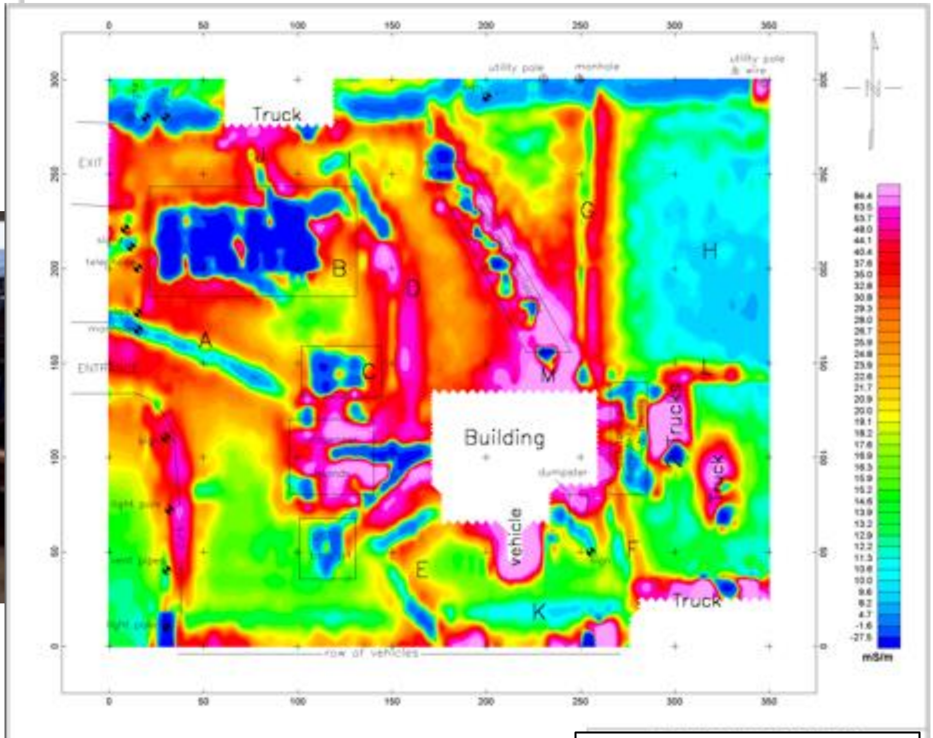
Total Magnetic Field Intensity (nT)

1. Finding USTs & subsurface infrastructure



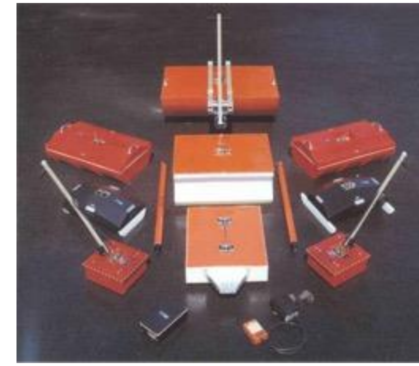


Geonics EM-31



EM 31 Quadrature

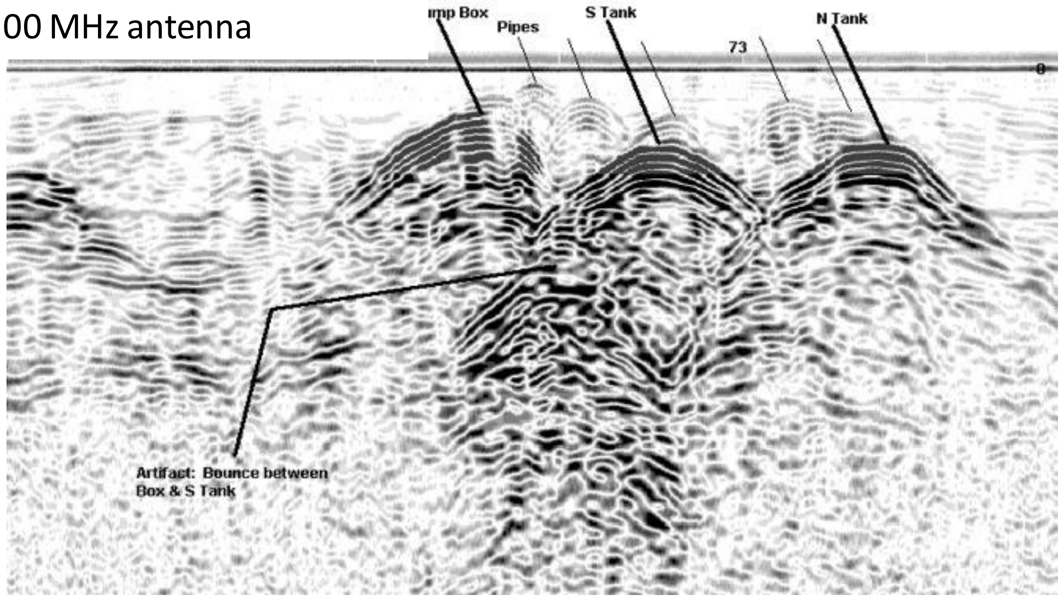
1. Finding USTs & subsurface infrastructure



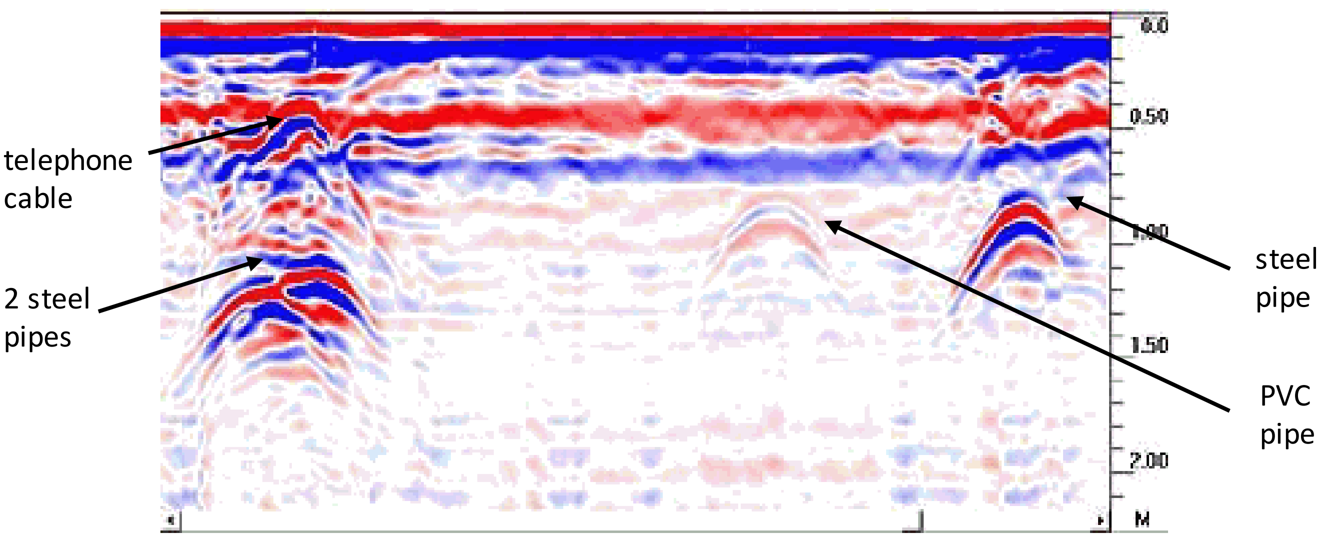
GSSI antenna

Ground Penetration Radar (GPR) UST and utility examples

A) 500 MHz antenna



B) 400 MHz antenna



- pipes oriented perpendicular to the profile.
- Darker reflections show higher amplitude due to greater electrical property impedance.
- Faint reflections show muted or low amplitude reflections due to the attenuation of the GPR energy from electrically conductive material.

Note: Hyperbolic Reflections

GPR sections from Bill Sauck

2. Mapping contaminant plumes

Direct Current (DC) Resistivity

Archie's Law for Porous Media w/o clay

$$\rho_e = a\,\phi^{-m}\,S^{-n}\,\rho_w$$

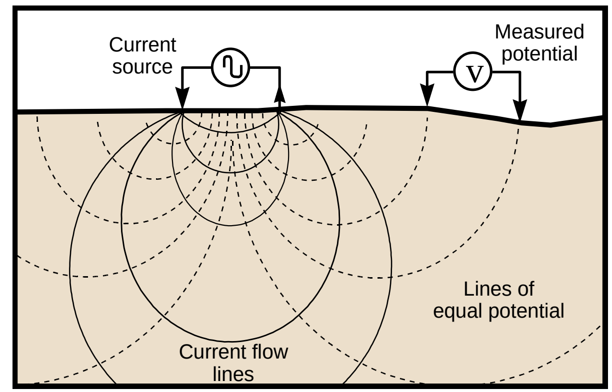
ρ_e = resistivity of the earth

ϕ = fractional pore volume (porosity)

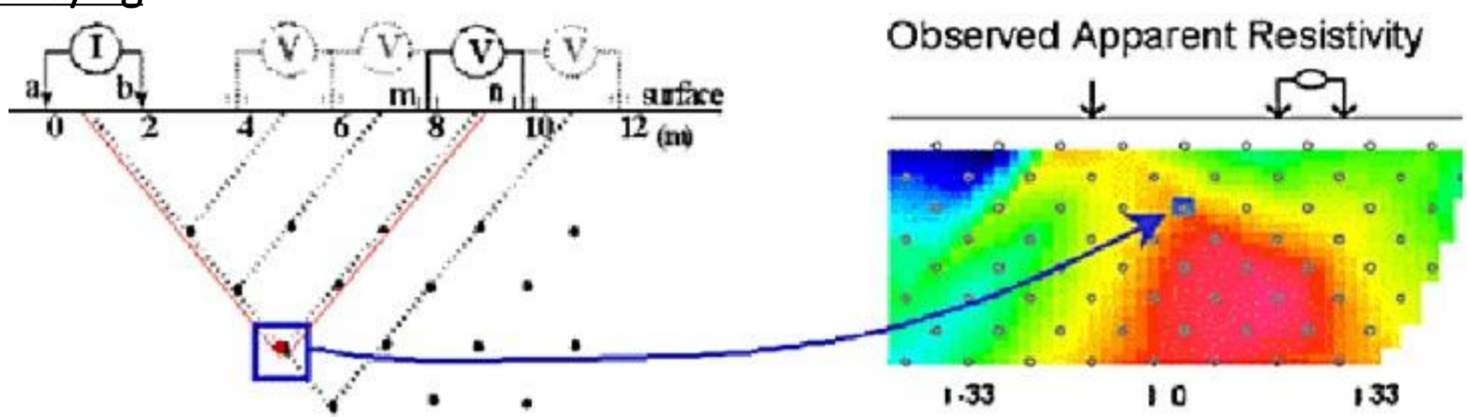
S = fraction of the pores containing fluid

ρ_w = the resistivity of the fluid

n, a and m are empirical constants



Resistivity Surveying



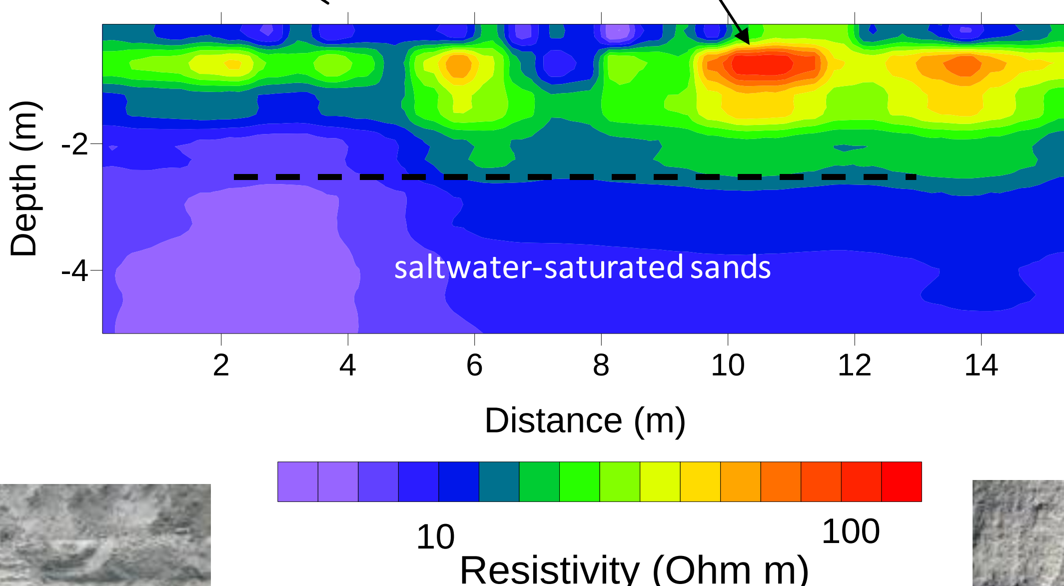
2. Mapping contaminant plumes

Deep Water Horizon Oil Spill Barrier Island Impact DC Resistivity Results

Zone of immature oil contamination imaged as resistive layer

Oil layer

NW ← *Inland* *thinning of oil layer?* *Offshore* → SE



Approximate location of ~0.3 m thick oil layer

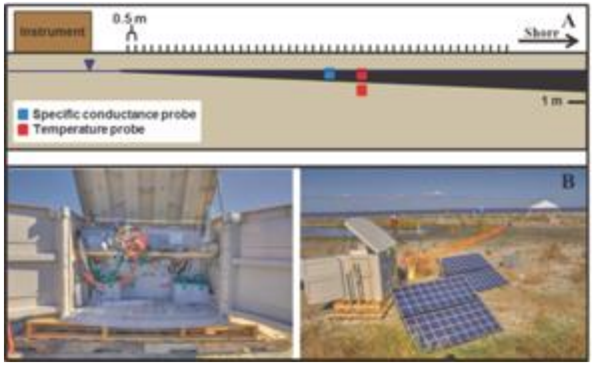
Oil layer

Oil impact thins away from the shoreline

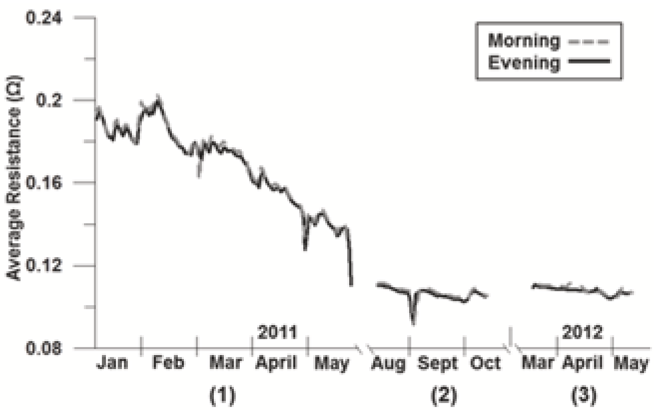
Heenan, J., Slater, L.D., Ntarlagiannis, D., Atekwana, E.A., Fathepure, B.Z., Dalvai, S., Ross, C., Werkema, D.D., and Atekwana, E.A., *Geophysics*, 2014

2. Mapping contaminant plumes

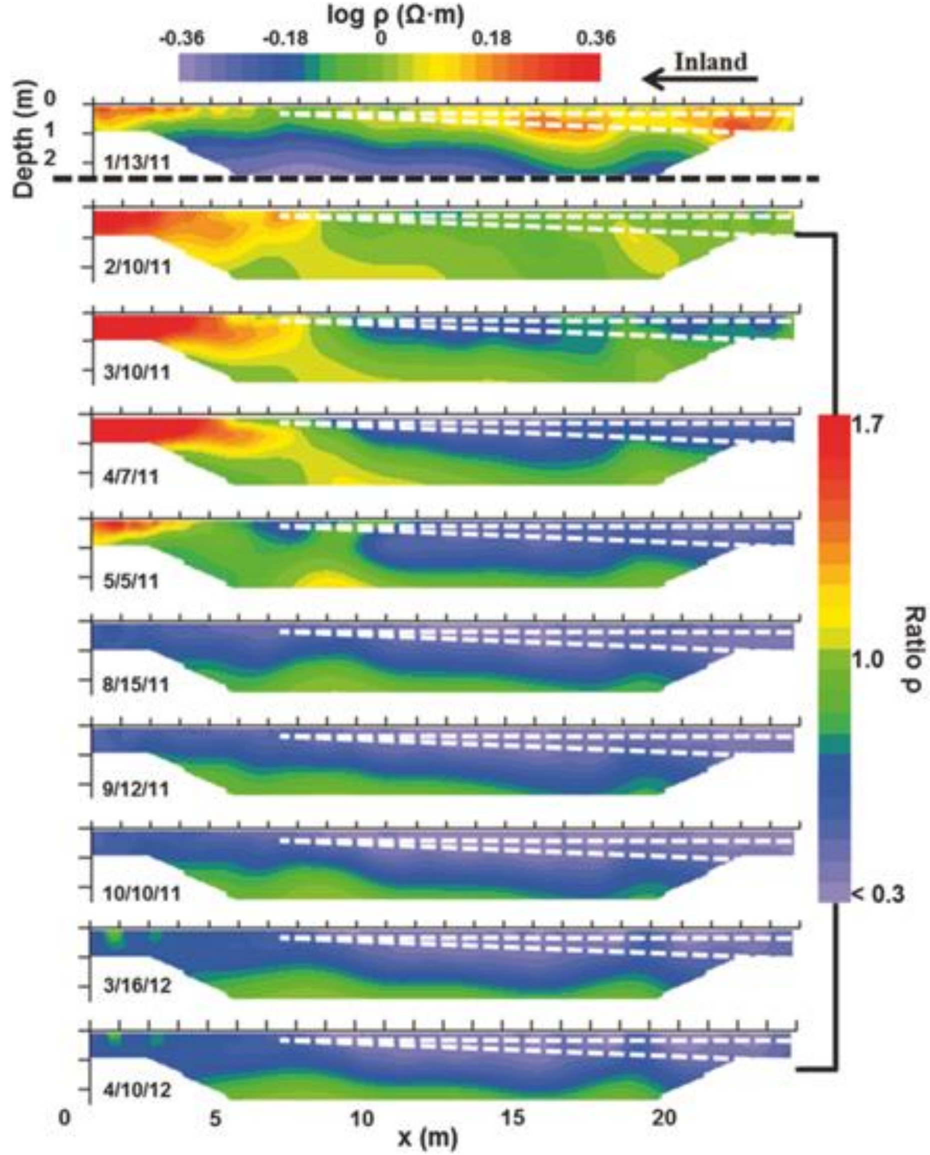
[DWH Barrier Island Time-Lapse]()



Adaptation of field resistivity system to remote solar power acquisition



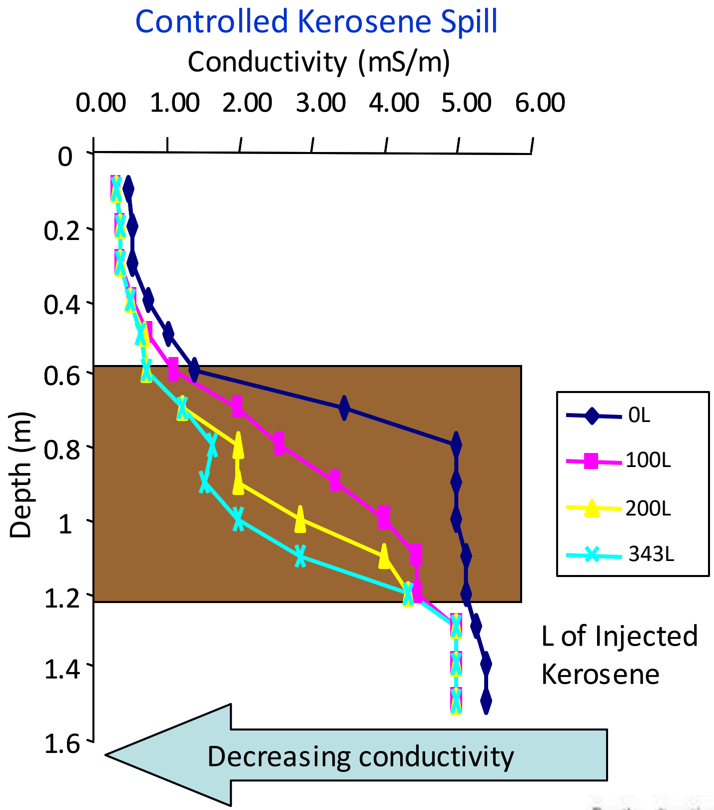
ave. resistance of anomaly vs. time



15 months resistivity

Heenan, J., Slater, L.D., Ntarlagiannis, D., Atekwana, E.A., Fathepure, B.Z., Dalvai, S., Ross, C., Werkema, D.D., and Atekwana, E.A., *Geophysics*, 2014

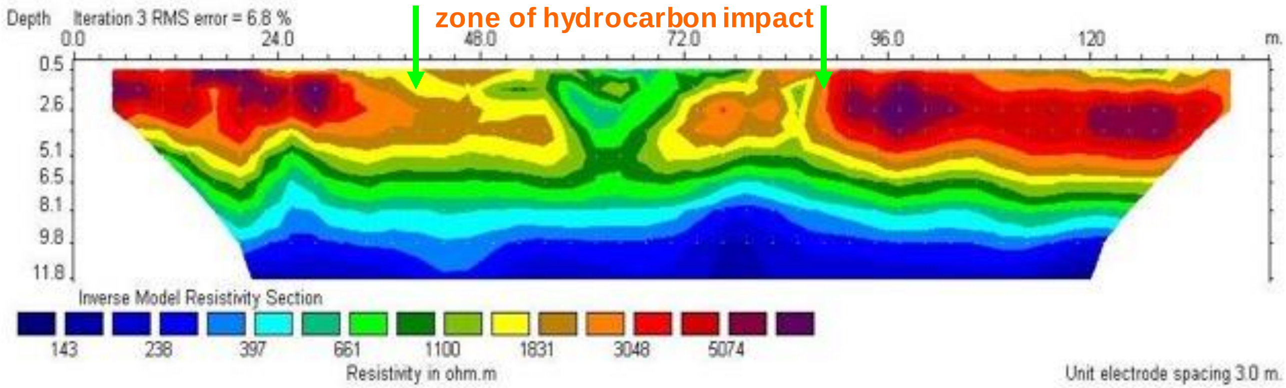
3. Remediation monitoring



De Ryck et al., 1993

Monitoring or measuring passive or active remediation using geophysics

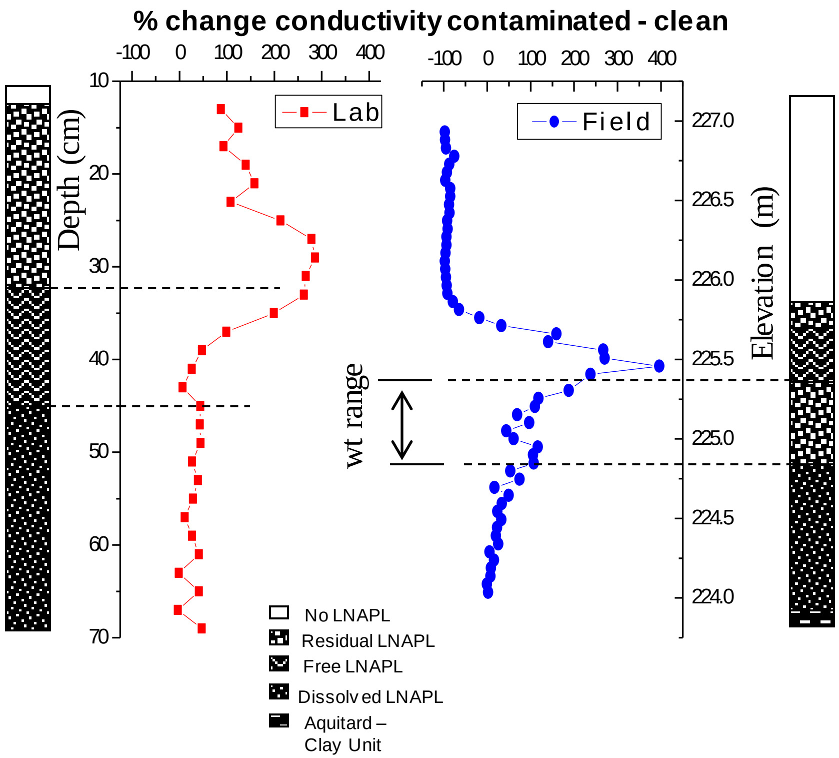
However…

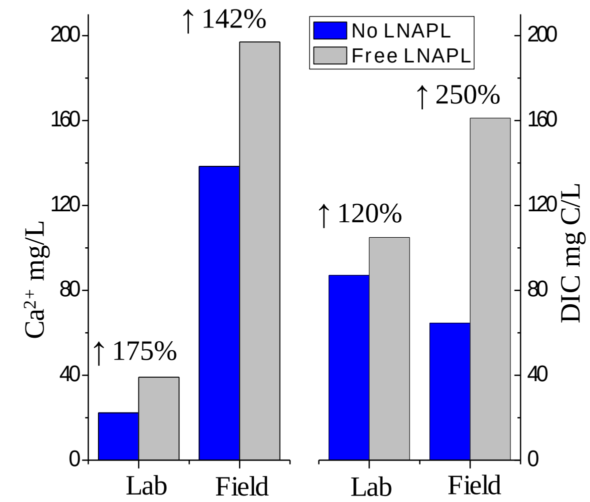


Maturity of plume should be considered

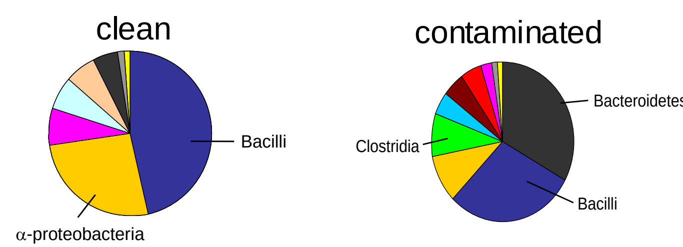
3. Remediation monitoring

Direct Current Resistivity of mature LNAPL plume





% change of Ca^{2+} and DIC



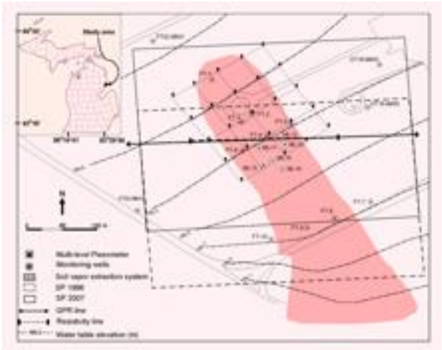
16S rRNA gene community composition

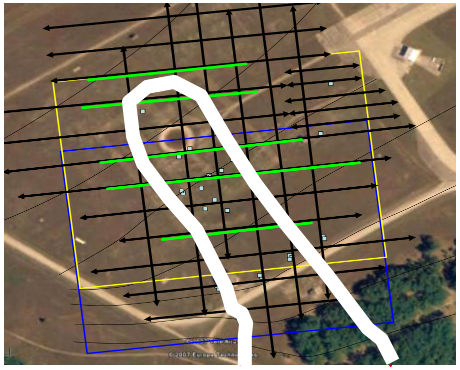
Geophysical response is coincident with microbiology and geochemical changes

Werkema Jr., D.D., Atekwana. E.A., Endres, A., Sauck, W.A. and Cassidy. D.P., *Geophysical Research Letters*, 2003

3. Remediation monitoring

Soil Vapor Extraction (SVE) monitoring using Self-Potential (SP)

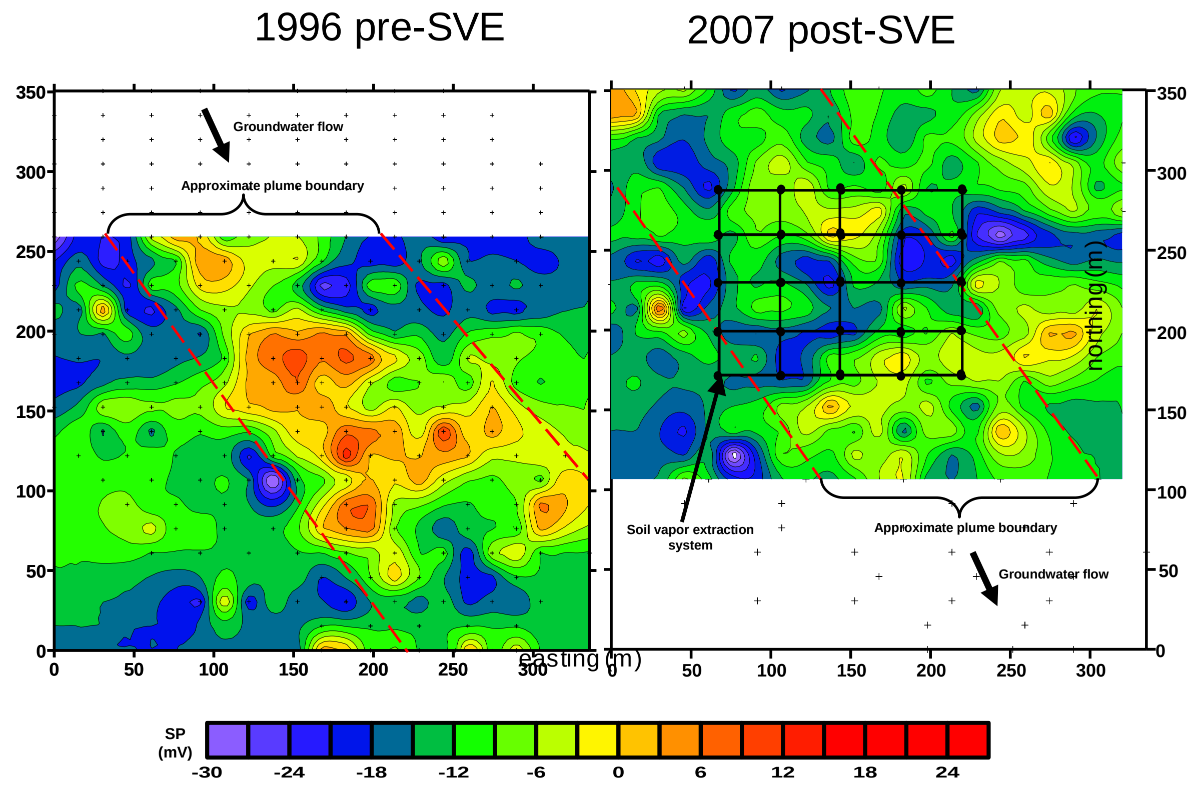




Former fire training facility, Oscoda, Michigan

Large quantities of fuel were burned.

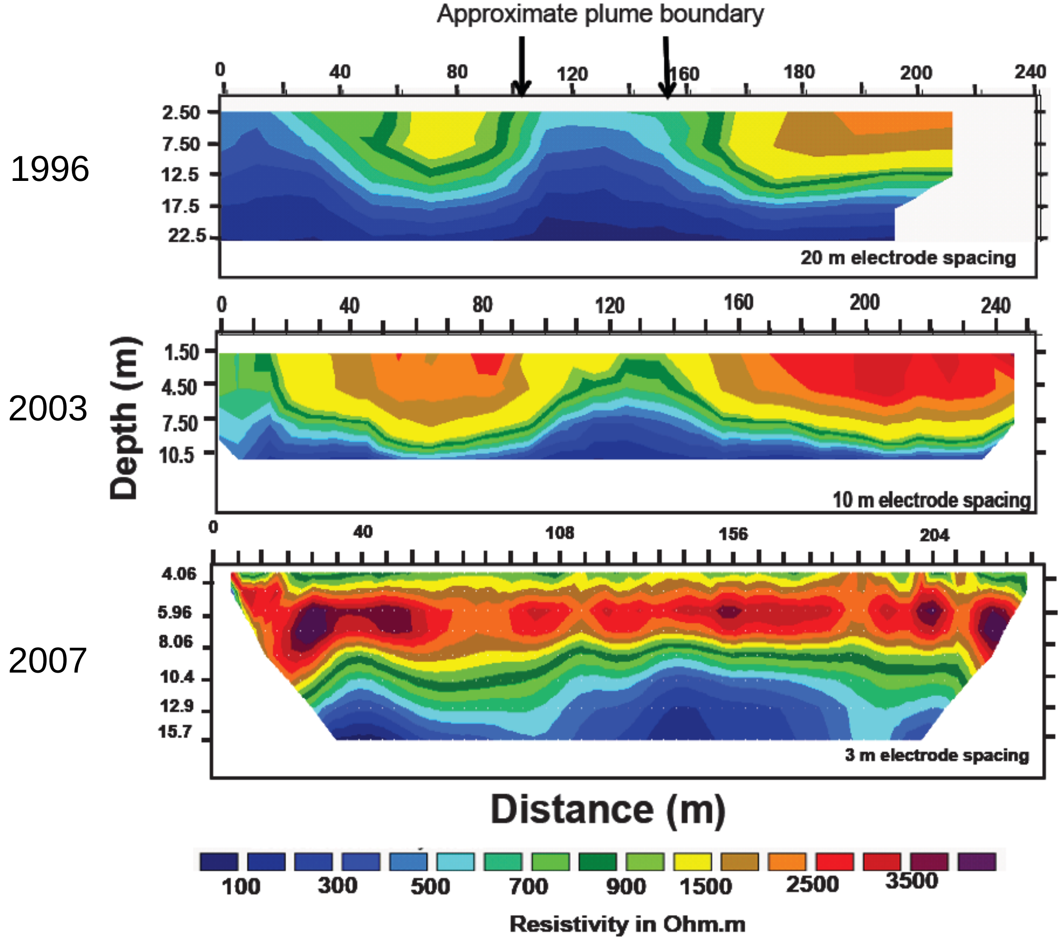
1990s, the free product 0.3 m thick and > 200 m down gradient



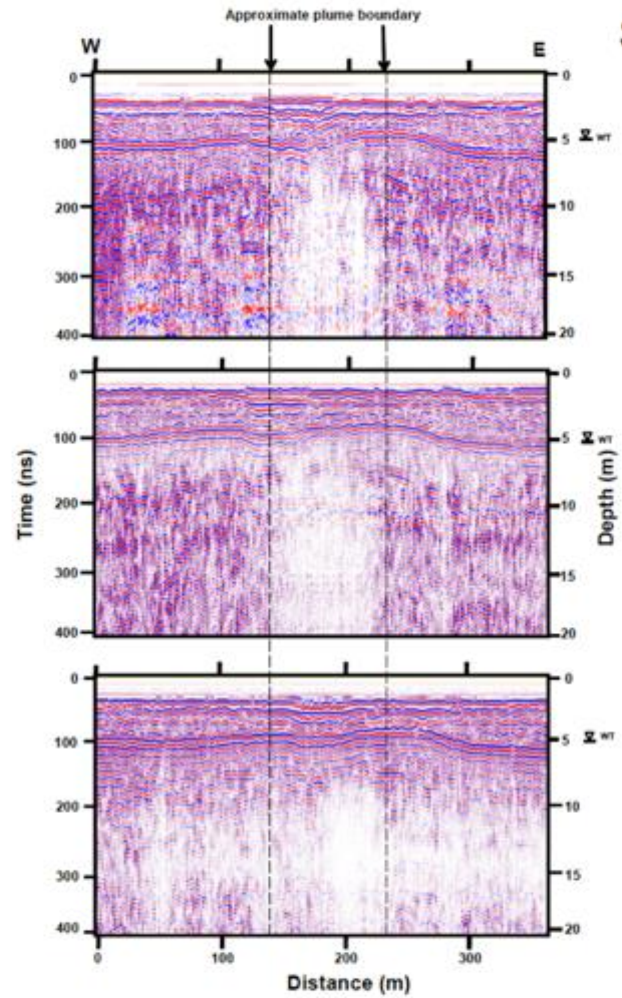
Vukenkeng C.A., Atekwana Estella.A., Atekwana, Eliot, A., Sauck, W.A., Werkema Jr., D.D., *Geophysics*, vol. 74, 2009

3. Remediation monitoring

DC Resistivity response to SVE system

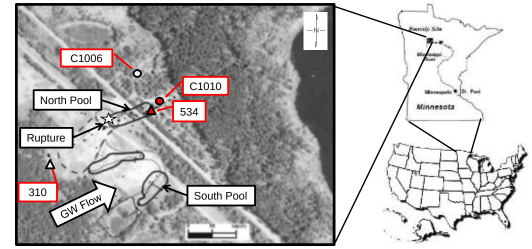


GPR Response to SVE System



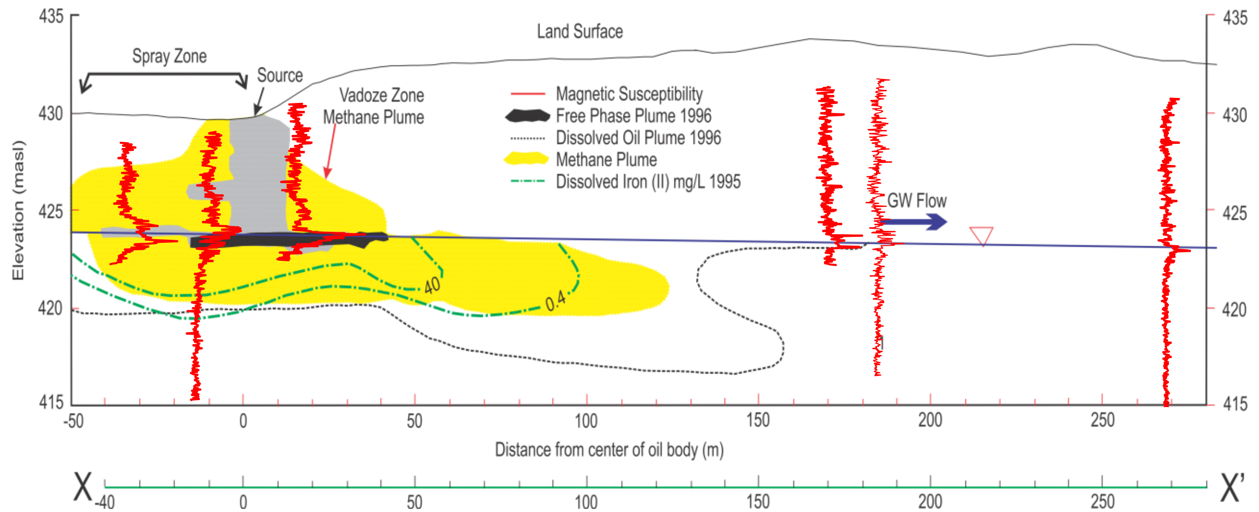
Vukenkeng C.A., Atekwana Estella.A., Atekwana, Eliot, A., Sauck, W.A., Werkema Jr., D.D., *Geophysics*, vol. 74, 2009

3. Remediation monitoring



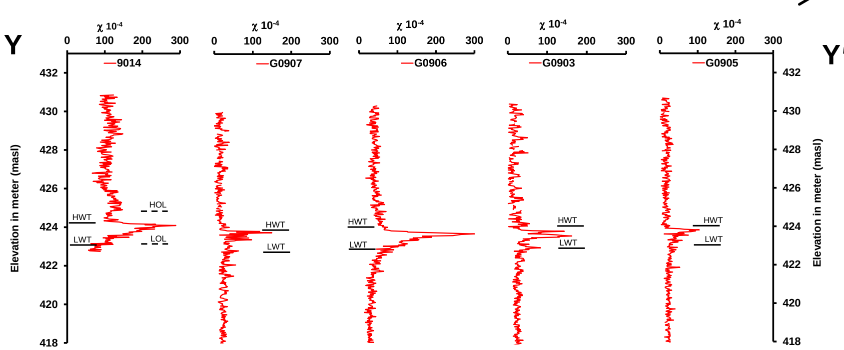
Magnetic Susceptibility (MS)

MS measurements of the accumulation of magnetite can be adopted as a non-invasive technology for monitoring long-term natural attenuation of crude oil in the subsurface



free phase plume (FPP)

dissolved phase plume (DPP)



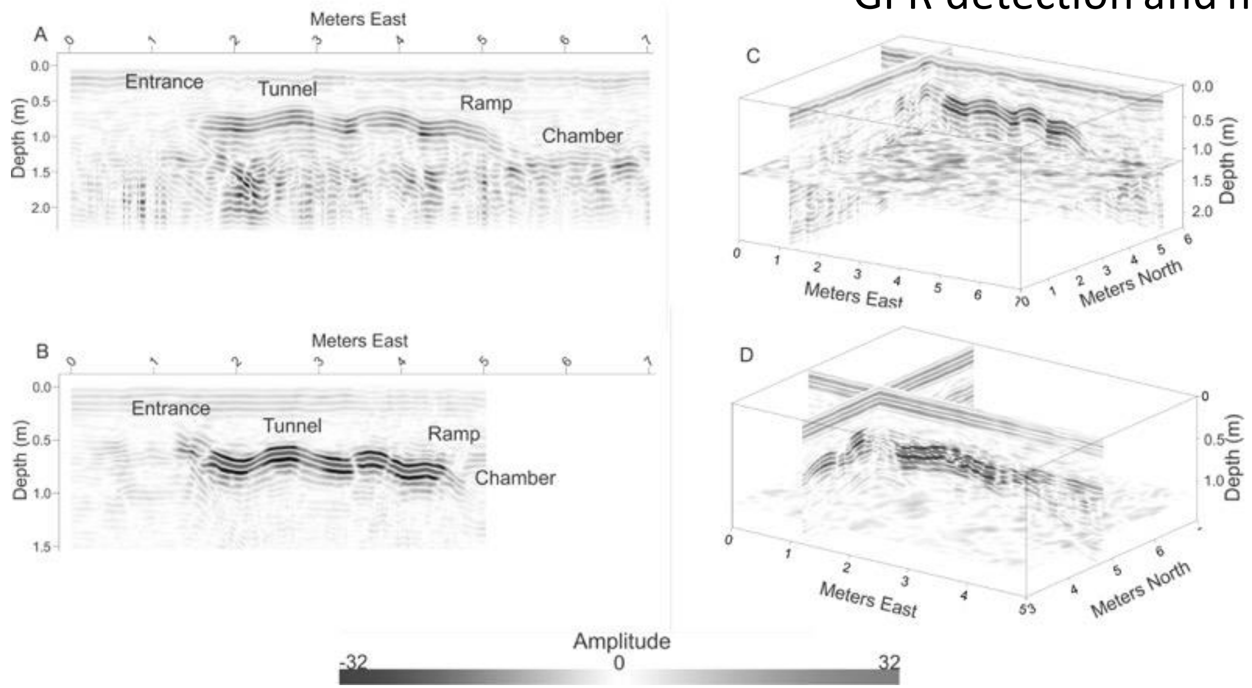
Atekwana, Mewafy, Abdel Aal, Werkema, Revil, and Slater, Journal of Geophysical Research, 2014

4. High Resolution CSM development

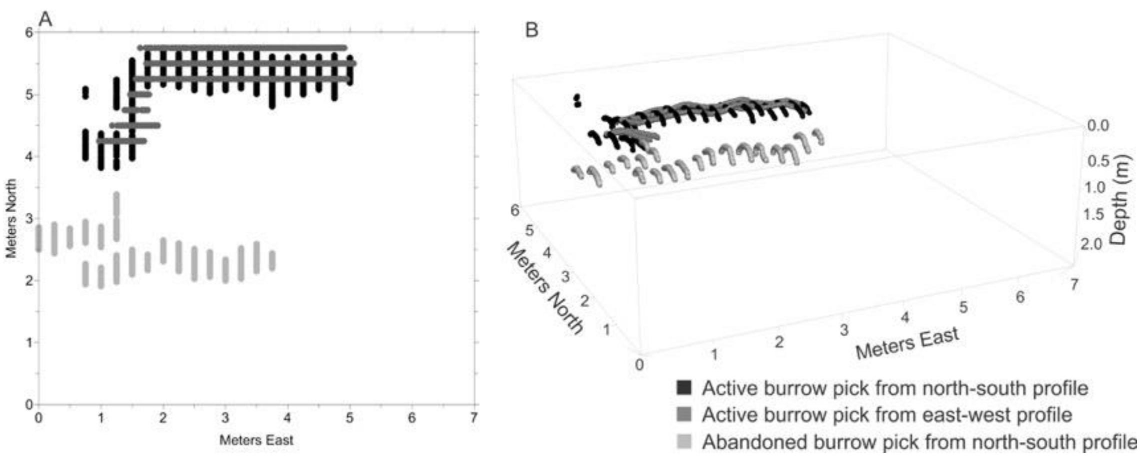
GPR detection and mapping of animal burrows

400 MHz

900 MHz



Groundhog burrow GPR image depicting the entrance shaft, tunnel, ramp, and chamber imaged with the 400 MHz antenna and the 900 MHz antenna.



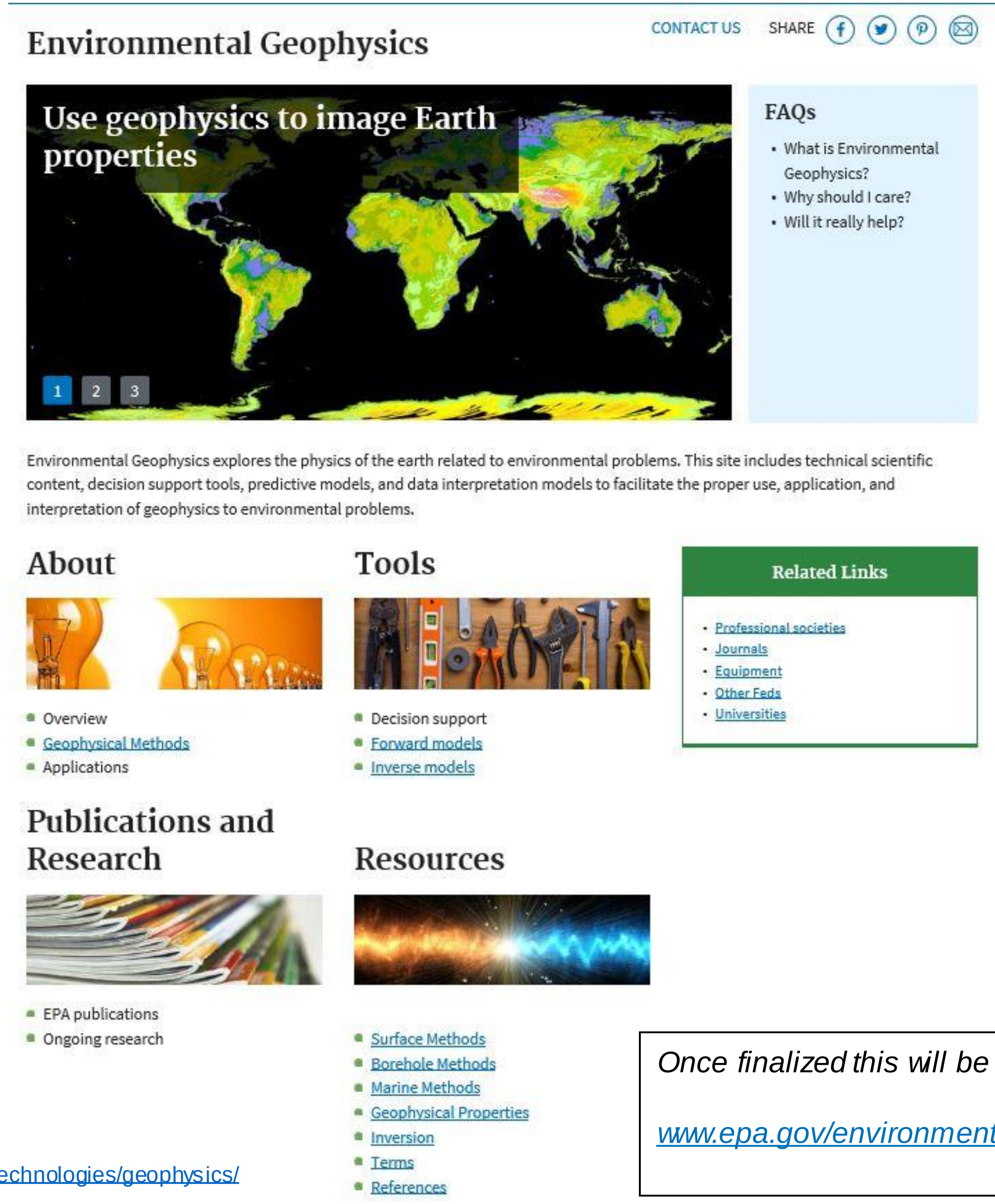
Manual picks chosen for the identification of the groundhog burrow system through hyperbolic reflections in the 400 MHz data.

Sherrod, L., Sauck, W., Simpson, E., Werkema, D., Swiontek, J., Case histories of GPR for animal burrows mapping and geometry, Journal of Environmental and Engineering Geophysics, In press, 2018

5. Models & Decision Support

ONLINE RESOURCES

Environmental Geophysics web presence: tech transfer, assistance, guidance, and decision support tools



Environmental Geophysics

CONTACT US SHARE

Use geophysics to image Earth properties

1 2 3

FAQs

- What is Environmental Geophysics?
- Why should I care?
- Will it really help?

Environmental Geophysics explores the physics of the earth related to environmental problems. This site includes technical scientific content, decision support tools, predictive models, and data interpretation models to facilitate the proper use, application, and interpretation of geophysics to environmental problems.

About

- Overview
- Geophysical Methods
- Applications

Tools

- Decision support
- Forward models
- Inverse models

Related Links

- Professional societies
- Journals
- Equipment
- Other Feds
- Universities

Publications and Research

- EPA publications
- Ongoing research

Resources

- Surface Methods
- Borehole Methods
- Marine Methods
- Geophysical Properties
- Inversion
- Terms
- References

Once finalized this will be found at:

www.epa.gov/environmental-geophysics

Beta version: https://clu-in.org/characterization/technologies/geophysics/

Surface Geophysical Methods

This section covers most of the commonly used surface geophysical methods.

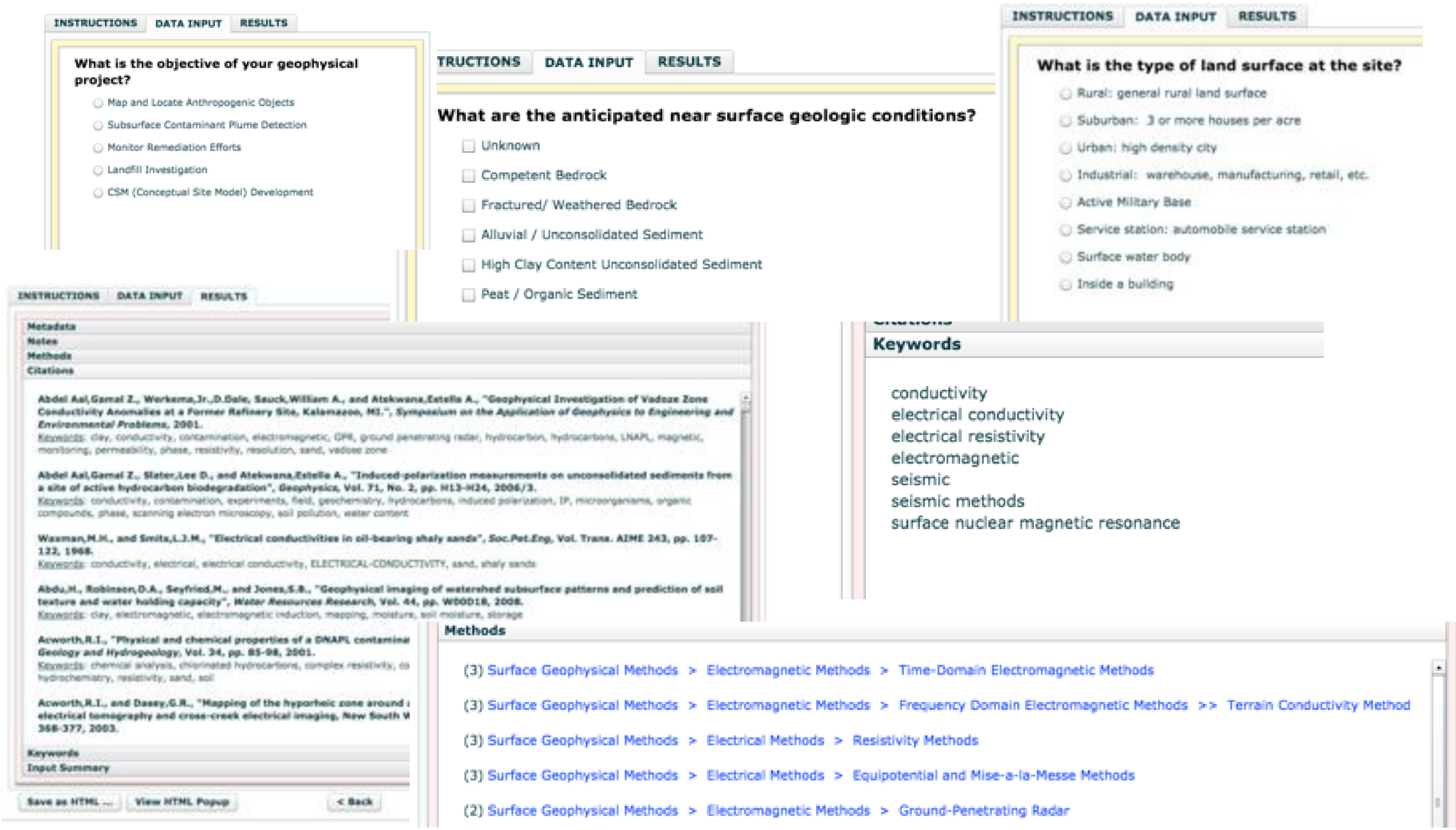
- Electrical Methods
  - Equipotential and Mise-a-la-Messe Methods
  - Induced Polarization
  - Resistivity Methods
  - Self-Potential (SP) Method
- Electromagnetic Methods
- Nuclear Methods
- Potential Field Methods
- Seismic Methods

Contact Us to ask a question, provide feedback, or report a problem.

5. Models & Decision Support

ONLINE RESOURCES

Geophysical Decision Support System (GDSS – Beta Version)

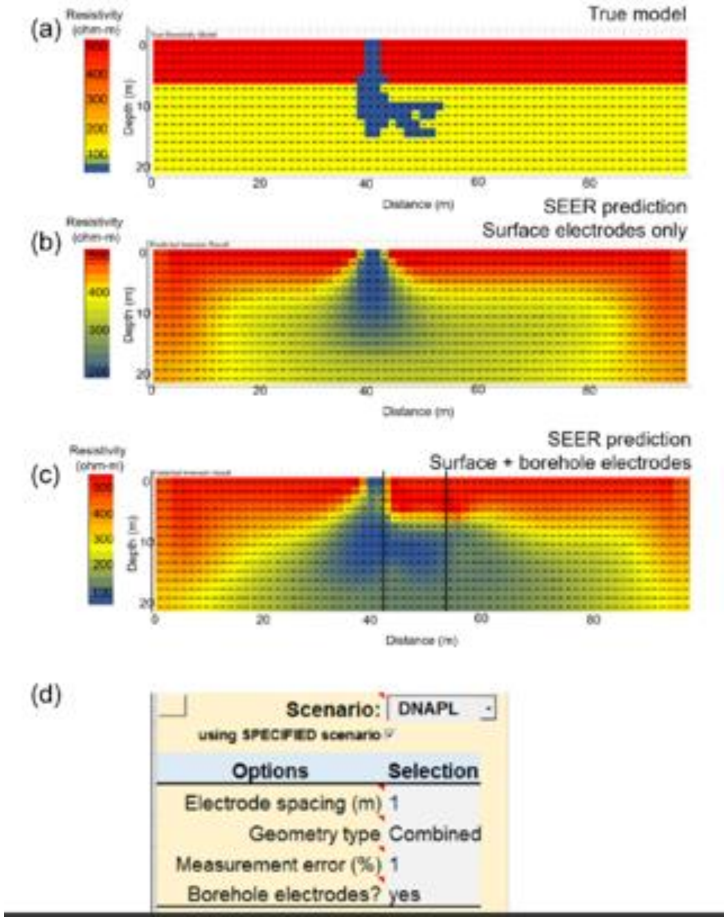


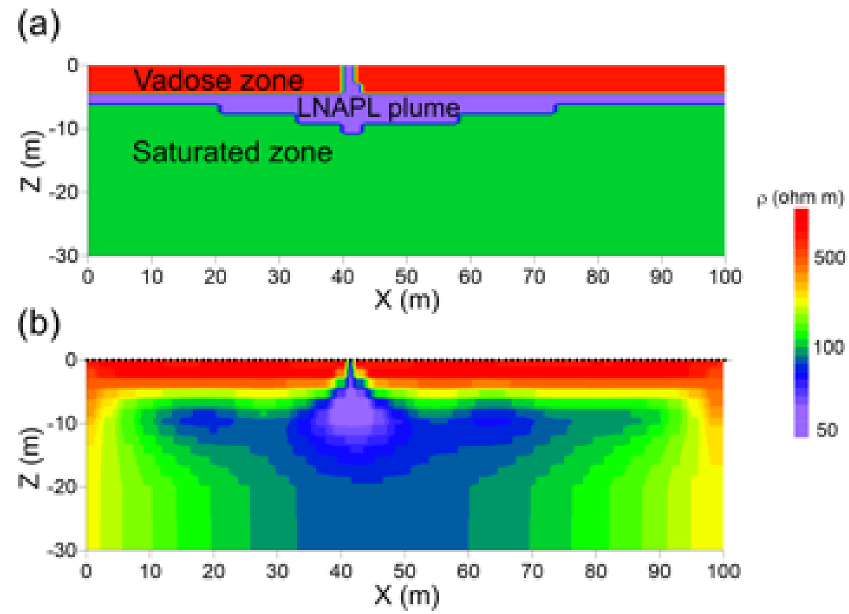
https://clu-in.org/characterization/technologies/geophysics/

Werkema Jr., D.D., Jackson, M., and Glaser, D., EPA/600/C-10/004, 2010

ONLINE RESOURCES

SEER – Scenario Evaluator for Electrical Resistivity



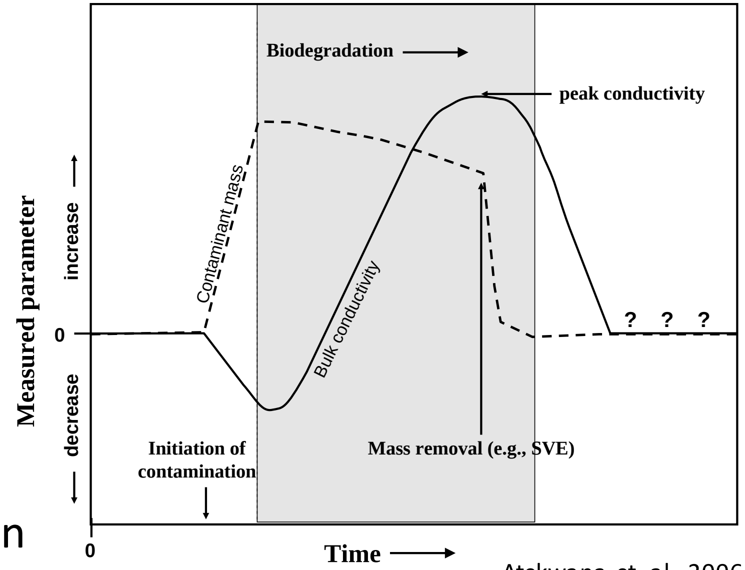


(a) hypothetic target consisting of a mature LNAPL plume on the water table, and electrodes with 1-m spacing at land surface

(b) the resultant electrical resistivity tomogram, assuming normally distributed random standard errors of 3%.

Terry, N., Day-Lewis, F., Robinson, J., Slater, L., Halford, K., Binley, A., Lane Jr., J., Werkema, D., 2017

Concluding Thoughts



Atekwana et. al., 2006

We can use, and are learning to use, geophysics to:

1. Find Underground Storage Tanks
2. Direct detection of some contaminants
3. Biological breakdown of contaminants and remediation
4. CSM development
5. Forward models and decision support systems help reduce uncertainty of results and inform stakeholders

The geophysical response is a function of the geology, hydrogeology, biology, and chemistry of the subsurface.

➢ Look for physical property contrasts, understand the mechanism of that contrast and if geophysical methods have the requisite resolution to detect the contrast.

What are the physical property contrasts?

Are these contrasts geophysically detectable?

Acknowledgement & Collaborators

- John Lane, Fred Day-Lewis, Marty Briggs, Carole Johnson, Eric White, Terry Neal: *USGS and University of Connecticut*
- Lee Slater, Dimitris Ntgarlantis, Judy Robinson, *Rutgers University*
- Estella Atekwana & Eliot Atekwana: *University of Delaware formerly OSU*
- Gamal Abdel Aal: *Assiut University, Egypt*
- Andre Revil: *Colorado School of Mines*
- Barbara Luke: *University Nevada-Las Vegas*
- Bill Sauck & Silvia Rossbach: *Western Michigan University*
- Yuri Gorby: *J. Craig Venter Institute*

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  - *UNLV:* Meghan Magill, Nihad Rajabdeen, Lisa Hancock
  - *Rutgers*: Jeff Heenan, Yves Robert-Personna, Sina Saneiyan, Sundeep Sharma, Angelo Lamousis,
  - *Oklahoma State U*: Farag Mawafy, Ryan Joyce, Dalton Hawkins, Brooke Braind, Cameron Ross, Carrie Davis, Che-Alota Vukenkeng,
  - *Colorado School of Mines:* Marios Karaoulis