2023 International Symposium on Bioremediation and Sustainable Environmental Technologies
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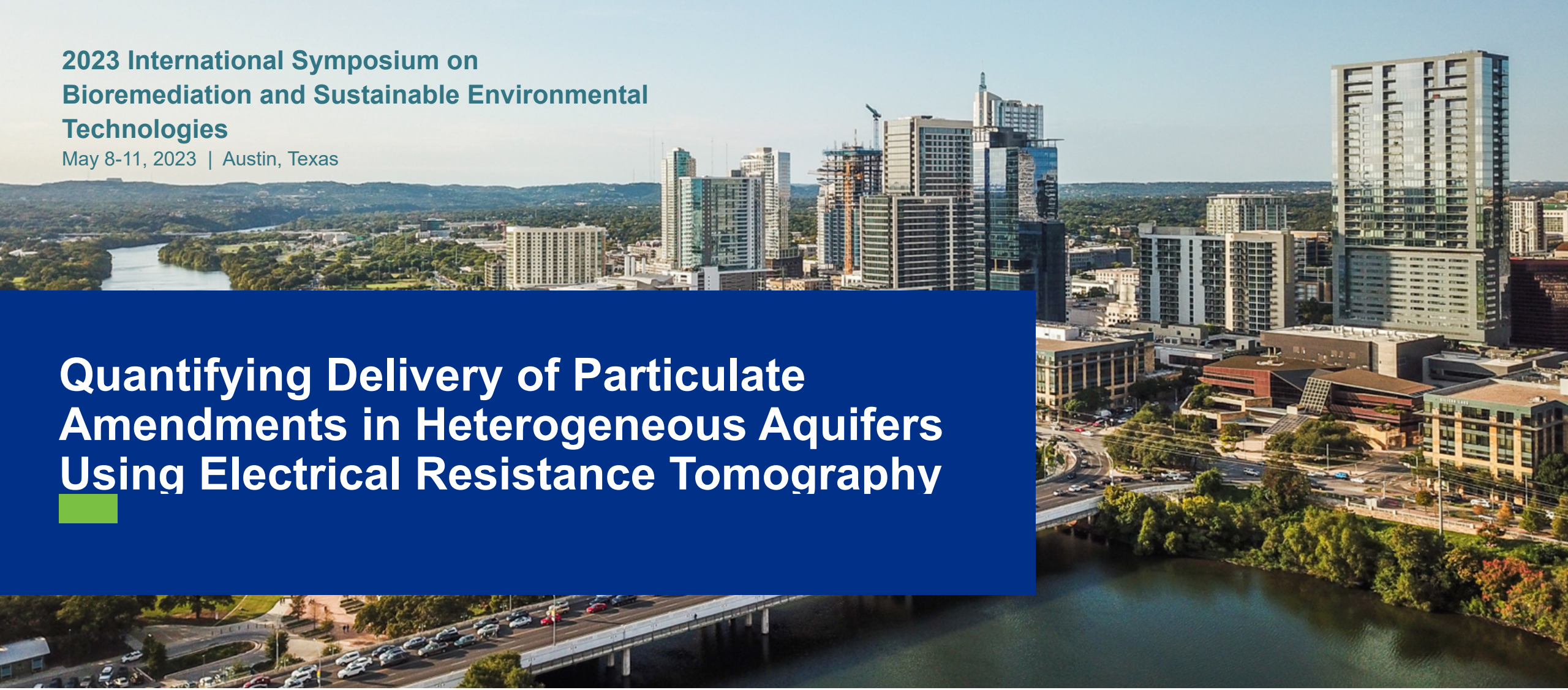

Quantifying Delivery of Particulate Amendments in Heterogeneous Aquifers Using Electrical Resistance Tomography

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CDM Smith

Technical Objectives

Overall: (1) improve the technical understanding of how activated carbon (AC) particles are distributed in the subsurface and (2) assess the performance of time-lapse electrical resistivity tomography (ERT) for three-dimensional (3D) remote monitoring of AC amendment emplacement

Product	Property	AC Particle Size [µm]	Target Contaminant	Vendor	Applicable Delivery Method
BOS 100®	GAC impregnated by ZVI	< 250	Chlorinated solvents	Remediation Products, Inc.	Trenching, soil mixing, **fracturing**
COGAC™	GAC mixed with calcium peroxide and sodium persulfate	2-10	Chlorinated solvents or petroleum hydrocarbons	Remington Technologies, LLC	DPT injection, **direct injection**, soil mixing, trenching, fracturing
PlumeStop®	Colloidal AC suspension with an organic stabilizer	1-2	Chlorinated solvents petroleum hydrocarbons; PFAS	REGENESIS, Inc.	DPT injection

Quantitative Performance Objectives #1

Objective

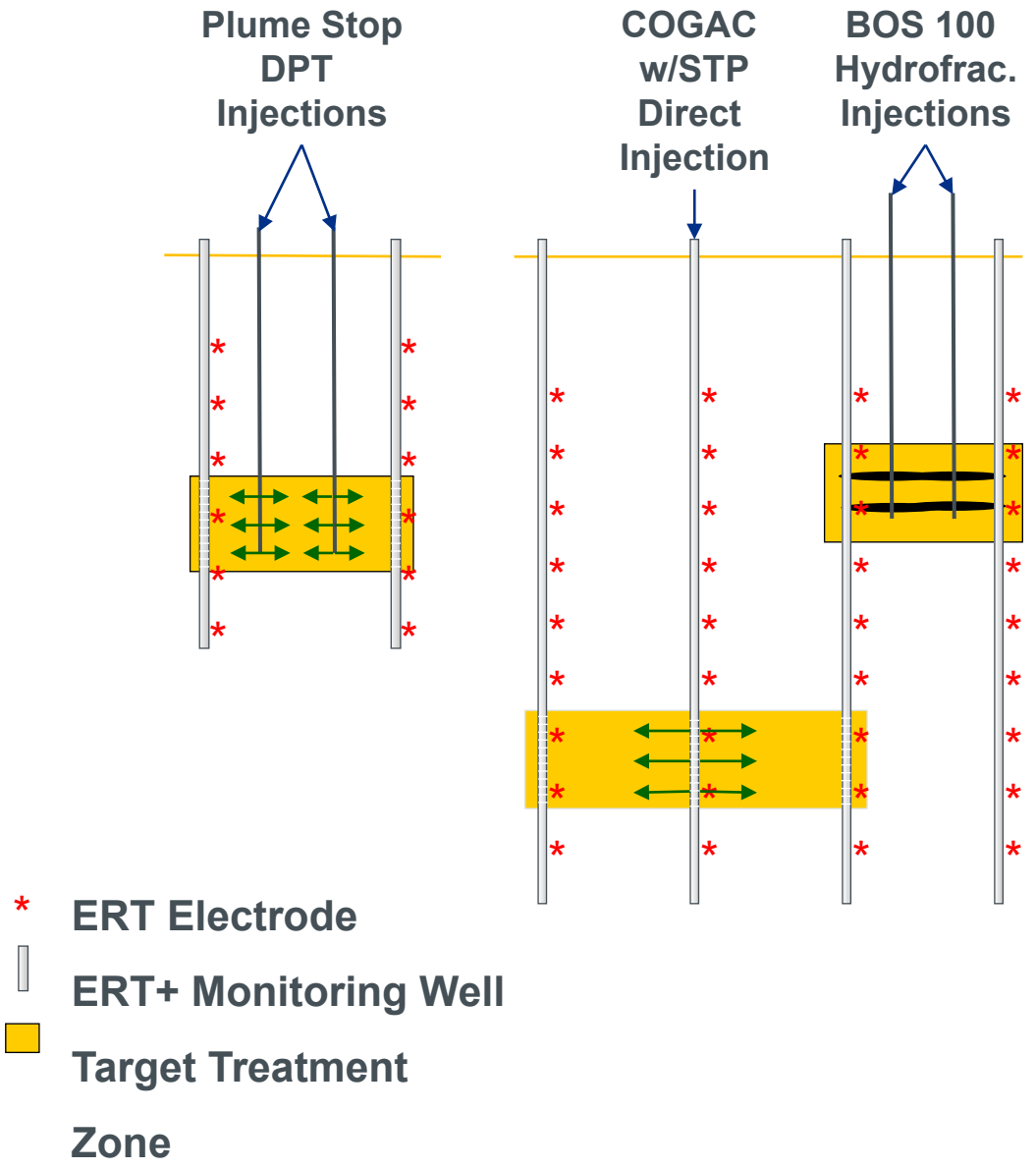
- Deliver target injection mass loading and distribution of AC for the three injection methods **(Tests 1-3).**

Data

- Baseline and Time-lapse ERT
- Monitoring well sampling
- Post-treatment coring

Metrics

- Deliver at least 75% of the target AC mass within the treatment volume of interest.



Quantitative Performance Objectives #2

Objective

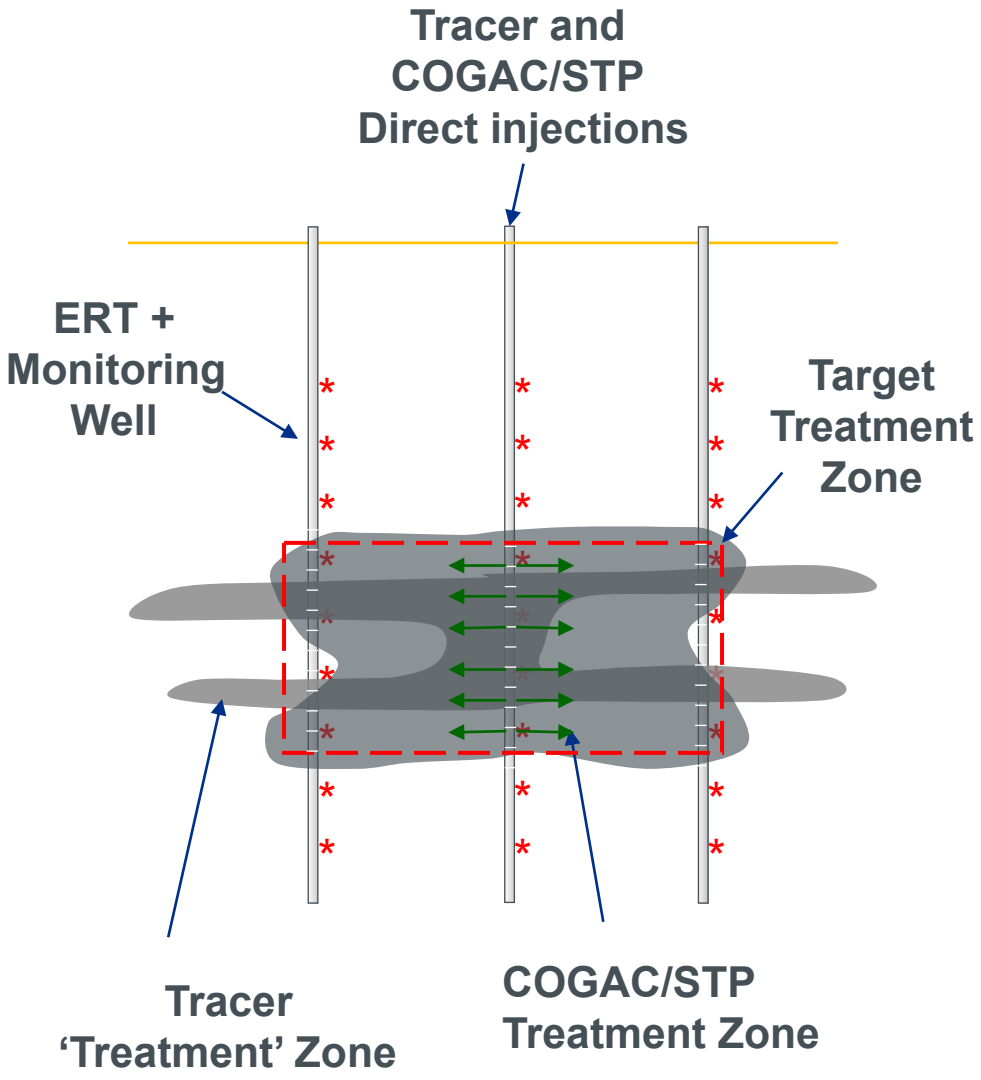
- Quantify improved AC amendment sweep efficiency with shear thinning polymer **(STP, Test 2)**

Data

- Baseline and time-lapse ERT non-reactive tracer
- Baseline and time-lapse ERT with STP and COGAC
- Groundwater sampling before, during after tracer and STP/COGAC injections

Metrics

- Enhance apparent effective injection porosity by 30% or more



Qualitative Performance Objectives #1

Objective

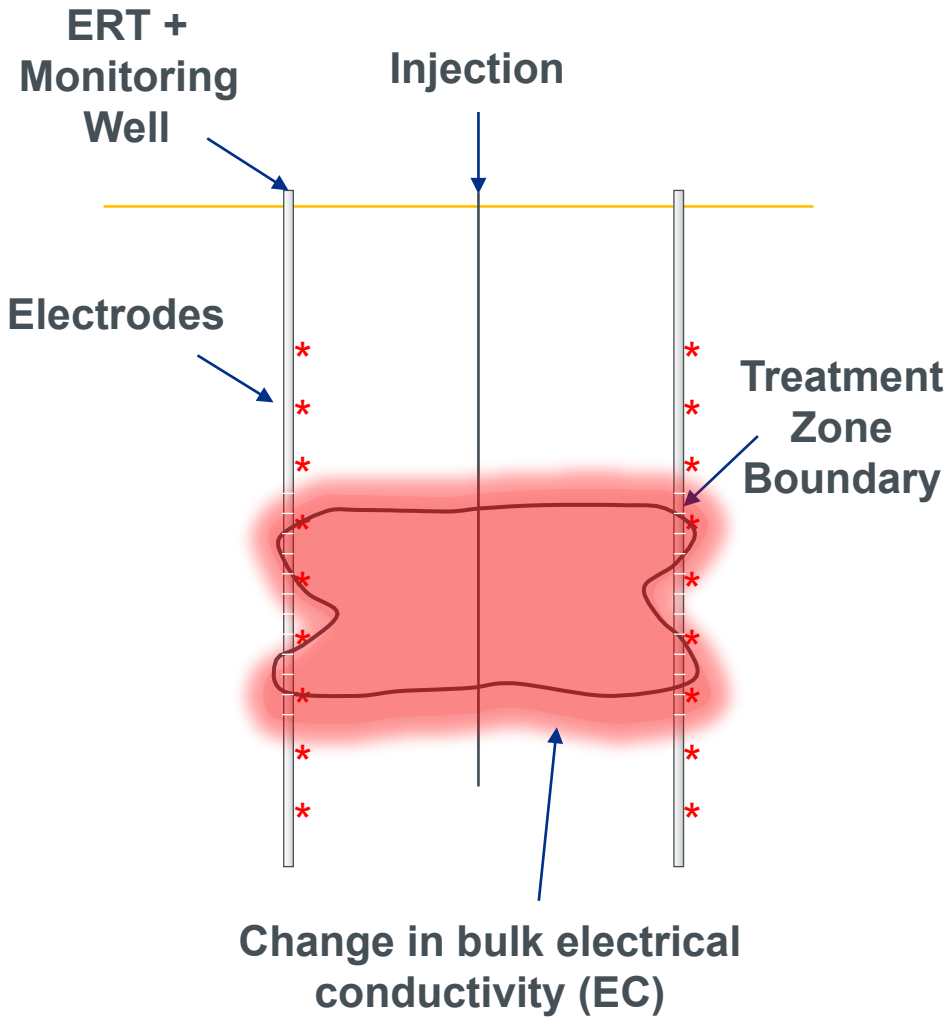
- Evaluate the effectiveness and accuracy of ERT to image the distribution of AC particulate amendment **(Tests 1-3).**

Data

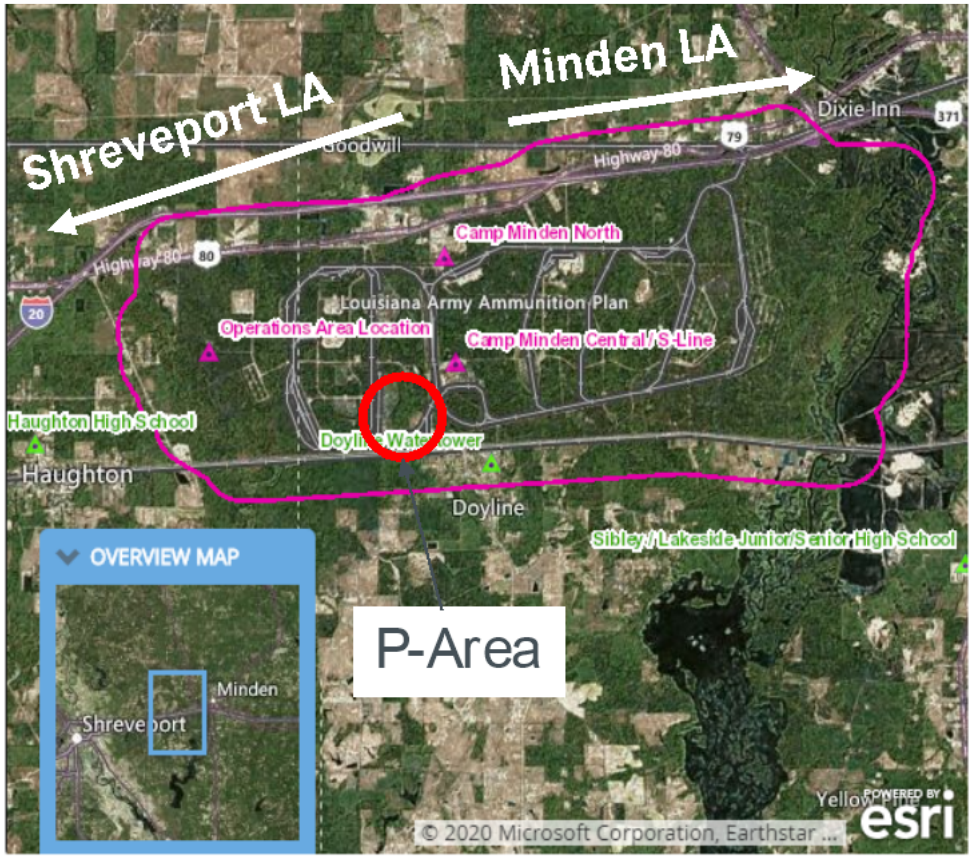
- ERT imaging results before, during and after injections
- Baseline and post-injection soil cores
- Baseline and post-injection groundwater sampling

Metrics

- Positive correlation between the increase in EC and the presence of AC and/or AC indicators at sample points



Site Description

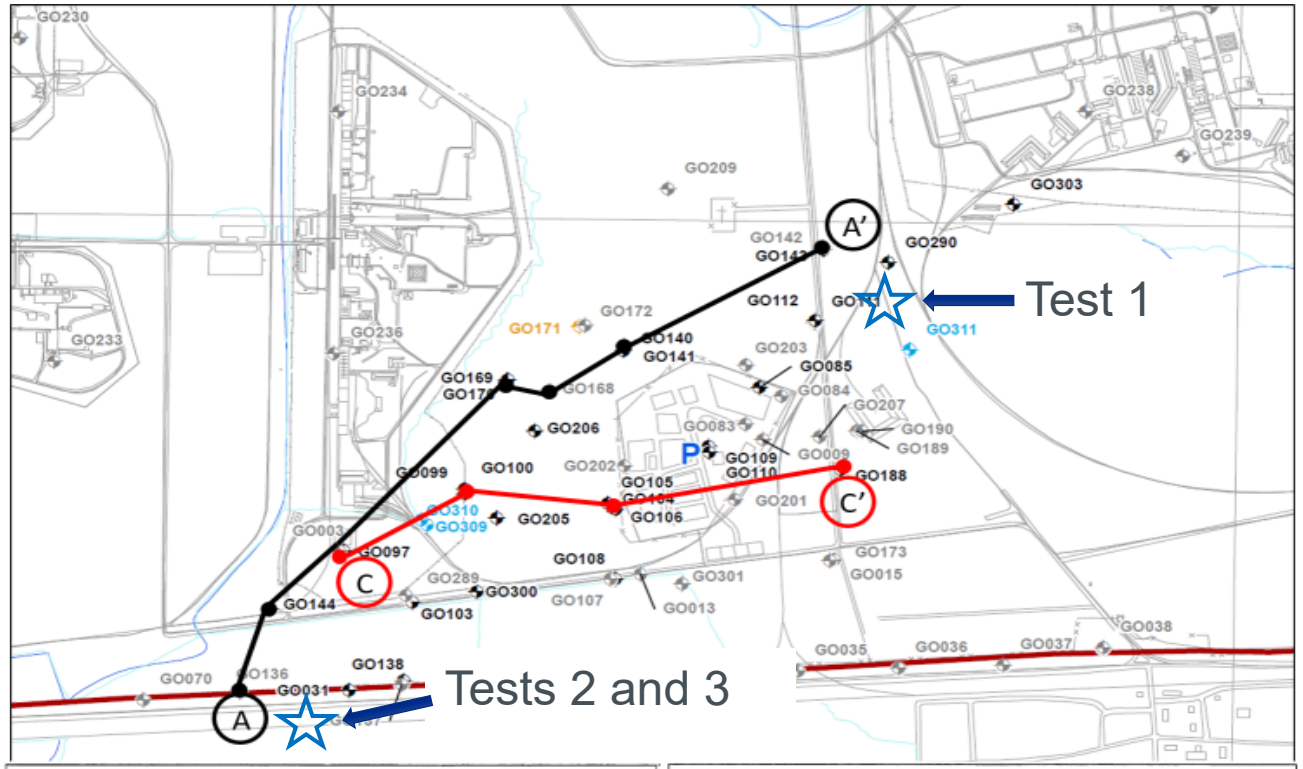


Camp Minden LA

- **Former munitions facility**
- **Current National Guard and correctional facility**
- **COCs:**
  - TNT, RDX, PCE
- **Geology suitable for both fracturing (hard clays) and direct AC injection (sand/silts) demonstrations**

Site Geology: P-Area

- Low to high plasticity clay, 10-20 feet thick suitable for fracture-based AC injection
- Sand, silty sand 15-20 feet thick, marginally suitable for direct AC injection



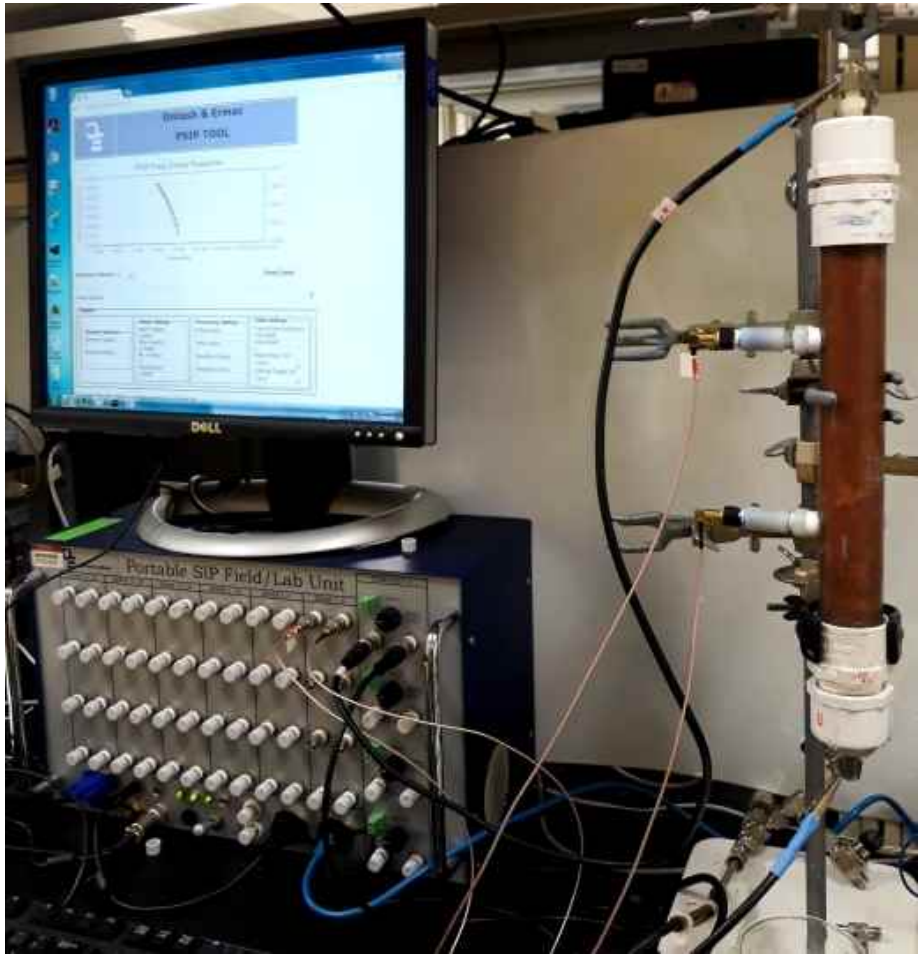
Test Cell Installations

Performance Assessment

From Go-No/Go Assessment:

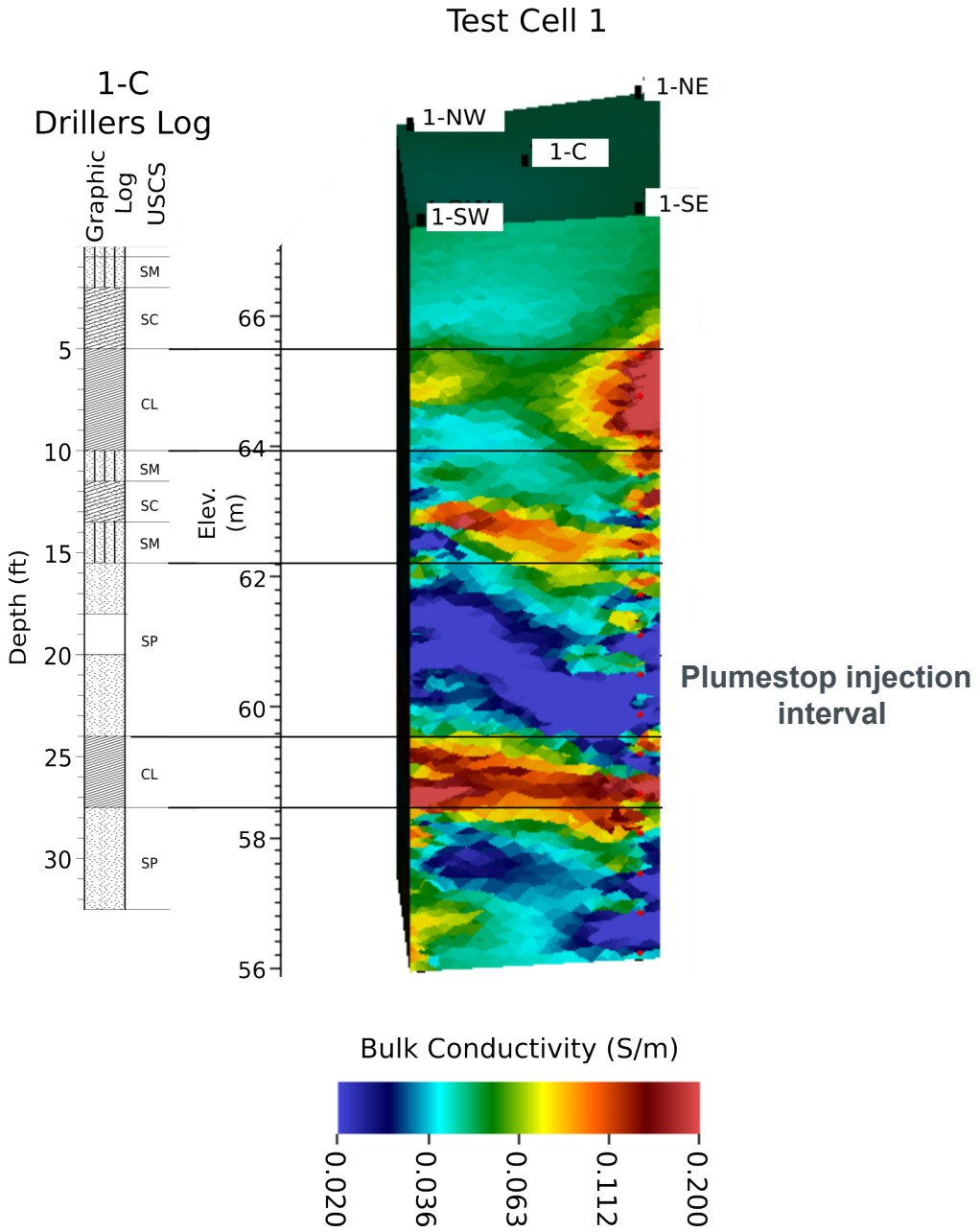
- BOS-100 ERT feasibility highly dependent on clay electrical conductivity
- Jan. 2021, clay conductivity measured
- Clay conductivity ~0.15 S/m
  BOS-100 Conductivity ~ 20 S/m
- Favorable for effective ERT imaging of BOS-100 emplacement

Bulk Electrical Conductivity Measurement of Camp Minden Clay

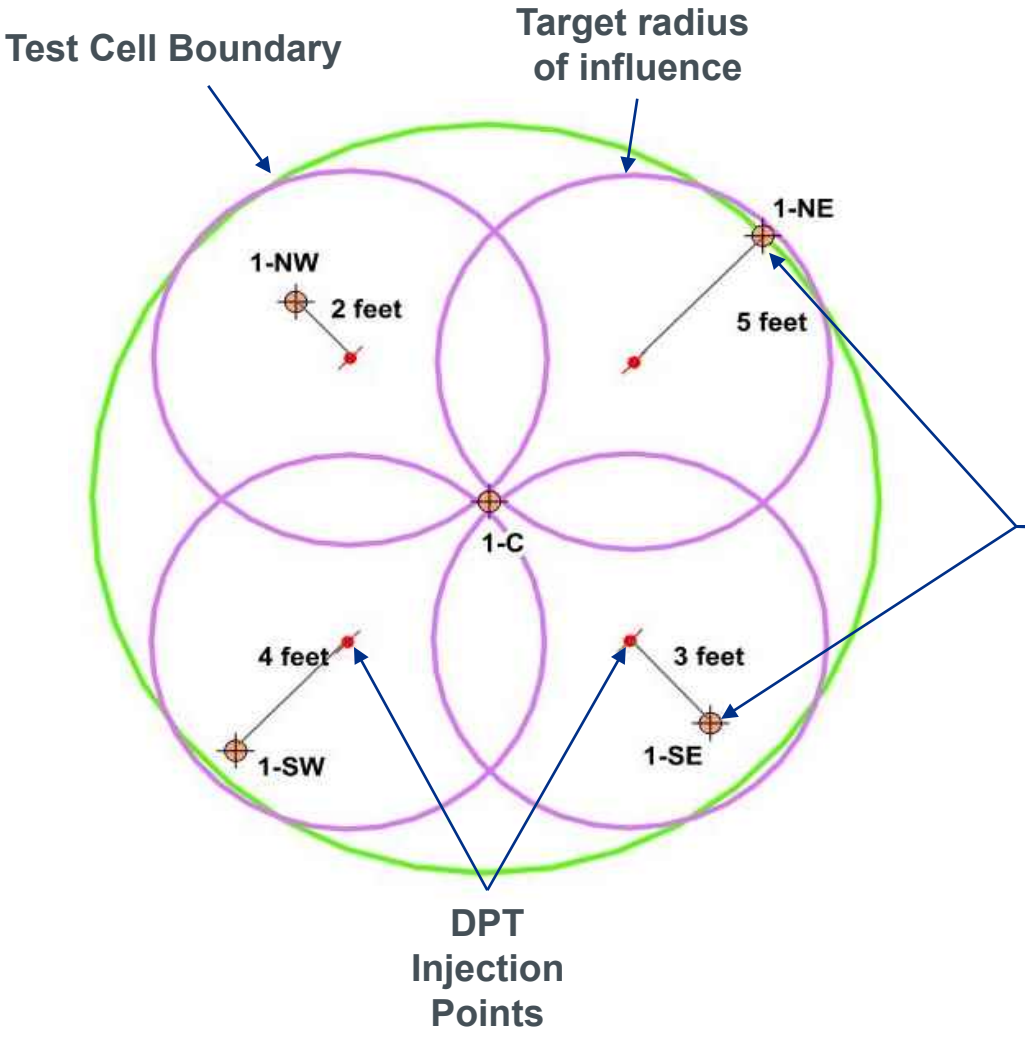


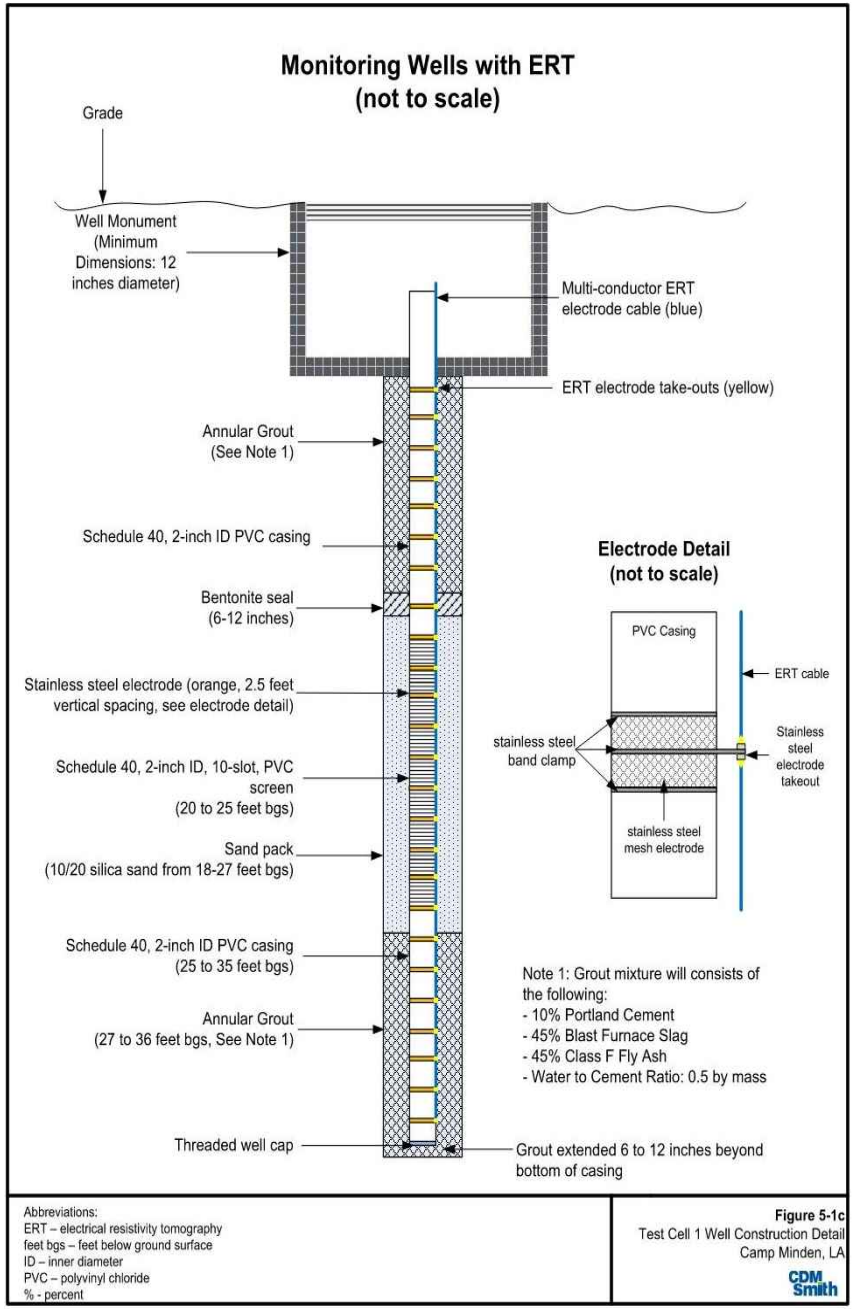
Test Cell 1 Baseline Imaging

- **Baseline ERT consistent with 1-D drillers log.**
  - Higher conductivity corresponds to a clay-rich zone
  - Lower conductivity corresponds to sandy zones



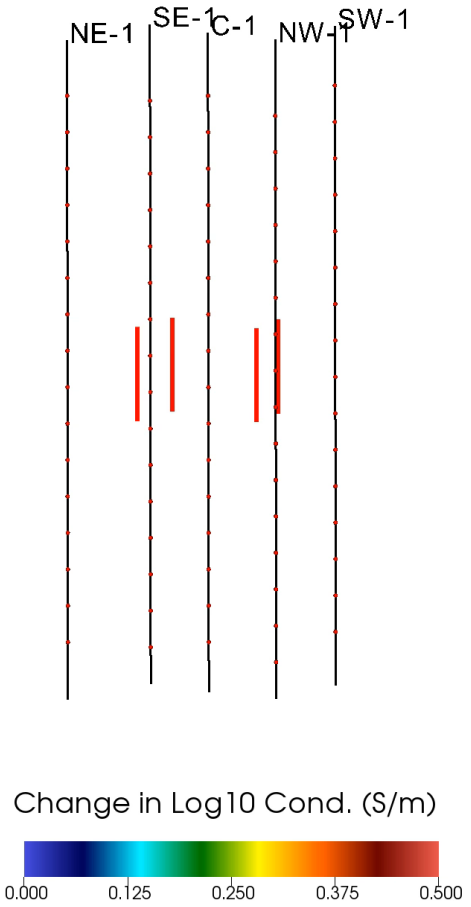
Test 1 Design (PlumeStop DPT Injection)



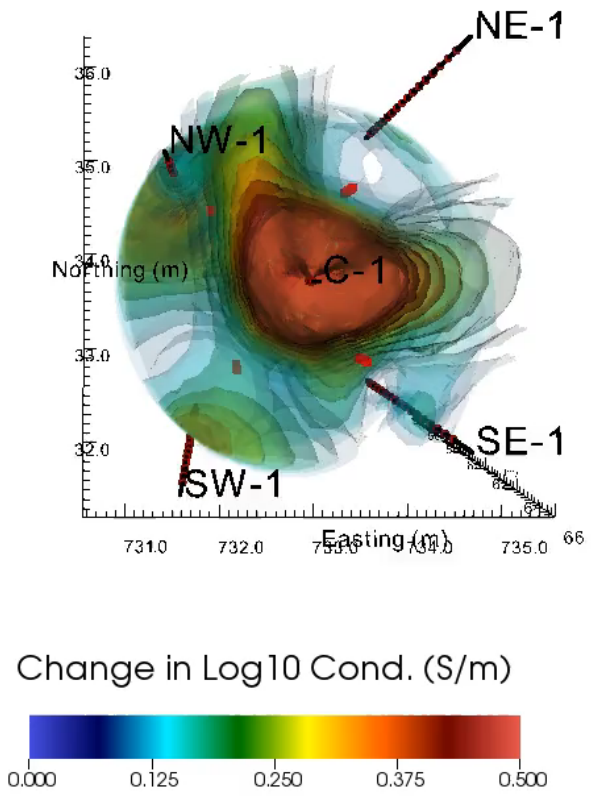


Test Cell 1 Plumestop Injection Imaging

Real-time 4D Imaging Results

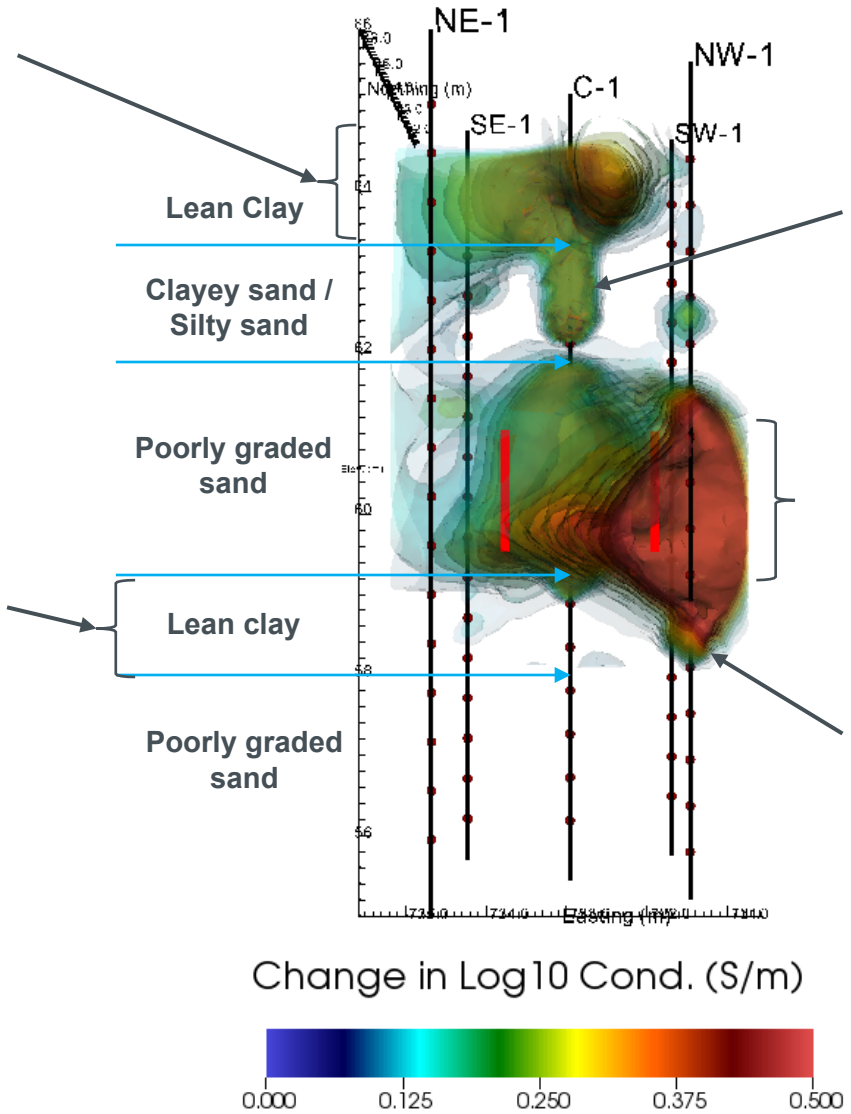


Final Image Fly-around View



Plumestop Injection Interpretation

Lateral spreading of AC in unit marked as lean clay in C-1 geologic log suggest relatively high permeability in this unit. Baseline ERT image shows horizontally discontinuous high conductivity, suggesting the presence of coarser grained materials in addition to lean clay.



Poor grout seal in C-1 enabled upward migration of AC through annulus. Presumably low-permeability sediments contain AC to annulus.

Good (not great) coverage in target zone.

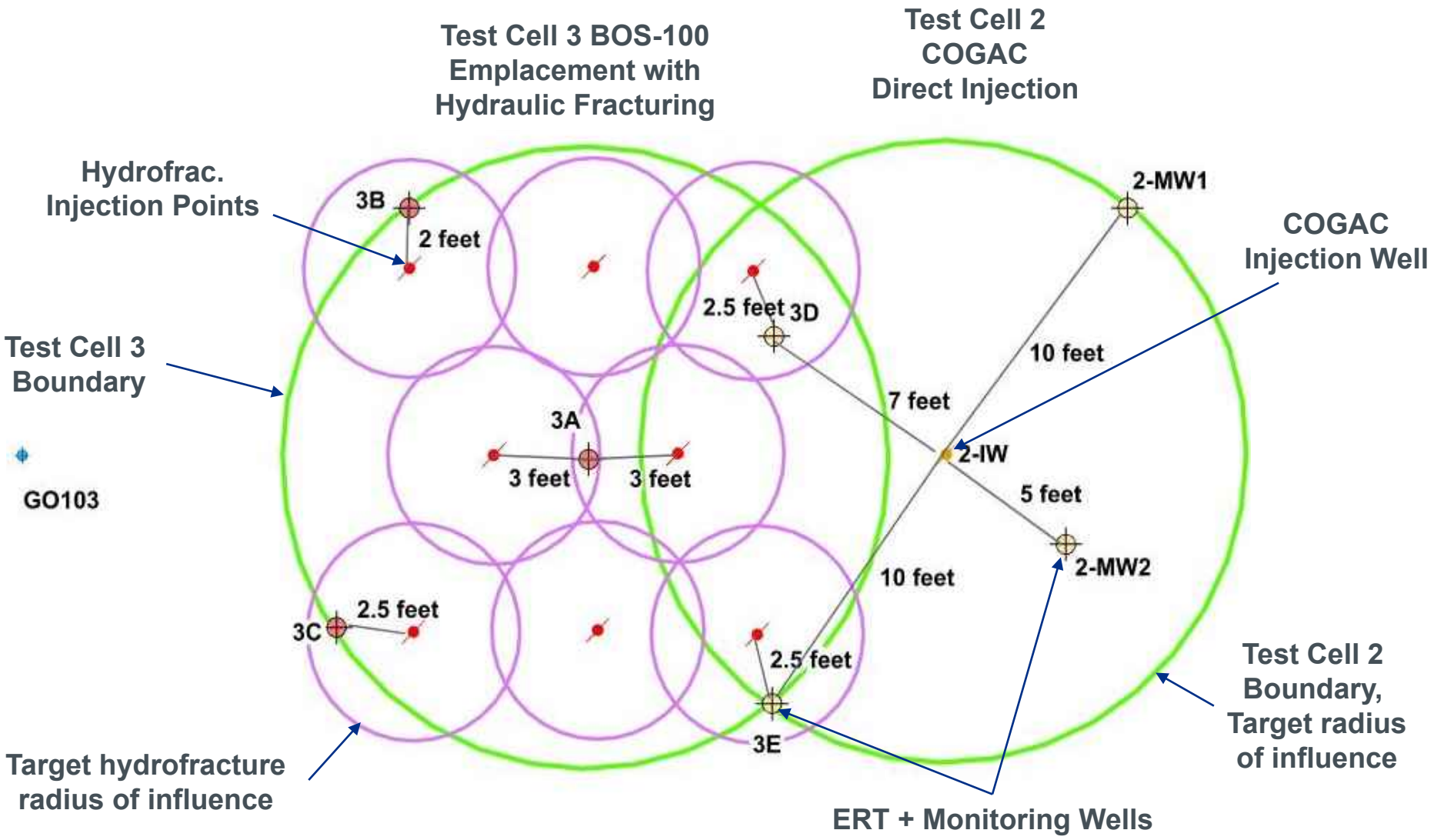
Lower grout seal in C-1 appears to be intact. Lean clay unit in C-1 geologic log

- **Appears laterally continuous in baseline ERT image.**
- **Appears to provide an effective lower boundary for AC migration.**

Partially compromised grout seal?

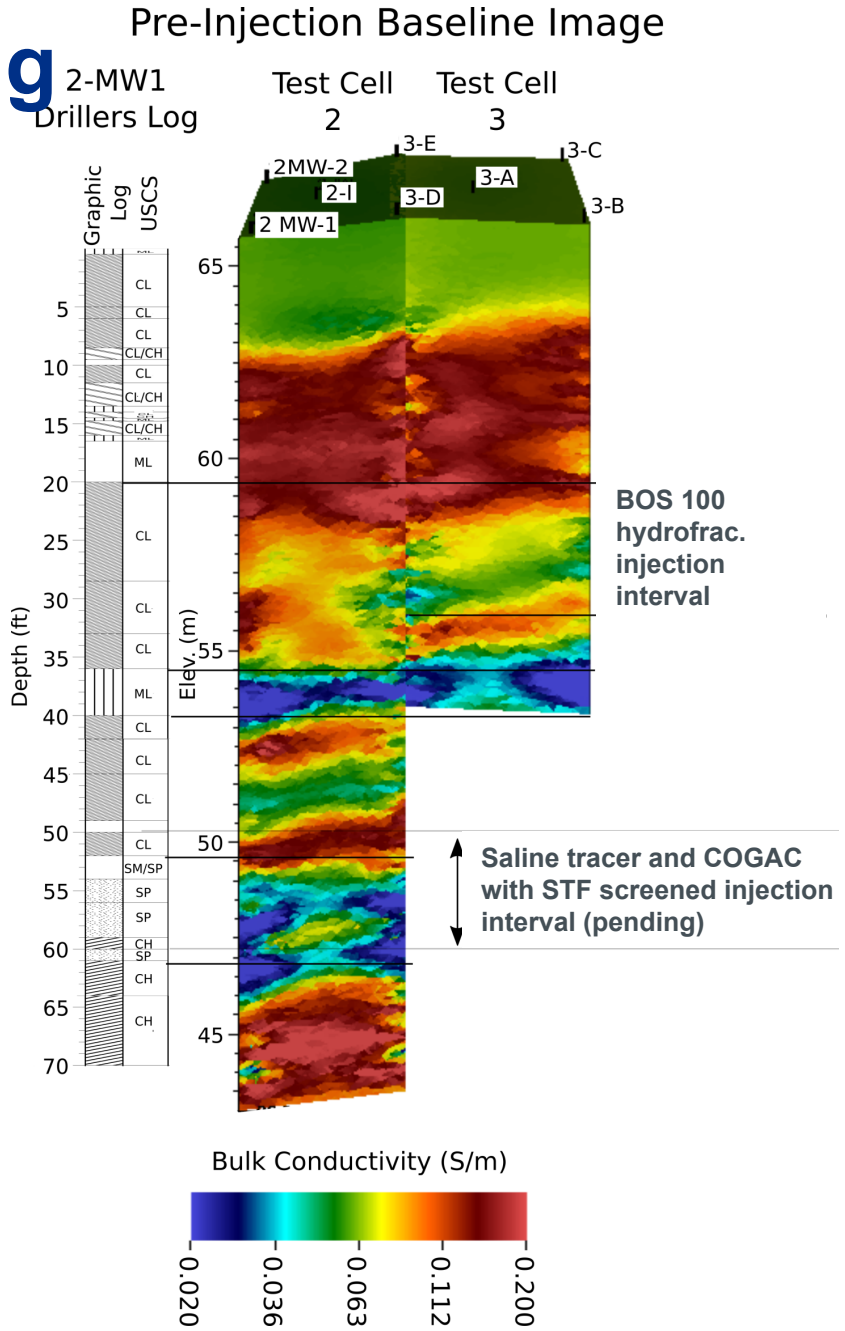
Note: Plumestop amendment ‘daylighted’ at the surface in C-1 during injections.

Test Cell 2 & 3 Design (COGAC & BOS 100)



Test Cells 2 and 3 Baseline Imaging

- **Baseline ERT consistent with 2-MW1 drillers log.**
  - Higher conductivity corresponds to clay-rich zone.
  - Lower conductivity corresponds to sandy zones.

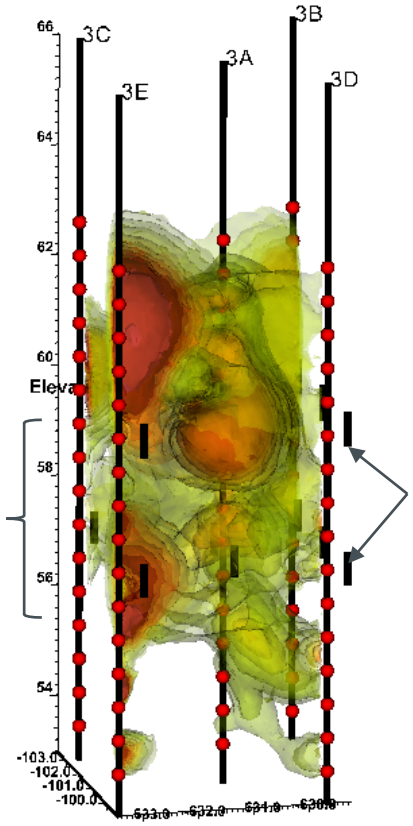


BOS-100 Post Hydrofracturing Injection Imaging

Vertical transport in annulus of 3A, 3B, and 3E. 3D and 3C appear to have effective grout seals.

Good (not great) distribution in target zone (gap between 3A and 3C).

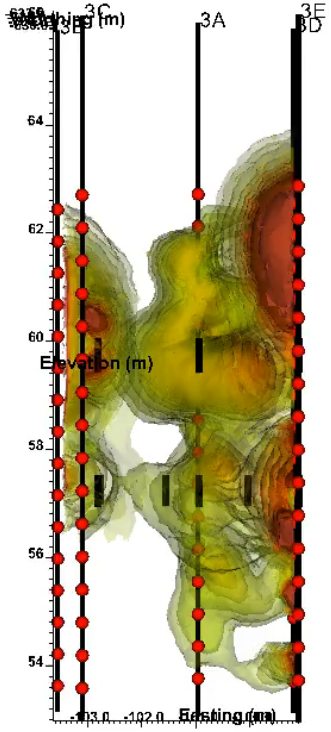
Static View



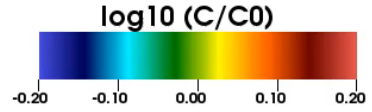
Injection intervals

Note: A few liter of BOS-100 ‘daylighted’ at 3E during injections.

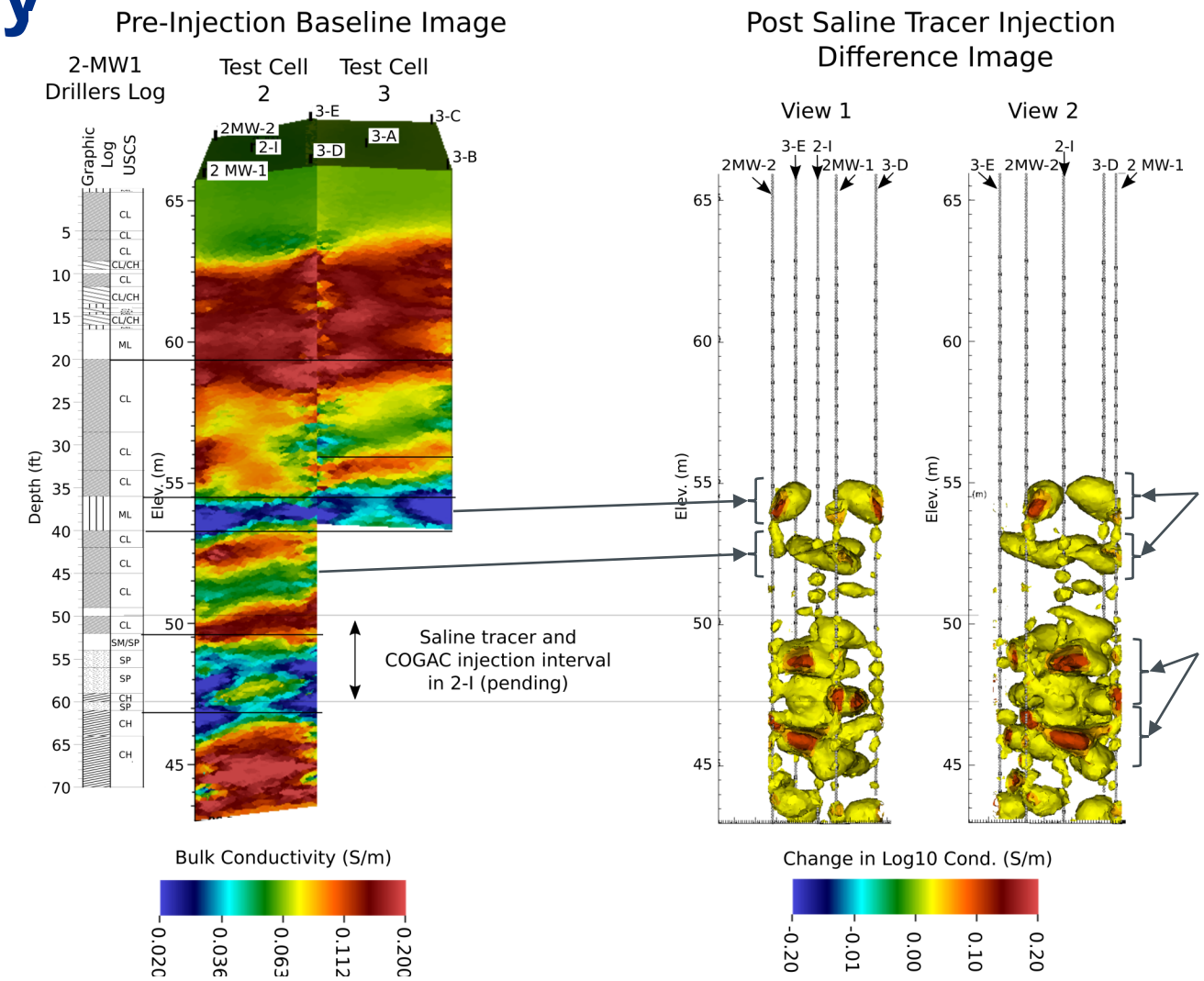
Fly-around View



Animation



Test Cell 2 Tracer Injection Imaging Summary



Upward migration to coarser-grained units (likely through grout seals) followed by lateral spreading

Heterogeneous distribution in target zone with significant downward migration beneath target zone.

Note: Injection was conducted at relatively high pressure, which may have contributed to vertical (upward and downward) migration from target zone.

Key Points

- **Post-injection coring and groundwater sampling in progress**
- **ERT images are consistent with field observations of daylighting**
- **Pending post-injection coring validation, ERT images have effectively captured the 3D distribution of AC amendment and tracer (Plumestop, BOS 100)**
- **AC amendment distribution is not uniform … significantly impacted by heterogeneity and failed wellbore seals**

Project Team

Pacific Northwest National Laboratory (PNNL)

- Tim Johnson: PI
- Katie Muller
- Lirong Zhong (Co-PI)
- Michael Truex: PI (retired)

CDM Smith (field design and implementation)

- Tamzen Macbeth: Co-PI
- Zoom Nguyen
- Ian Lo

USACE (site interface, field design input)

- Jacob Lalley
- Mandy Michalsen (Co-PI)

ESTCP

Thank You!

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