Demonstrating A Geophysics Strategy for Minimally Invasive Remediation Performance Assessment

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Federal Remediation Technology Roundtable, November 2, 2016

Outline

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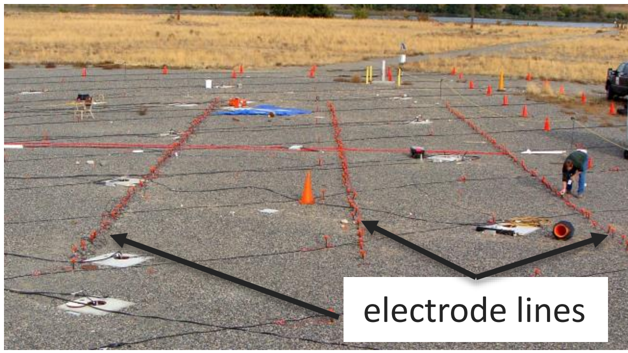
- Basic Theory and Operation
  - Deployment, measurements, processing
- Application Sampler
  - Characterization Imaging
  - Time-lapse Imaging
  - Real Time Imaging
- Managing Expectations, Limitations and Pitfalls
  - Consequences of Limited Resolution
  - Tools and Approaches for Reducing Risk
- Case Study
  - Brandywine M.D. Defense Reutilization Marketing Office

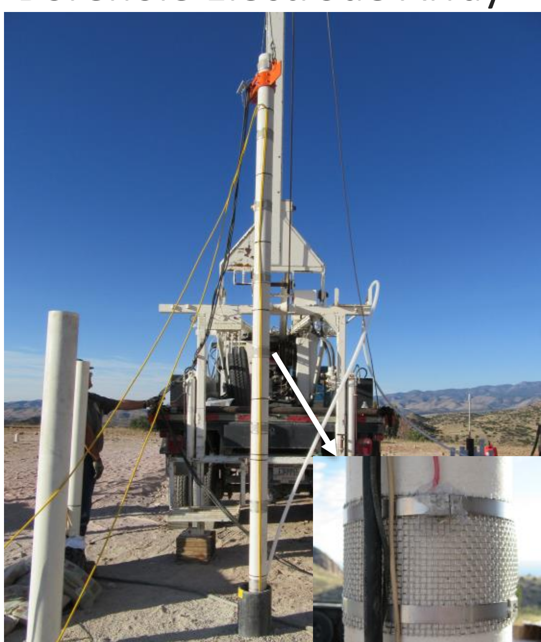
Electrical Imaging Step 1: Deploy Data Collection Hardware

Surface Electrode Array



Step 1: Electrode arrays are installed in the field and connected to a data collection system.

Borehole Electrode Array



Data Collection System

Step 2: Collect Tomographic Data

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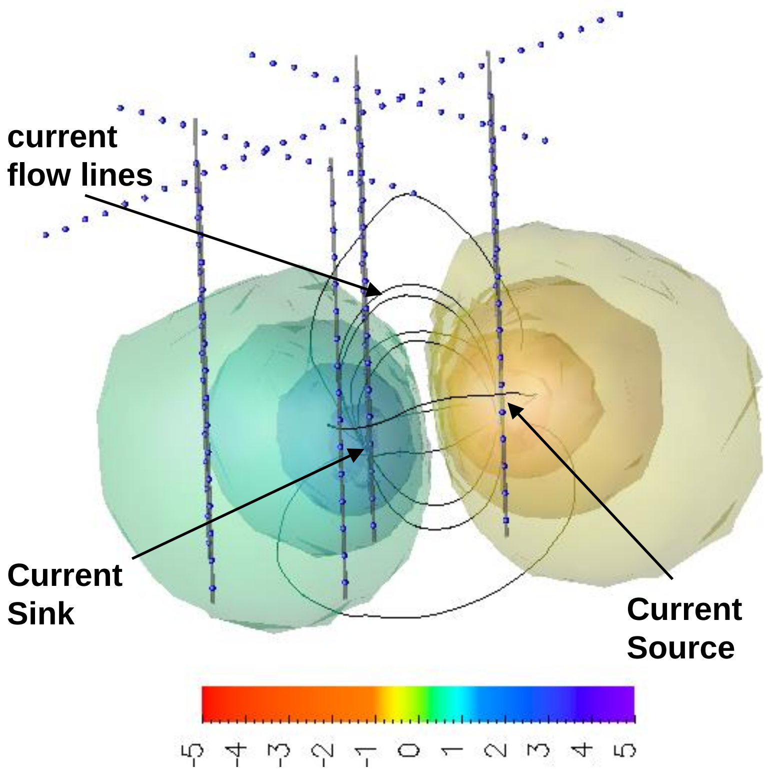
Current Injection and Potential Field

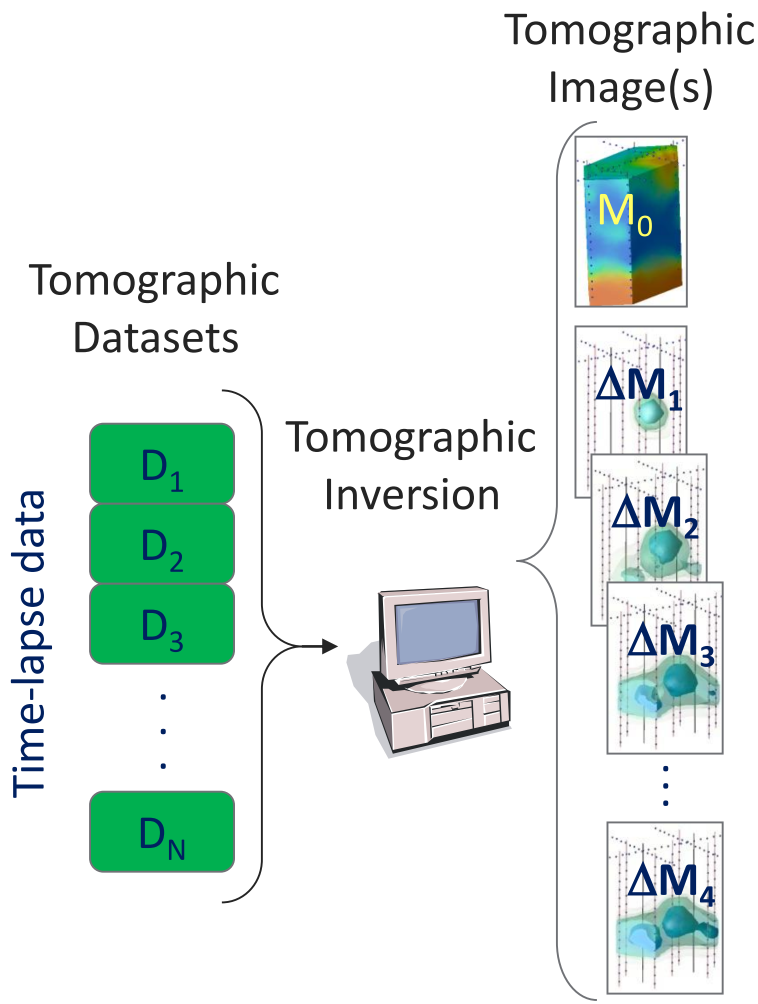


Subsurface Potential (Volts)

Step 2:

- Current is inject between a pair of electrodes
- Voltage is measured across another pair
- Many such measurements are collected to form a tomographic data set.

Step 3: Convert measurements to images via tomographic inversion



Step 3:

- Data sets are inverted to recover “images” of electrical properties
- Static images show absolute properties
- Time-lapse images show changes over time
- Conductive and capacitive properties

What can electrical properties tell us about the subsurface?

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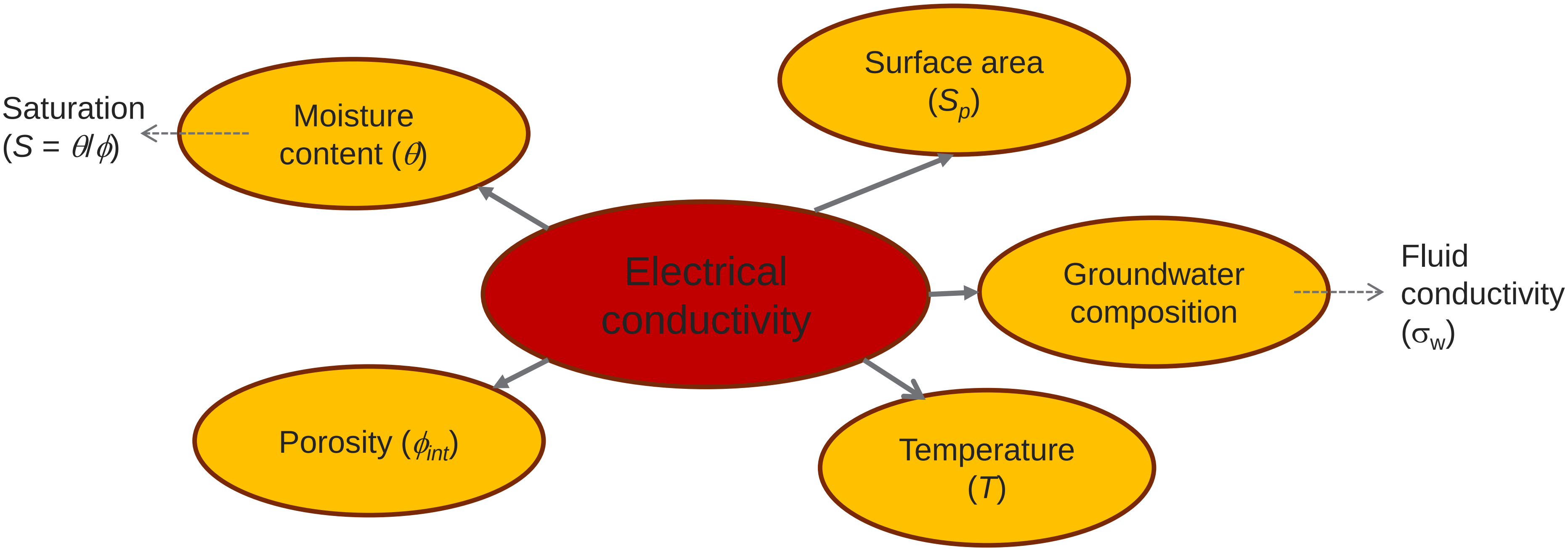
A geophysical property dependent on many subsurface properties….



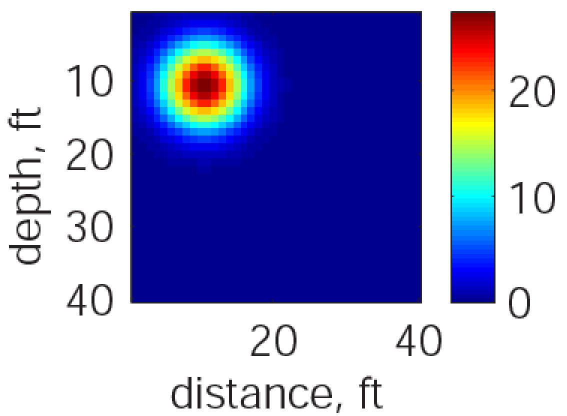
$$\sigma_{earth} = \frac{1}{\rho_{earth}} = \sigma_w(T)\phi_{\text{int}}^m S_w^n + \sigma_{surf}\left(S_p, \sigma_w, S, T\right)$$

m and n are exponents related to pore space connectivity/tortuosity

The Detection Problem: Finding a plume

Electrical Resistivity Anomaly (plume)

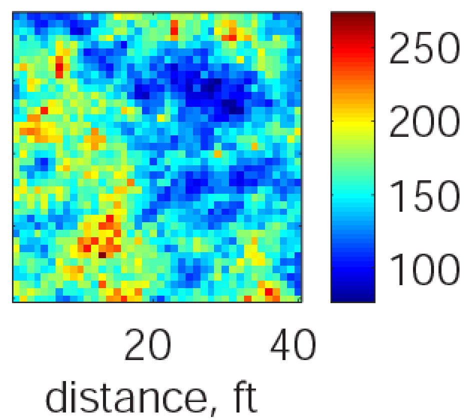
ohm-m



"The Needle"

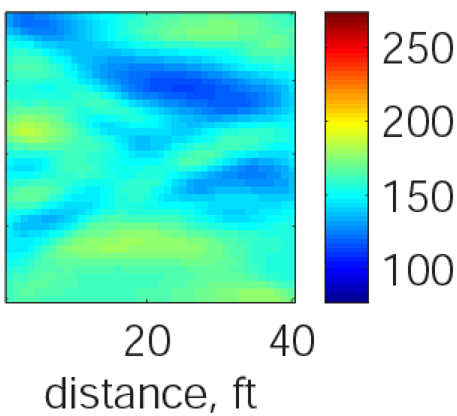
Electrical Resistivity Cross section

ohm-m



"The haystack + needle"

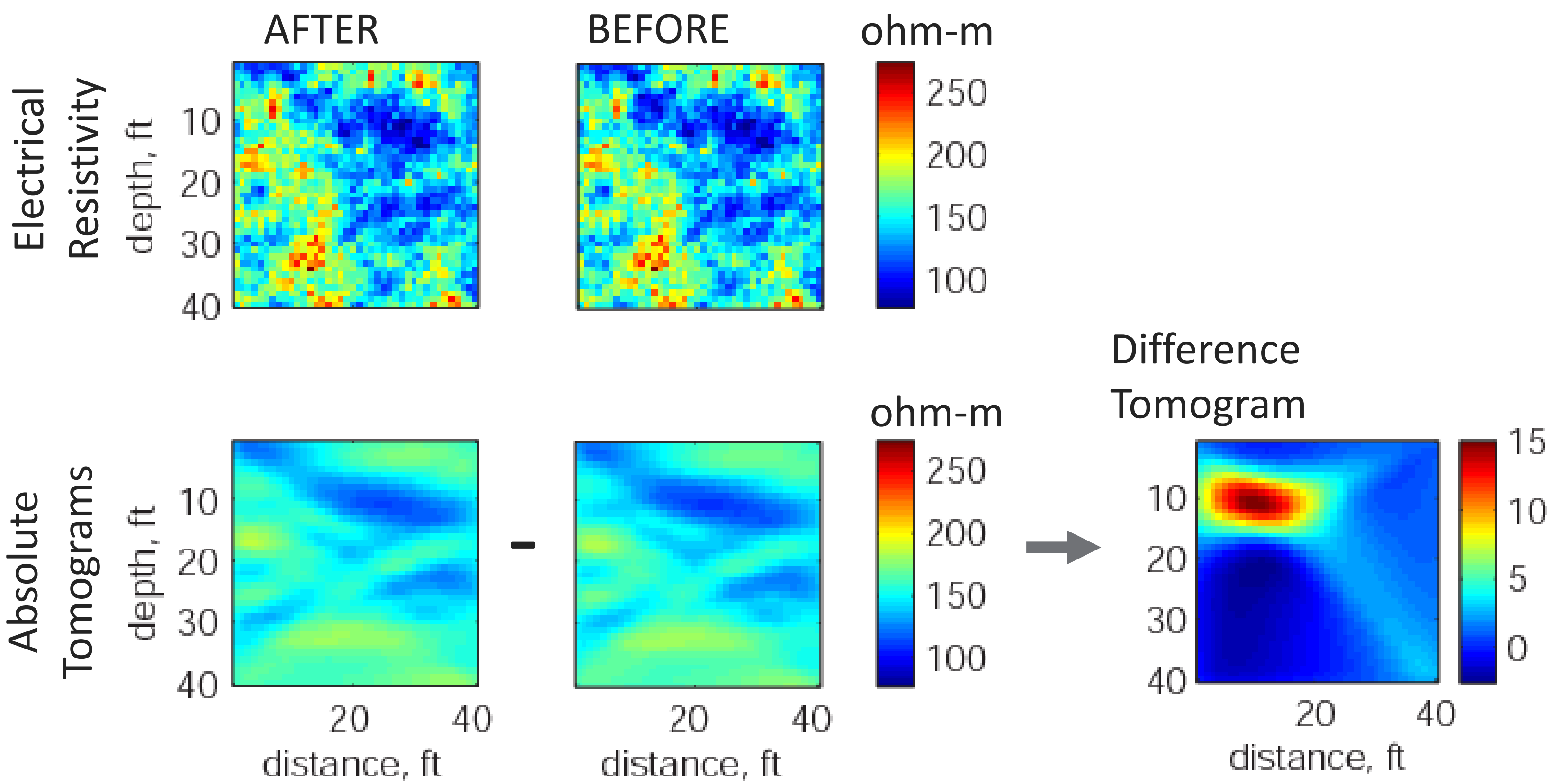
Electrical Resistivity Tomogram



"Blurry Haystack"

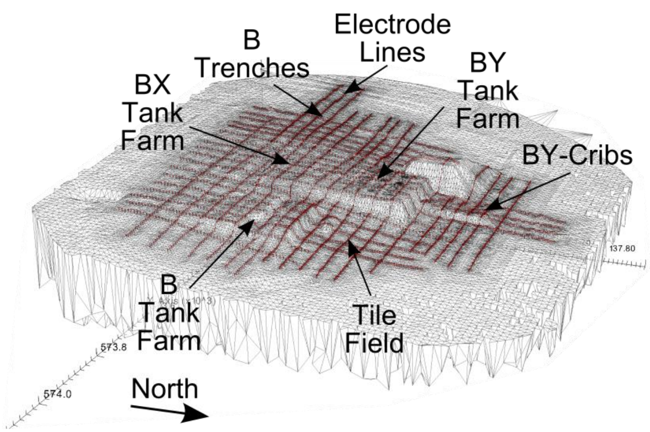
→ ***Plume is masked by geologic heterogeneity***

Time Lapse Difference Imaging



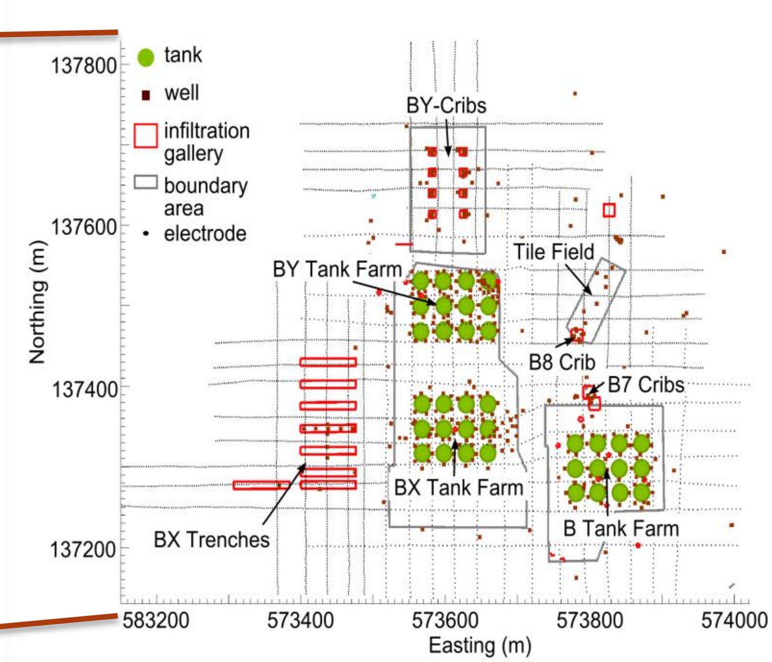
→Plume is revealed by subtracting out pre-injection background, removing unrelated spatial contrasts; i.e., we removed the haystack

Implementation Example 1: Imaging Vadose Zone Contamination (Hanford)



High conductivity zones correspond to elevated saturation and high nitrate concentrations from past waste infiltration.

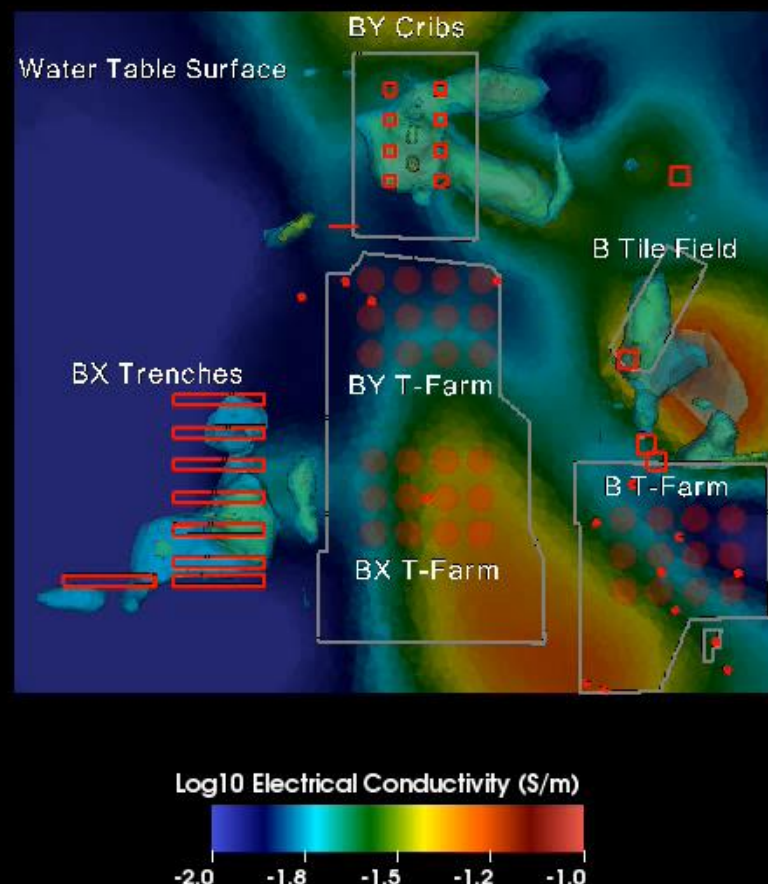
2006/2007 Surface ER Survey



Data courtesy HydroGeophysics, Inc.

Implementation Example 1: B-Complex 3D-ERT Fly around View

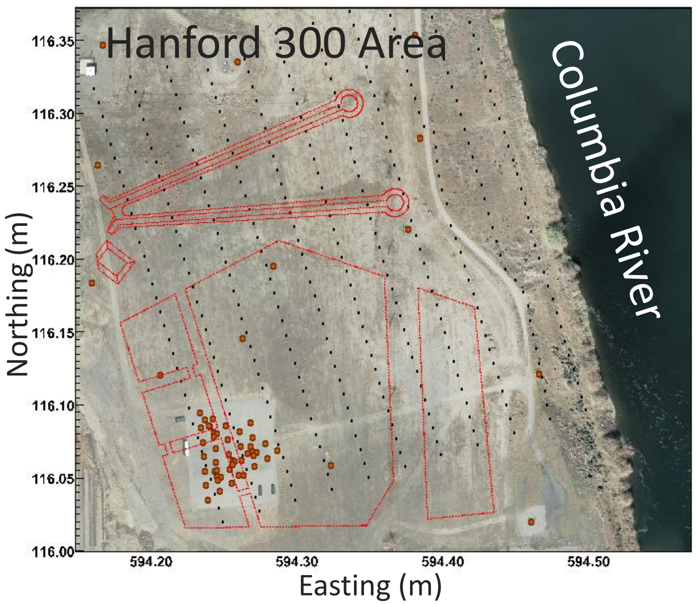
Hanford B-Complex Subsurface Contaminant Imaging

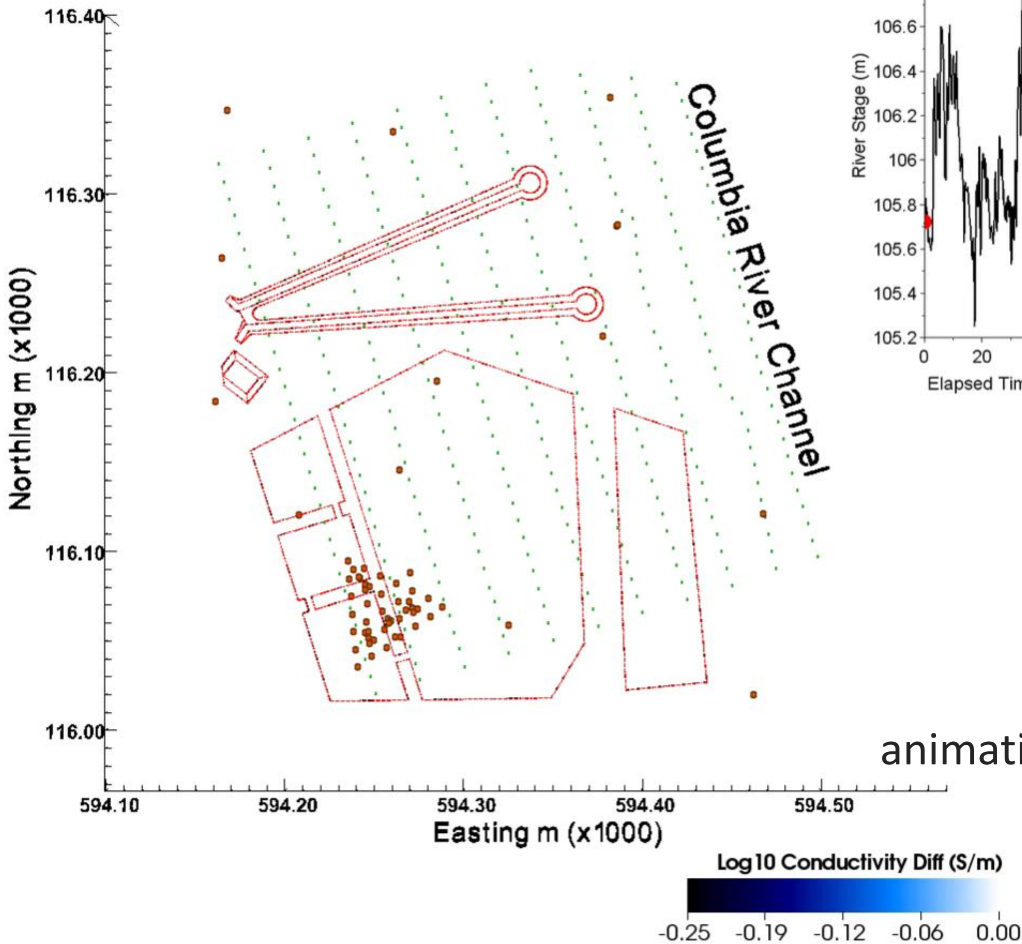


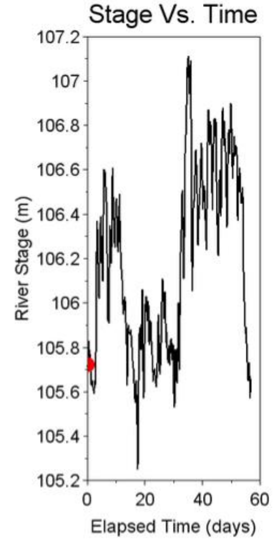
animation

Example 2: Time-lapse monitoring of stage-driven river water intrusion

Fluid conductivity (e.g. specific conductance) contrast between river water and groundwater enables river water to be imaged as it infiltrates into the aquifer during high stage.







animation

Example 3: Real-Time monitoring of amendment delivery via surface infiltration

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Plan view of 300 Area Treatment Site

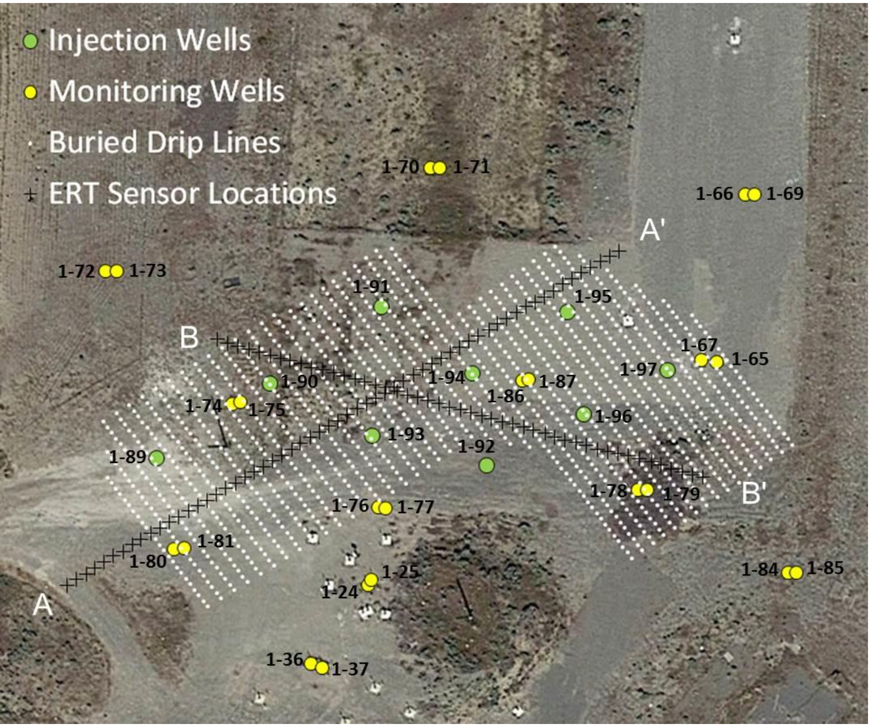
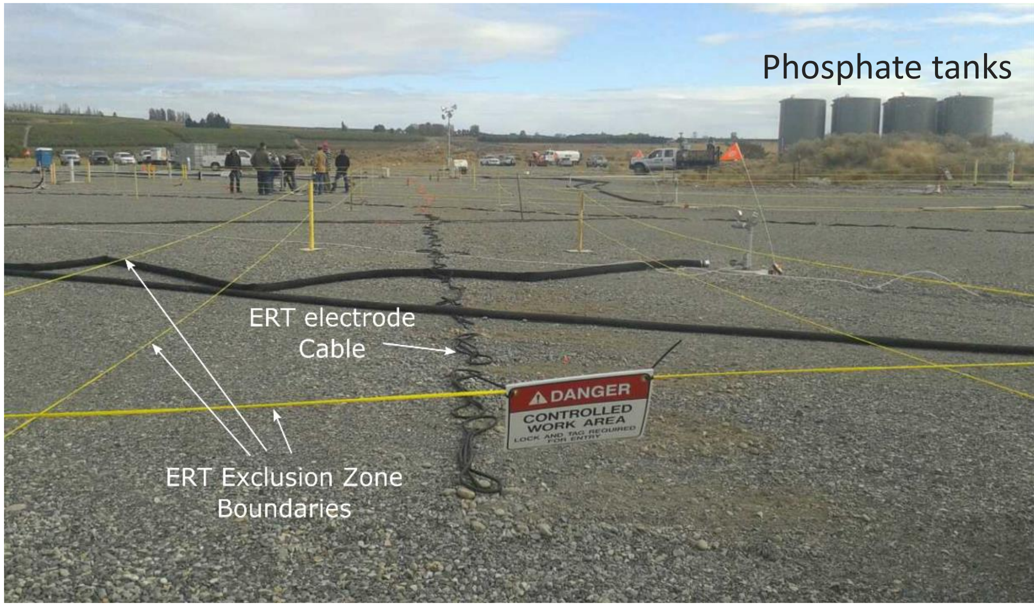
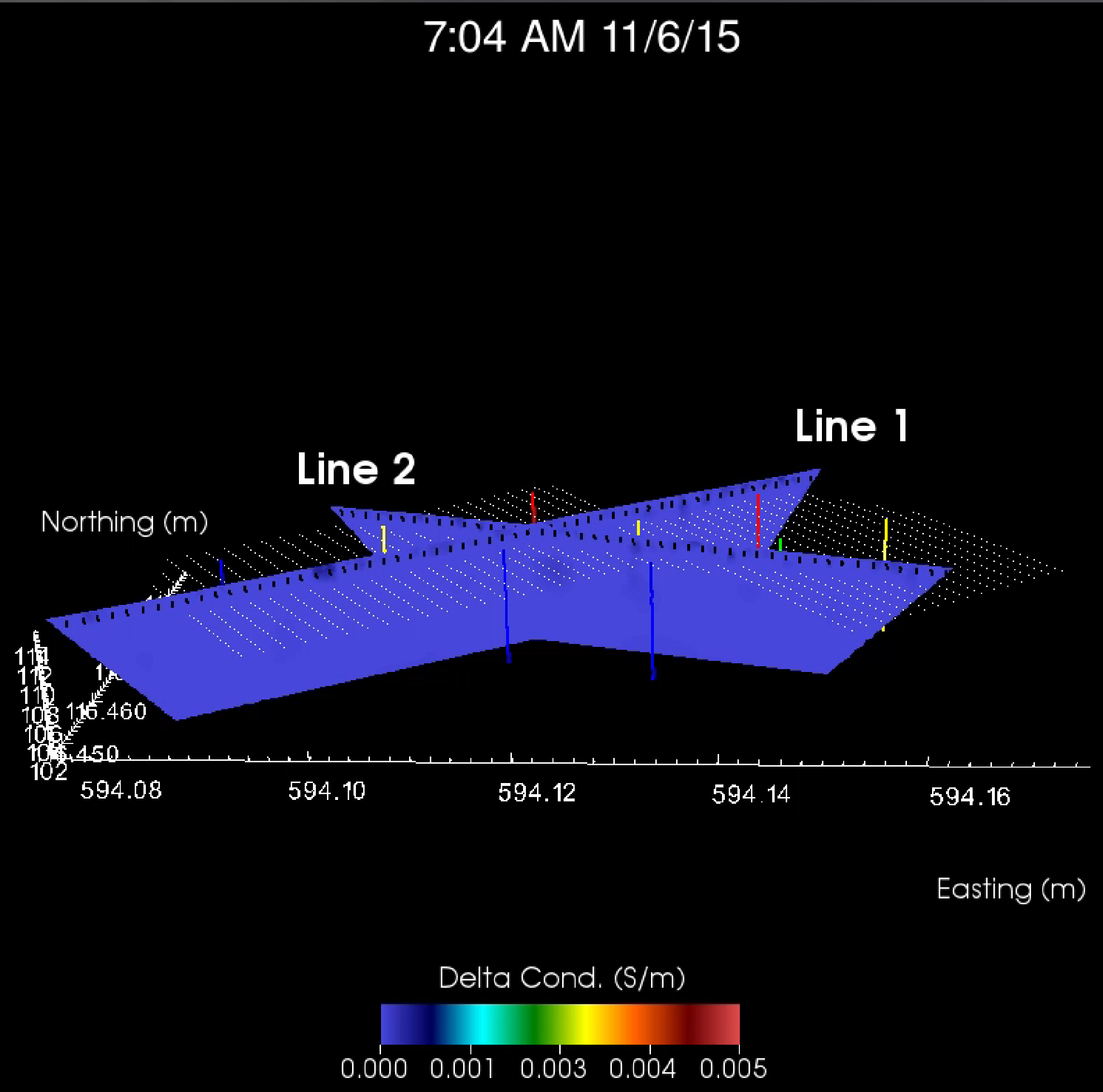


Photo at A facing A’



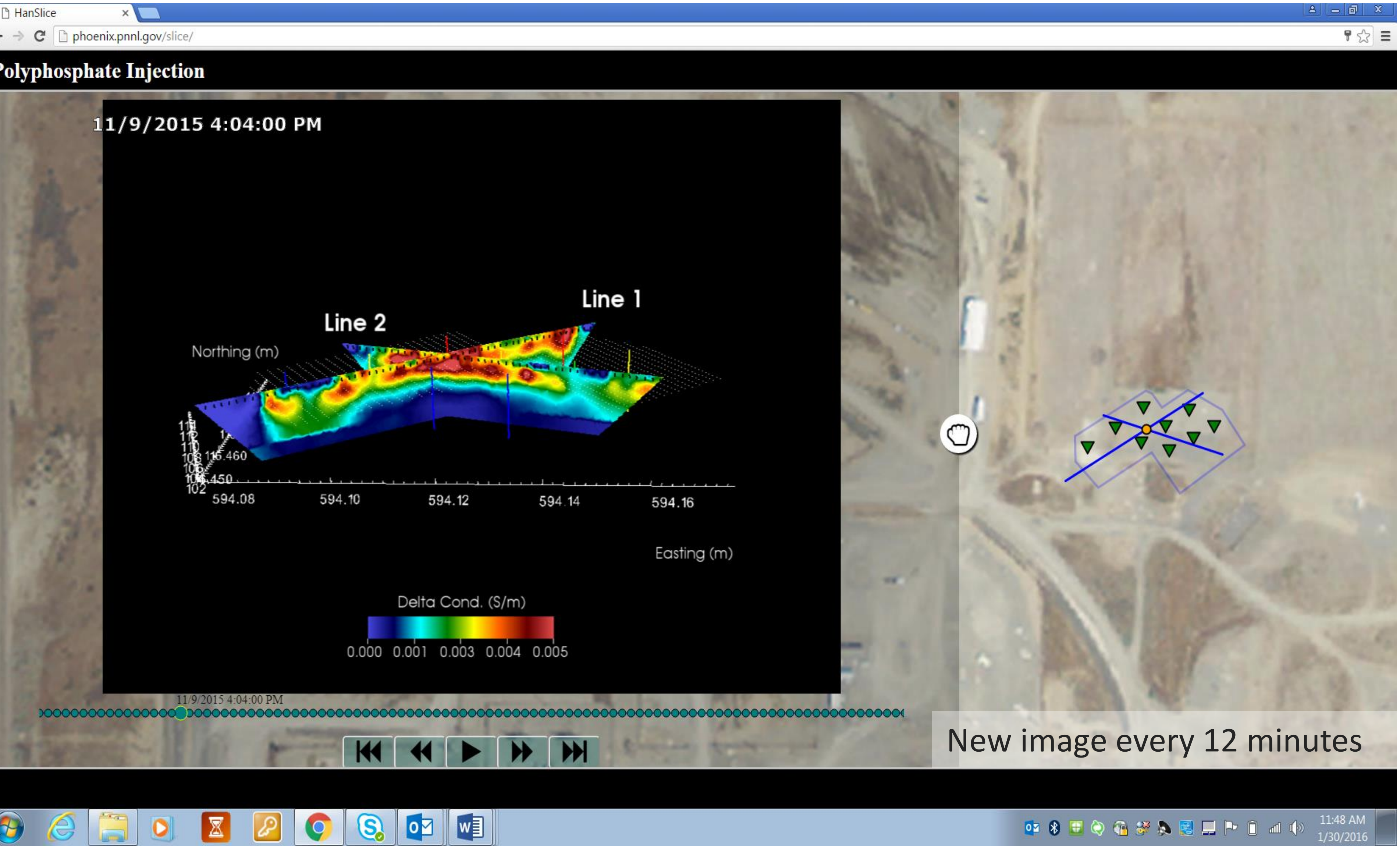
- ~ 10 m thick uranium contaminated vadose zone
- saturated zone hydraulically connected to Columbia River
- phosphate amendment binds uranium to sediments

Example 3: Results

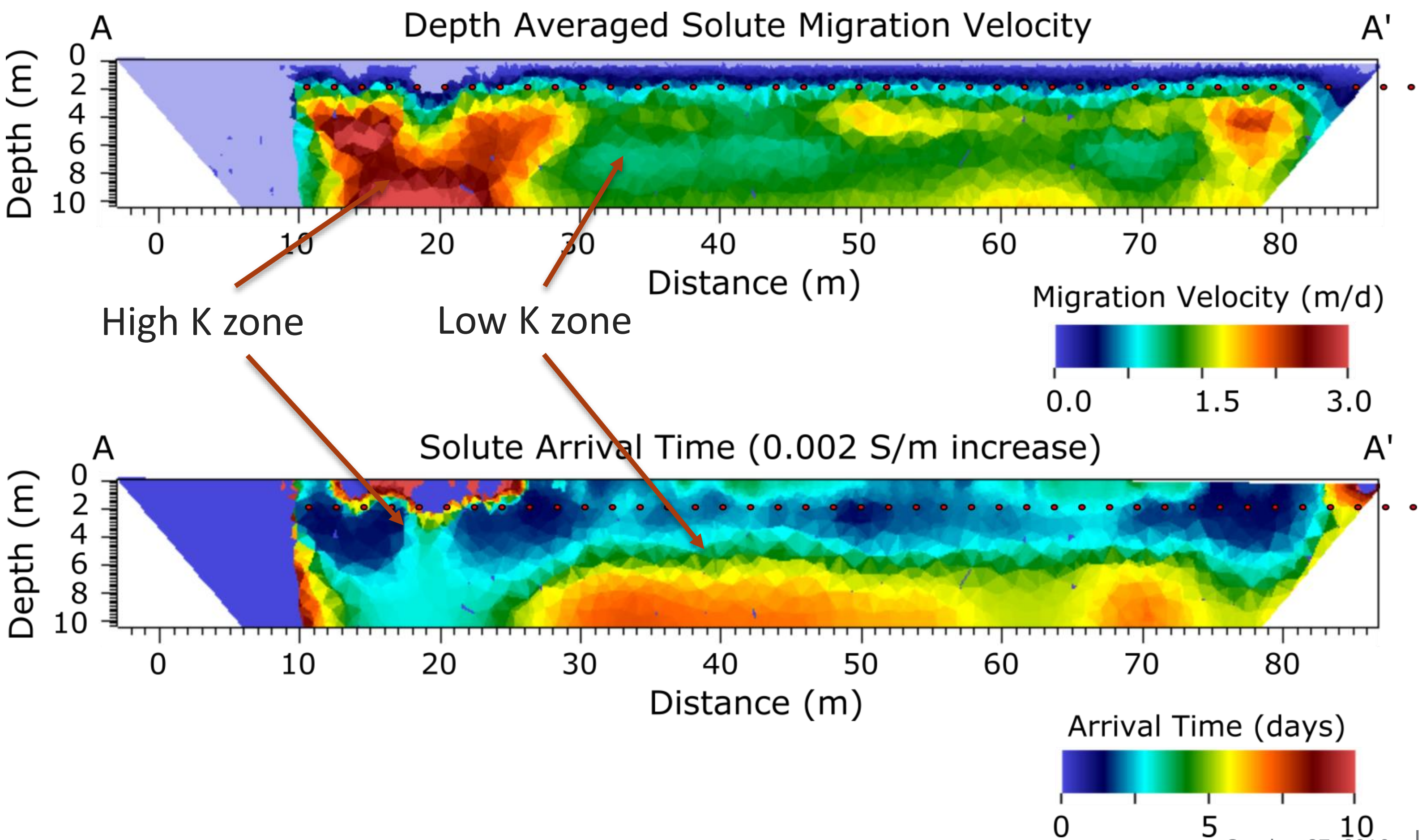


animation

Example 3: Real Time Web Delivery



Solute velocity and arrival time analysis

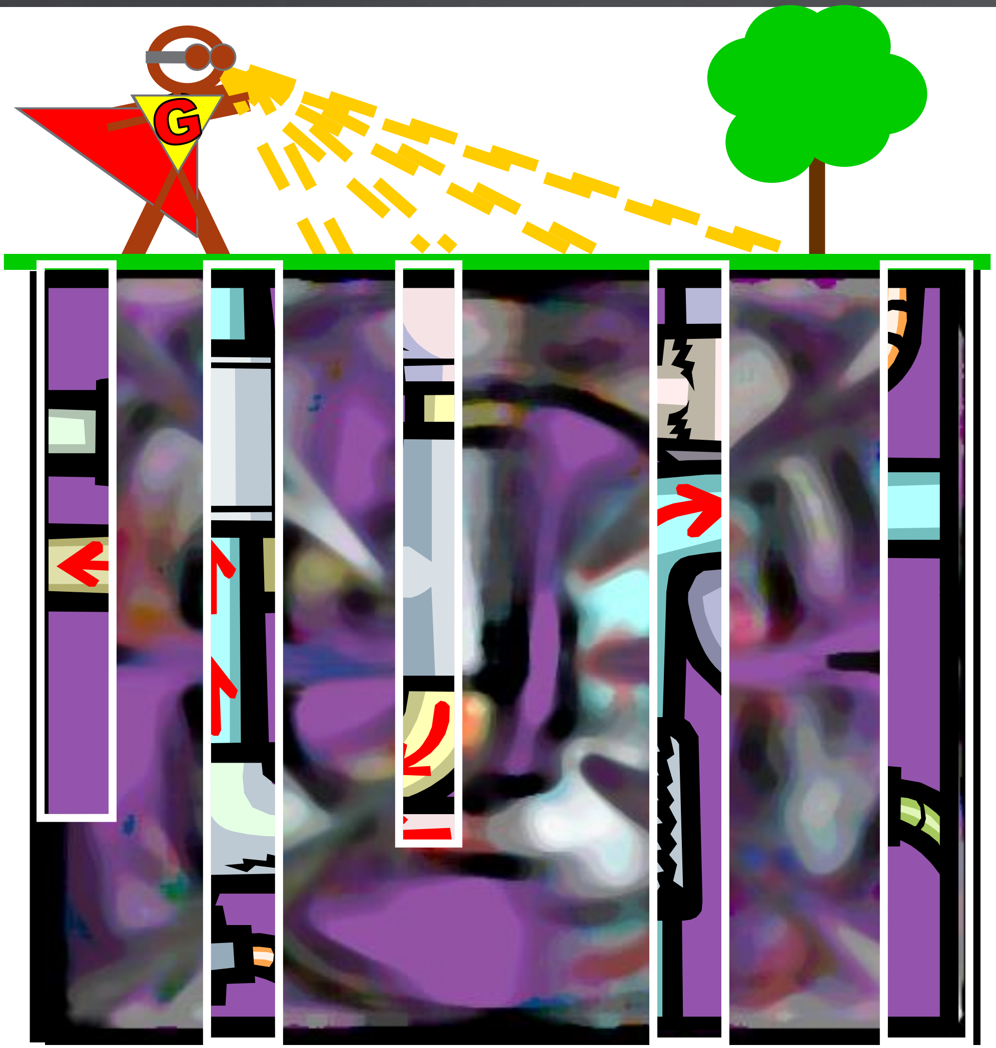


October 27, 2016

Developing Realistic Expectations

Pros:

- Minimally invasive
- Relatively low cost
- Can cover a large area
- ‘Sees’ in between wells
- Good at the “when and where”

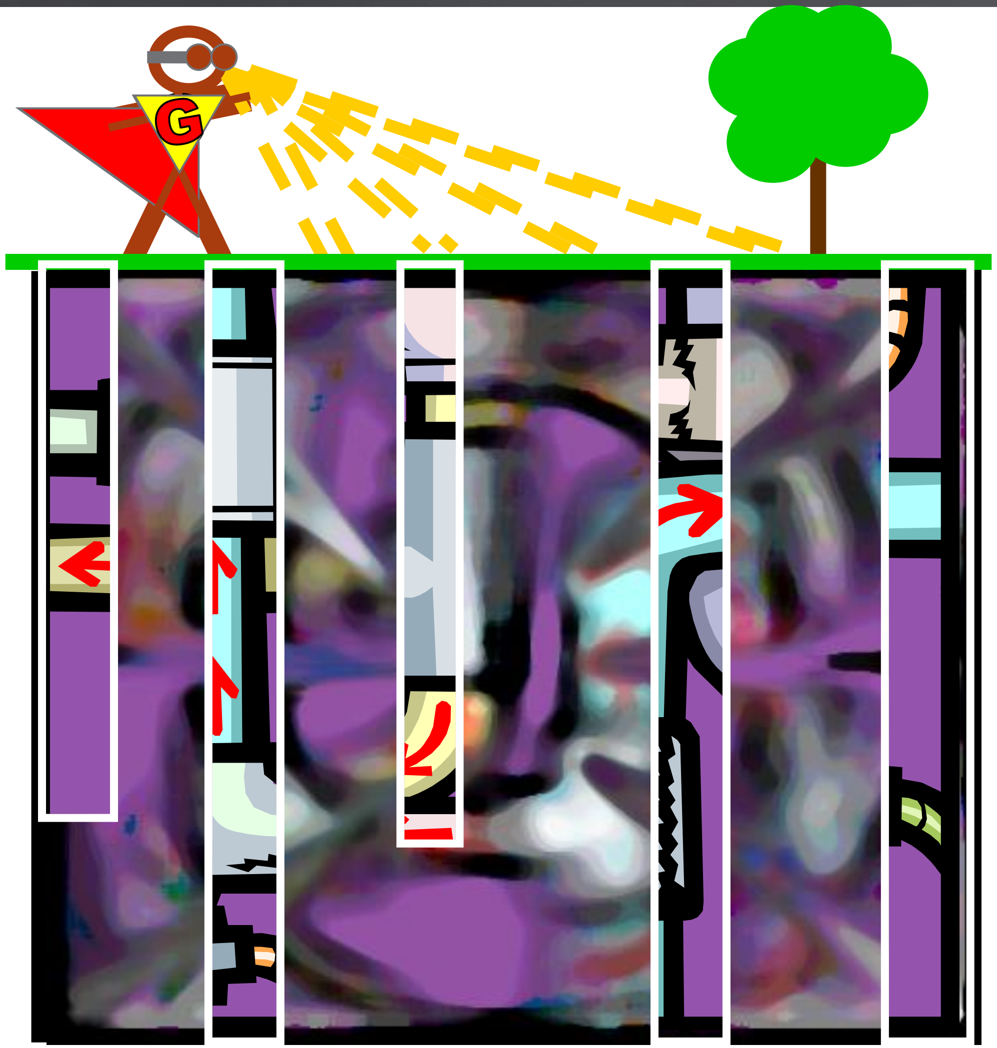


Developing Realistic Expectations

Pros:
- Minimally invasive
- Relatively low cost
- Can cover a large area
- ‘Sees’ in between wells
- Good at the “when and where”

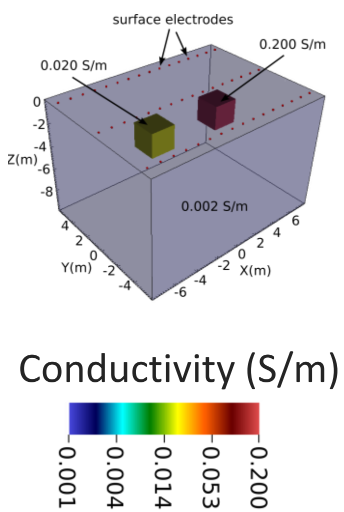
Cons:
- Indirect – correlation or interpretation requires
- Limited resolution
- Not good at the “what”

Not an either/or proposition! Geophysics is most powerful when used in combination with conventional measurements!

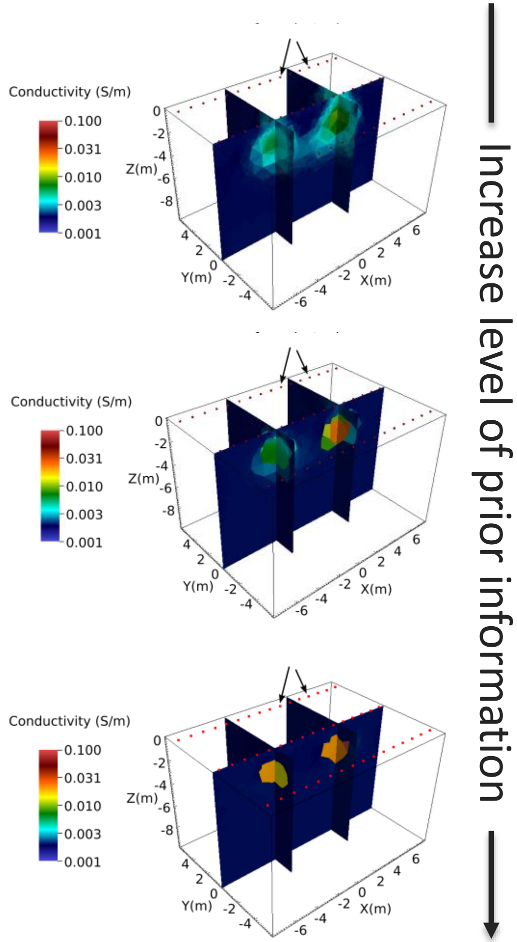


Consequences of Limited Resolution

True Conductivity



3D Images



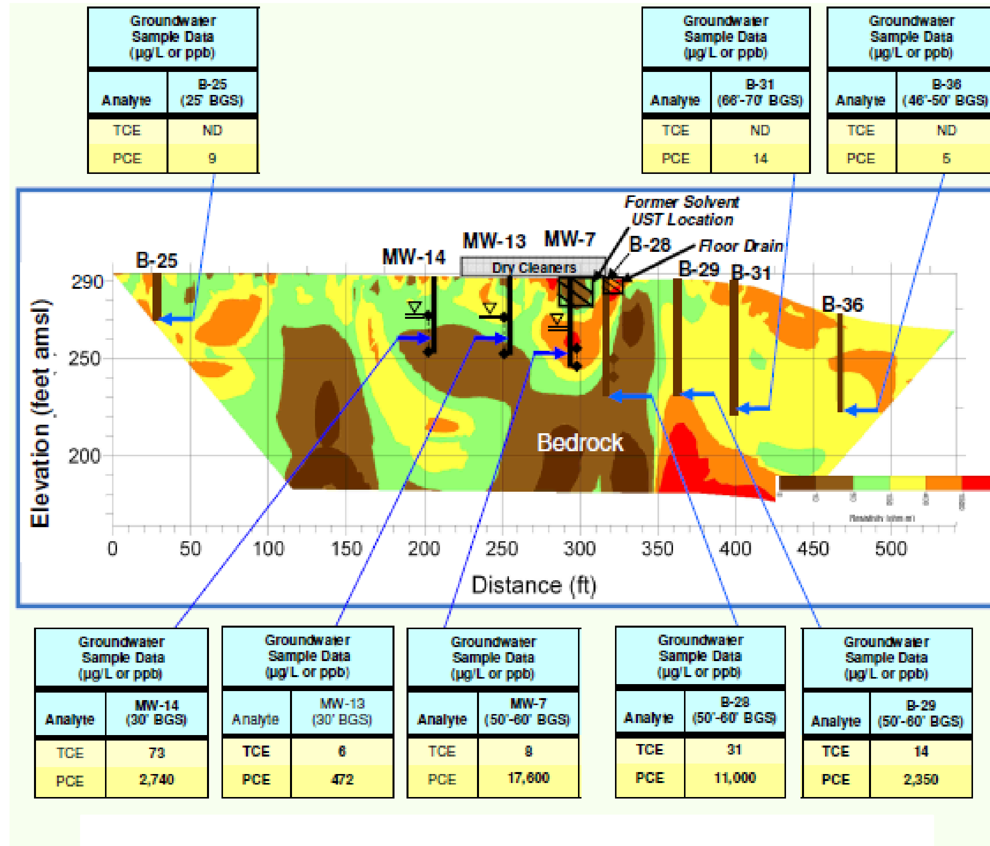
Consequences of limited resolution

- Images are smeared versions of reality
- Averaging (high values are under-predicted, low values are over-predicted)
- Laboratory scale measurements do not translate directly to field scale
- Resolution decreases with distance from electrodes
- Prior information can improve resolution (buyer beware)

Beware of Misuse/Overselling

- Blatant overselling of capabilities by service providers is common

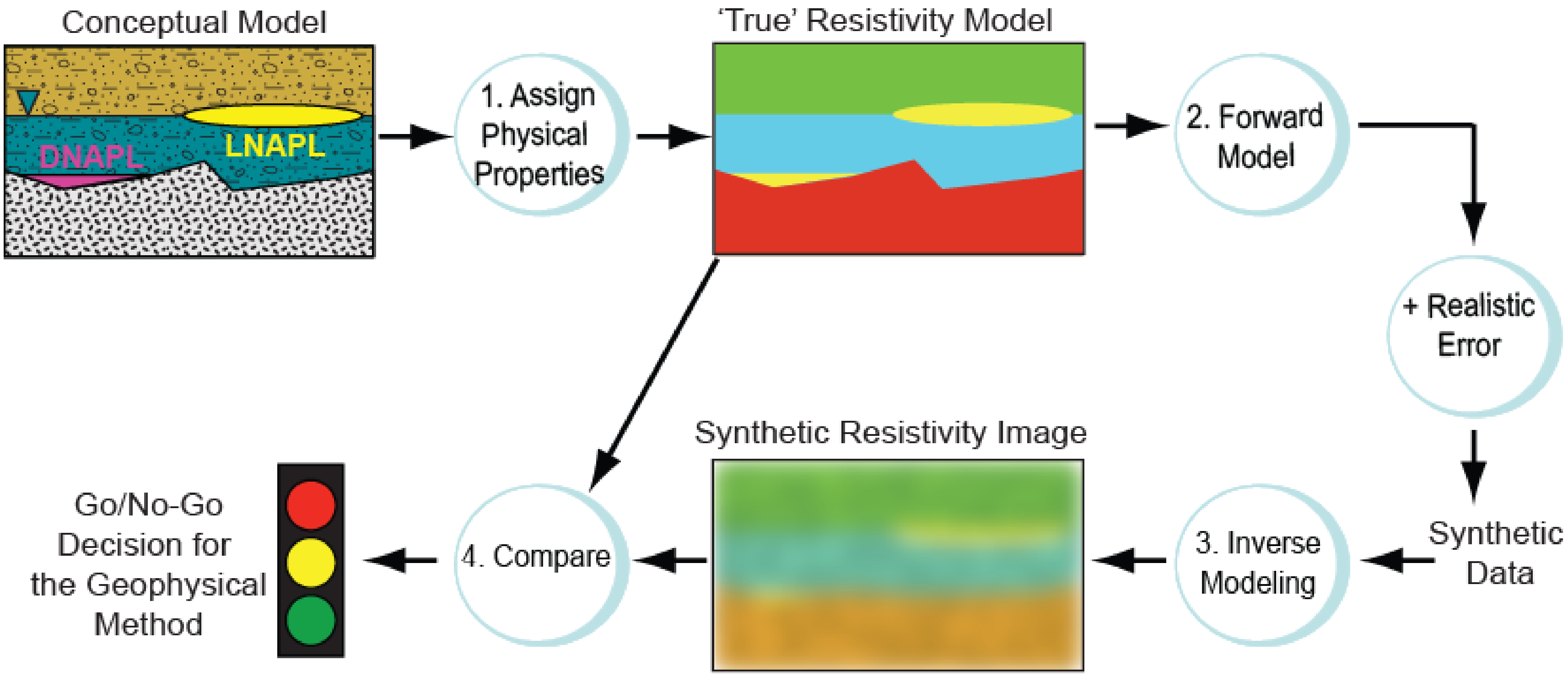
- **Tools and approaches are available to test feasibility and reduce risk**



Bottom Line:

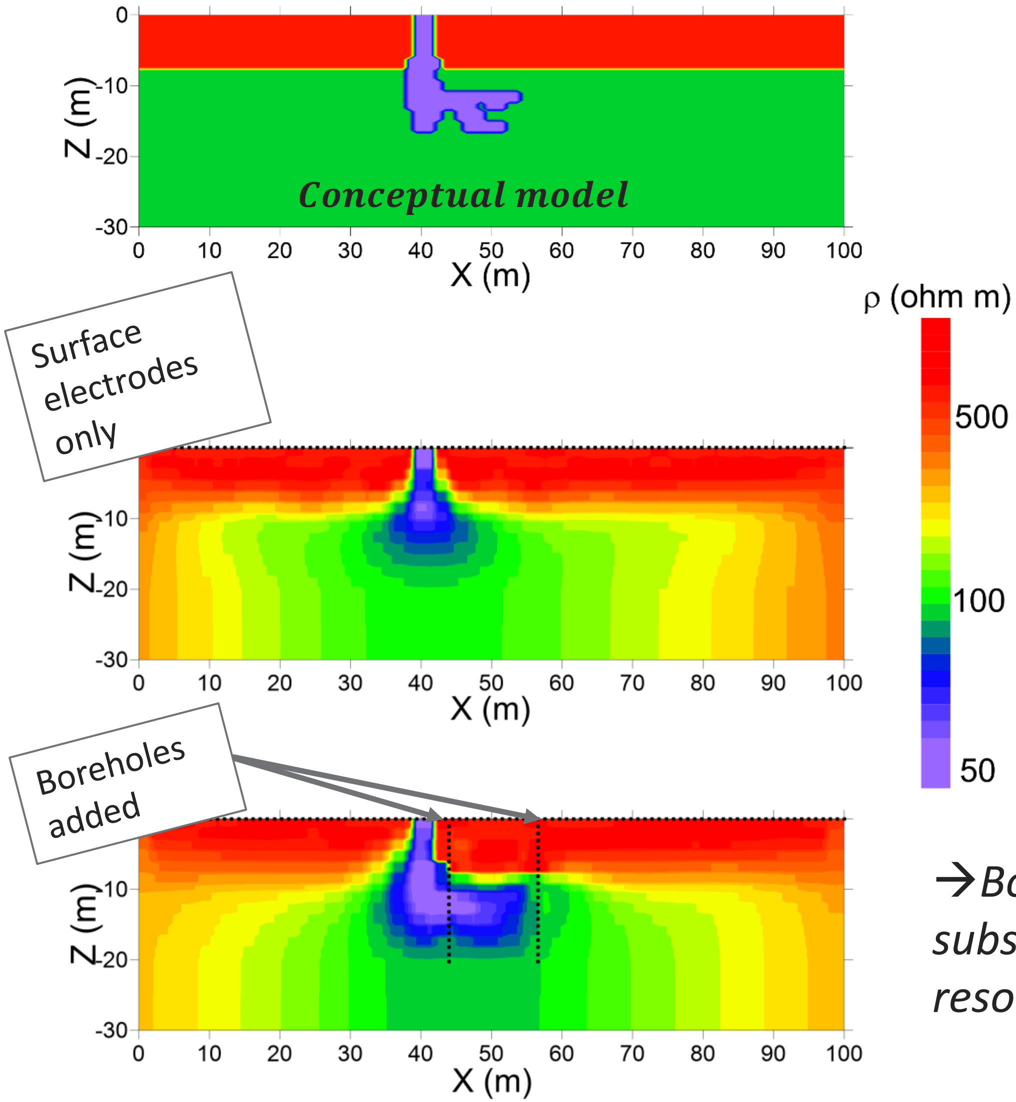
- √ Highly resistive (ORANGE/RED) - high dissolved phase concentrations and/or DNAPL
- √ Moderately increased resistivity (YELLOW) - low dissolved phase concentrations
- √ Medium resistivity (GREEN) - mostly clean or low impact areas
- √ Low resistivity/highly conductive (BROWN) - weathered (likely) DNAPL and/or related dissolved phase contamination

Managing expectations and reducing risk through pre-modelling feasibility assessment



Note … represents best case scenario

Example: Pre-modelling a DNAPL Spill



More info at:

https://www.serdp-estcp.org/Tools-and-Training/Webinar-Series/07-28-2016

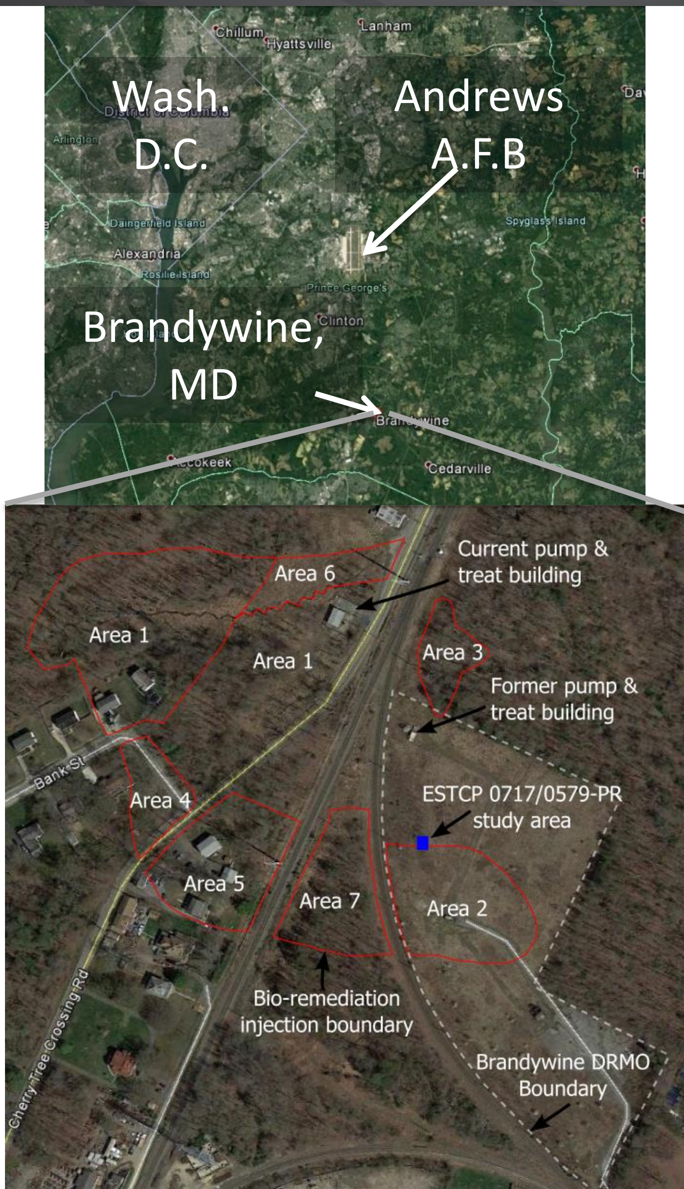
https://www.serdp-estcp.org/Tools-and-Training/Webinar-Series/06-30-2016

http://water.usgs.gov/ogw/frgt

http://e4d.pnnl.gov

→Borehole electrodes substantially improve resolution of the plume

Case Study: Brandywine M.D. DRMO



Brandywine Defense Reutilization Marketing Office (DRMO)

- Eight-acre former storage facility owned by Andrews AFB
- Contaminated with PCE (soil) and TCE (groundwater), both onsite and offsite
- Record Of Decision specified enhanced bioremediation
- Amendment injections occurred 2008-2010
- Original ESTCP project: Optimized Enhanced Bioremediation Through 4D Geophysical Monitoring and Autonomous Data Collection, Processing and Analysis (ER200717), Major et al. (2014)

ER 200717 Project Summary

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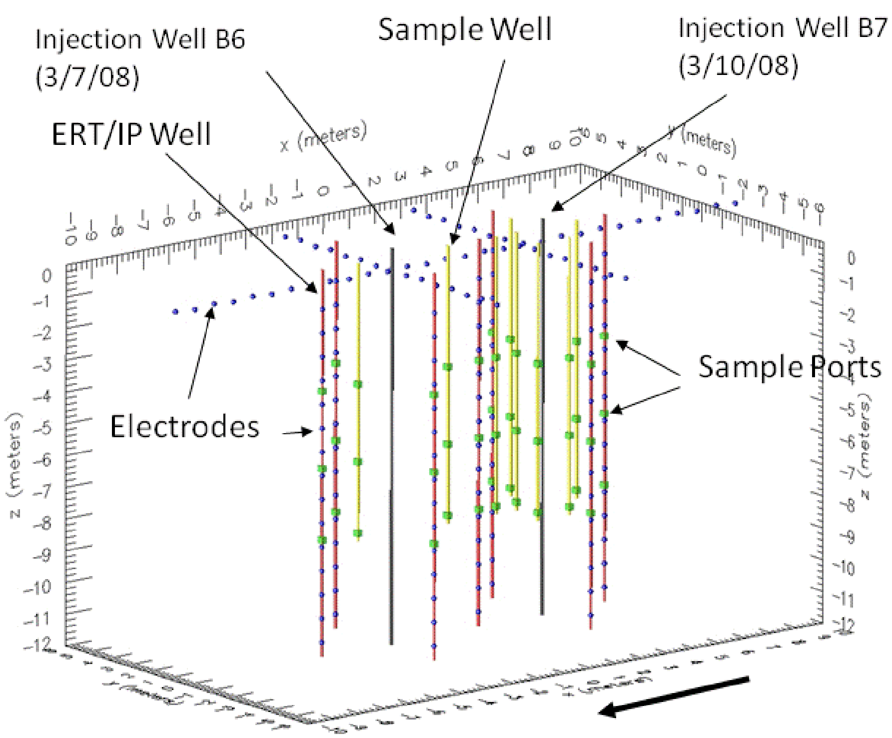
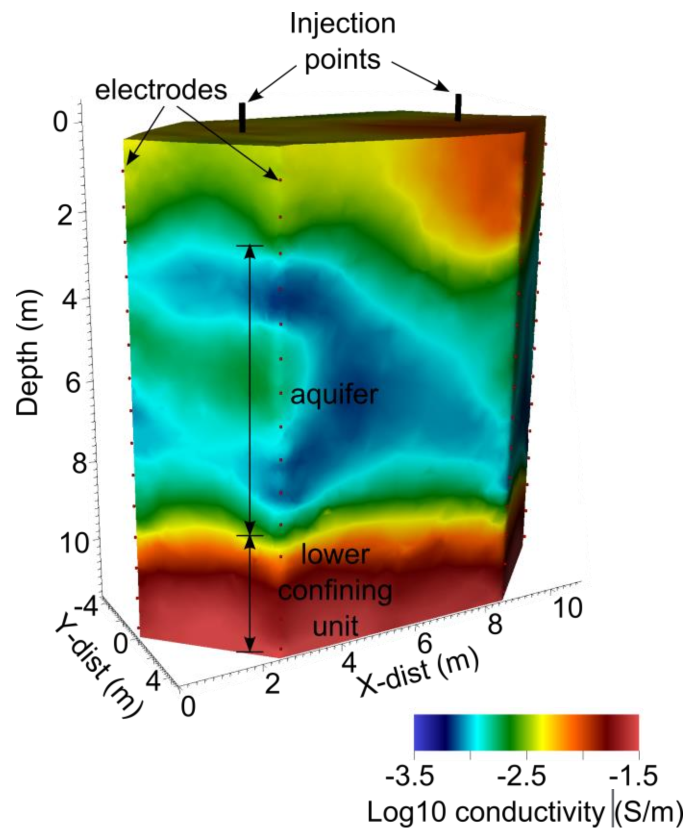
Primary Objective: Demonstrate the capability to autonomously image 3D bio-amendment distribution with time.

Test Site Configuration



Baseline ERT Image



ER 200717 Imaging Results

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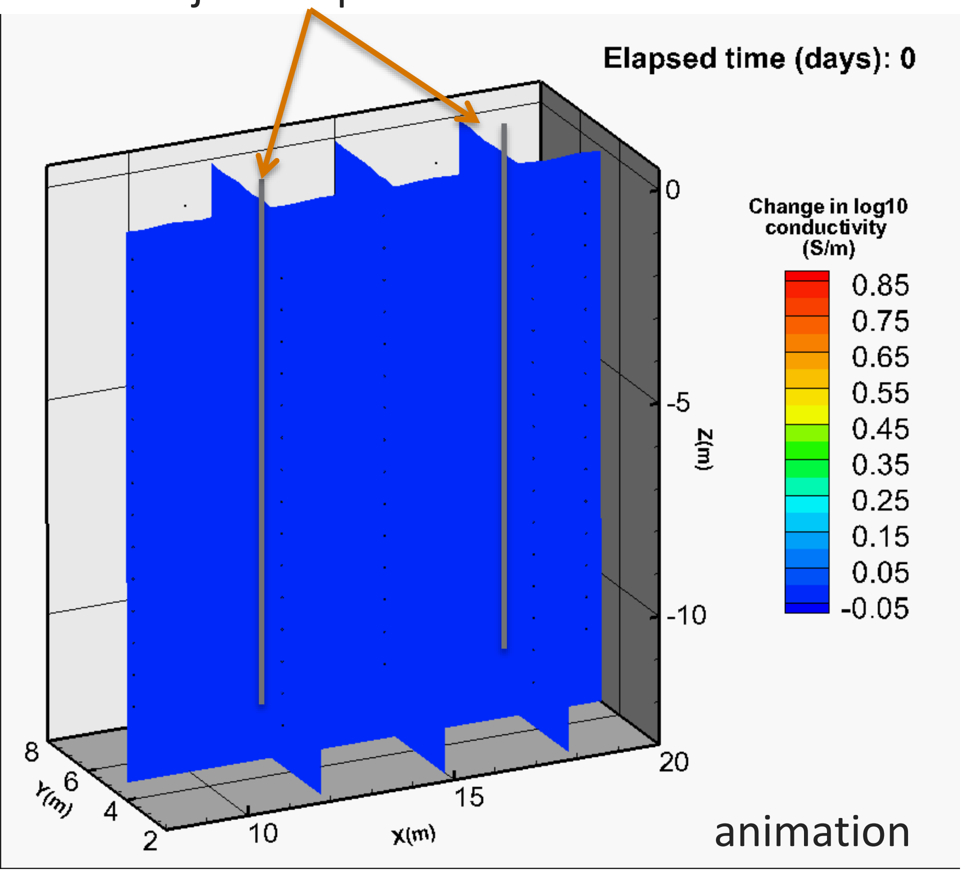
Injection points



animation

Summary

- Successfully imaged the 3D emplacement and migration of amendment.
- Observed secondary increase in conductivity within the treatment zone after about 1 year.
- Validated the cause of the secondary increase to be bio-induced solid-phase transformation (likely FeS precipitation).

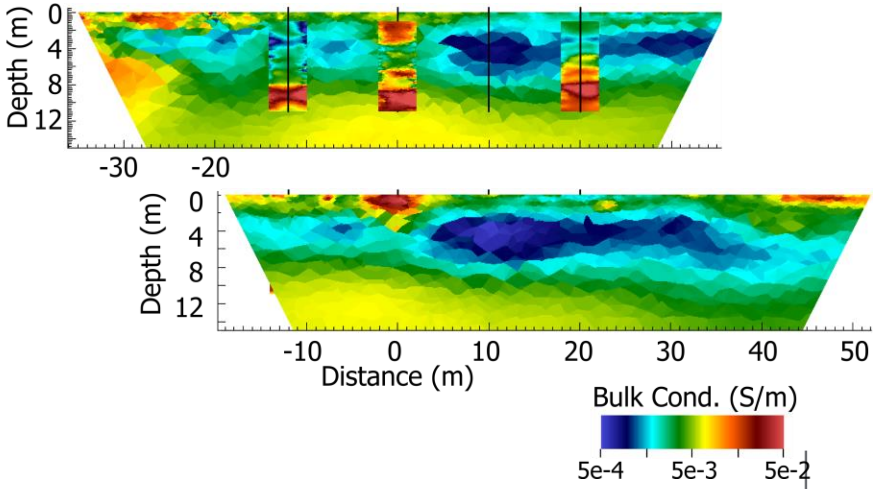
Johnson, T.C., Versteeg,R.J., Day-Lewis, F.D., Major, W., and Lane, J.W., 2015. *"Time-Lapse Electrical Geophysical Monitoring of Amendment Emplacement for Biostimulation",* Ground Water53(6):920-932. doi:10.1111/gwat.12291

Post Remediation Assessment Objectives

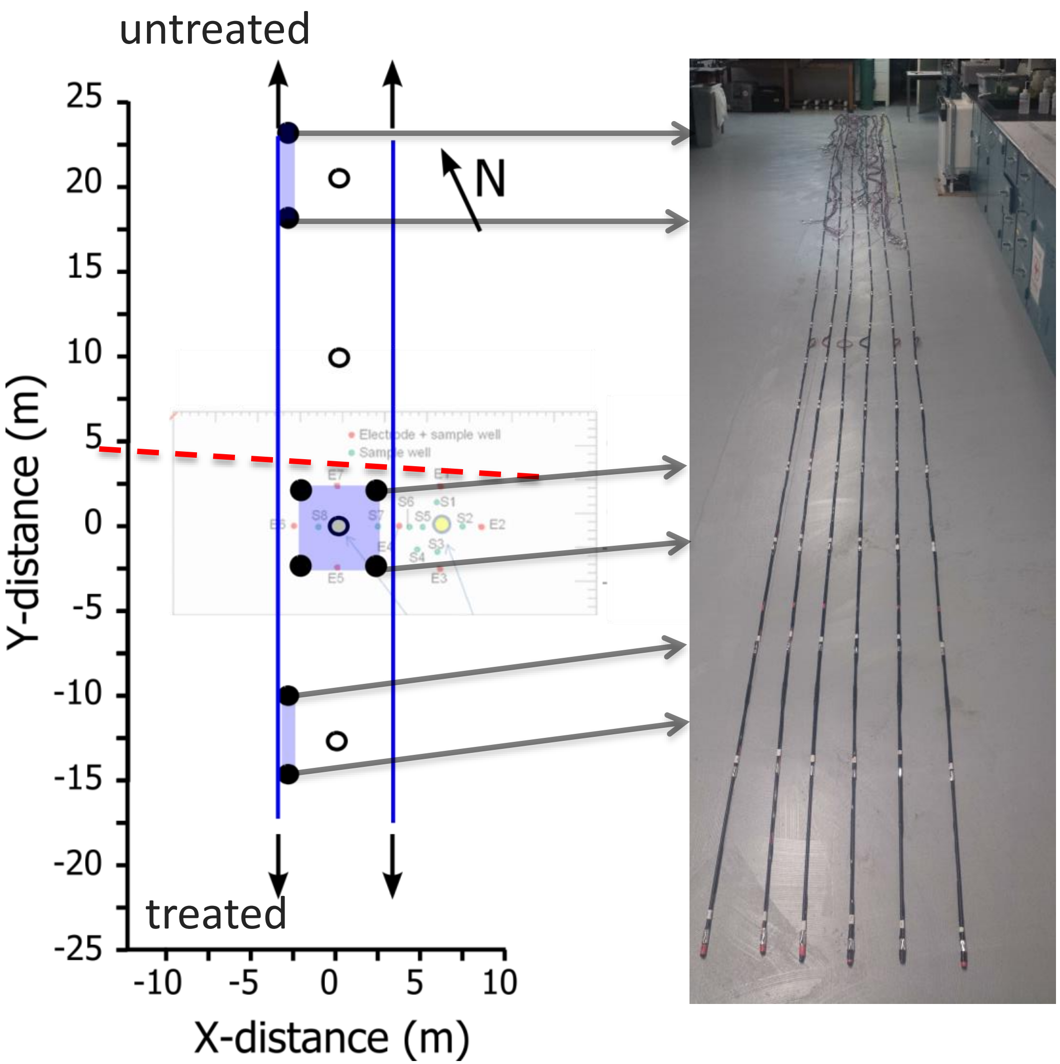
1. *Identify the long-term geophysical footprint of active bioremediation at a VOC contaminated site.*

2. *Determine the significance of the geophysical footprint with respect to solid phase mineral transformations and/or biofilms induced by the treatment process*.

3. *Demonstrate the use of 1 and 2 above to map gradients in the geophysical footprints of biostimulation along a transect crossing the boundary of the treatment area at an active remediation site, and interpret those gradients in terms of long-term biogeochemical impacts.*



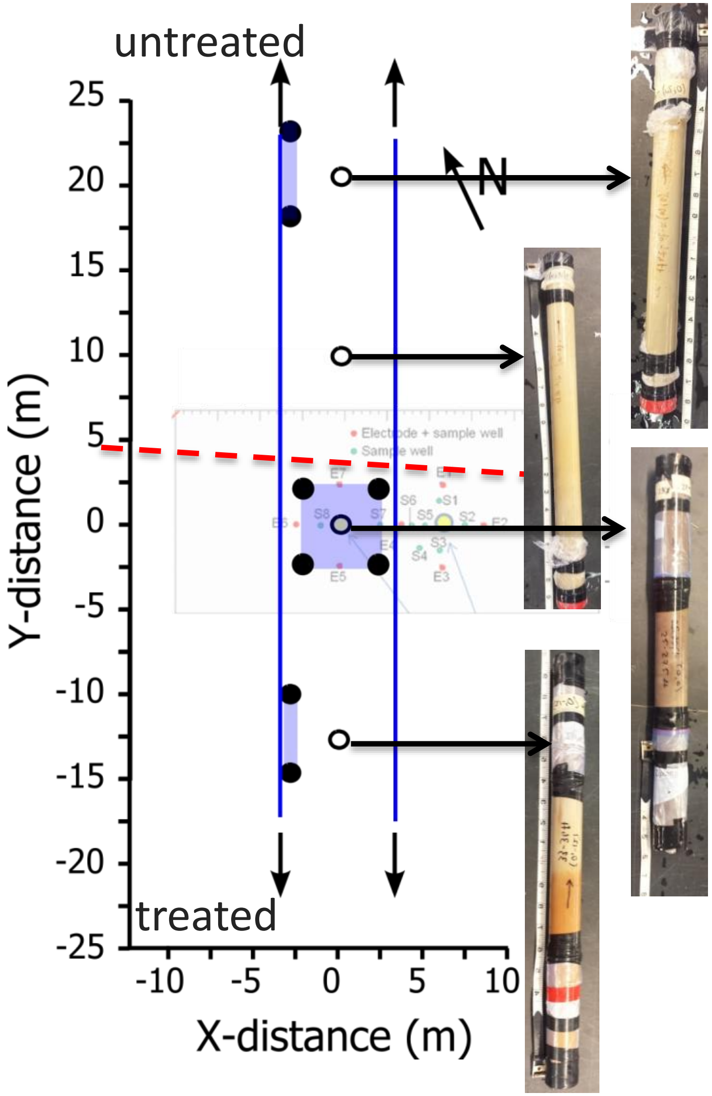
Crosshole Imaging/Fluid Sampling Arrays



Eight vertical arrays installed via direct push

- Each array includes 24 electrodes and 3 fluid sampling ports
- Enables 3D crosshole imaging directly in the ER0717 injection zone
- Enables 2D crosshole imaging inside and outside of the treatment area.
- Enables depth-discrete pore fluid sampling inside and outside of treatment zone

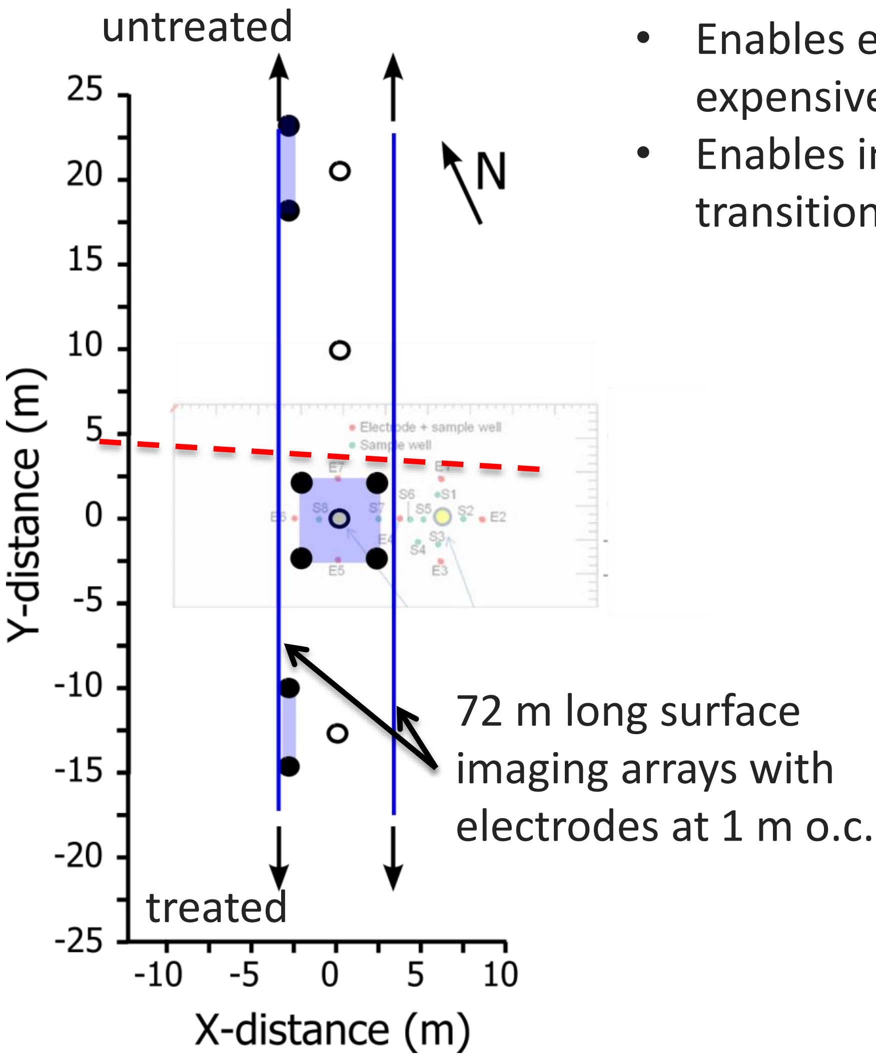
Core Sampling/Logging Holes



Four continuous core boreholes completed with pvc

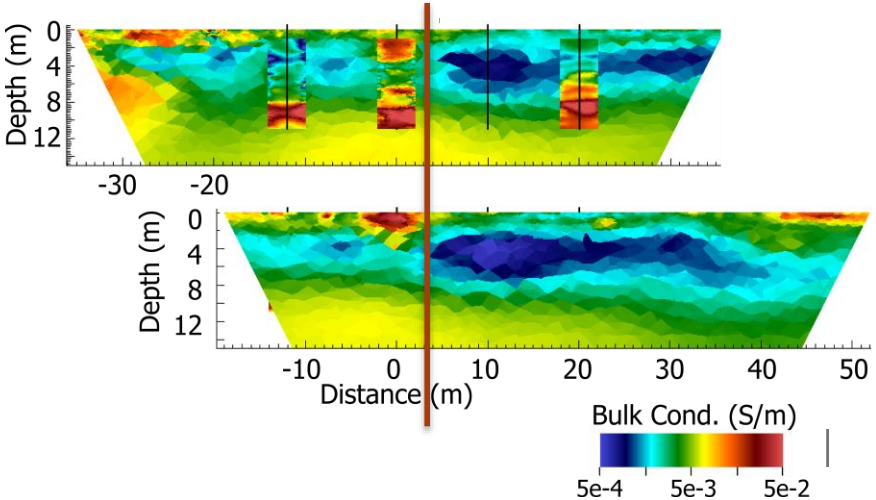
- Enables direct lab measurement of electrical geophysical properties with depth, inside and outside of treatment zone
- Enables assessment of microbial communities and biogeochemical solid phase product inside and outside of treatment zone.
- Enables 1D geophysical logging profiles.
- Critical to relate field-scale images to long-term biogeochemical impacts

Surface Imaging Arrays

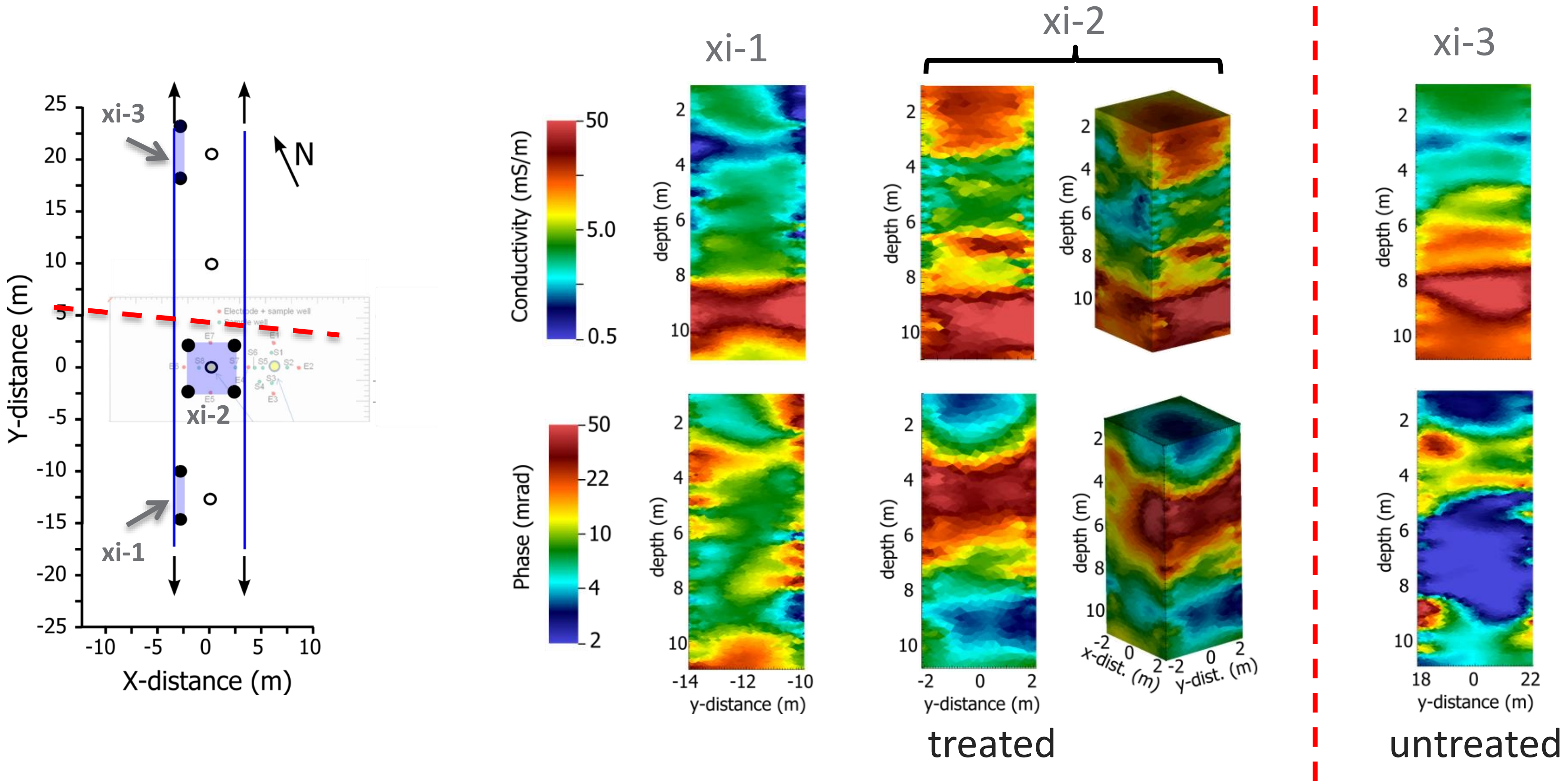


Surface ERT Arrays

- Enables evaluation of larger scale, lower resolution, less expensive surface based imaging for impact assessment.
- Enables inspection of the treated-to-untreated transition zone.

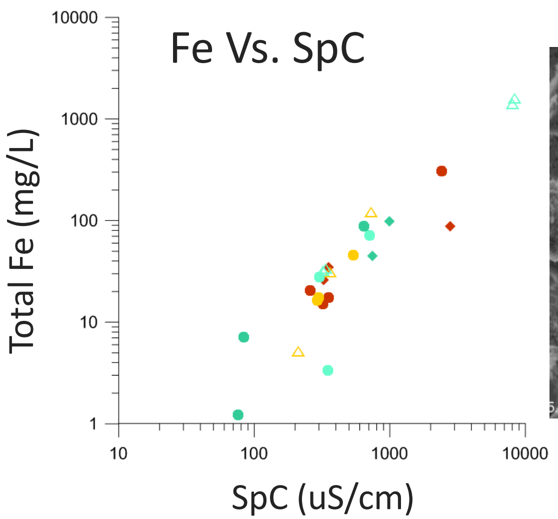


Borehole Imaging Results

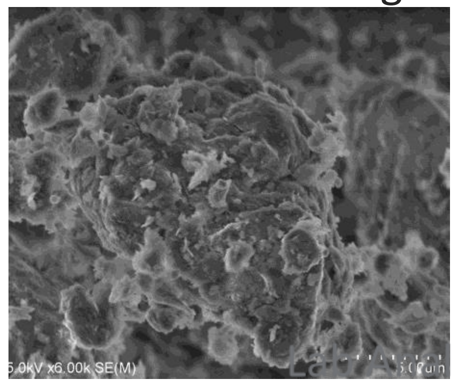


- High phase (polarization) in the treated zone relative to untreated
- Highest polarization and conductivity occur in the vicinity of the injection well (profile xi-2)

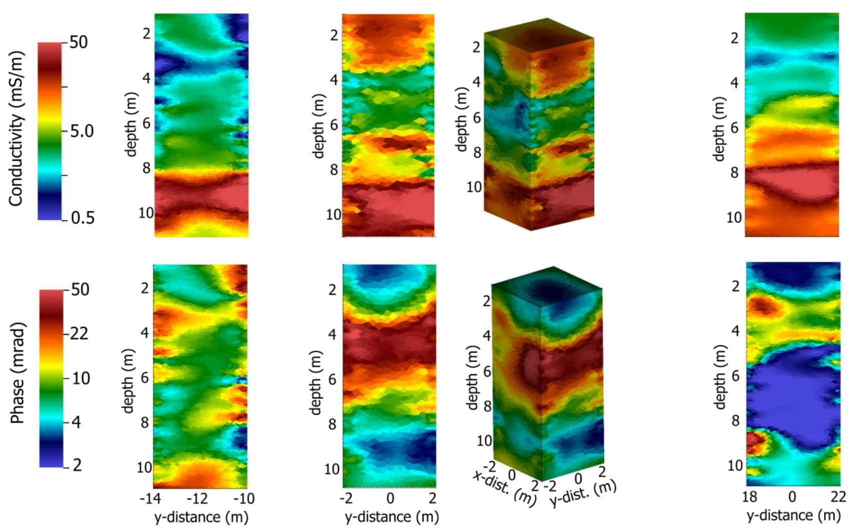
Project Status



5 micron SEM Image



Lab Analysis



Field Images

- ✓ Long-term geophysics footprint of bioremediated site exists and is identified
- ❑ Origin of geophysical signature in terms of solid phase mineral transformations and/or biofilms (in progress)
- ❑ Interpretation of images in terms of long-term biogeochemical impacts

Summary

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- Remediation performance assessment using geophysical imaging is advancing
  - Reduced monitoring costs, autonomous, continuous in space and time, minimally invasive, good at the “when and where”
- Important to understand limitations, avoid overselling
  - Feasibility and expectations through pre-modelling
- Quantitative interpretation requires coupling with laboratory analysis → site specific relationships between geophysical and geochemical parameters → mapping geochemical property estimates

USGS science for a changing world

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NAVFAC Naval Facilities Engineering Command ENGINEERING AND EXPEDITIONARY WARFARE CENTER

Supplementary Slides

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science for a changing world

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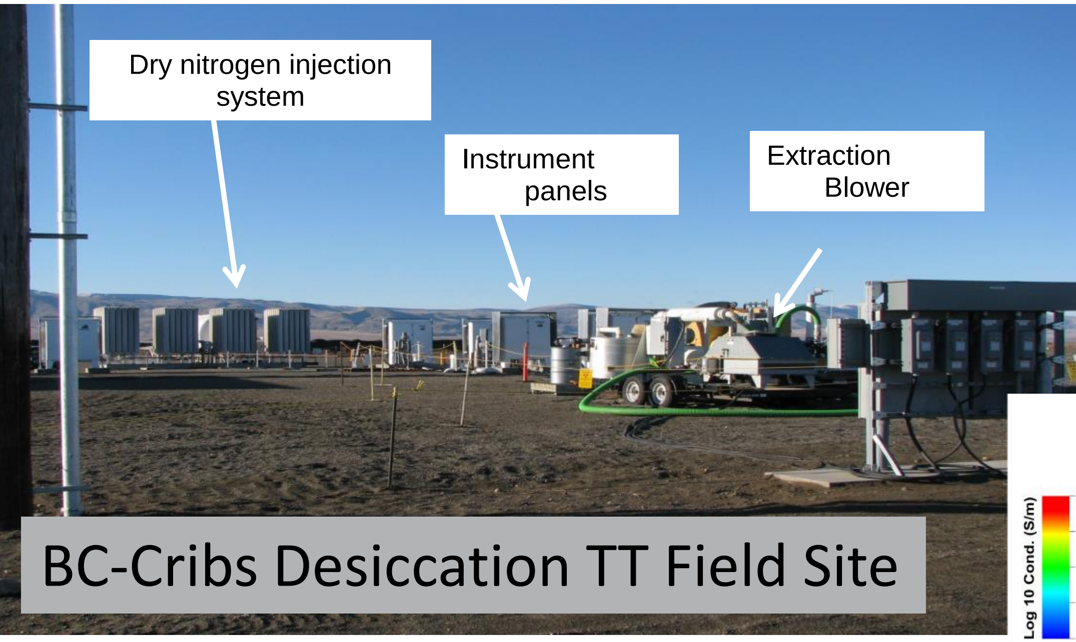
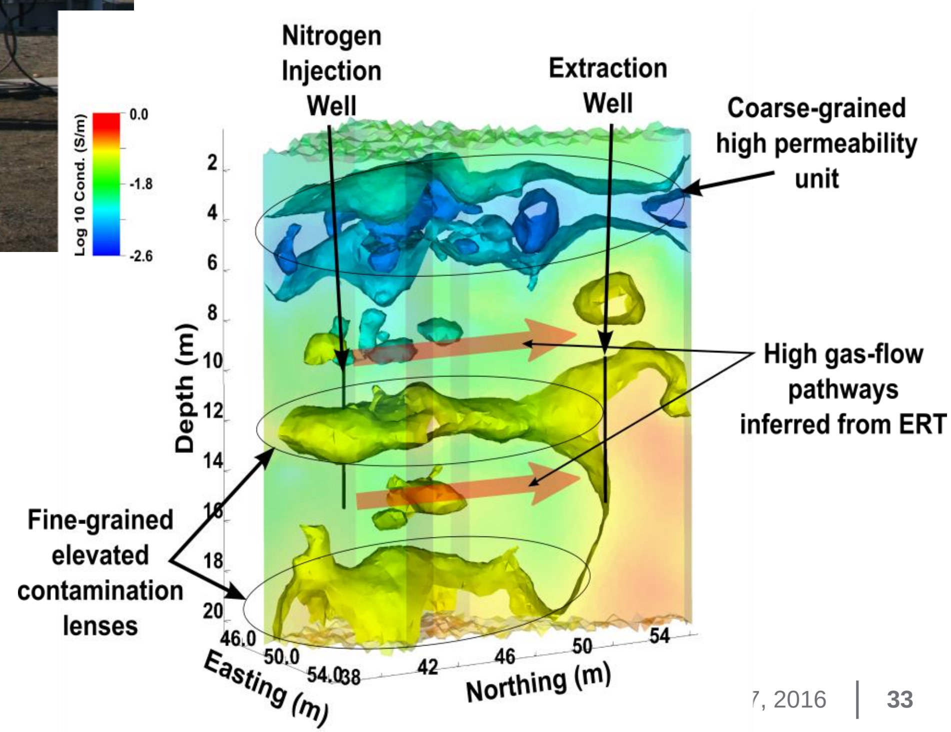
Engineered Vadose Zone Desiccation

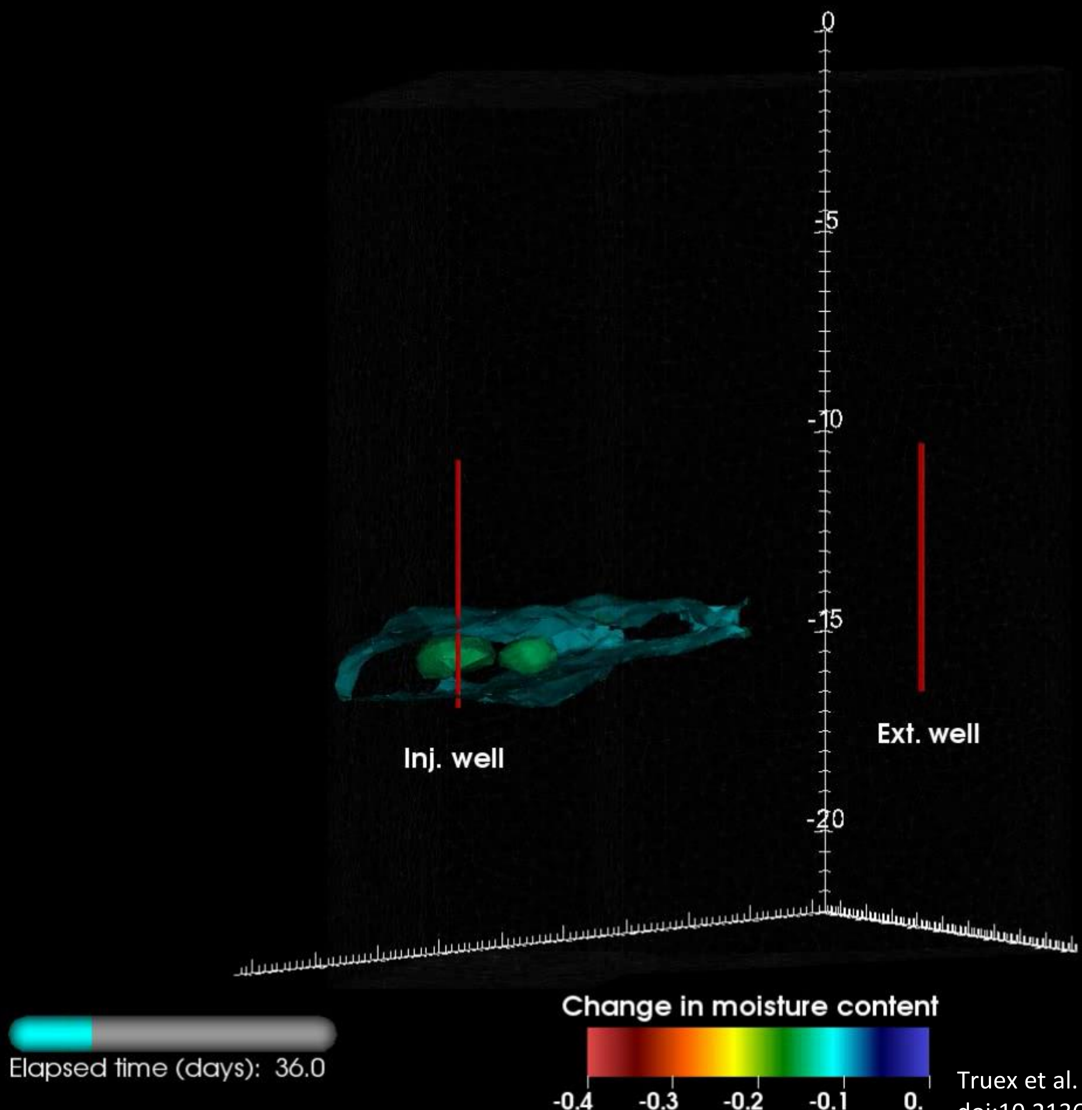


Pre-desiccation ERT Image



Autonomous 3D Monitoring of Vadose Zone Desiccation

Time-lapse 3D imaging of engineered vadose zone desiccation

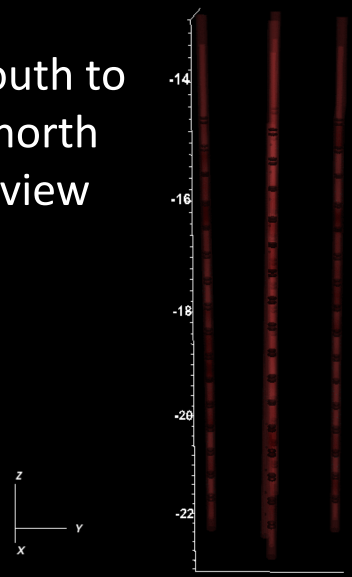


animation

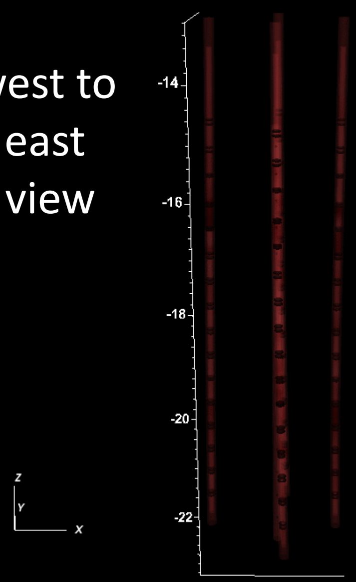
Truex et al. (2013), Vadose Zone Journal 12(2):, doi:10.2136/vzj2012.0147

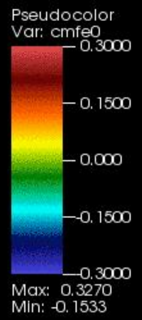
Real Time Imaging of Flow in Fractured Rock

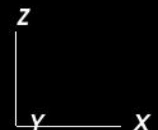
south to north view

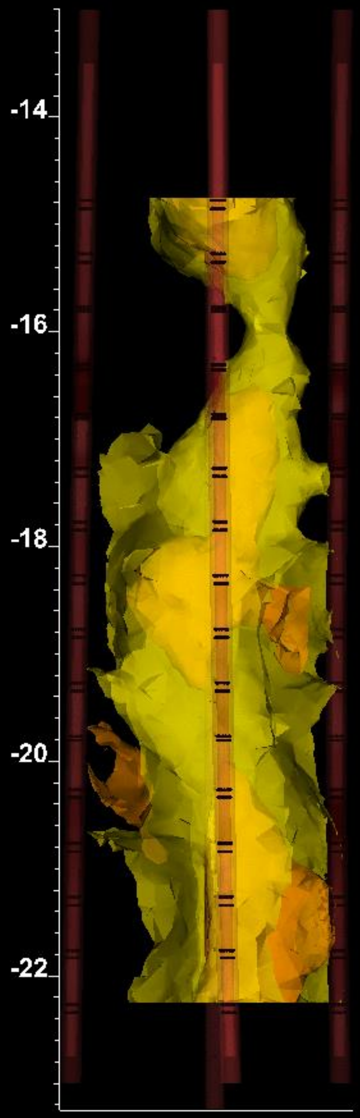


west to east view









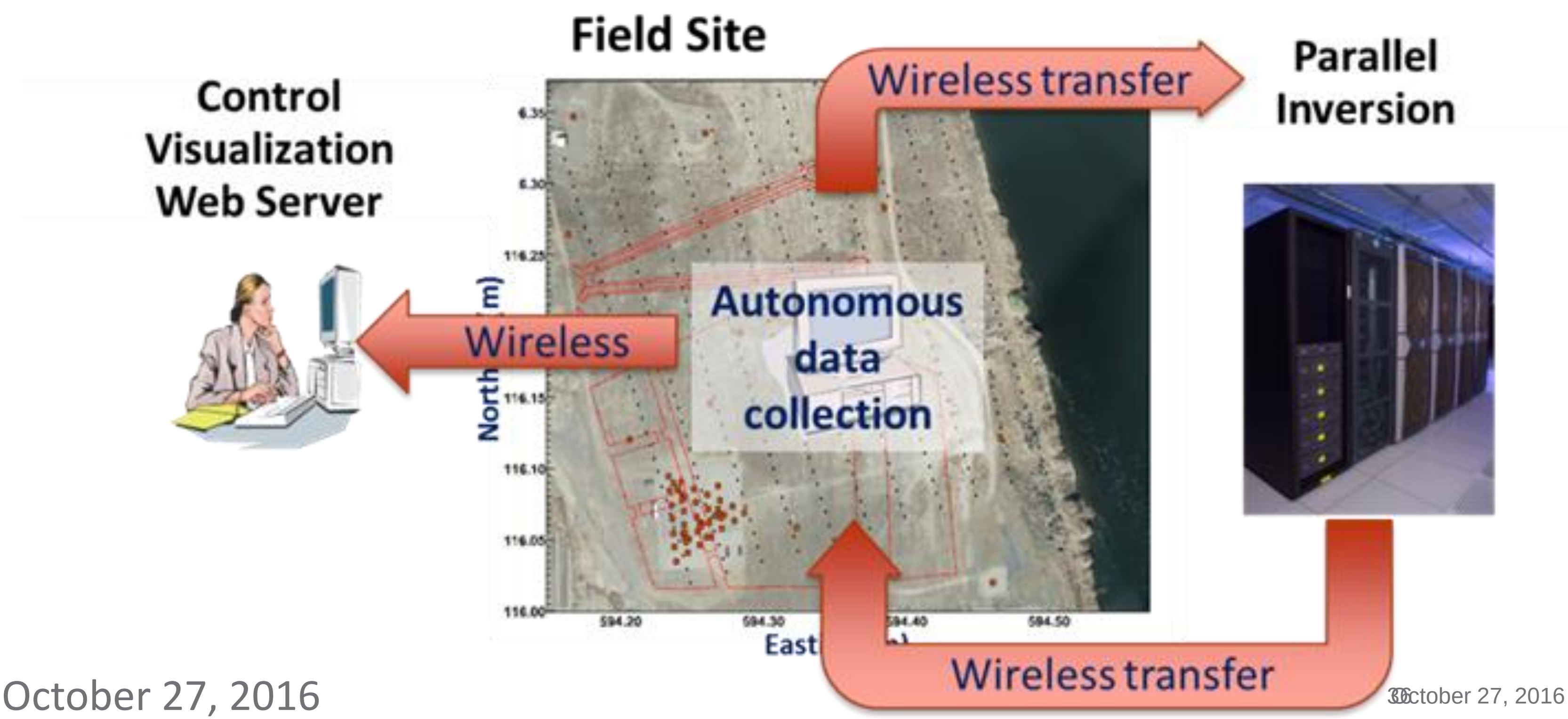
fly-around view

animation

Real-time Imaging

Challenges

- Wireless communications
- Secure supercomputer access
- Coordination between supercomputer and field system
- *How do we set the inversion parameters before we see the data?*



http://e4d.pnl.gov