3D time-lapse electrical resistivity imaging: Field examples and application potential for leak detection at industrial sites

NRC Leak Detection Workshop

Feb. 15, 2012

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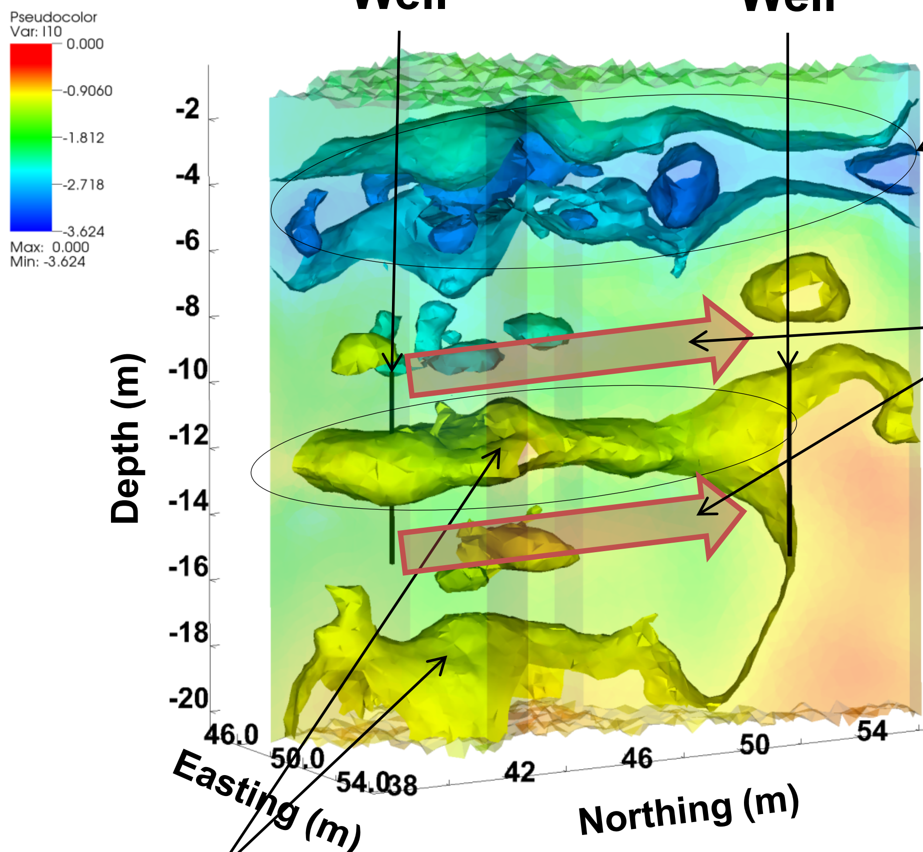
Outline

- Electrical Resistivity Tomography (ERT) imaging examples (characterization and monitoring)
- How ERT works
- The infrastructure problem
- Can it be "fixed"
- Ideas/Recommendations for leak detection and monitoring

Vadose zone desiccation monitoring at the Hanford BC-Cribs site

Nitrogen Injection Well

Extraction Well



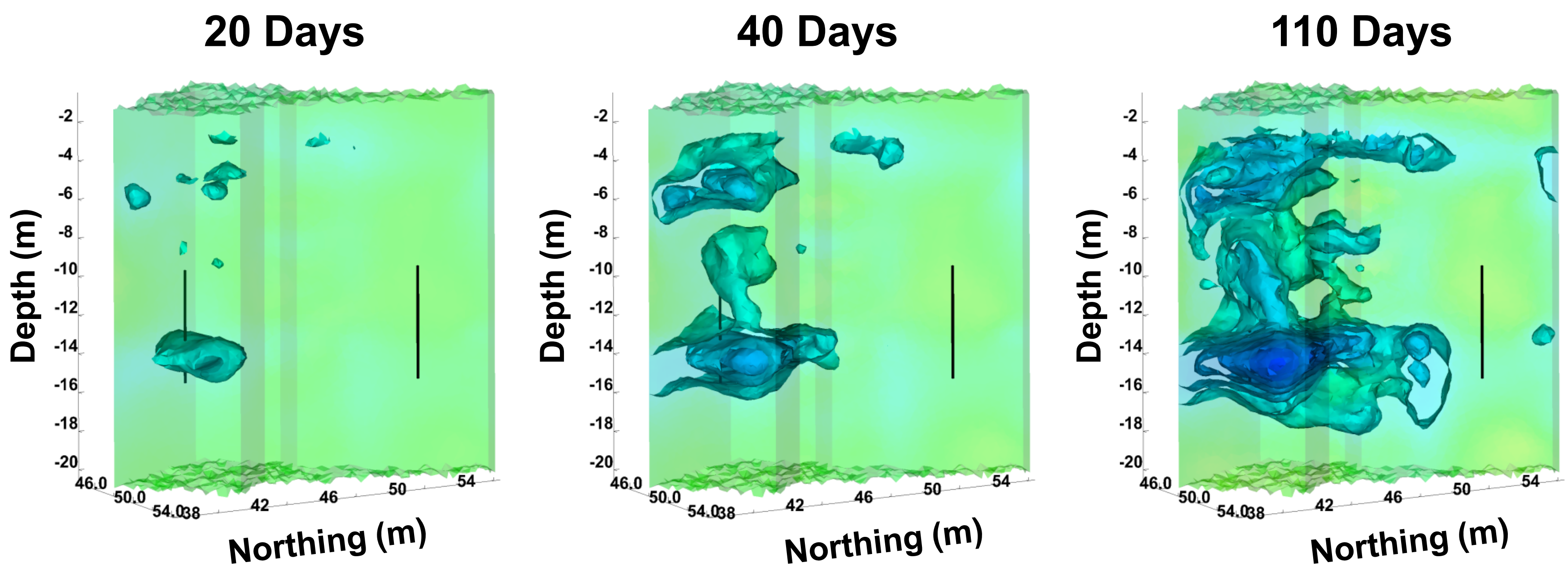
Coarse grained / high permeability unit

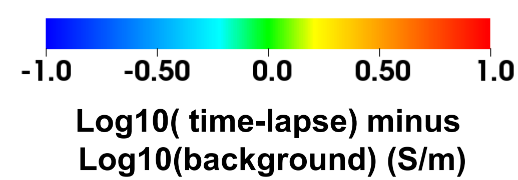
High gas flow pathways presumed from ERT

Baseline provides volumetric characterization info important for remedial design.

Fine-grained elevated contamination lenses

Still images of desiccated volume with time





- Shaded area shows volume resolved by ERT system
- Color scale represents relative change in conductivity during desiccation
- Electrical conductivity decreases with water content (dryer soil = lower conductivity)
- Primary zone of desiccation appears at 14-16 m deep, just below presumed fined grained contaminated lens
- Images produced twice per day.

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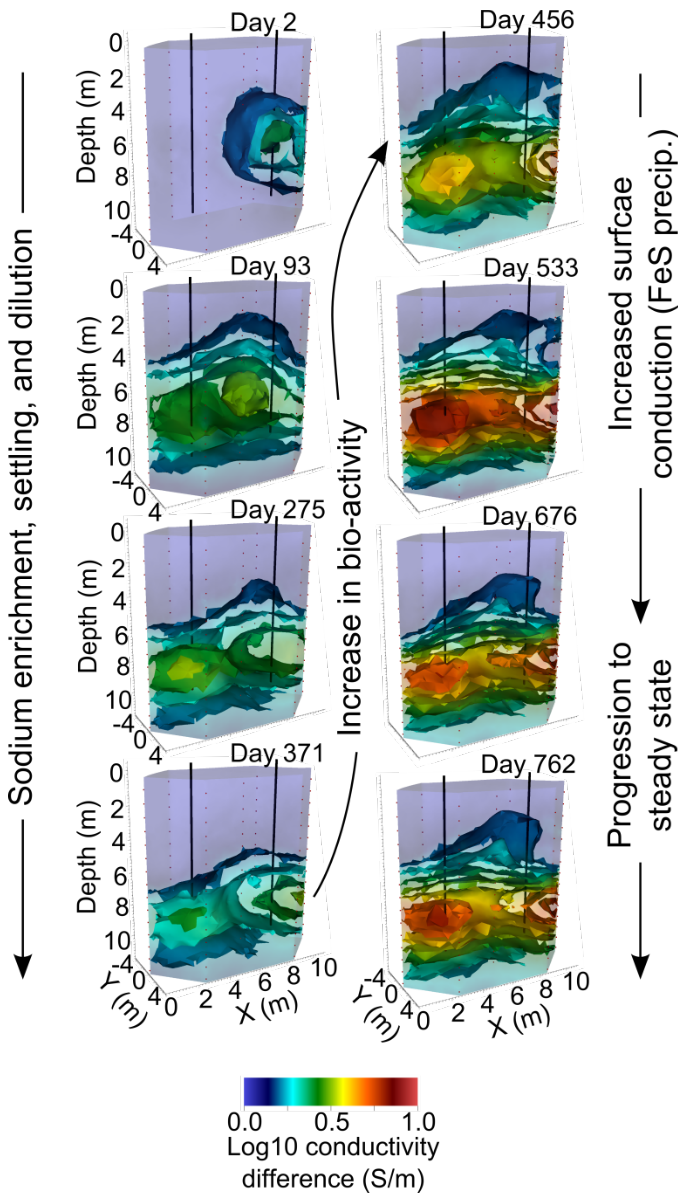
Brandywine MD bioremediation monitoring



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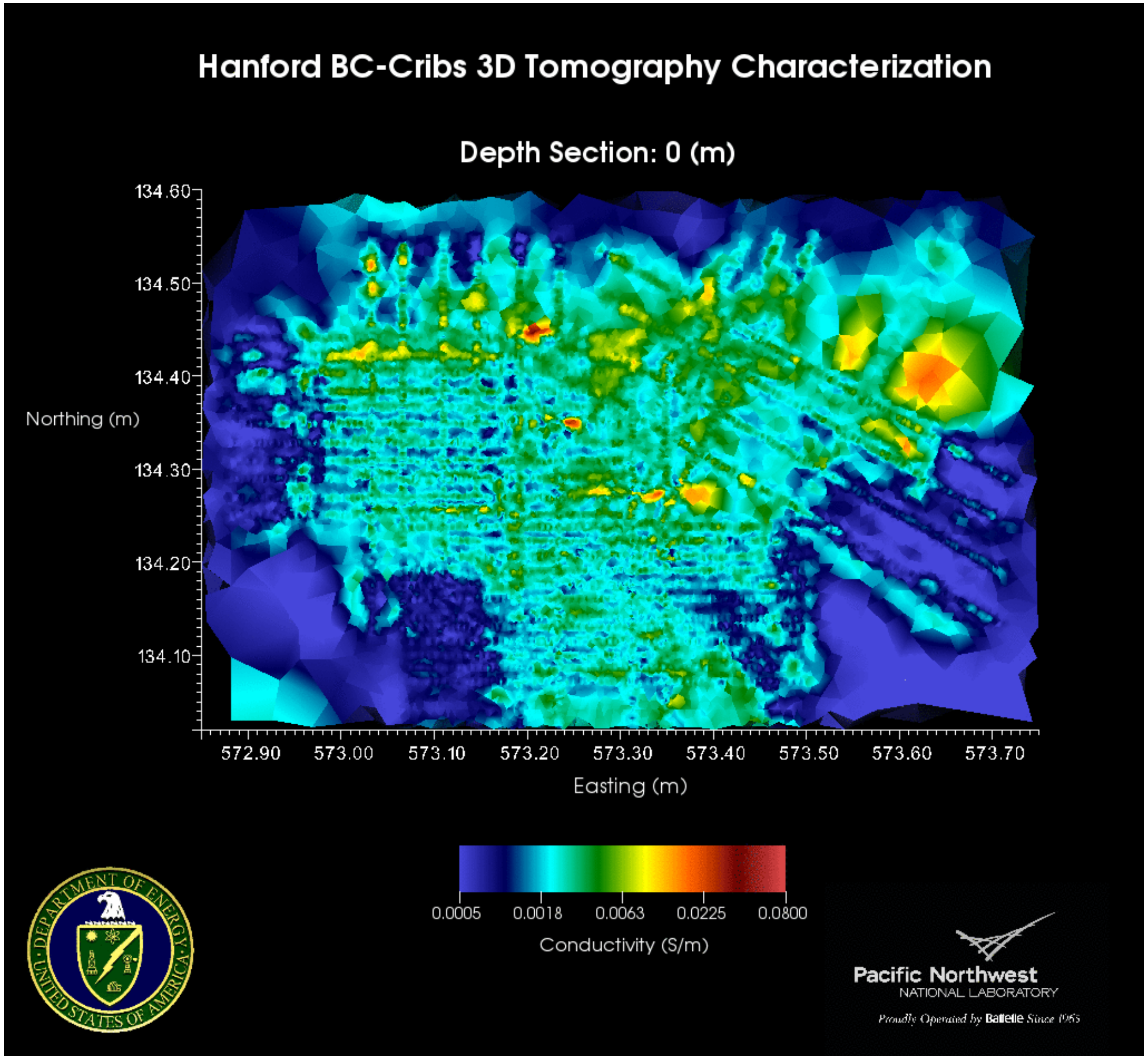
Large-scale characterization of the Hanford BC-Cribs Site



This slide contains an animation

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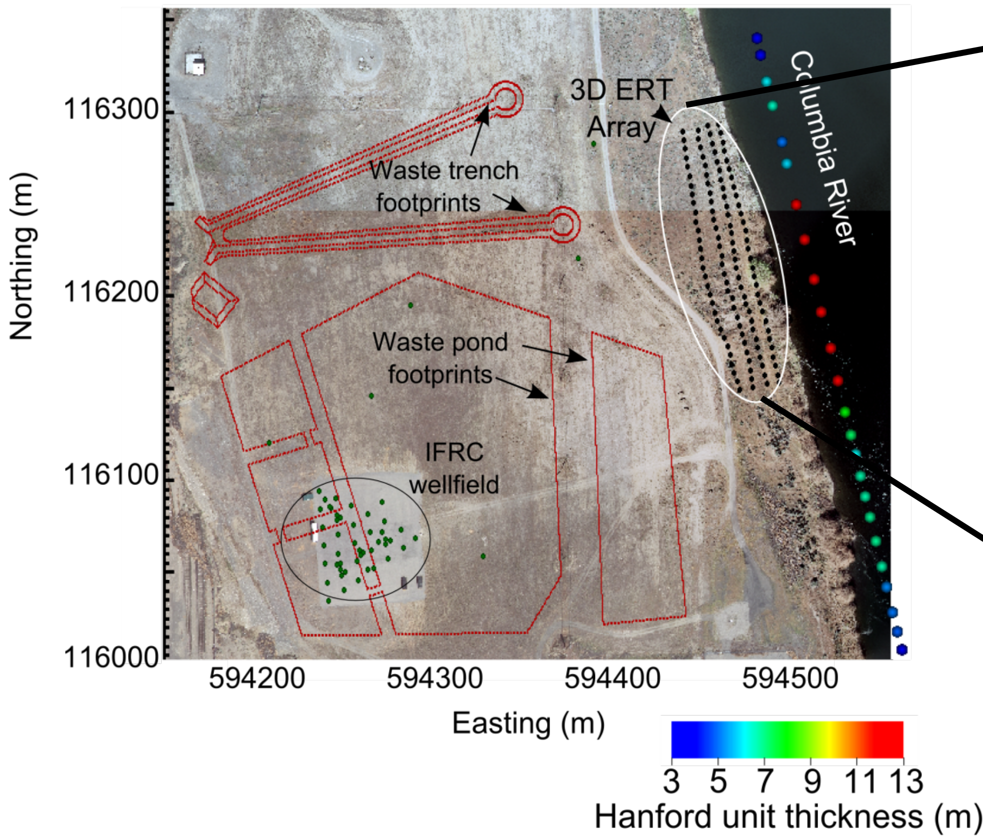
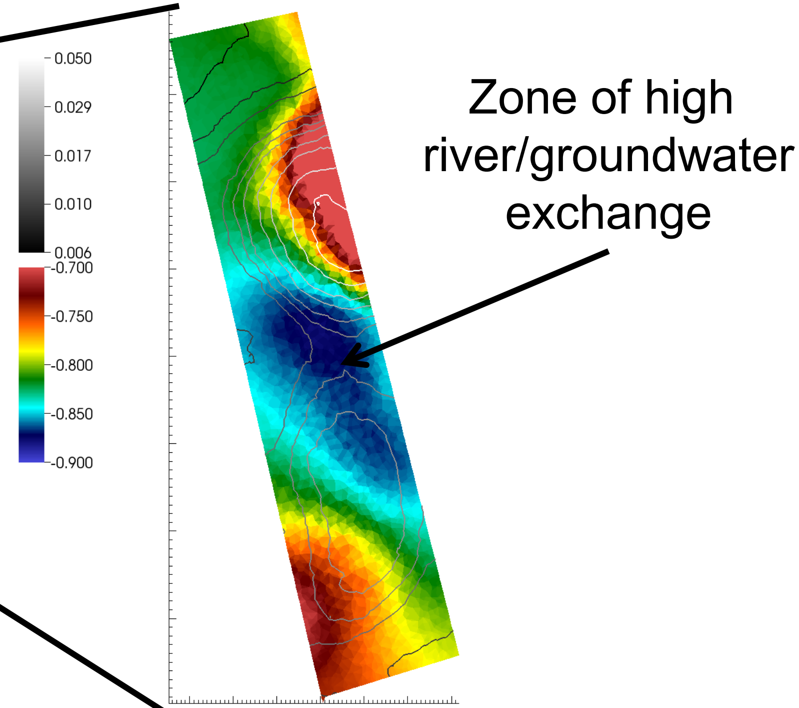
Groundwater-Riverwater monitoring at the Hanford 300-Area

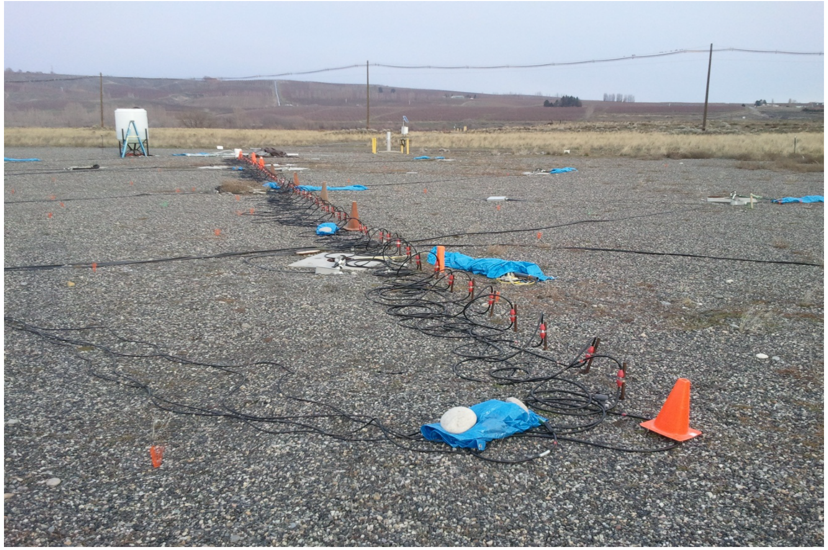
- **Objective:** Leverage the contrast between river water and ground water conductivity to monitor when and where river water enters the 300 area

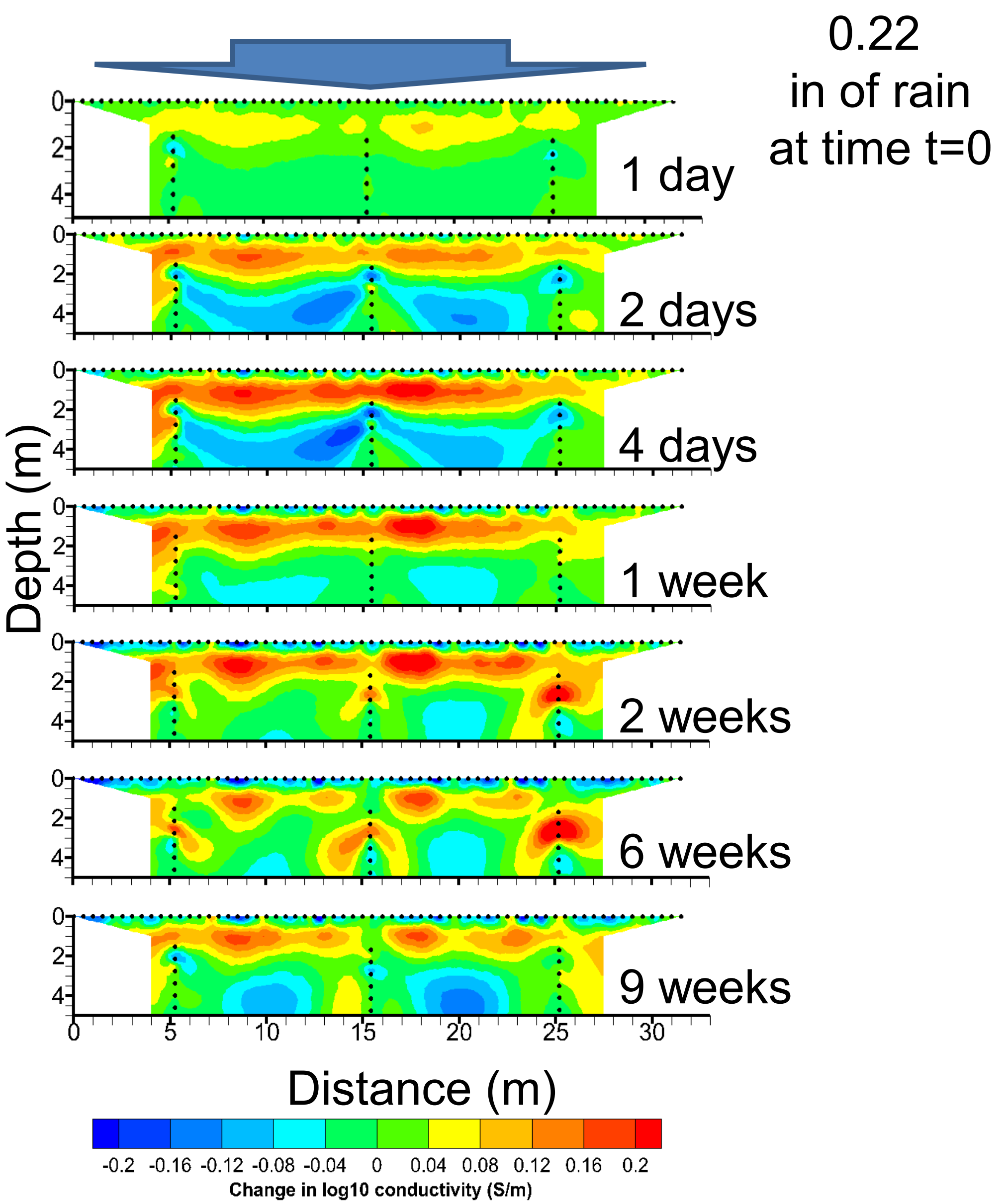




Monitoring surface infiltration in the 300 area.

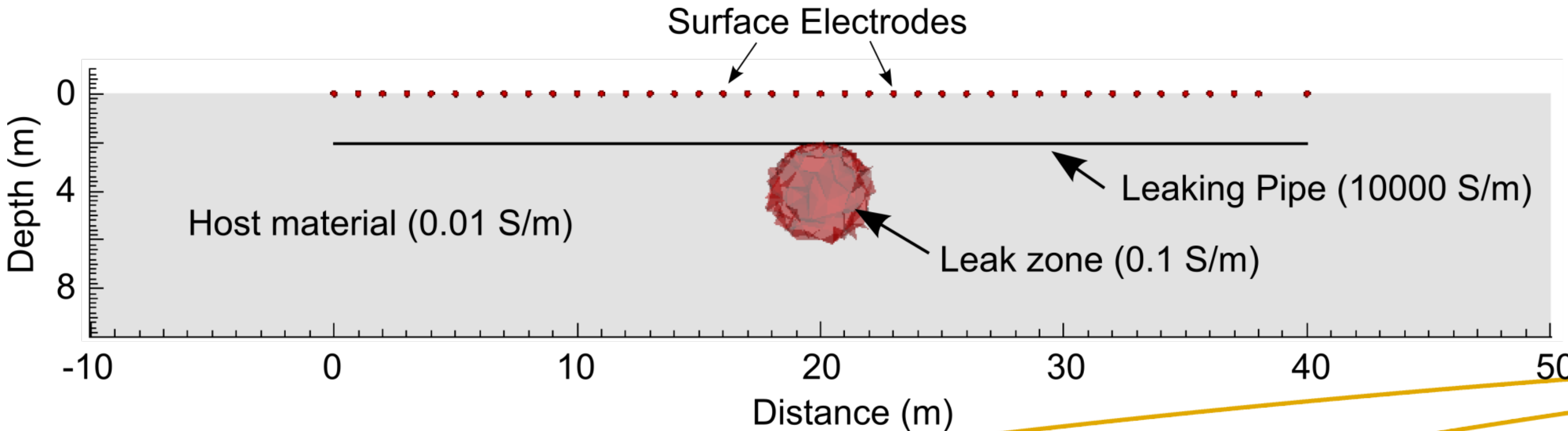
- **Objective:** Use ERT to image changes in saturation in order to determine if meteoric water infiltrates to the water table.



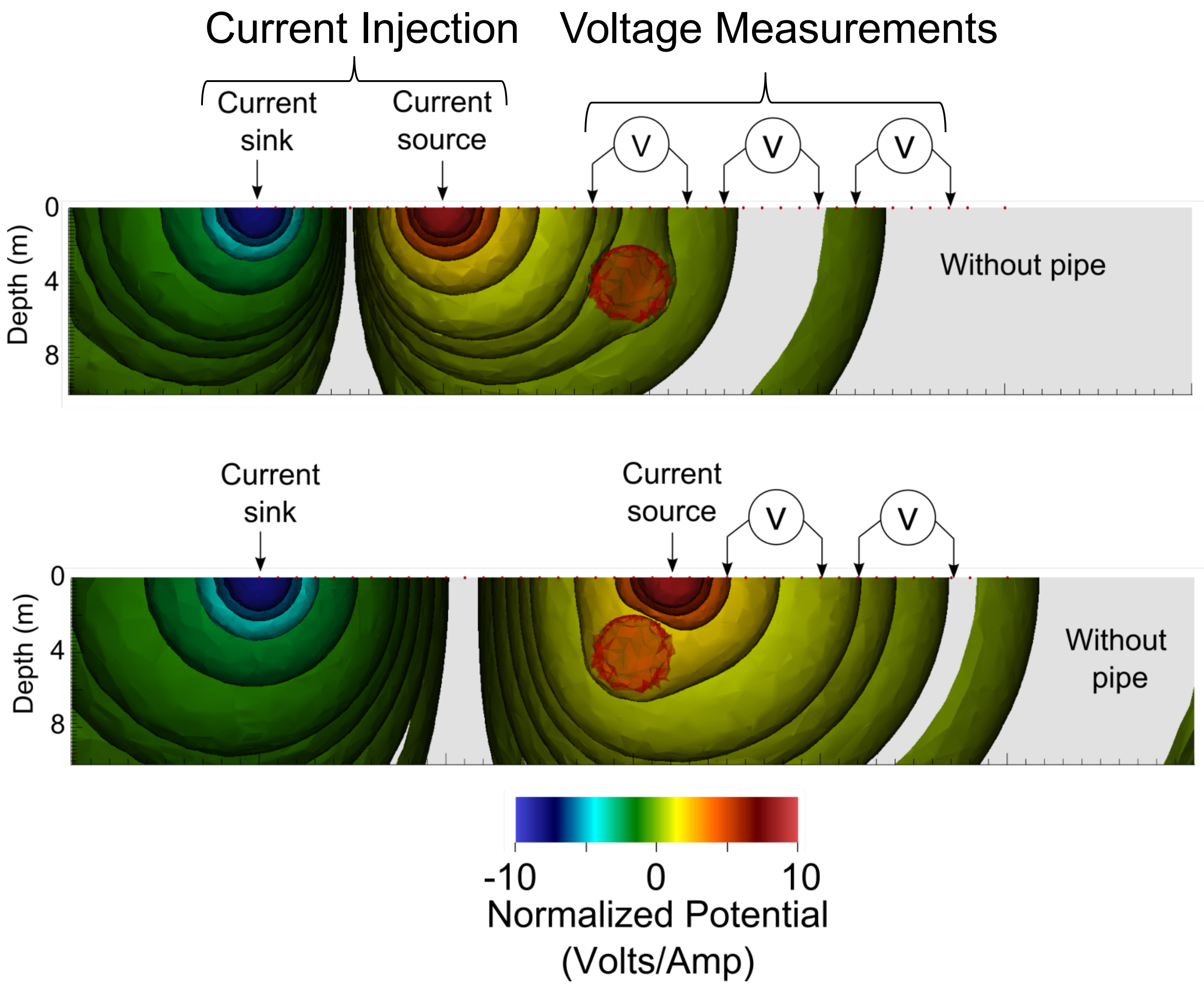


How does ERT work?

- Synthetic demonstration of a leak imaging problem
  - Leaks originate from infrastructure, so ….
  - Let’s image along a section including a pipe
  - Difficult for ERT, but a practical in terms of implementation
- Two steps: survey and inversion



ERT measurements (the survey)…



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ERT Inversion/Imaging

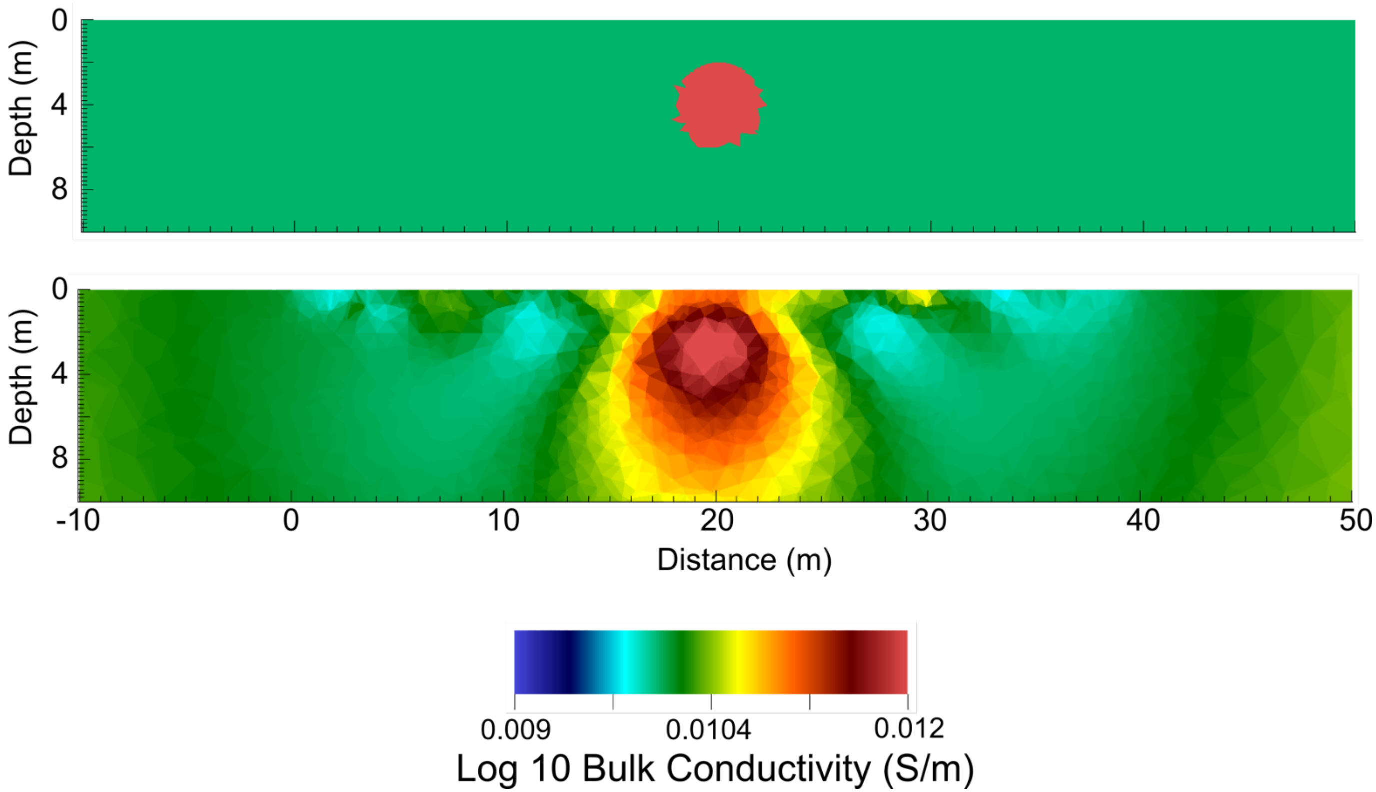
- **Objective: produce the subsurface electrical conductivity structure that gave rise to the measurements (i.e. image the leak)**
- Important issues
  - Many conductivity distributions will honor the data (i.e. the solution is non-unique).
  - We give the algorithm information concerning which model to choose (i.e. chose the most homogeneous solution that honors the data)
  - Numerical model must be able to provide accurate simulations when provided the actual subsurface conductivity
- Time-lapse inversion

Results for the synthetic (no-pipe) problem

- The leak zone is imaged in the absence of the pipe

True bulk conductivity

ERT image



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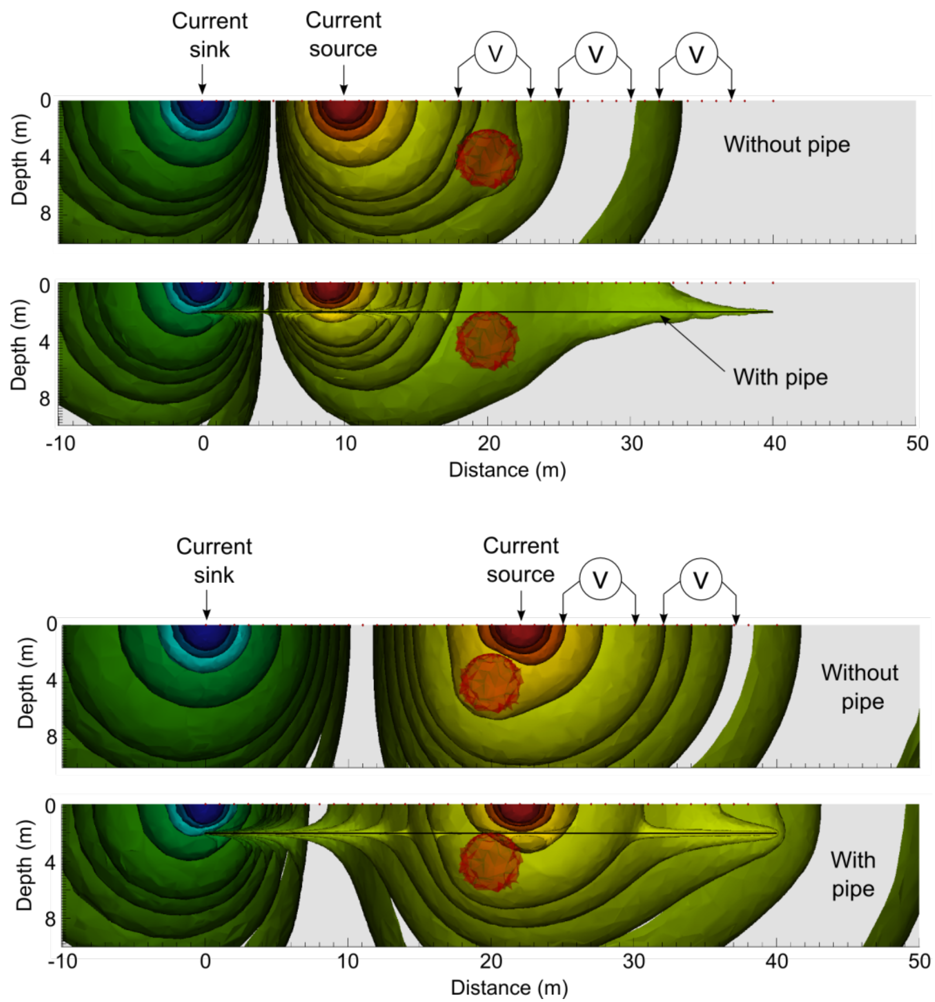
The problem with conductive infrastructure…

- Current is channeled through the pipe, causing a distortion in the potential field

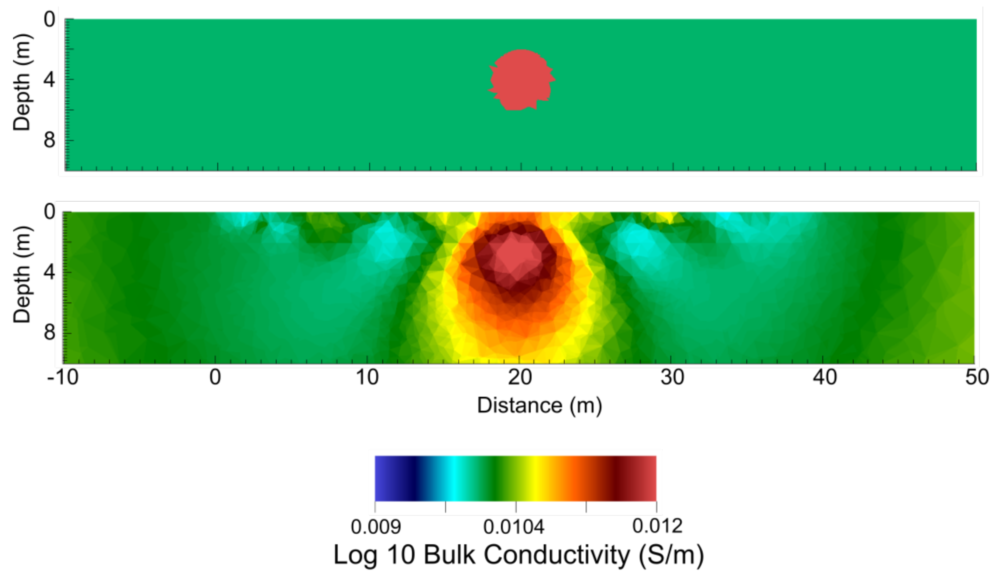
- Potential is still sensitive to the leak zone, but masked by pipe effect.



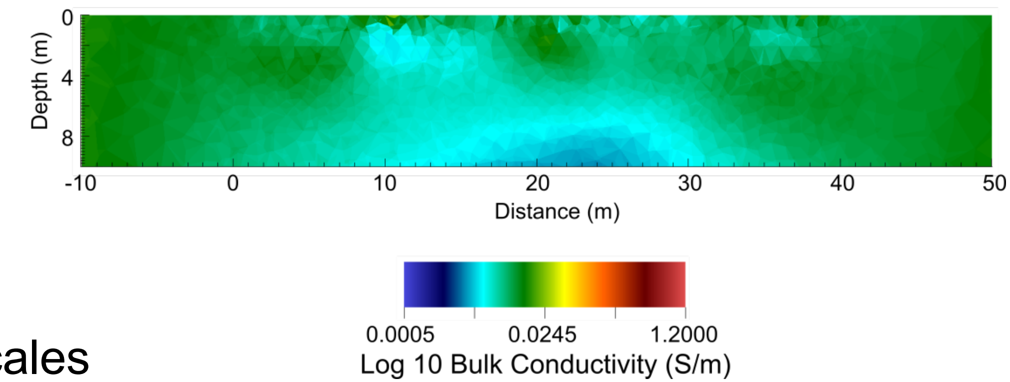
Results for the synthetic problem with pipe

True bulk conductivity

ERT image with no pipe effects



ERT image with pipe effects



Note change in color scales

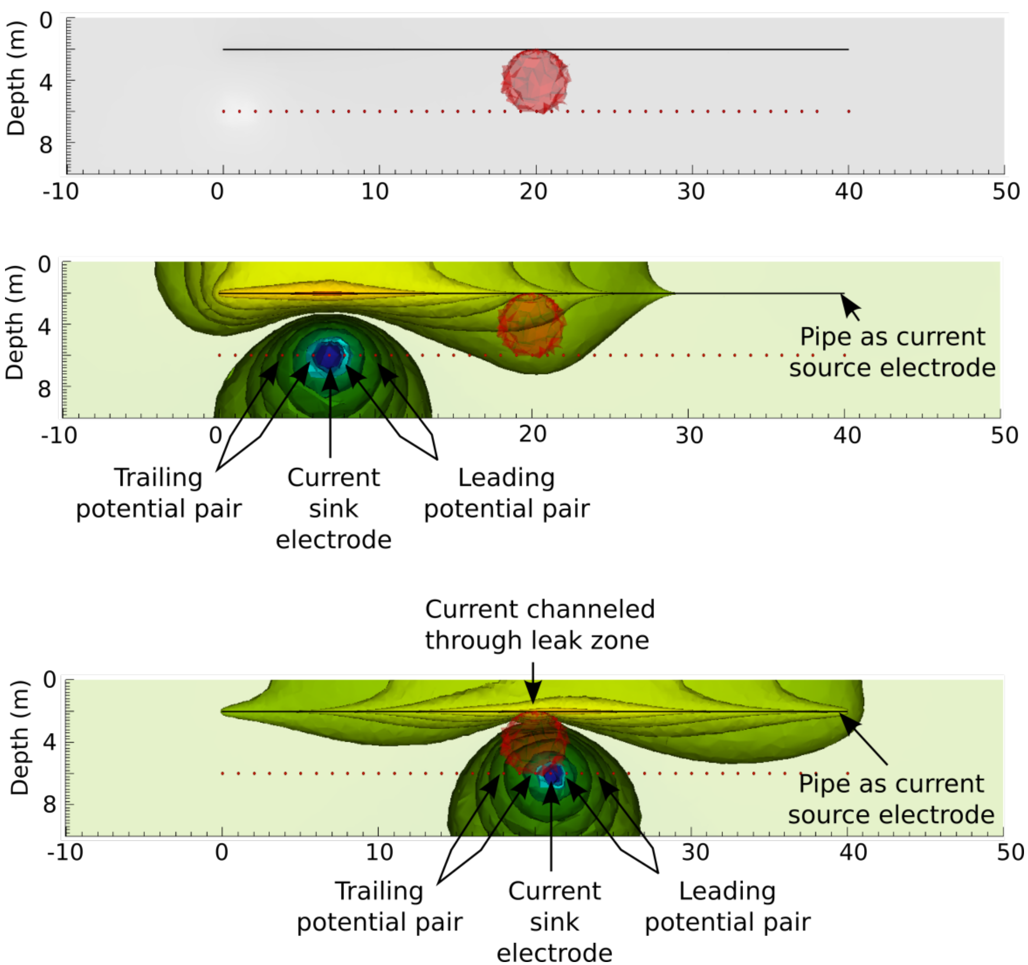
Two primary issues with ERT imaging around infrastructure ….

- ERT data become less sensitive to the target zone (i.e. the leak zone)

- ERT numerical models are not capable of simulating subsurface infrastructure … so no chance of fitting data.
  - Meshes are too coarse to model infrastructure
  - Large conductivity contrasts cause numerical instability
  - Smoothing constraints are inconsistent with reality

- **Recommendation: a two-stage approach (detection and imaging)**

Stage 1: Detection using the pipe



- Detection sensitivity can be increased by
  - Using the pipe as a source electrode (or potential in reciprocal measurement)
  - Placing electrode beneath pipe so that electrodes straddle leak.
  - Current flows through leak zone … increasing sensitivity.

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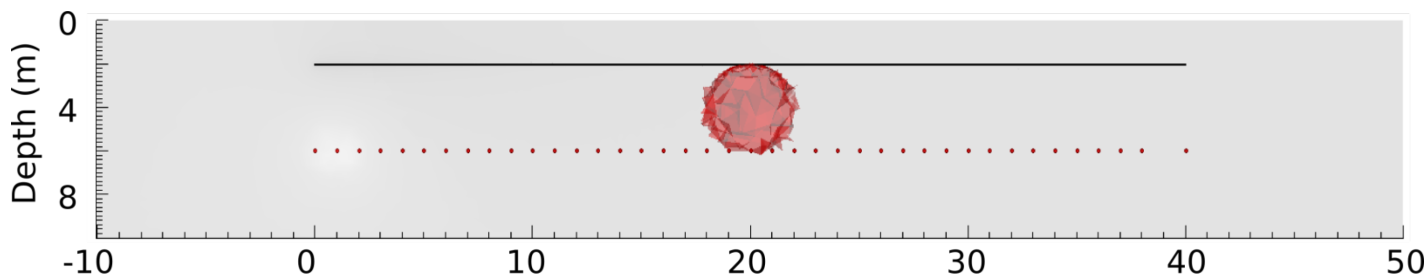
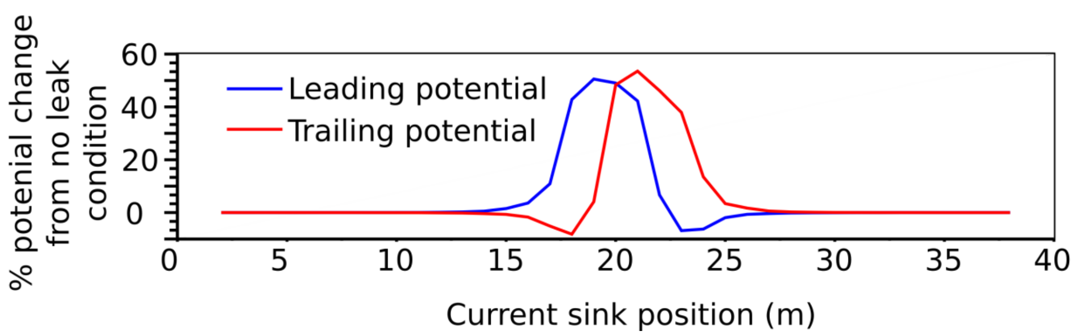
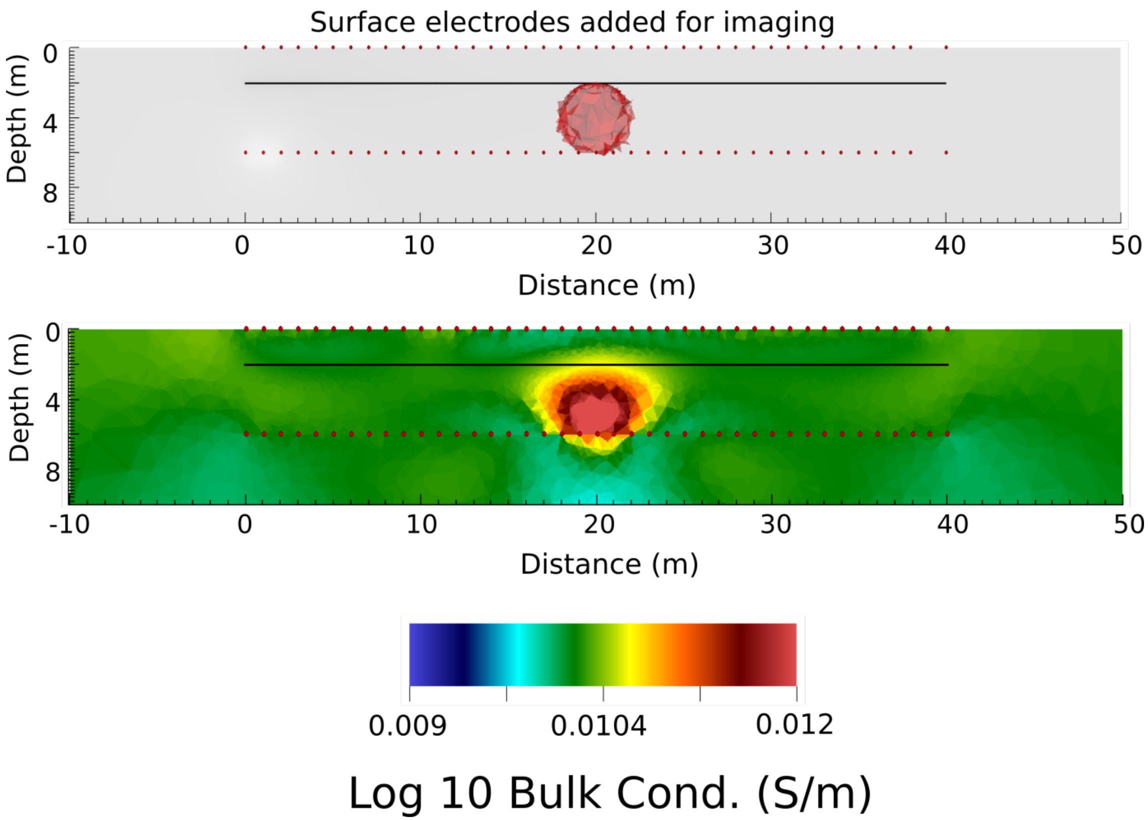
Synthetic detection results

- Relatively modest increase in conductivity (0.01 to 0.05) results in ~50 percent change in potential from background
- Surface electrodes only provided ~5 percent change.



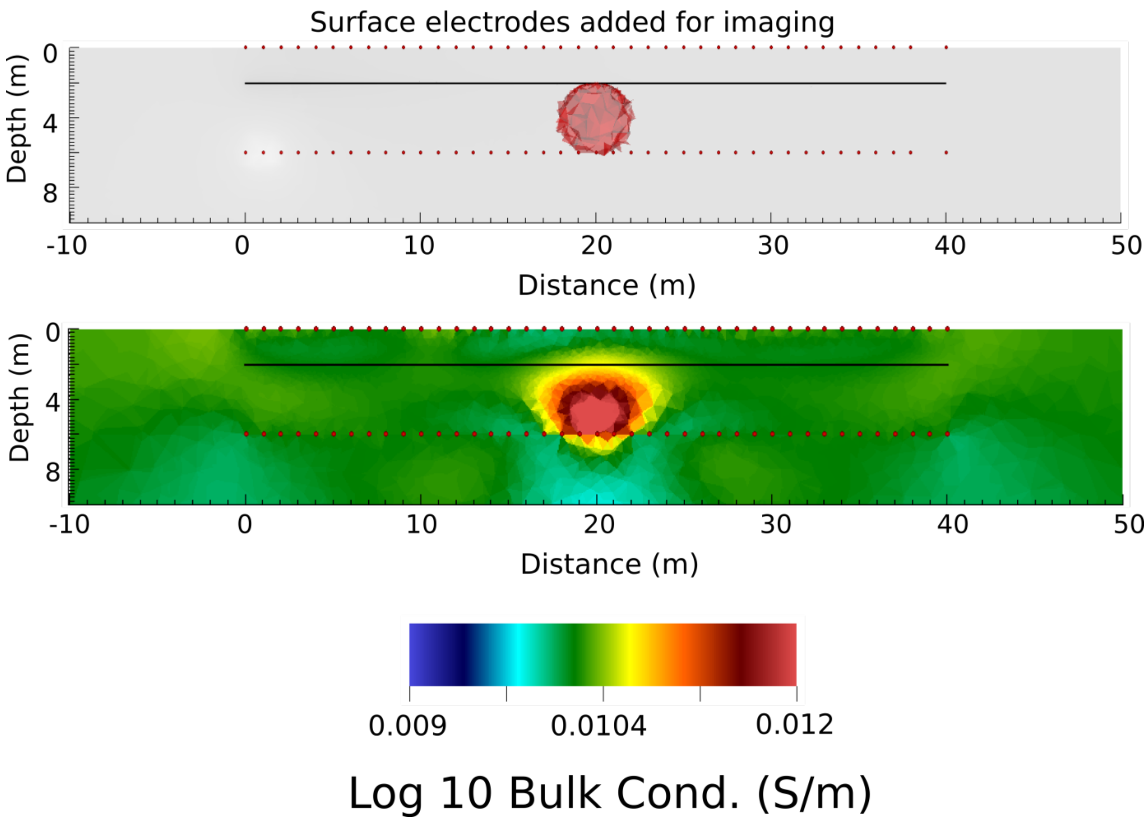


Stage 2: Imaging



- Surface electrodes added to provide high resolution imaging zone.
- Pipe is modeled explicitly
- Pipe is “disconnected” from host (allows large contrast without penalty)

Stage 2: Imaging



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Notes on imaging

- Very refined 3D mesh required (~1E6 elements for this example.
  - Requires HPC resources and code … not practical
  - Could be addressed with specialized modeling
  - Reduced to 2D inversion (desktop capable)
- Pipe conductivity assumed to be known and uniform
  - Actual pipe unknown conductivity may vary in space
- **Not field proven … more work needed**.

Summary

- ERT imaging has “potential” for leak imaging, but infrastructure effects must be addressed.
- Autonomous, robust, low maintenance long-term systems.
- Detection approach likely robust, but smart design required for adequate sensitivity
- Imaging may be possible, but code developments and field testing needed.