

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

NRC Leak Detection Workshop
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Outline

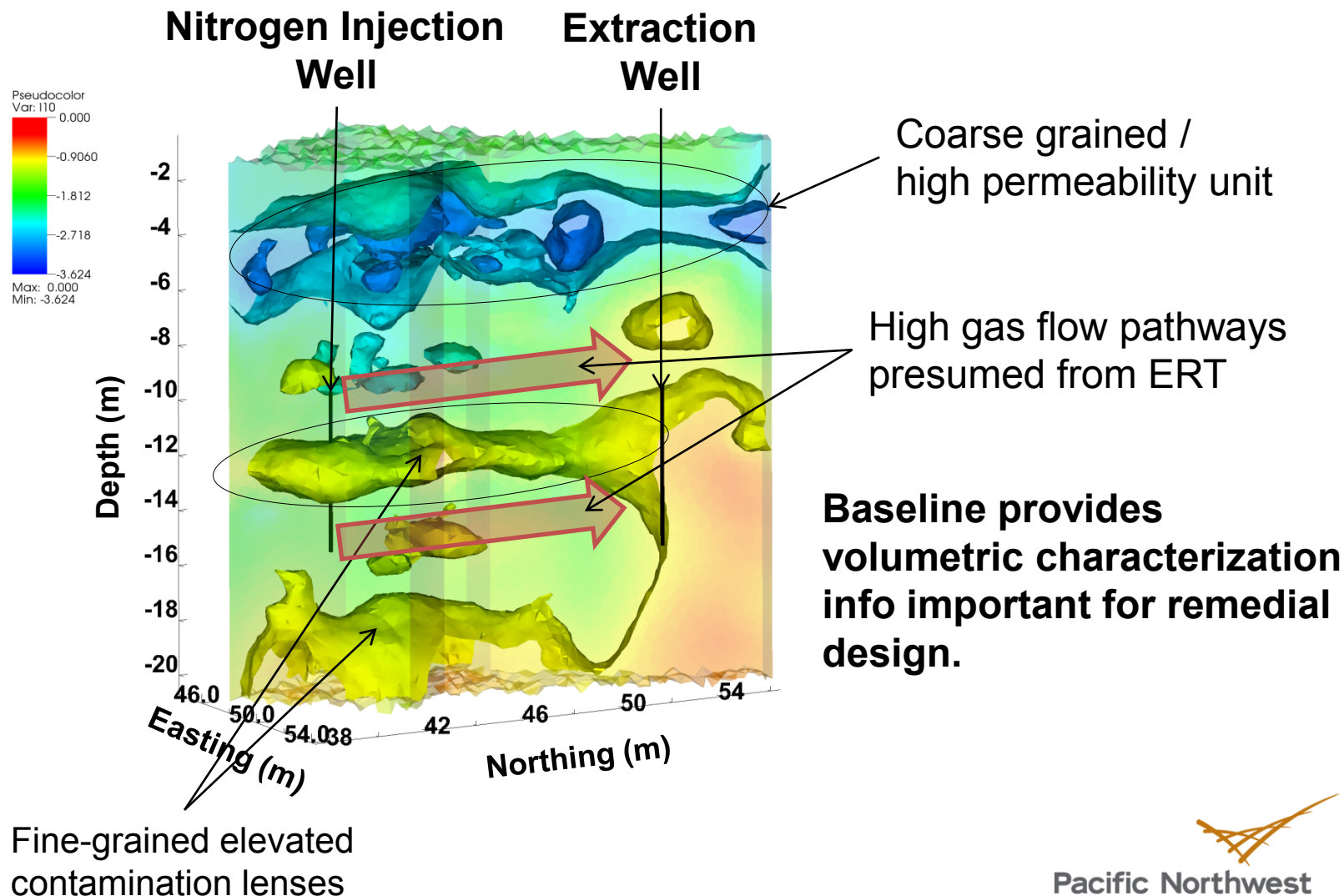
- ▶ Electrical Resistivity Tomography (ERT) imaging examples (characterization and monitoring)
- ▶ How ERT works
- ▶ The infrastructure problem
- ▶ Can it be “fixed”
- ▶ Ideas/Recommendations for leak detection and monitoring



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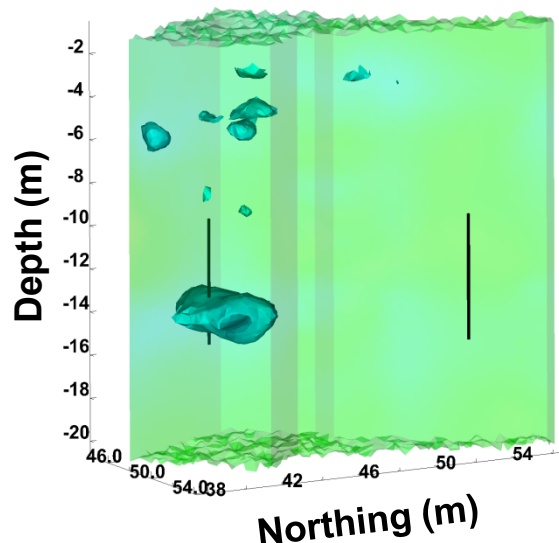
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Vadose zone desiccation monitoring at the Hanford BC-Cribs site

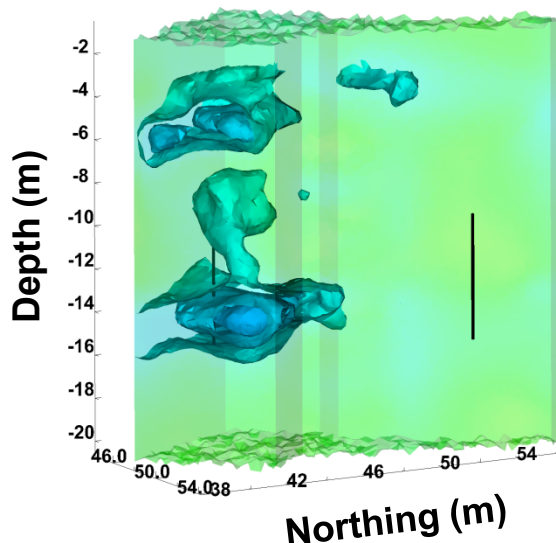


Still images of desiccated volume with time

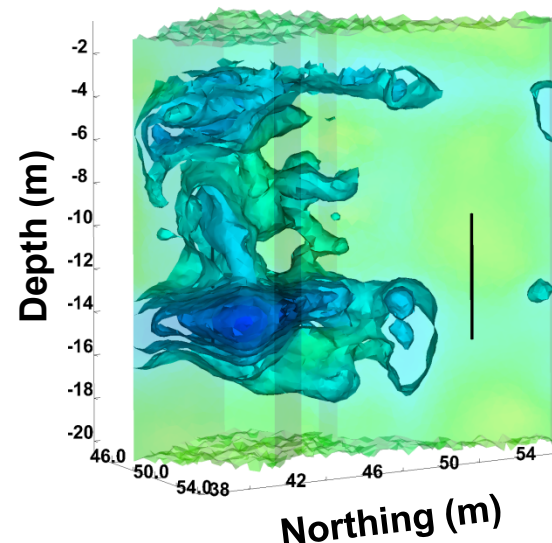
20 Days



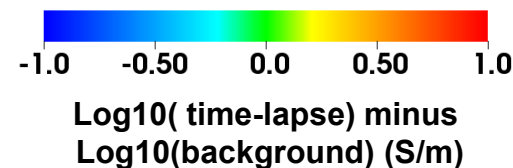
40 Days



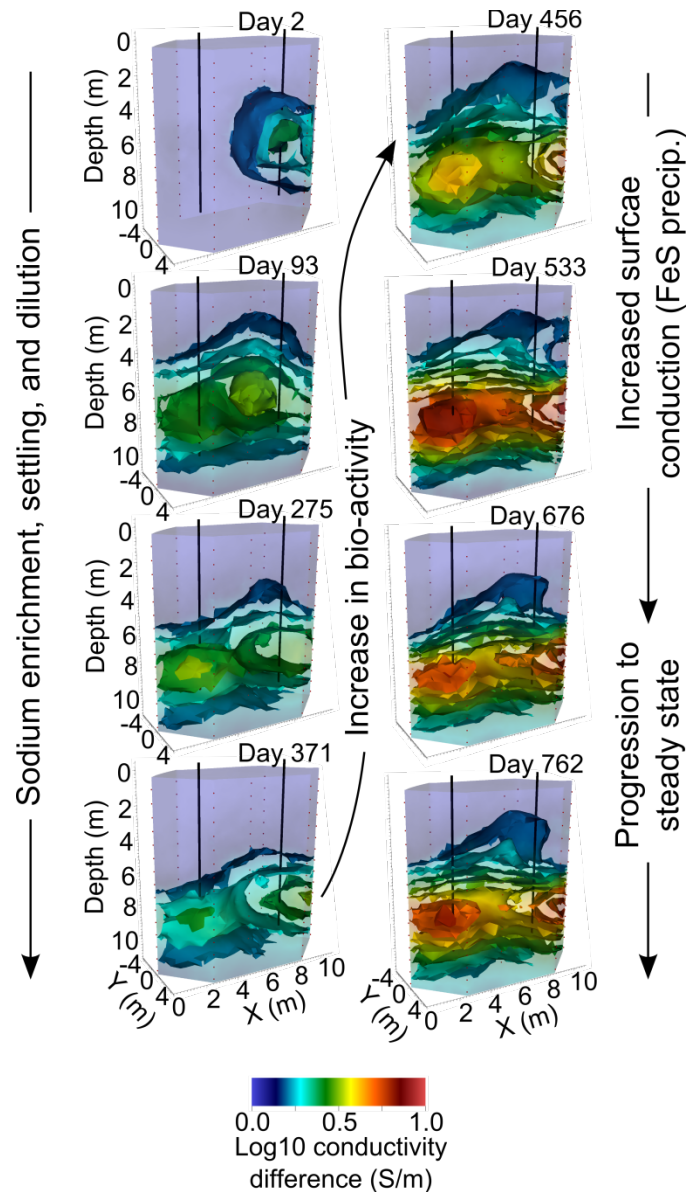
110 Days



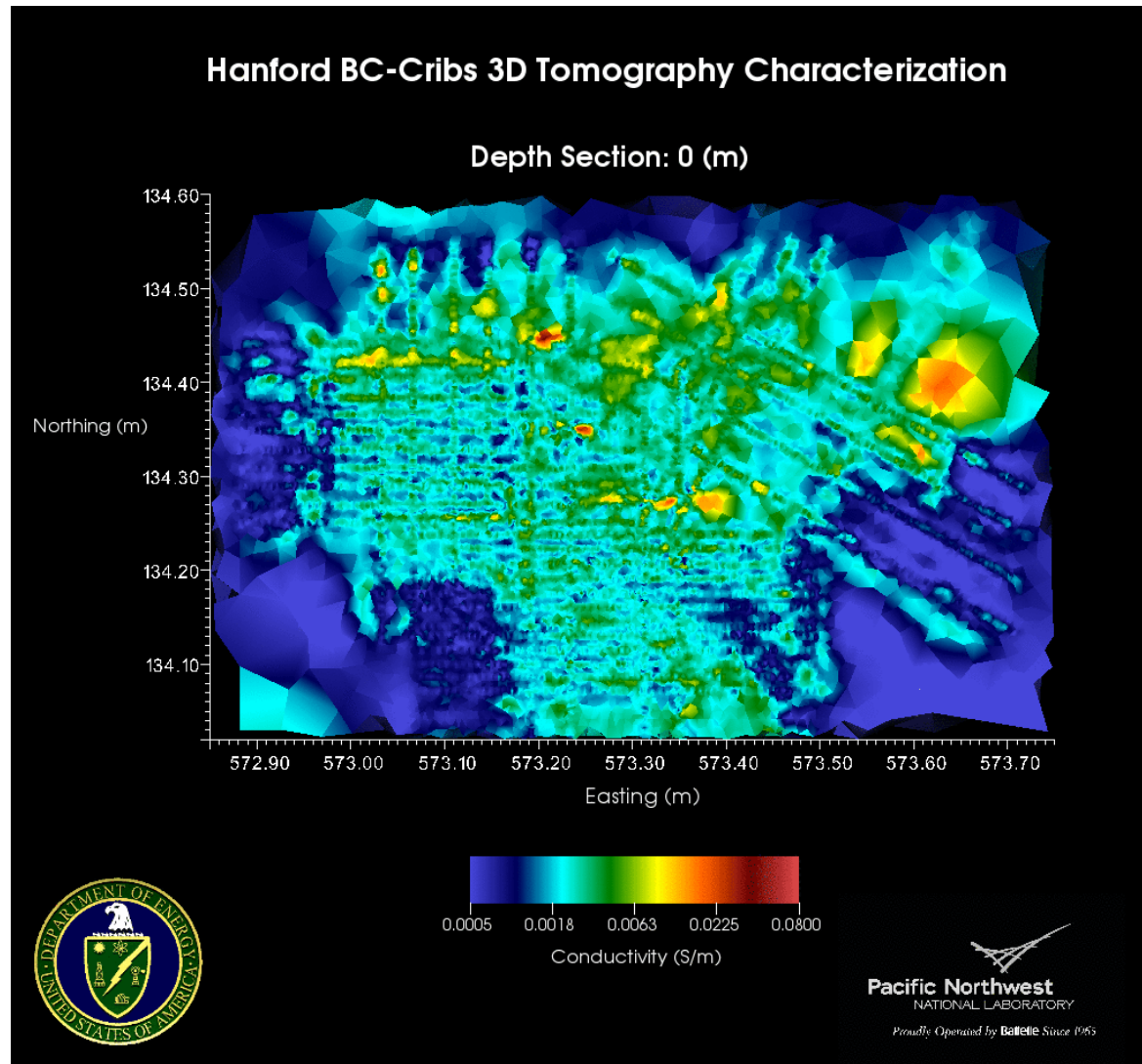
- Shaded area shows volume resolved by ERT system
- Color scale represents relative change in conductivity during desiccation
- Electrical conductivity decreases with water content (drier soil = lower conductivity)
- Primary zone of desiccation appears at 14-16 m deep, just below presumed fine grained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



Brandywine MD bioremediation monitoring

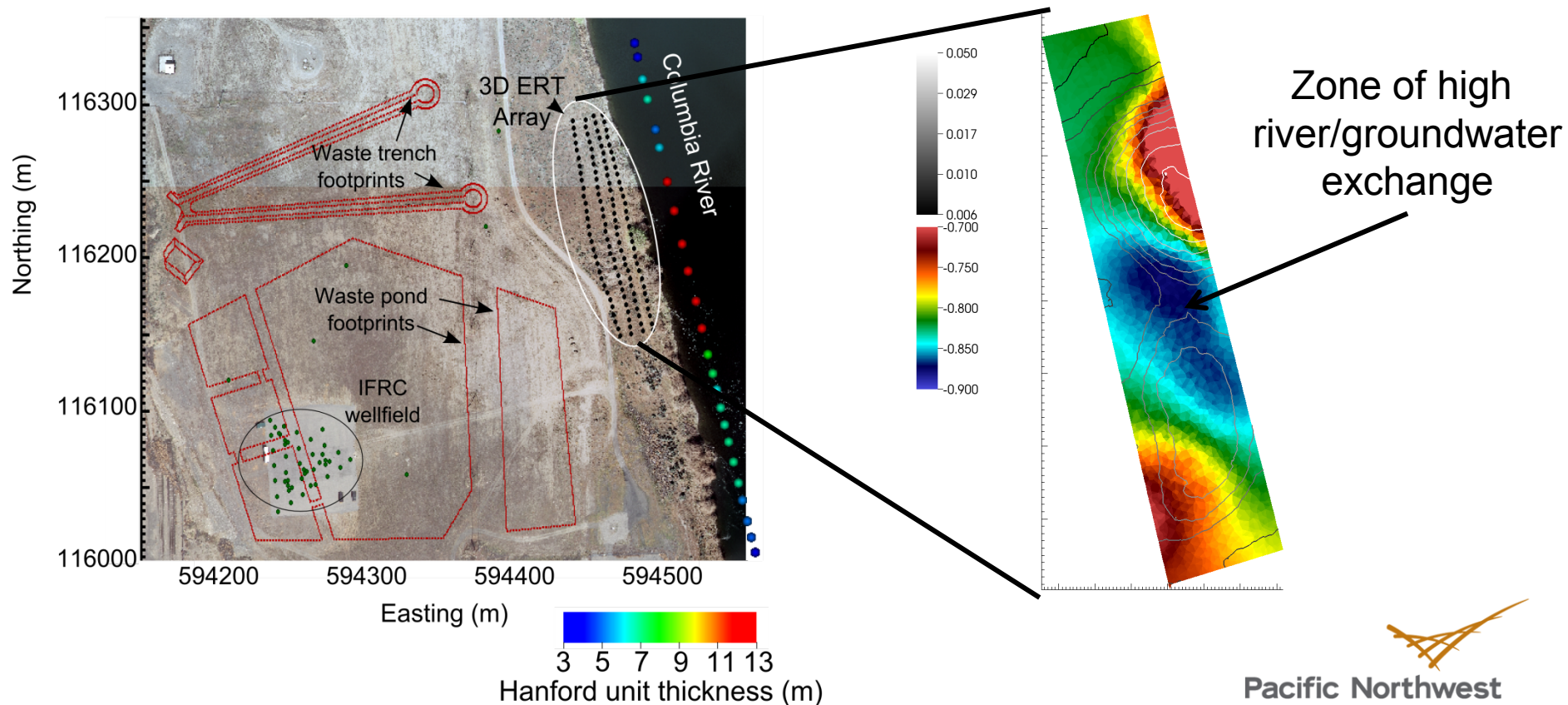


Large-scale characterization of the Hanford BC-Cribs Site



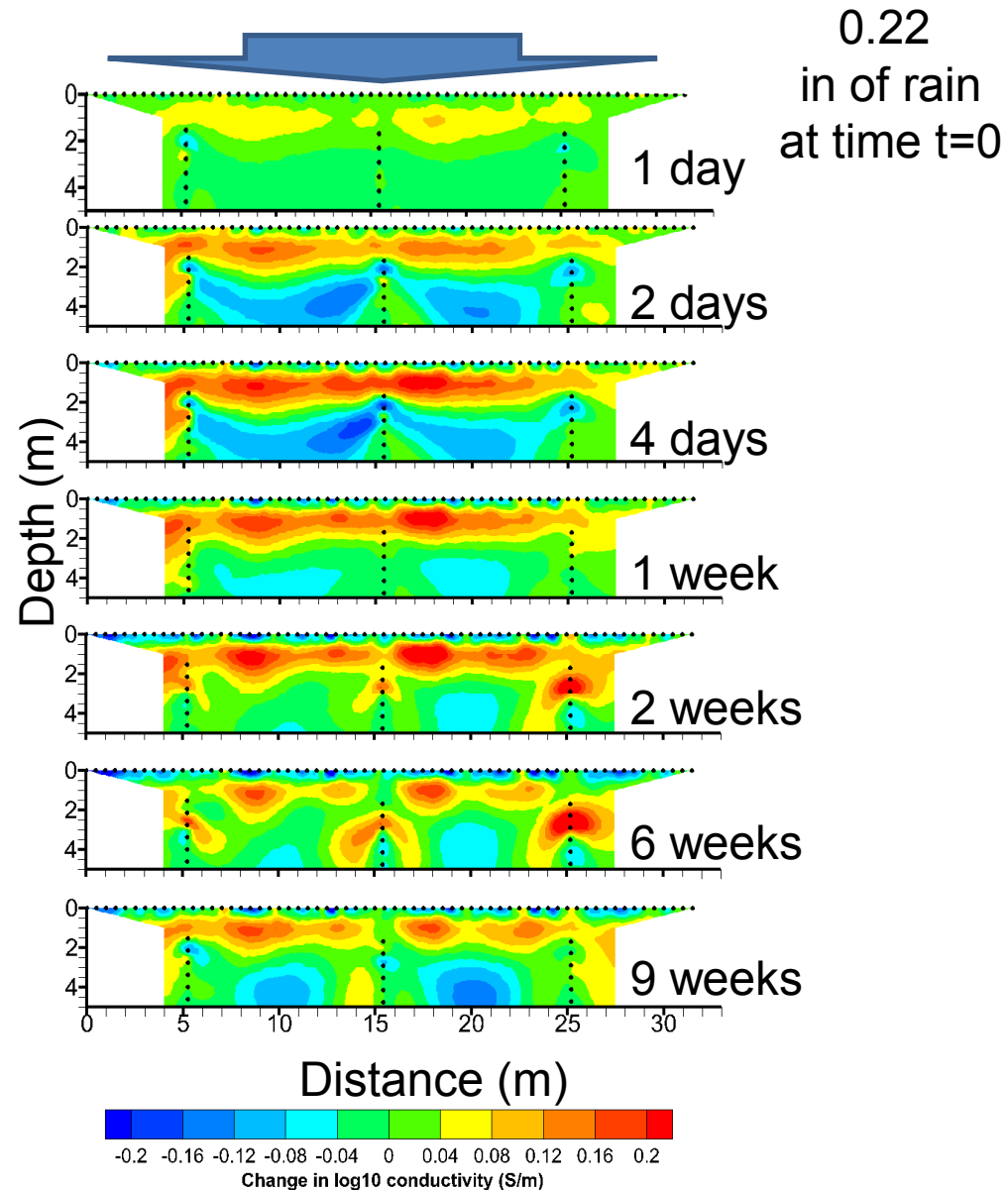
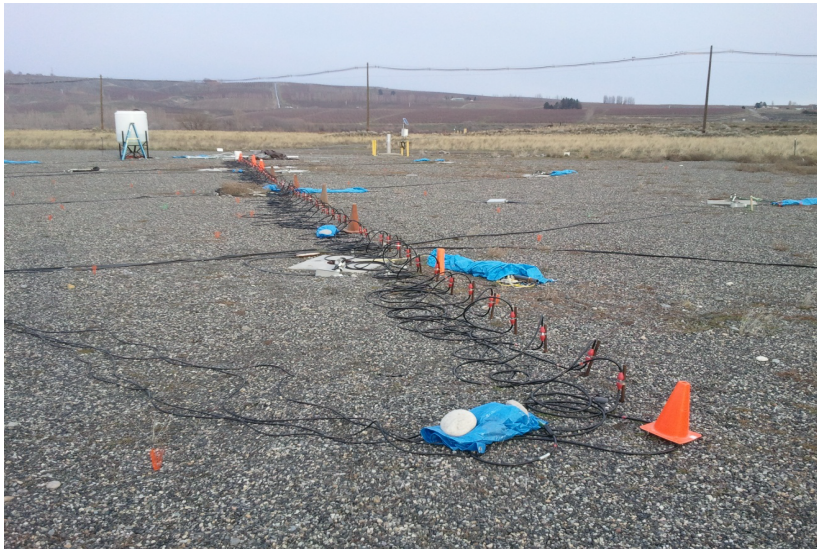
Groundwater-Riverwater monitoring at the Hanford 300-Area

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



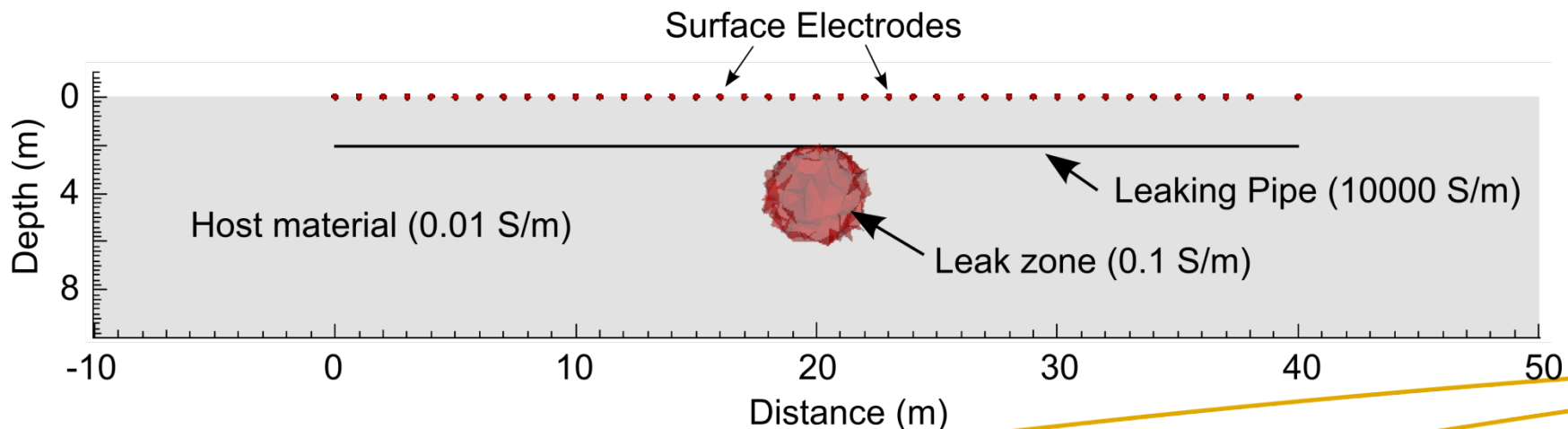
Monitoring surface infiltration in the 300 area.

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

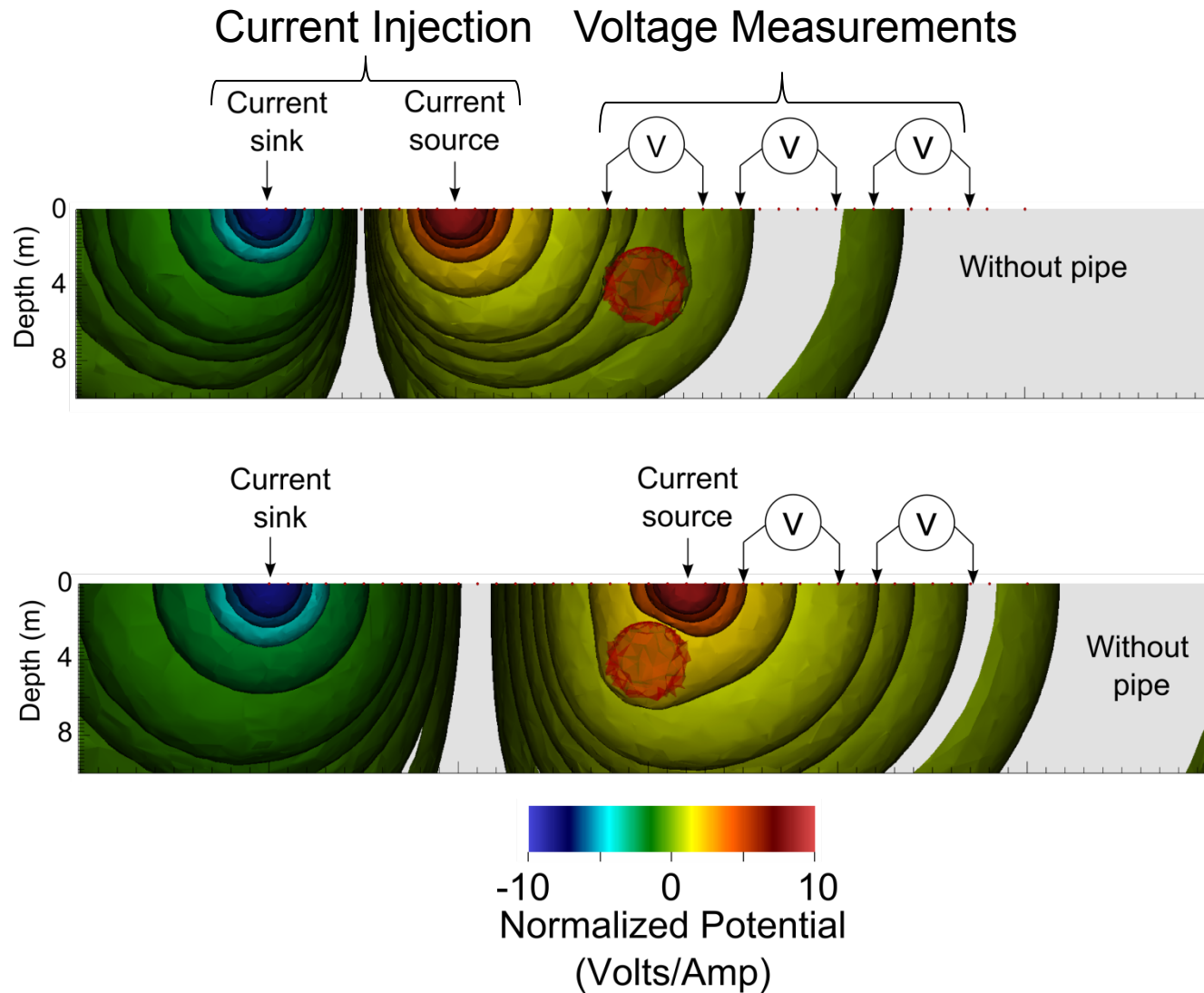


How does ERT work?

- ▶ 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)...



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**

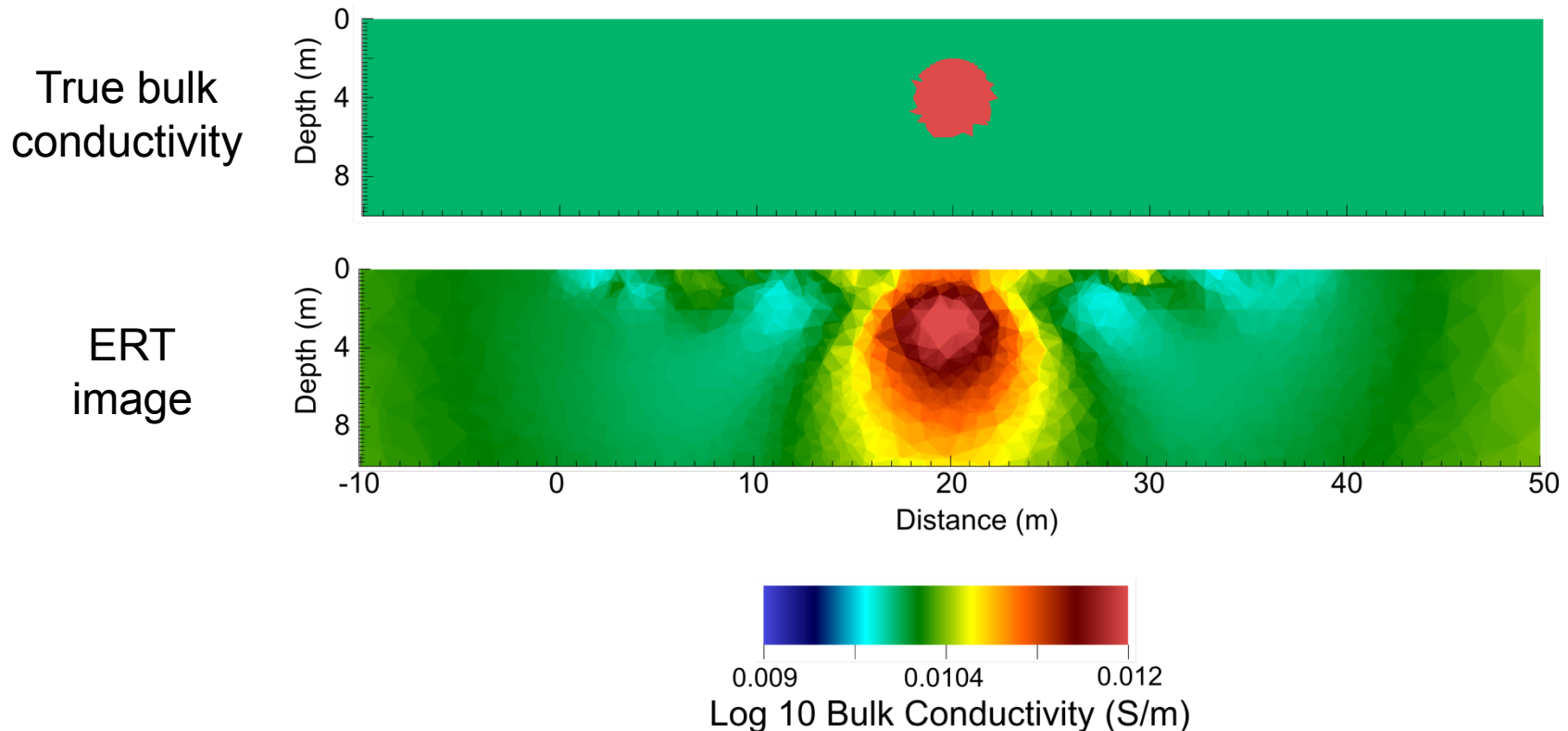


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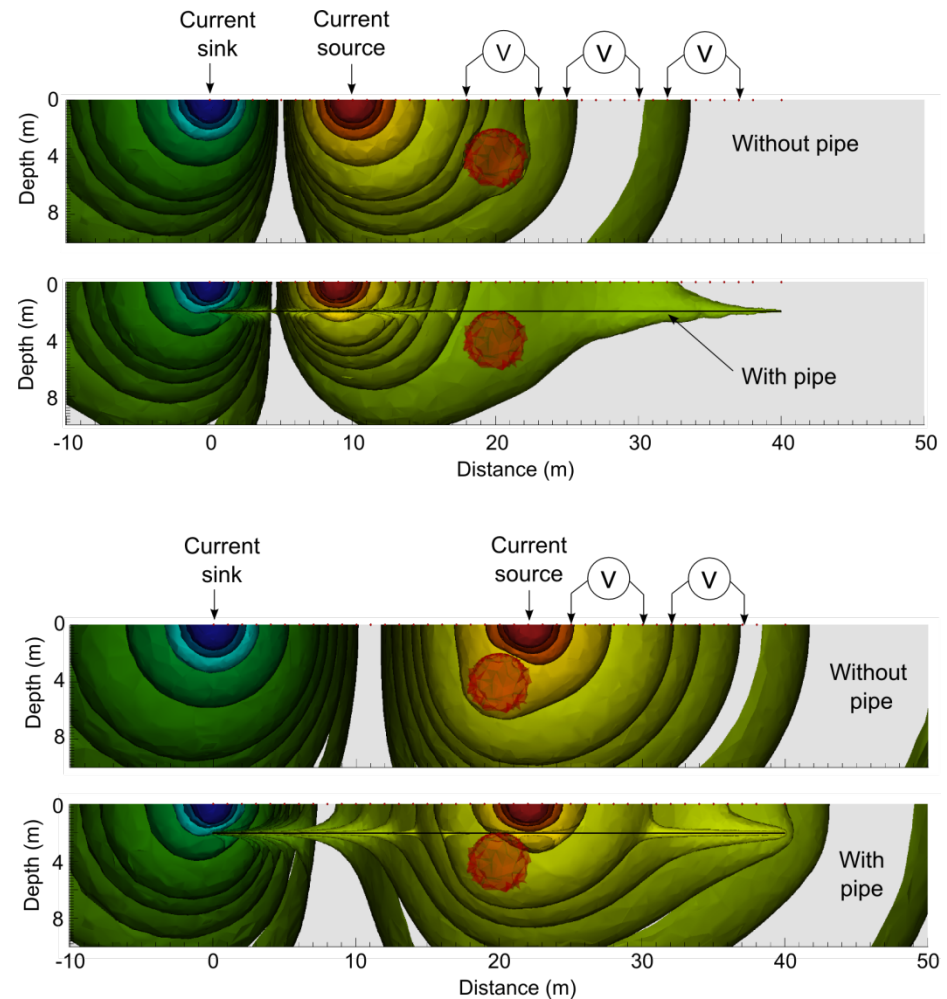
Results for the synthetic (no-pipe) problem

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



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.



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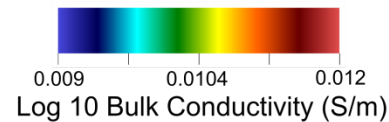
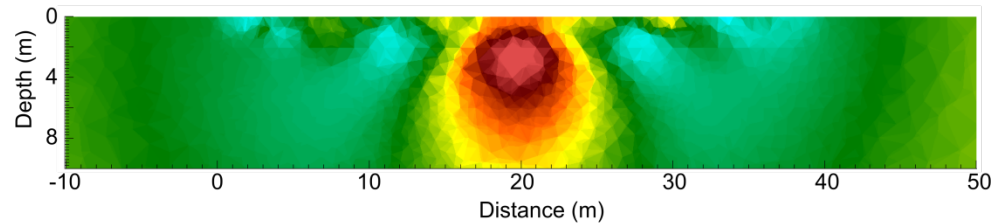
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Results for the synthetic problem with pipe

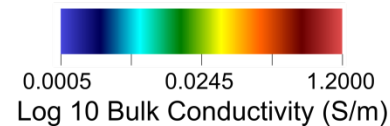
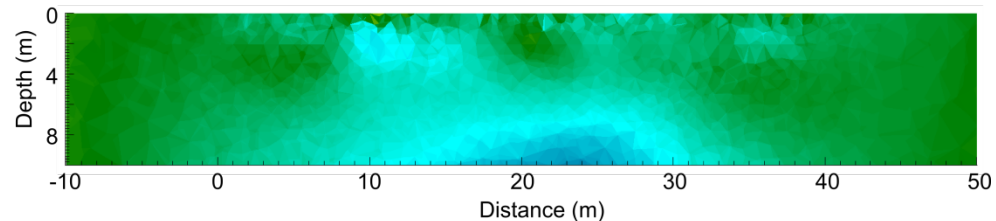
True bulk
conductivity



ERT image
with no pipe effects



ERT image
with pipe effects



Note change in color scales

Two primary issues with ERT imaging around infrastructure

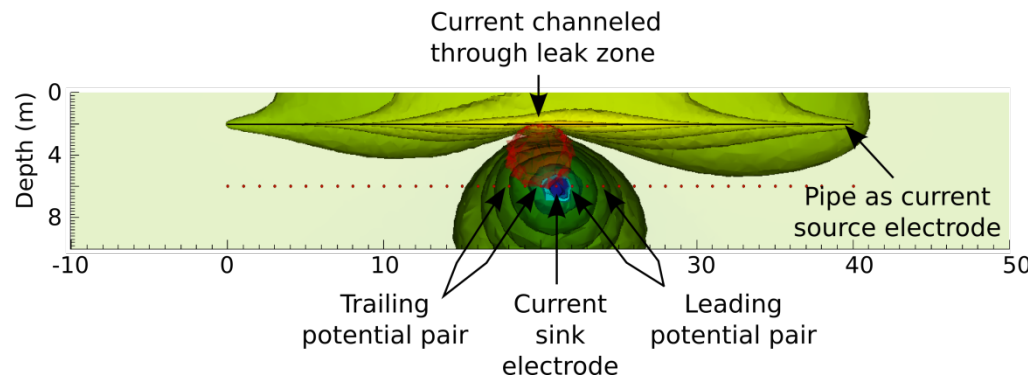
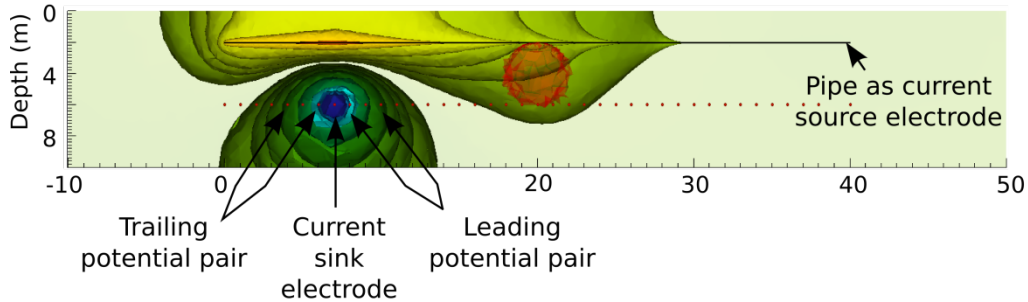
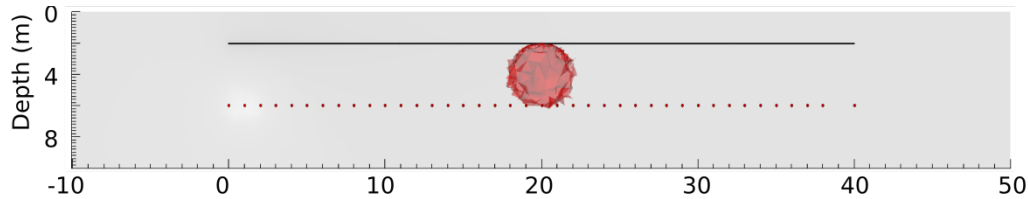
- ▶ ERT data become less sensitive to the target zone (i.e. the leak zone)
- ▶ ERT numerical models are not capable of simulating subsurface infrastructure ... so no chance of fitting data.
 - Meshes are too coarse to model infrastructure
 - Large conductivity contrasts cause numerical instability
 - Smoothing constraints are inconsistent with reality
- ▶ **Recommendation: a two-stage approach (detection and imaging)**



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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.

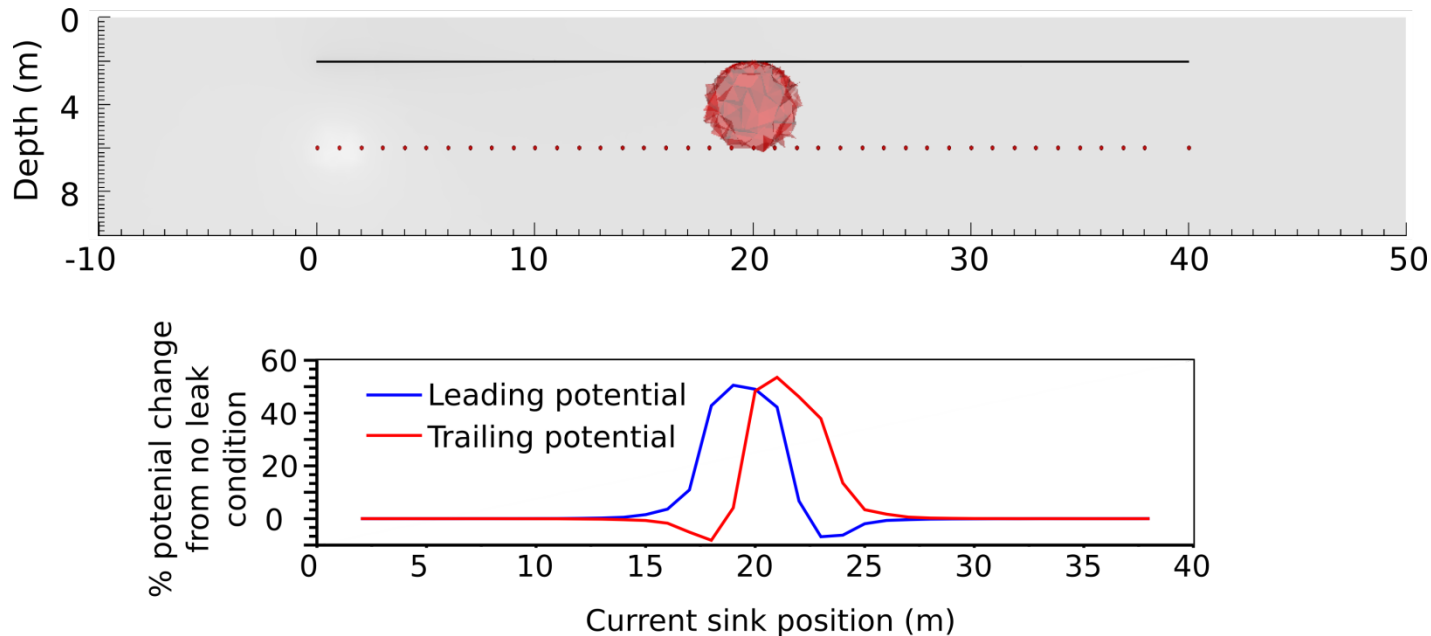


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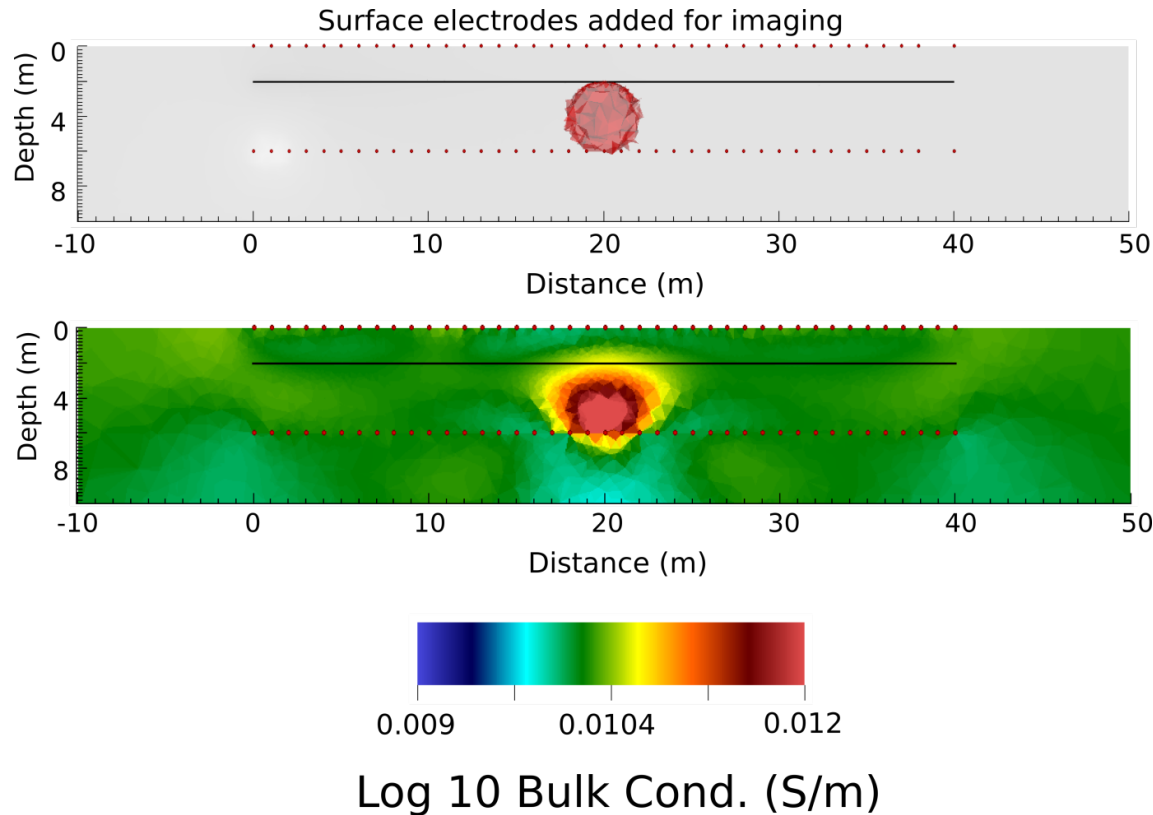
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Synthetic detection results

- ▶ 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



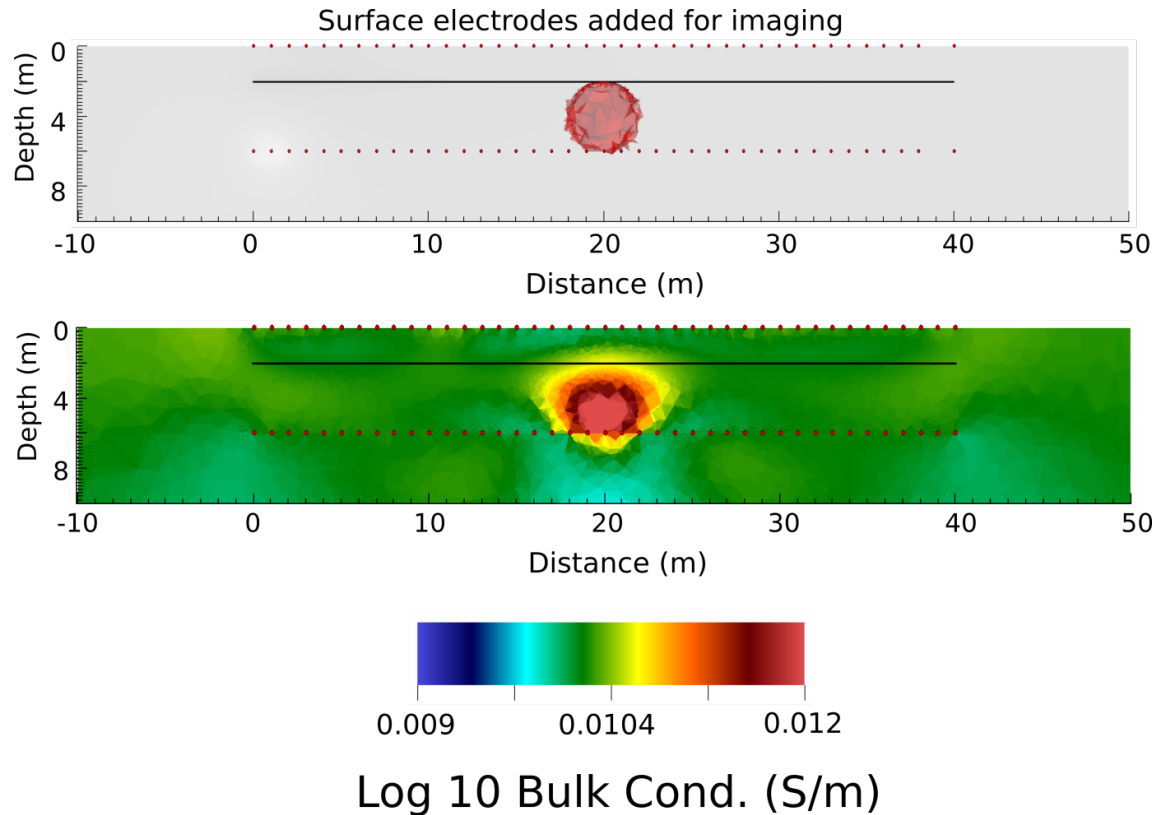
- ▶ Surface electrodes added to provide high resolution imaging zone.
- ▶ Pipe is modeled explicitly
- ▶ Pipe is “disconnected” from host (allows large contrast without penalty)



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Notes on imaging

- ▶ Very refined 3D mesh required ($\sim 1\text{E}6$ 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.**



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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.



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