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DEEP VADOSE ZONE PROGRAM @PNNL

4D Electrical Resistivity Tomography Monitoring of Vadose Zone Soil Flushing at the Hanford 100-K East Reactor Facility: A Machine Learning Based Assessment

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U.S. DEPARTMENT OF ENERGY BATTELLE

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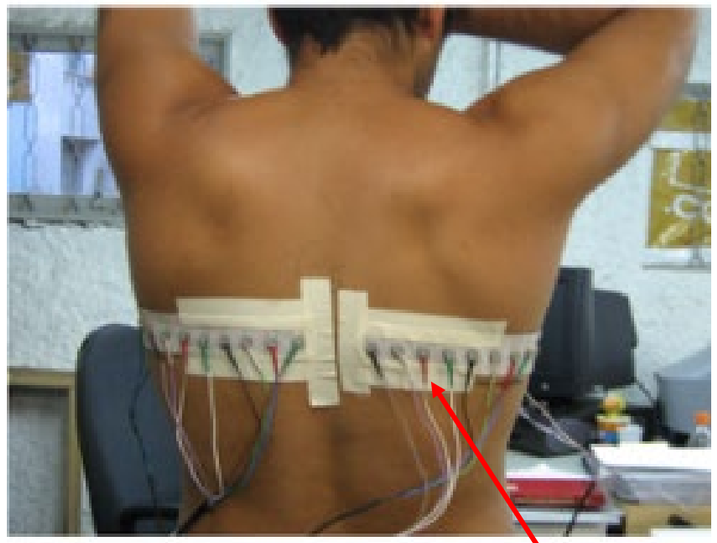
PNNL-SA-198319

Basic Theory: What is Electrical Resistivity Tomography (ERT)

Medical Imaging Analog: Electrical Impedance Tomography

Data Collection



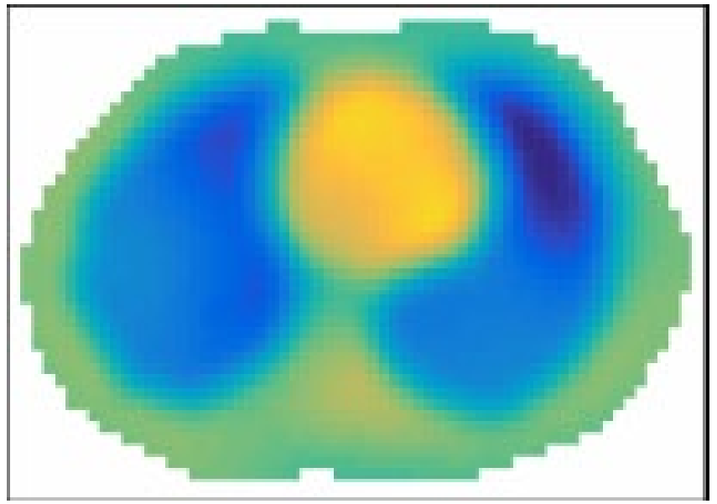
Courtesy Sarah Hamilton

Electrodes

Data Processing

(Inversion)

Tomographic Image

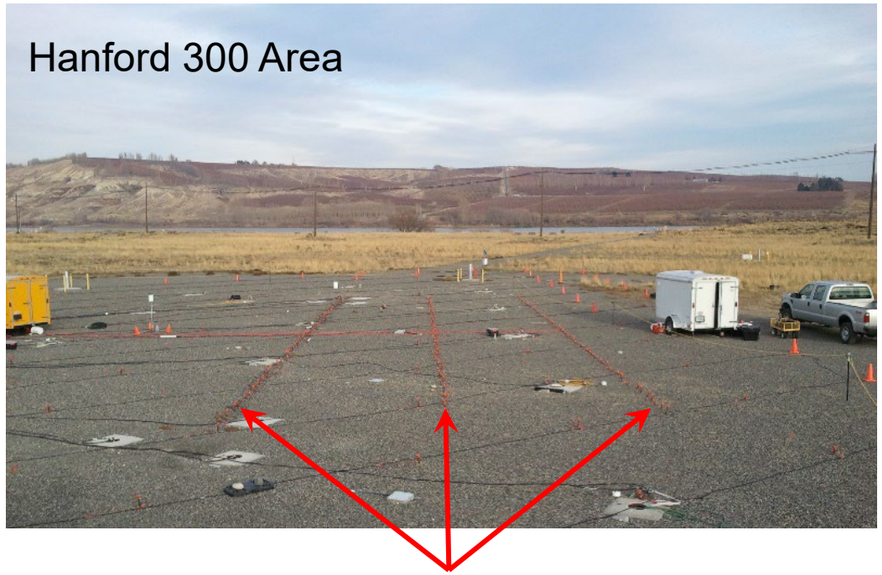


(http://www.marquette.edu/mscs/facstaff-hamilton.shtml
Hamilton et al., 2012.

Basic Theory: What is Electrical Resistivity Tomography (ERT)

Subsurface Imaging: Electrical Resistivity Tomography

Data Collection

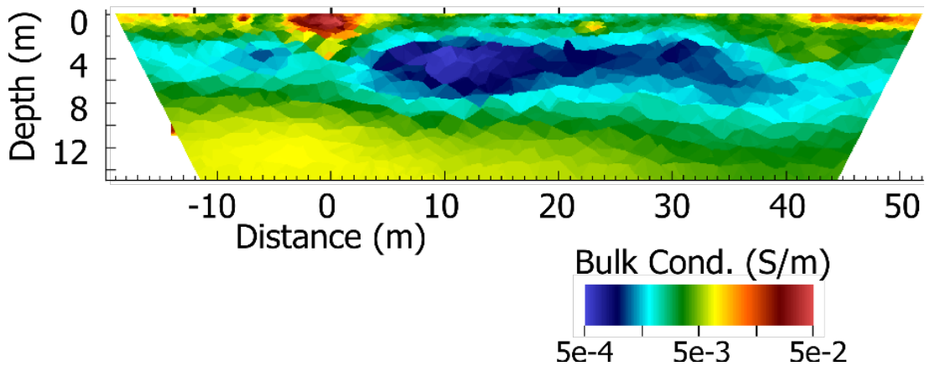


Surface electrode lines

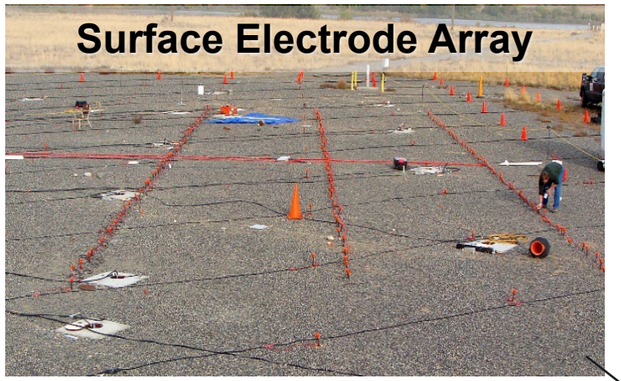
Data Processing

(Inversion)

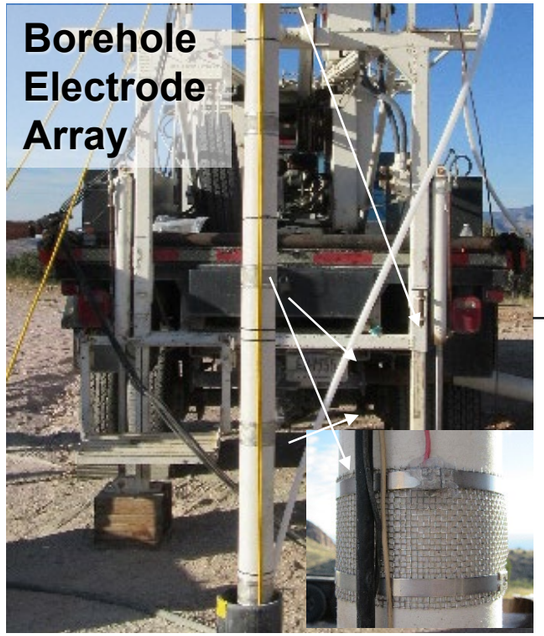
Tomographic Image



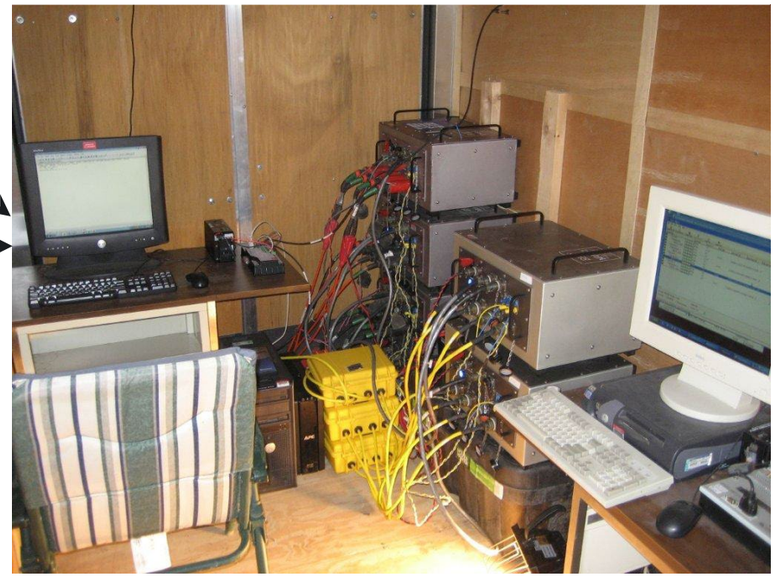
ERT Data Collection Hardware



- Autonomous operation (facilitates monitoring)
- Multi-channel – many potential pairs per current injection (enables rapid data collection)
- Remote accessibility (facilitates autonomous imaging)
- No metal casing
- In-borehole electrodes can be used in screened zone

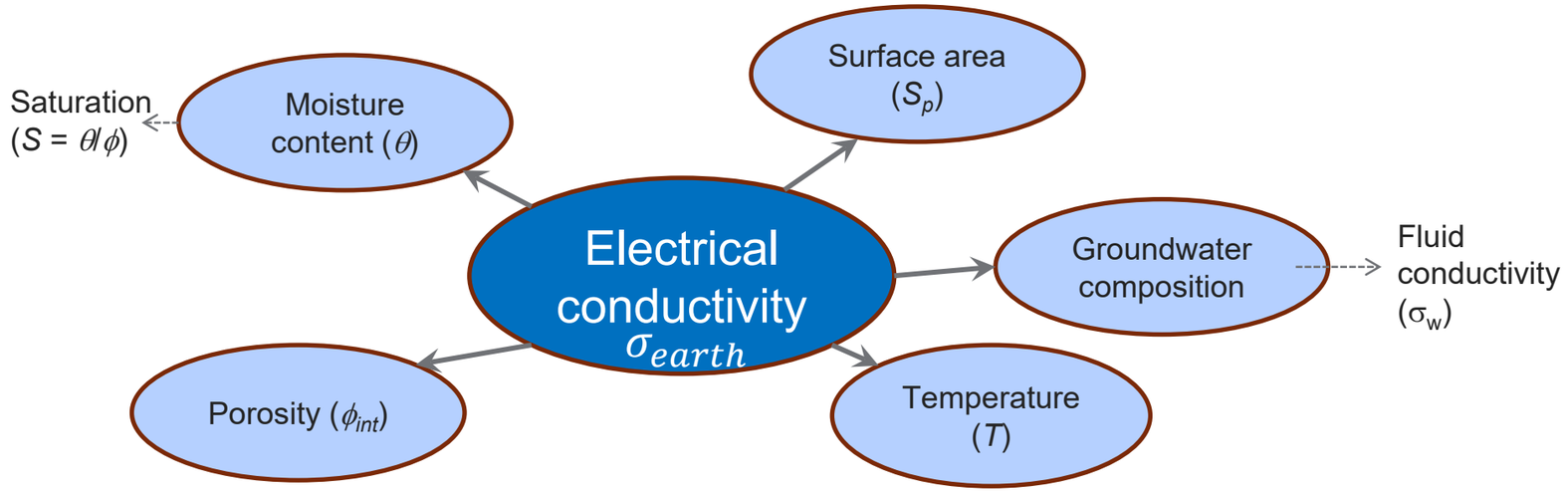


320 Electrode Data Collection System



Bulk Electrical Conductivity: Why It's Useful

- ERT images the electrical conductivity distribution of the subsurface
- Electrical conductivity is governed by several properties important to remediation performance



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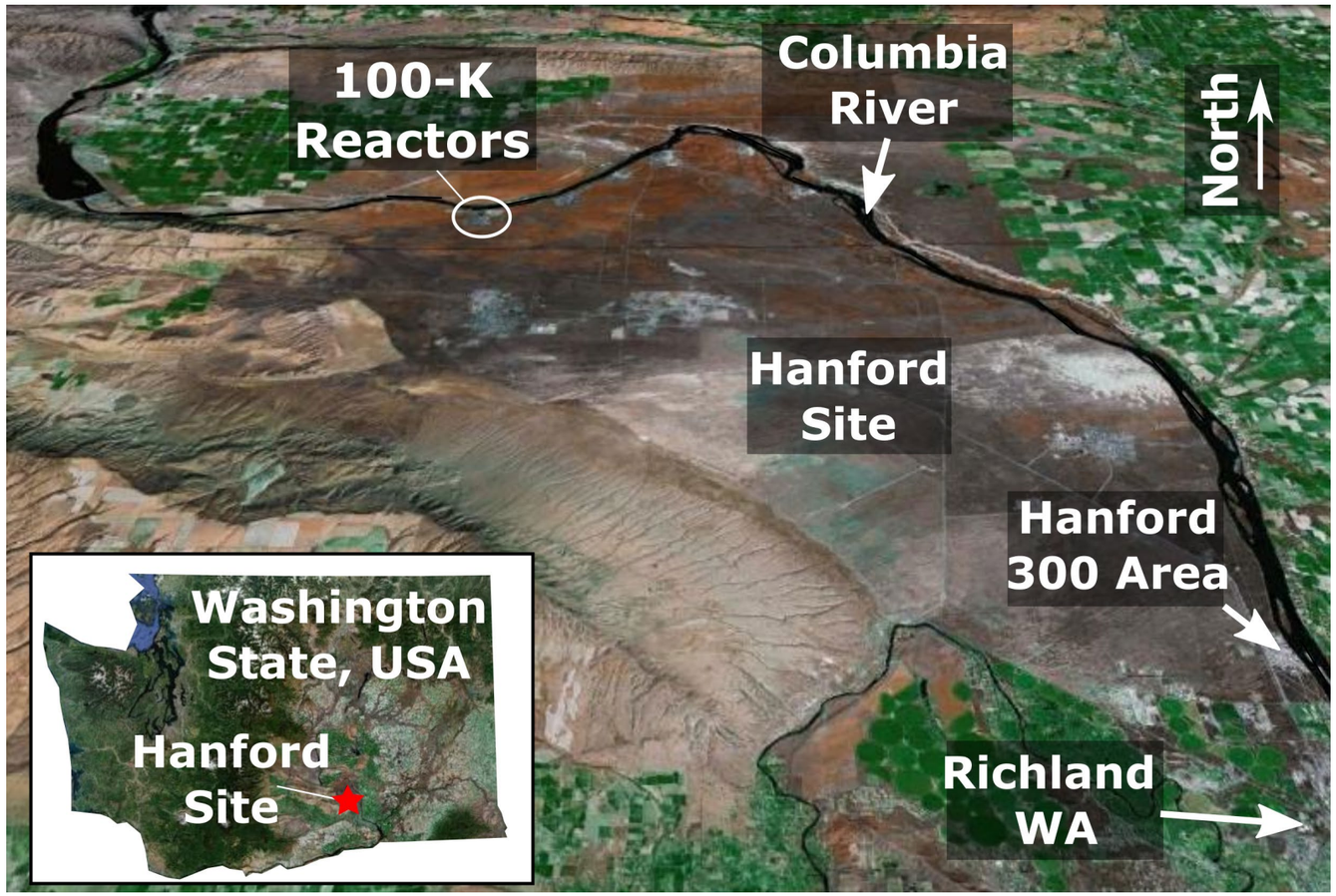
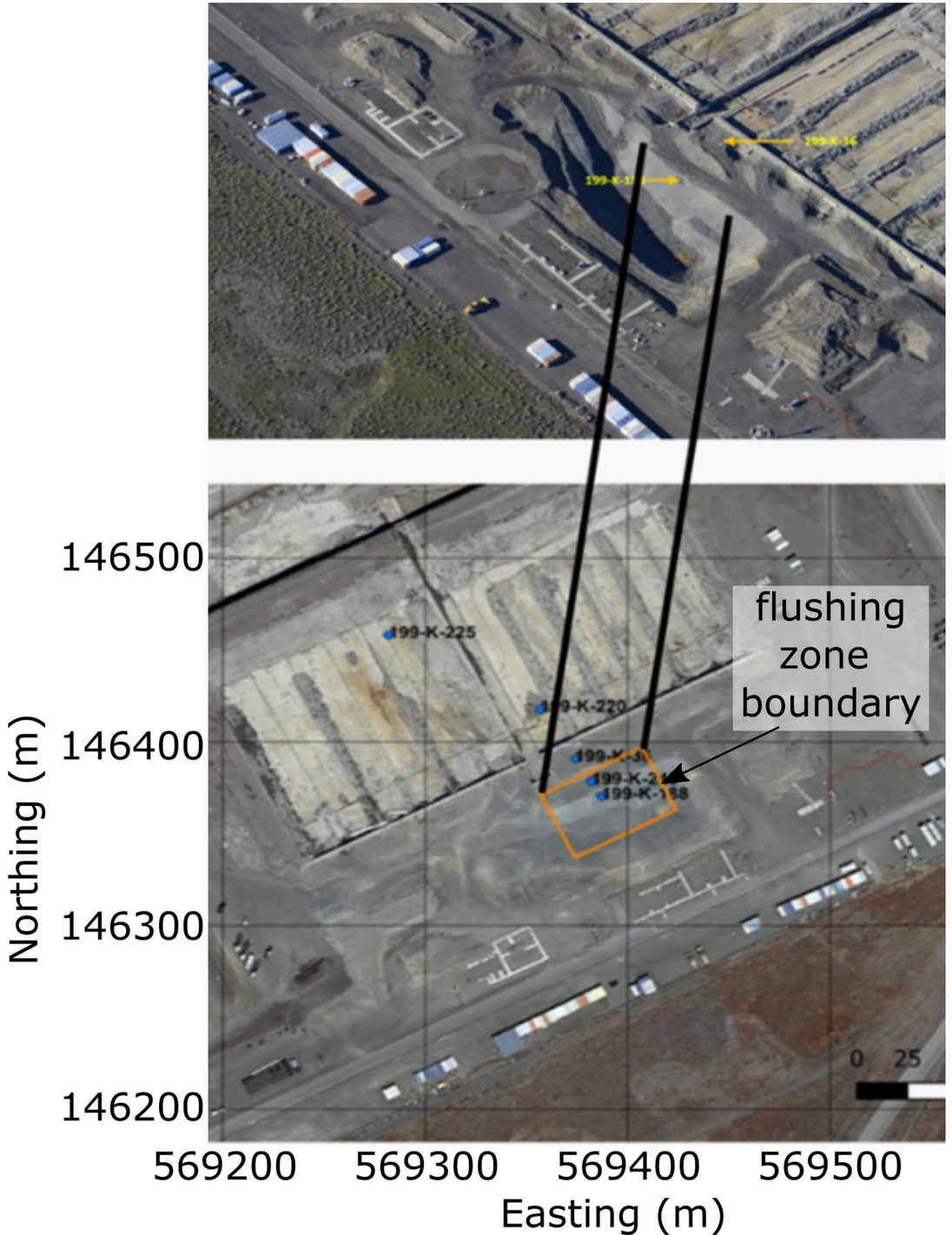
Hanford Site

- Produced plutonium for U.S. weapons production
- 9 production reactors
- 5 plutonium extraction facilities
- 212 million liters radioactive waste stored in tanks
- 1.7 trillion liters lower-level liquid waste discharged to ~100 m thick vadose zone
- Cleanup operations since late 1980's



100 K Chromium Source Term Remediation

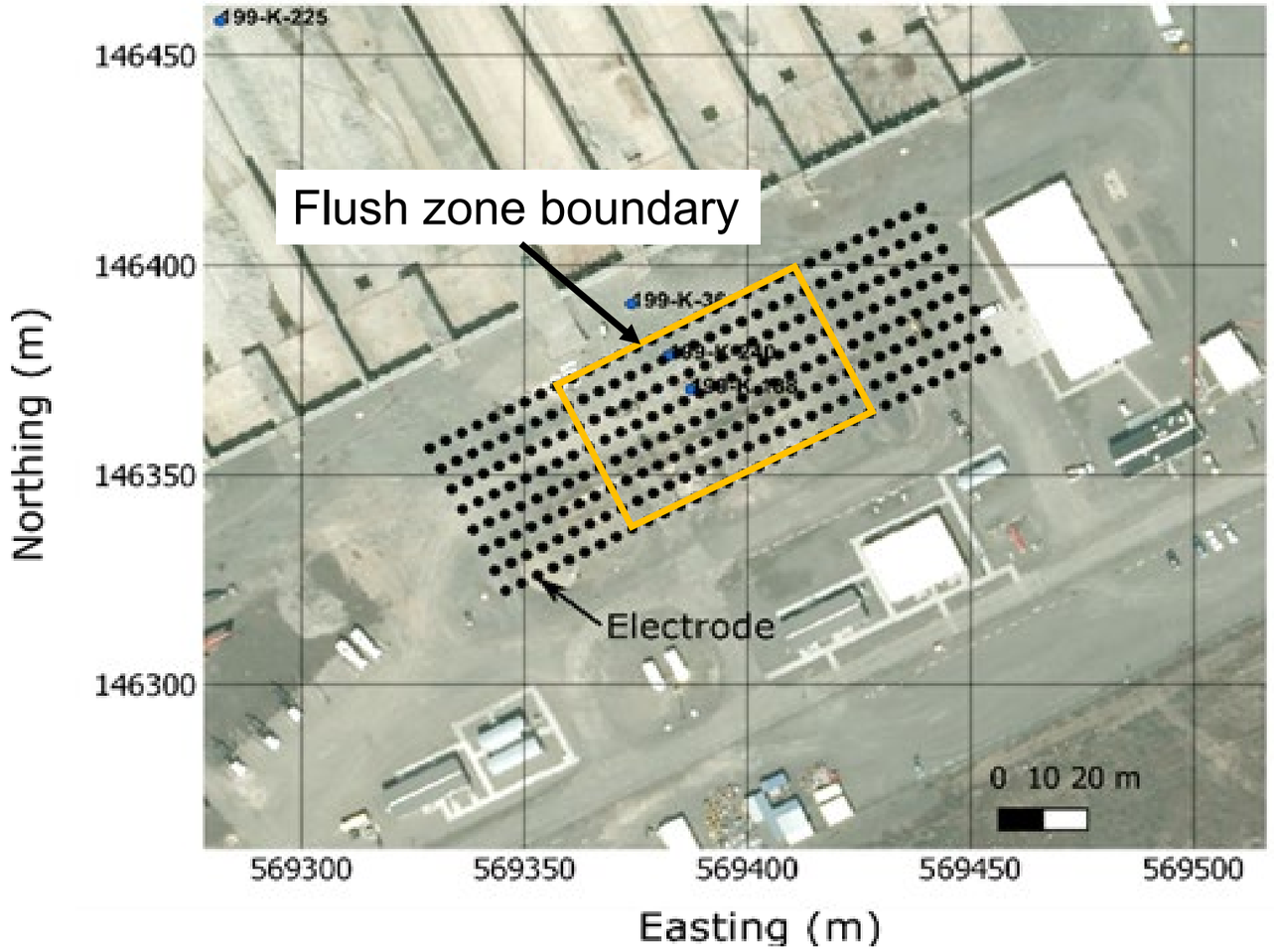
- Plan A: Excavate
  - Incomplete source removal
- Plan B: Soil Flushing
  - Backfill excavation pit
  - Apply clean water at surface to flush chromium to water table
  - Pump and treat



Surface ERT Monitoring Array

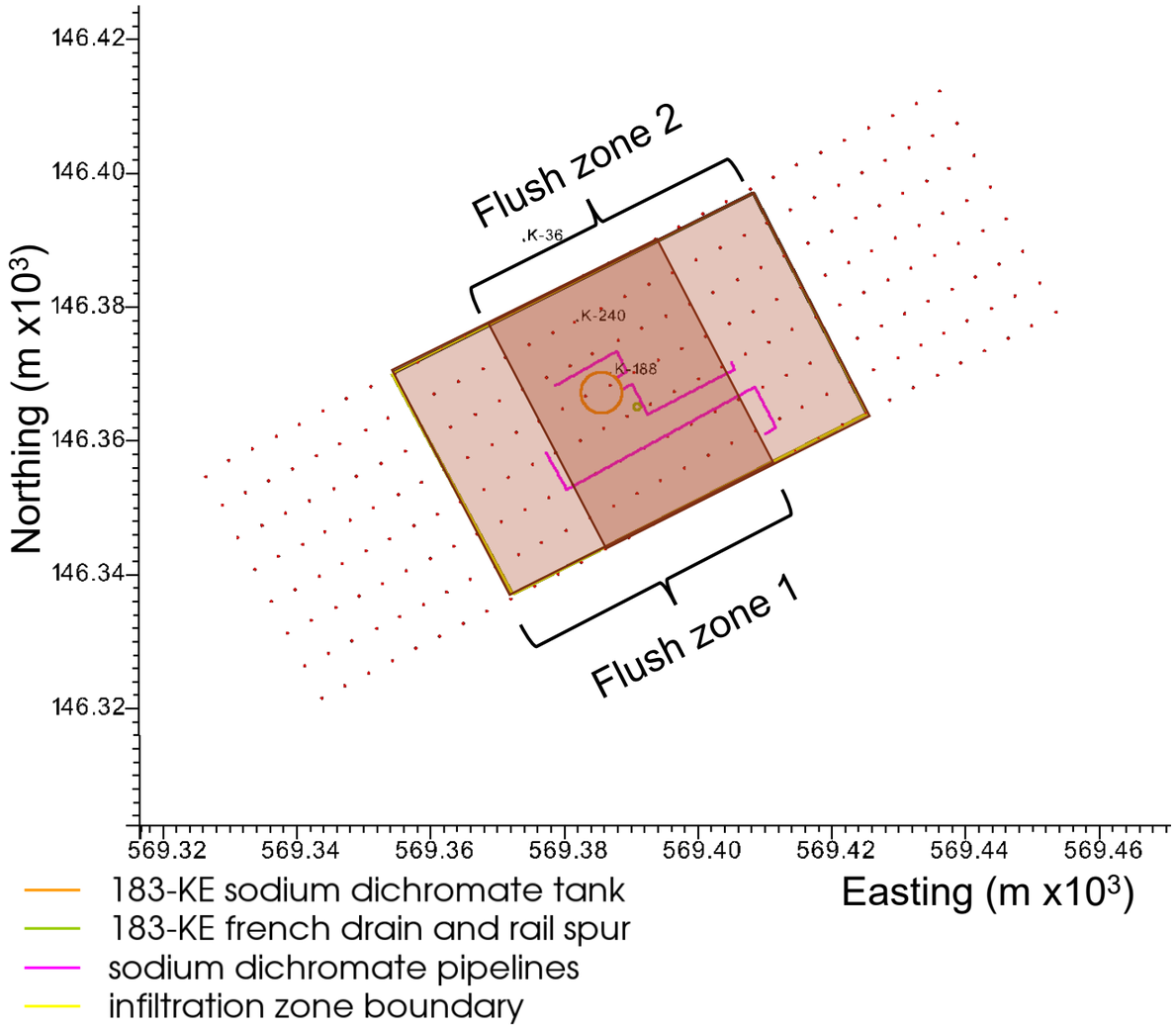
ERT Monitoring Array

- 8 lines (124 m / 407 ft long)
- 5.4 m between lines
- 4 m between electrodes
- 256 electrodes
- 3D acquisition
- Surveys every 2 hrs. for 3 months

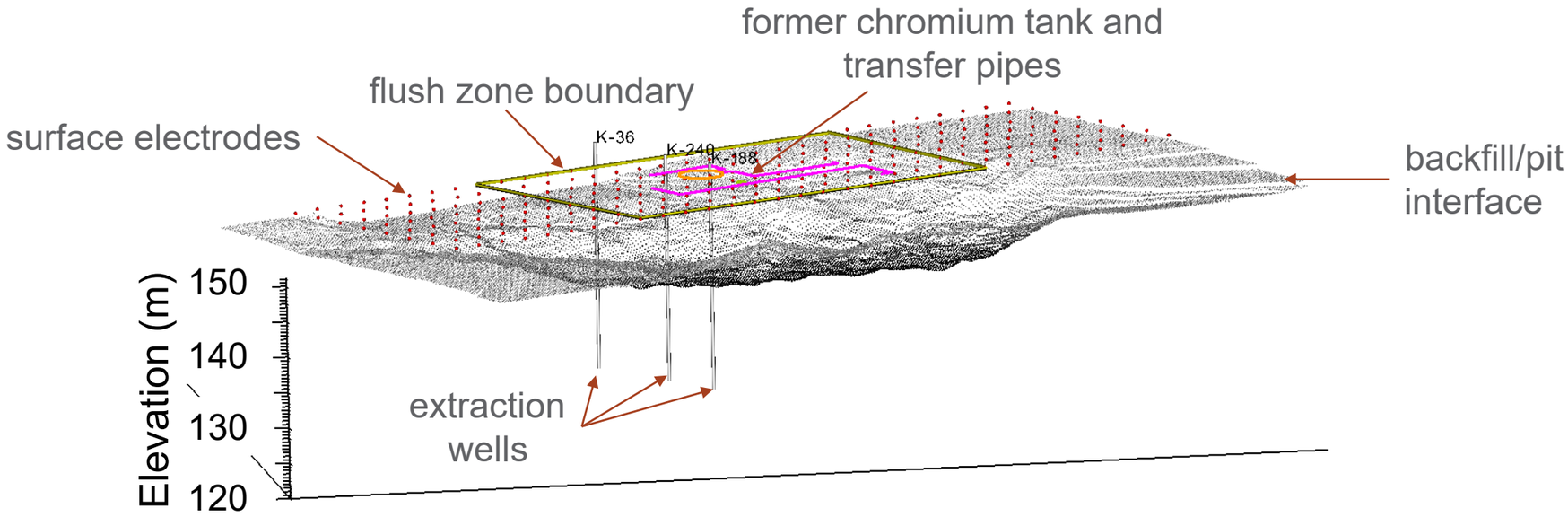


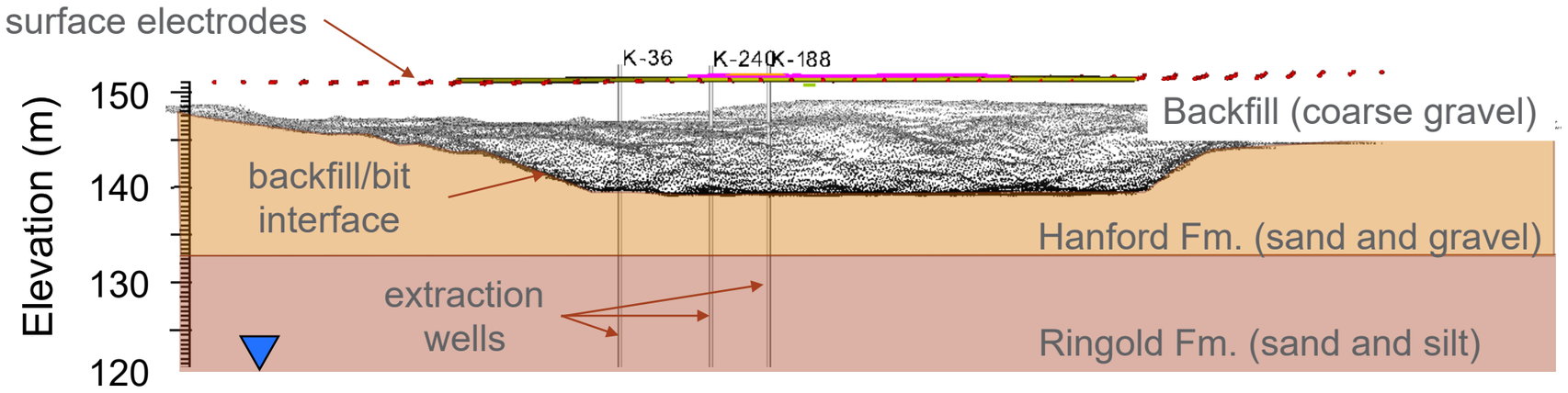
Flushing Operations

- Flush water application alternated weekly between zones 1 and 2
- Continuous application
- Started at 340 liters/min (90 gal/min)
- Increased to 454 liters/min (120 gal/min) over time



100 K Geology





Soil Flushing in Action …

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Real-Time 4D ERT Imaging Summary: April 2023

- 10 baseline (pre-flushing) data sets collected to assess data quality and set filter parameters
- 12 surveys/day
  - Autonomously transferred to offsite computing resources, processed, inverted, archived
- Posted to secure interactive website accessible to operators and stakeholders

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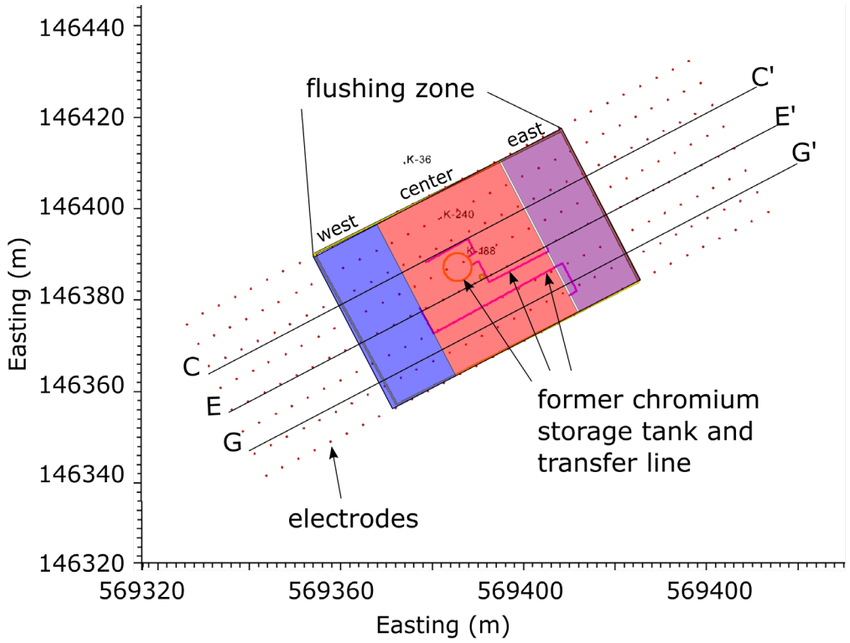
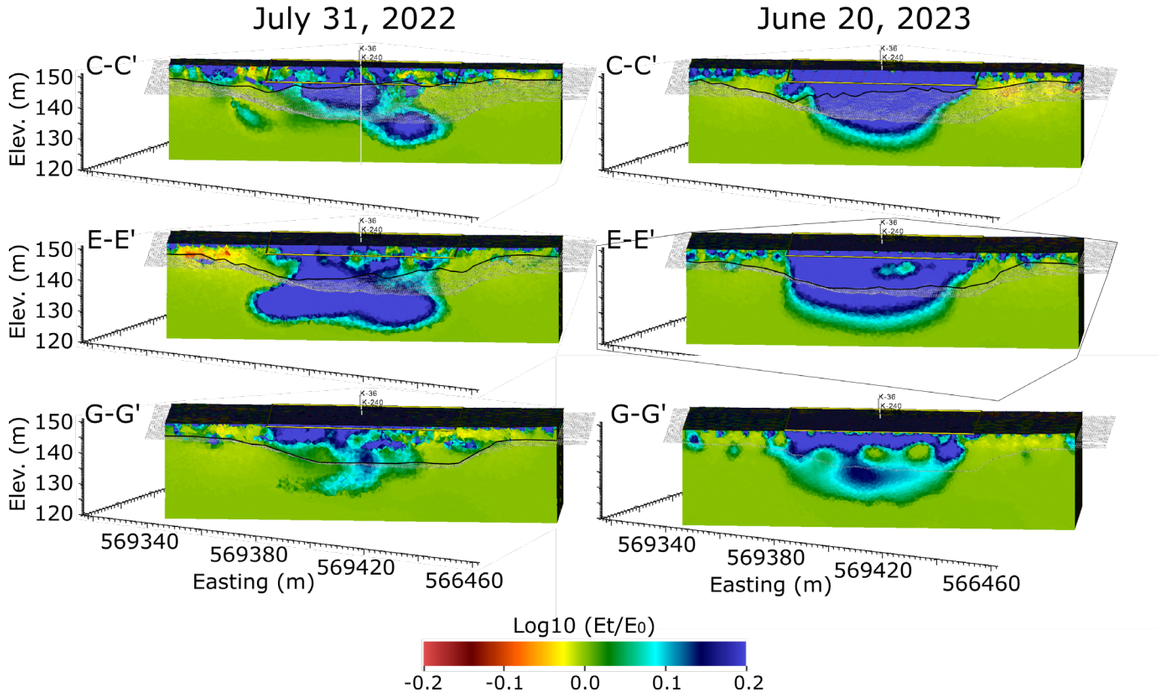
Real-time Visualization Web Interface

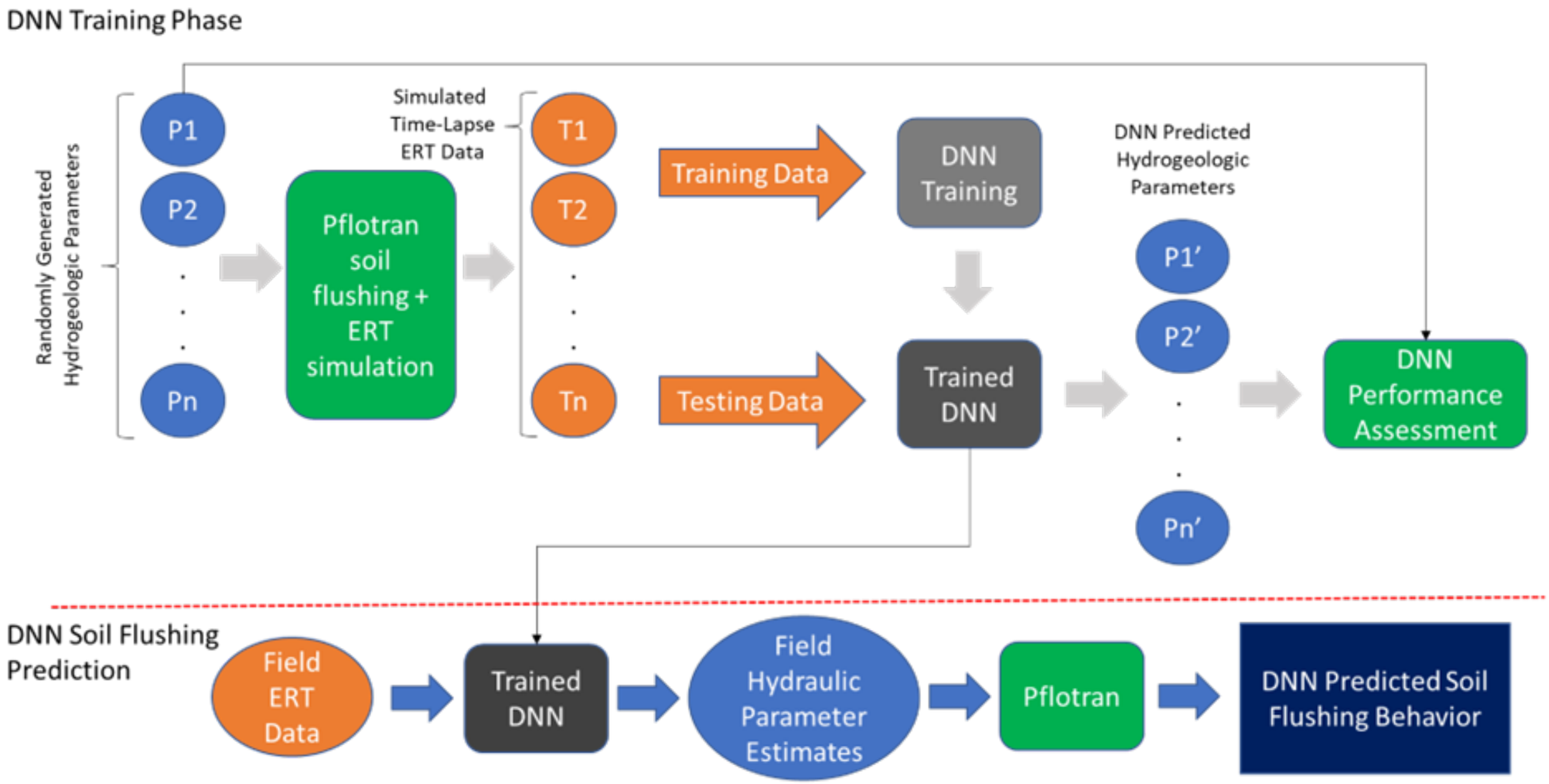
ERT Imaging Based Assessment Flush Water Delivery

- Larger flush water flow evident in 2023 compared to 2022
- Flush water migration impacted by interface between pit bottom and Hanford formation, geologic heterogeneity



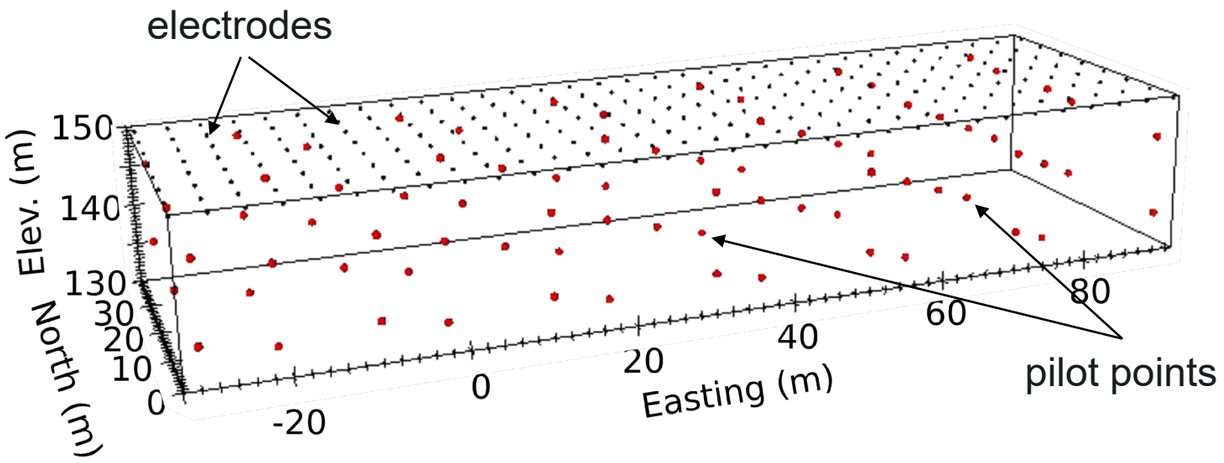


Deep Neural Network (DNN) Based Assessment



Pilot Point DNN Joint Inversion

- Hydrogeologic properties are ‘randomly’ chosen at pilot points
- Properties are kriged to computational mesh
- Parallel simulations produce ERT training data
- DNN is trained to interpret/invert field ERT to estimate pilot point properties



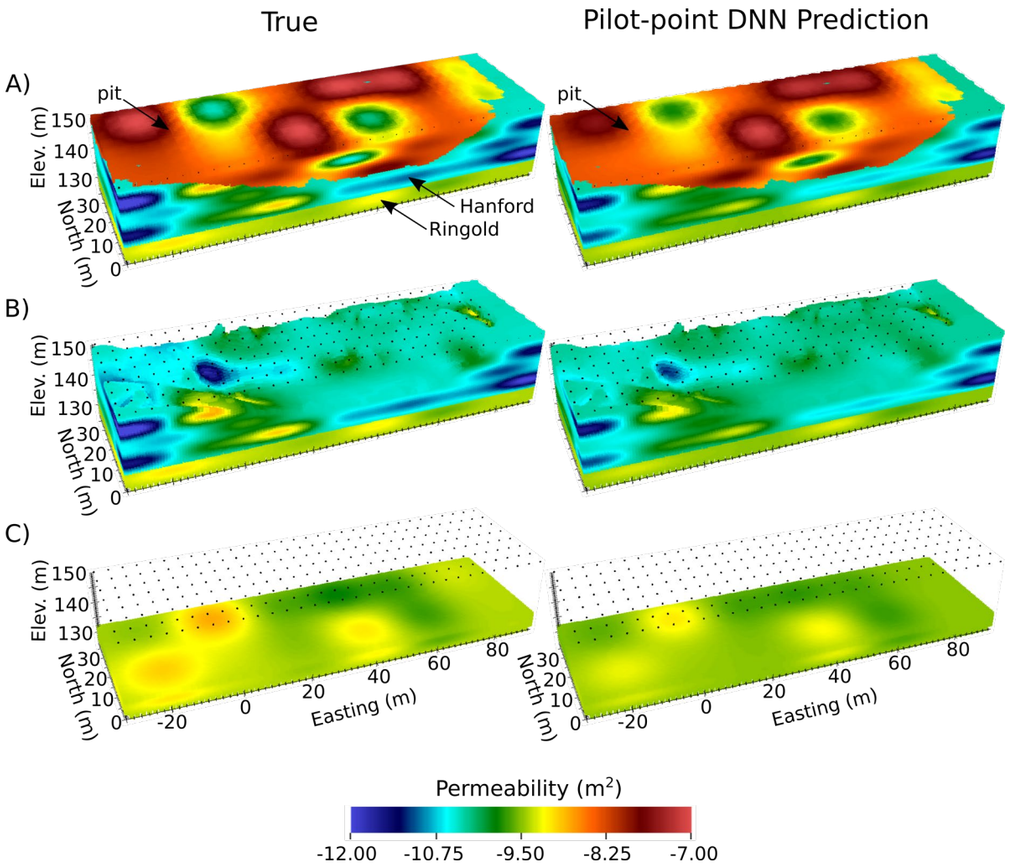
Training Data Generation

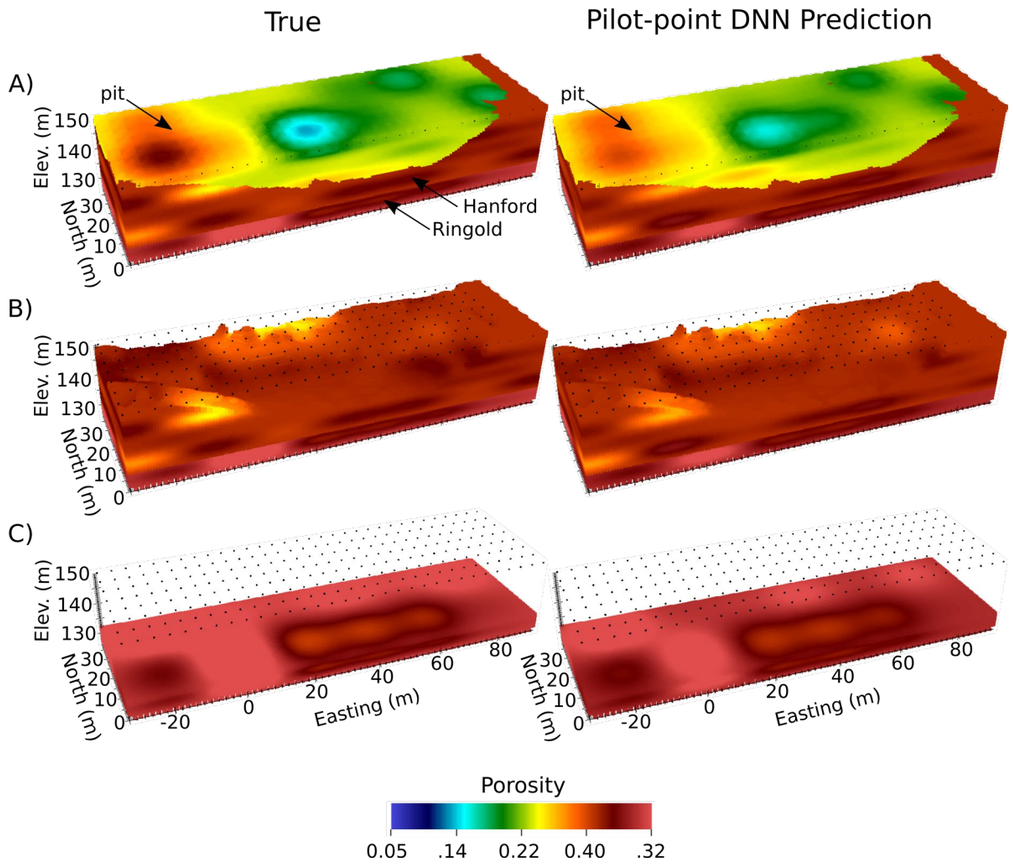
- 500 simulations
- 1 hr./simulation on 64 CPU’s
- 32,000 CPU-hours

DNN Training

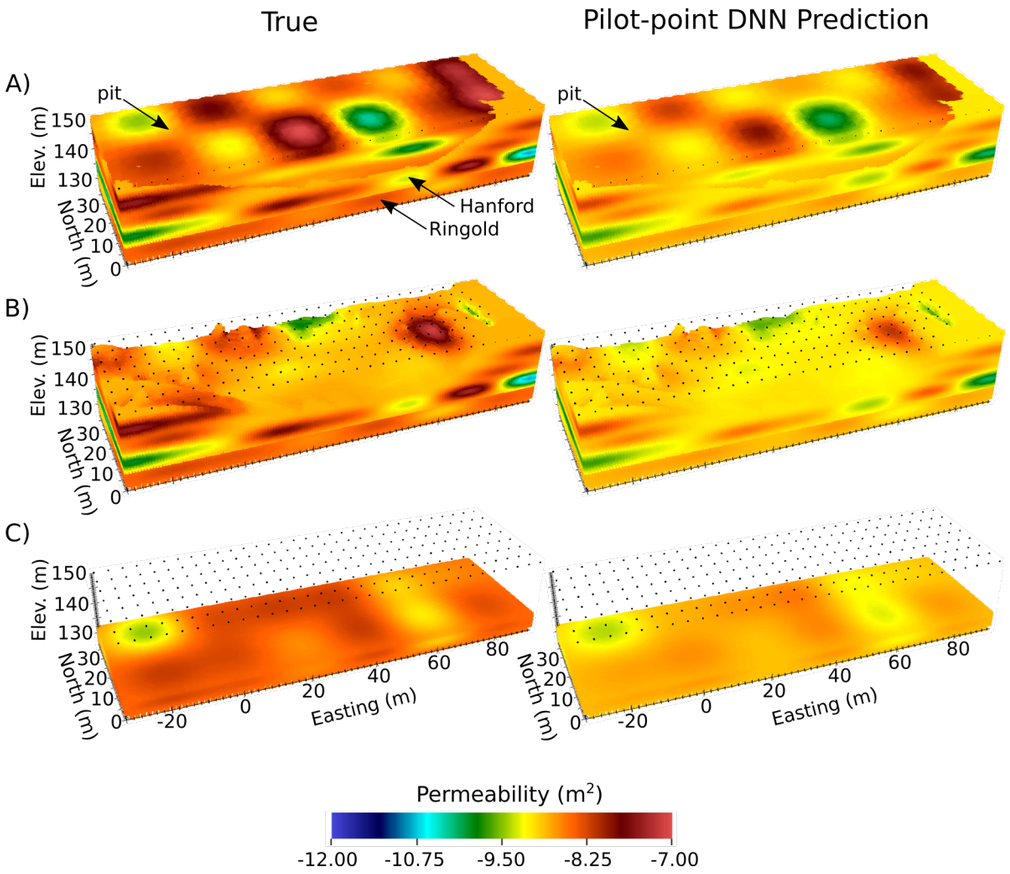
- Data compression ~30 minutes, 1 CPU
- DNN Training ~10 minutes on multi-core GPU

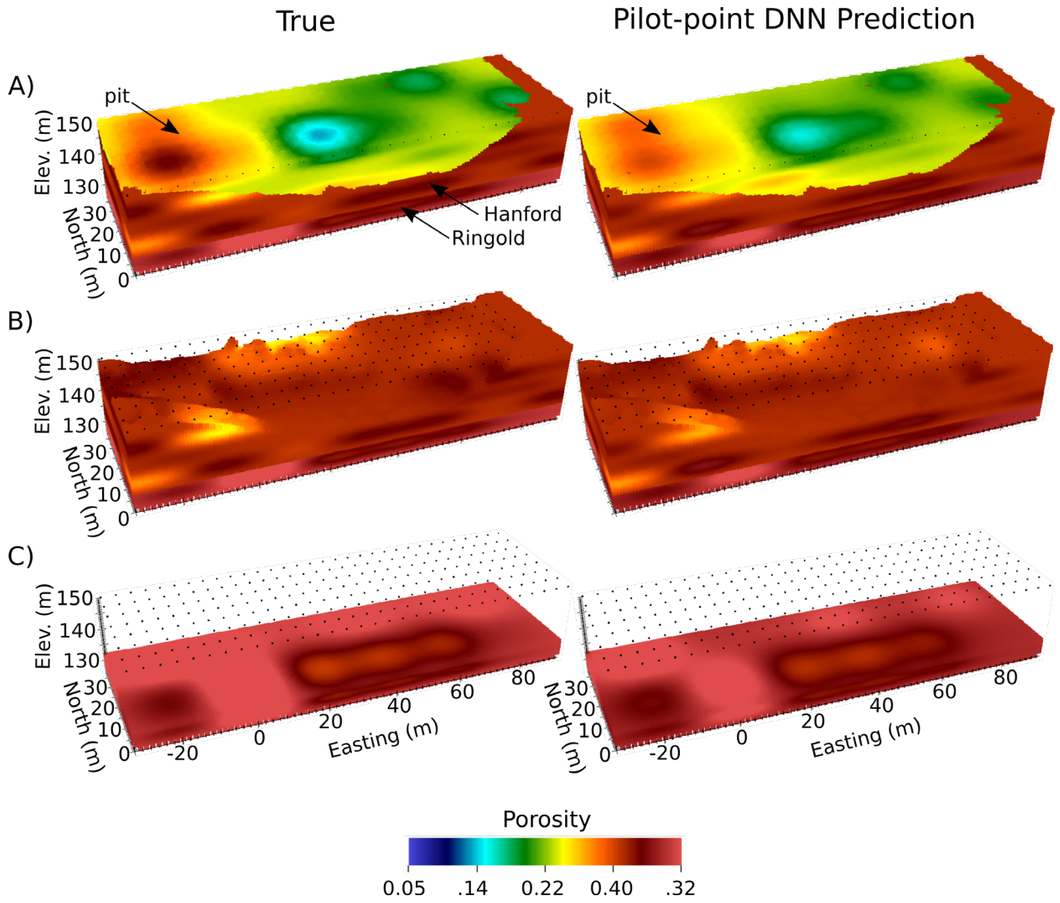
DNN Performance Test: Example 1





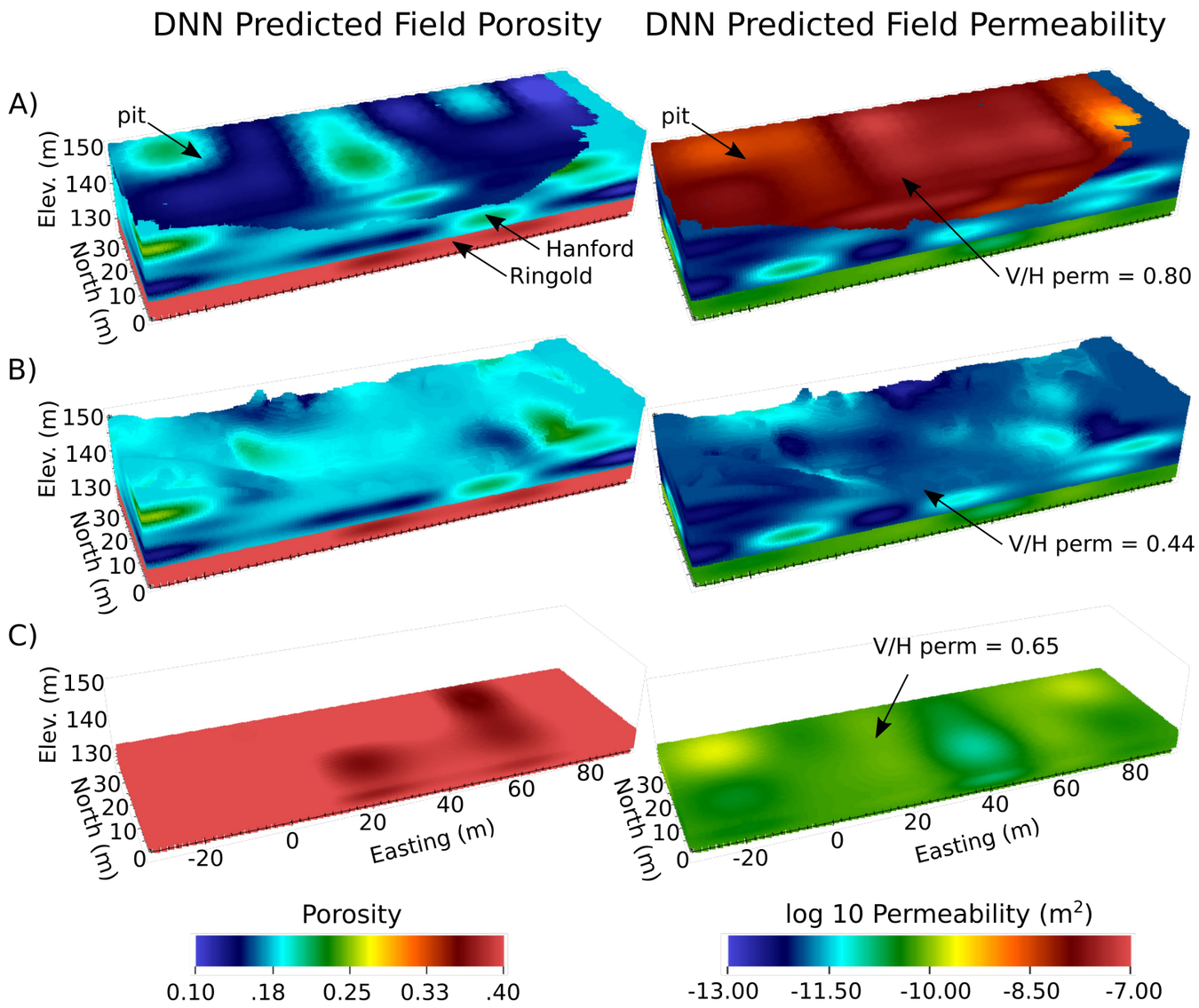
DNN Performance Test: Example 2





100 KE DNN Soil Property Prediction

- Consistent with laboratory derived published values
- Consistent with observed soil flushing behavior
- Enables enhanced analysis of soil flushing performance through simulation (to-do)



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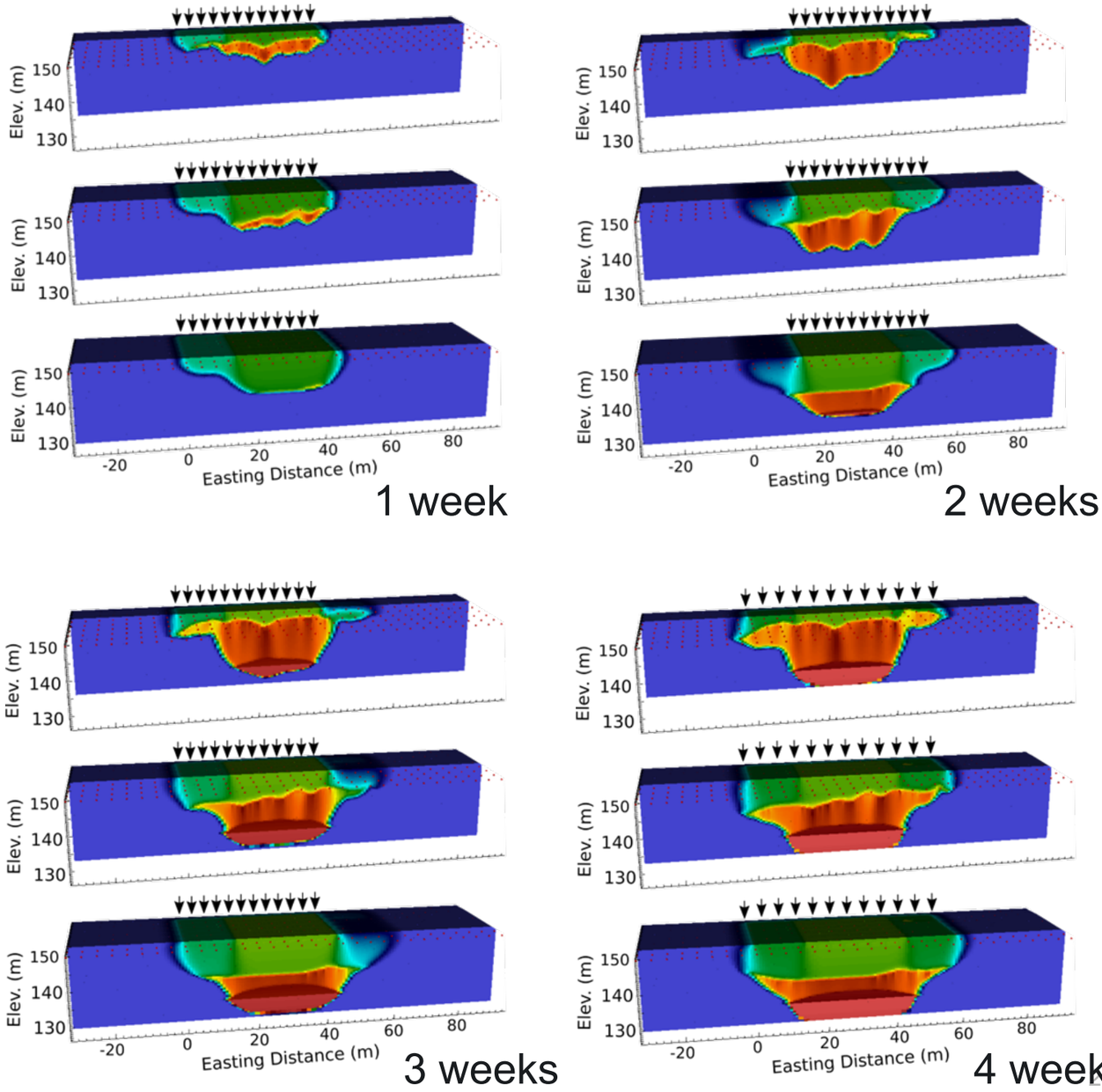
Summary

- Rich hydrogeologic information in time-lapse ERT data
- Information extraction enabled by:
  - Multiphysics HPC
  - Machine learning
- ML enabled ‘joint inversion’ to significantly improve subsurface process monitoring and understanding

Simulated Change in Saturation Based on DNN-Estimated Soil Properties



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Thank you