

Temporal Electrical Monitoring to Understand Injectate Distribution

Todd Halihan, Ph.D., P.Gp.
Oklahoma State University/Aestus, LLC

Stuart McDonald, P.E.
Aestus, LLC



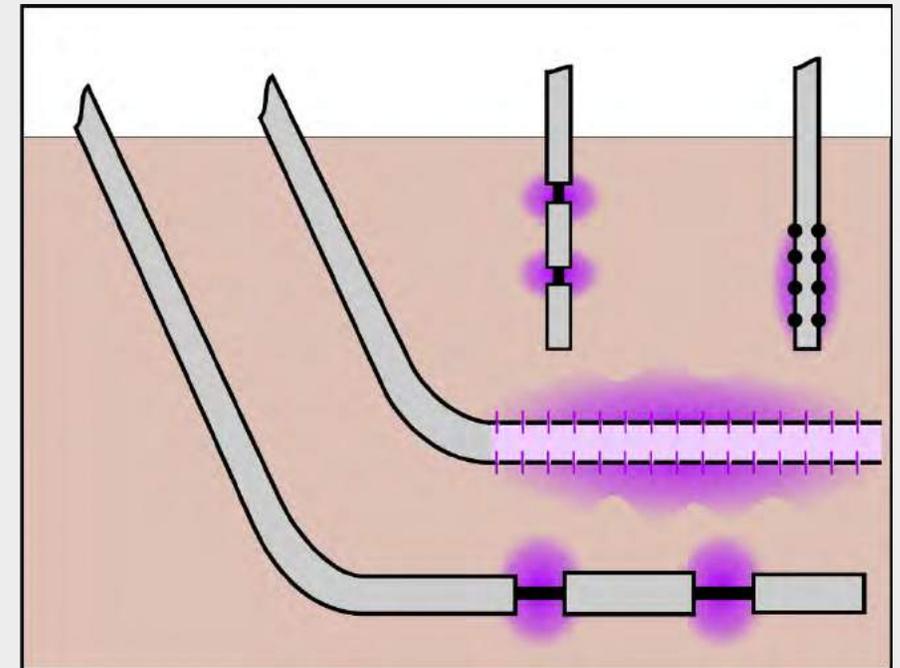
Industry Challenge: Injectate Distribution from Wells?



- Have great injection treatments for compound(s) of interest!
- How do we make them meet?

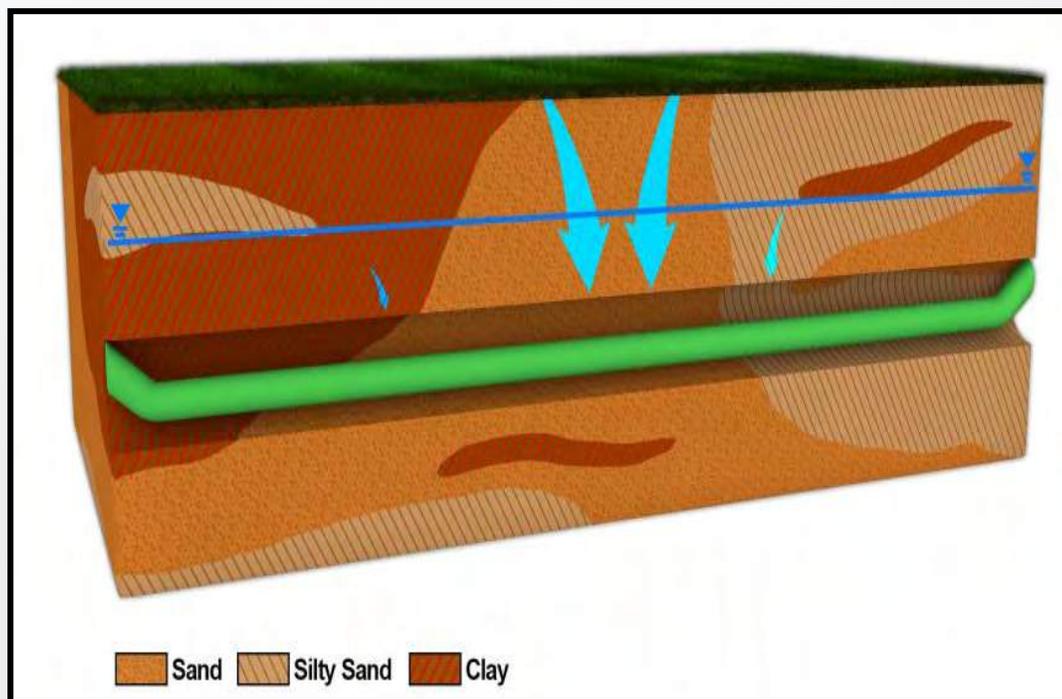
Industry Challenge: Injectate Distribution from Wells?

- Traditionally wells can “see” 10 m+ resolution
 - Impacts
 - Hydraulic conductivity variability?
- Well construction
 - Quality control of grout?
 - Screens in high K regions?
 - Horizontal or Vertical wells?
- Injectate
 - Moves through anisotropic, high K regions
 - Has reactions occurring, but where?

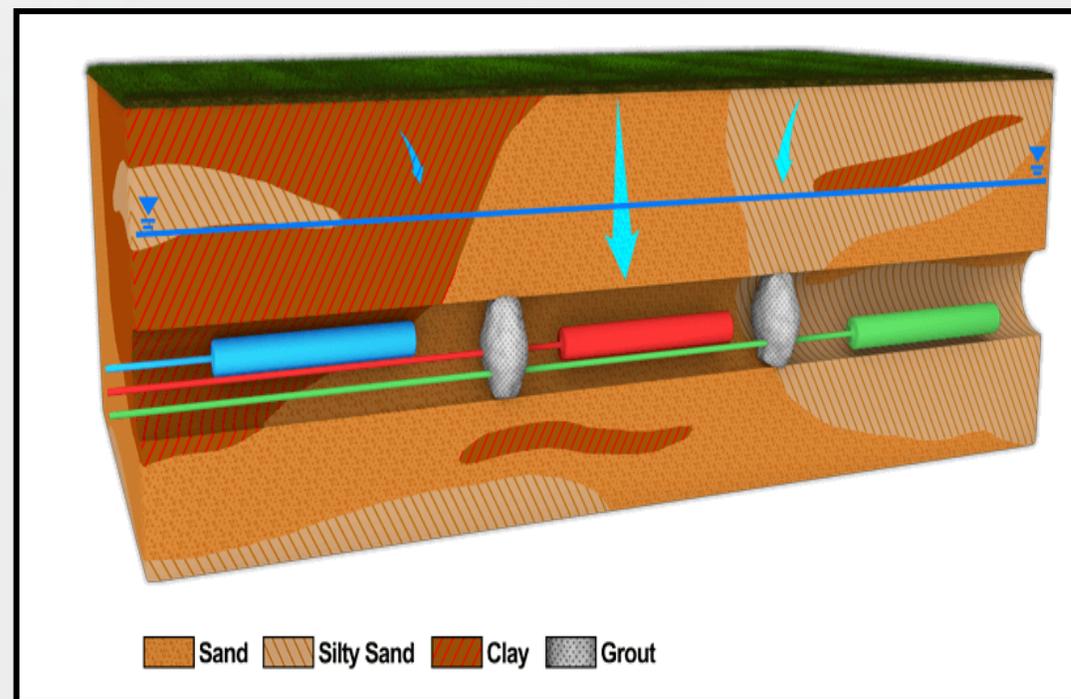


Horizontal Well Configurations in 3D Space

Long Lateral Wells

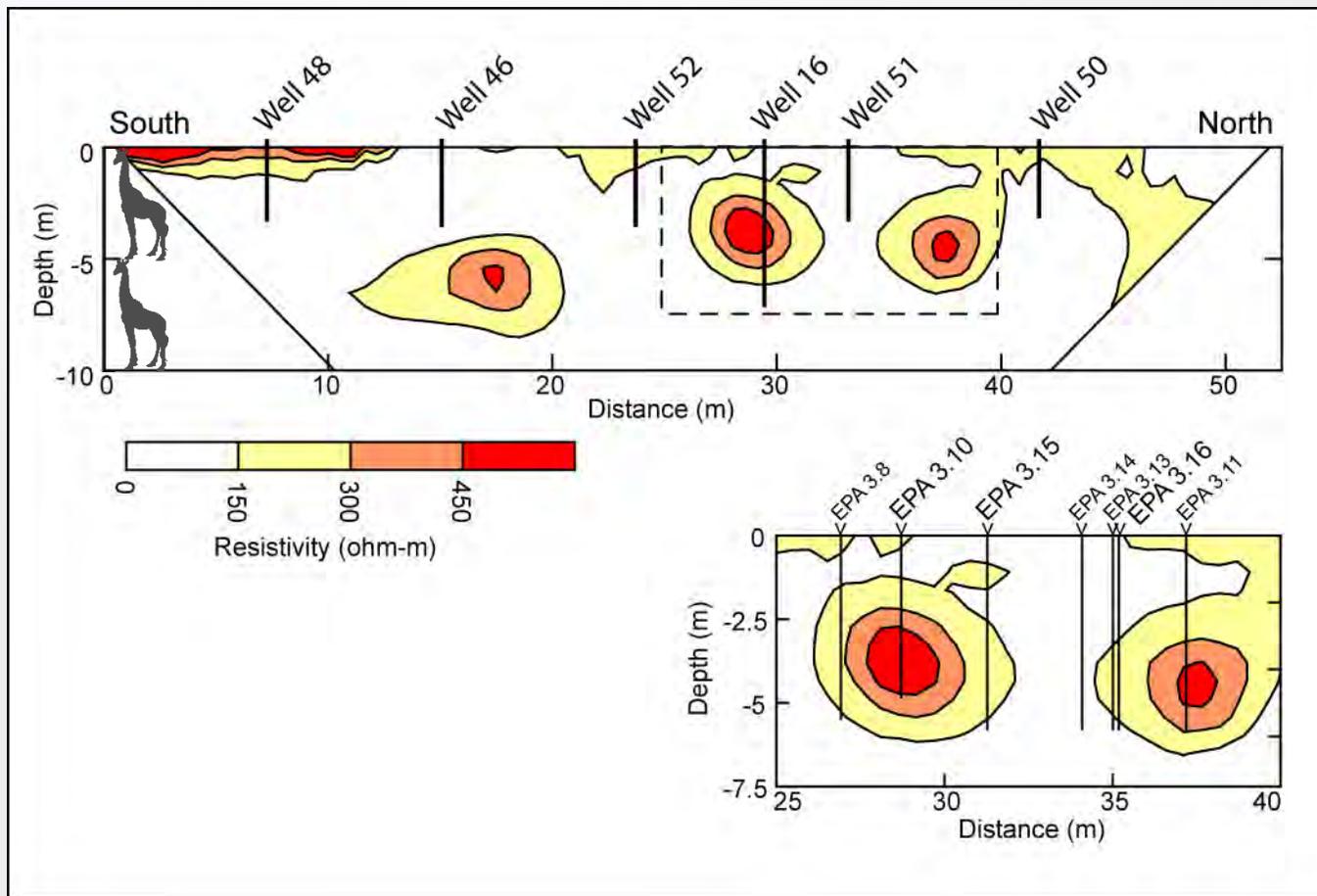


Segmented Wells



Images from EN Rx, Vertebrae™ Well Systems

Characterization: GeoTrax Survey™ Drillable Kilopixel Images

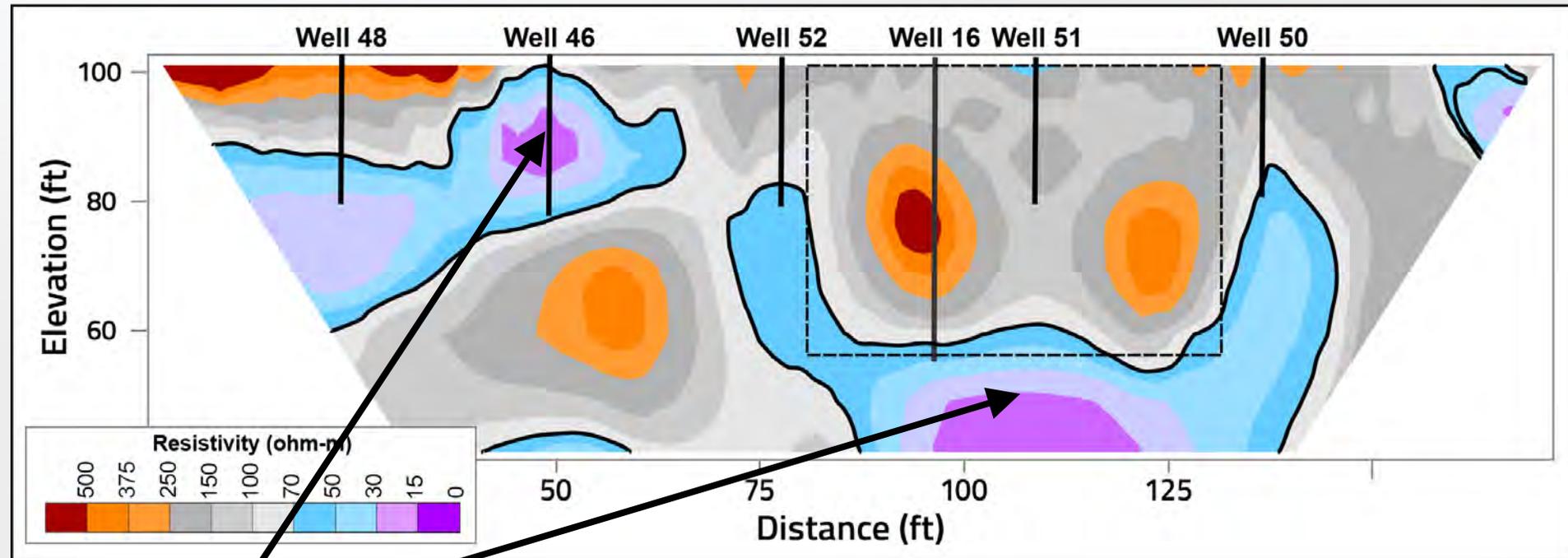


Halihan et al., 2005

- Started imaging resistors (dark spots) for NAPL or sand channels
- Found datasets rich for hydrogeologic analysis
- Found nature pretty weird

Characterization: GeoTrax Survey™ Images

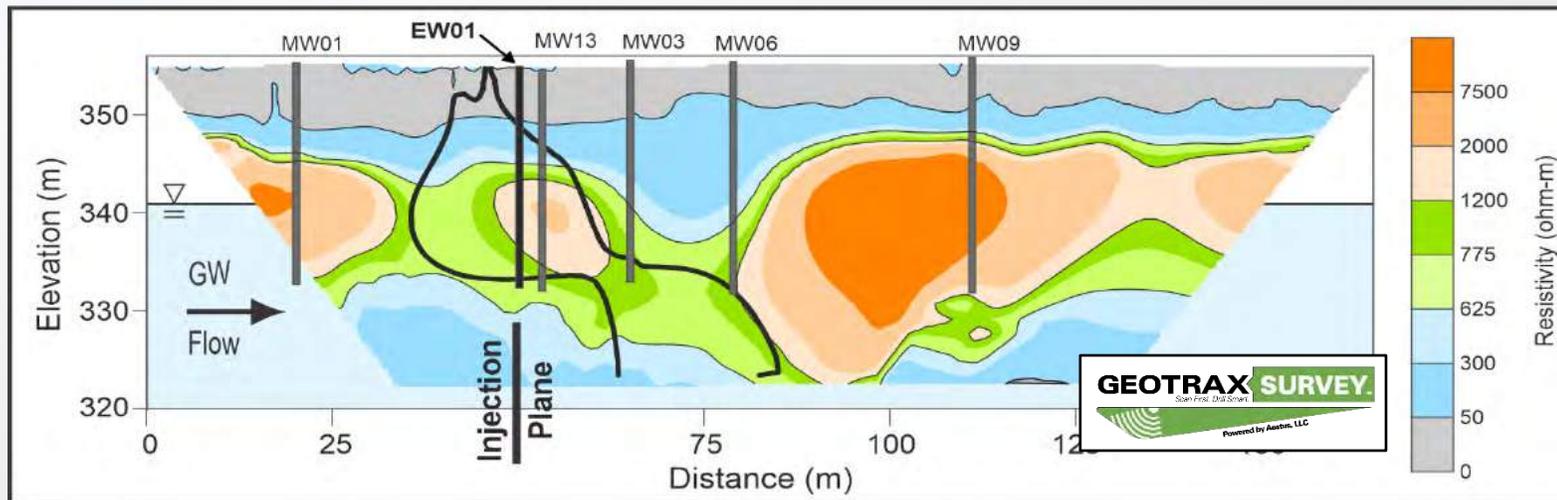
Surfactant View



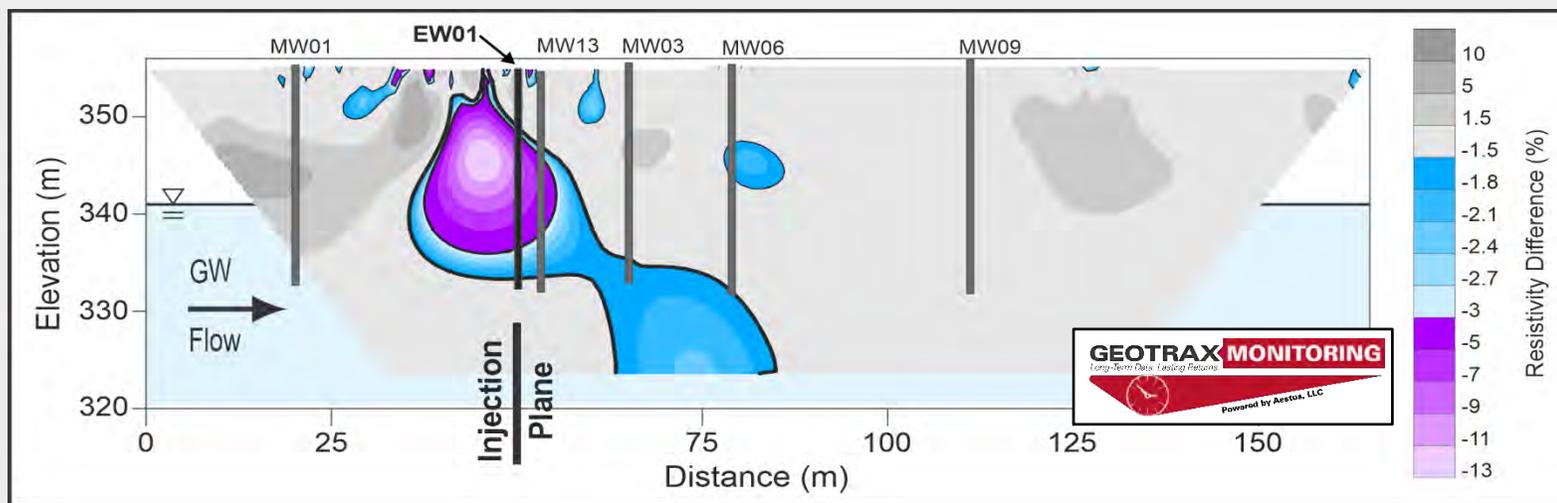
Surfactant signature?

Do injectates “squirt” into the subsurface?

Monitoring and Remediation: Temporal Electrical Resistivity Imaging of Injectate



Resistivity
(ERI)



Temporal
Resistivity
(TERI)

modified from Halihan et al, 2011

Catching Injectate with TERI

- Temporal ERI: changes in bulk electrical conductance over time
- Many injectates are electrically conductive fluids or can be spiked with salts for easier tracking
- Increasing conductance: location of injectate
- Magnitude of conductance: \propto concentration
- Specialty high sensitivity method required to “see injectates” (GeoTrax Monitoring™)

Installation Methods and Data Quality

Noise must be minimized in temporal imaging –
3 installation methods possible:

1. Temporary electrode stakes (noisy)
2. Semi-permanent electrode stakes with accessible caps
3. Buried electrode cables (electrical well)



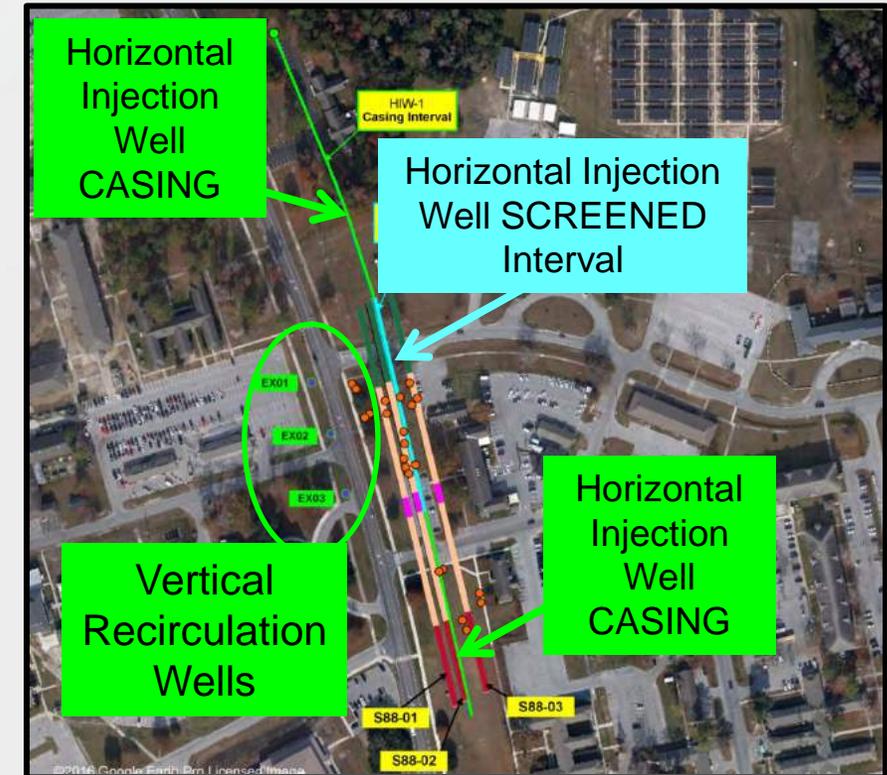
Case 1: Eastern North Carolina

Long horizontal well
with & without pumping controls from vertical wells

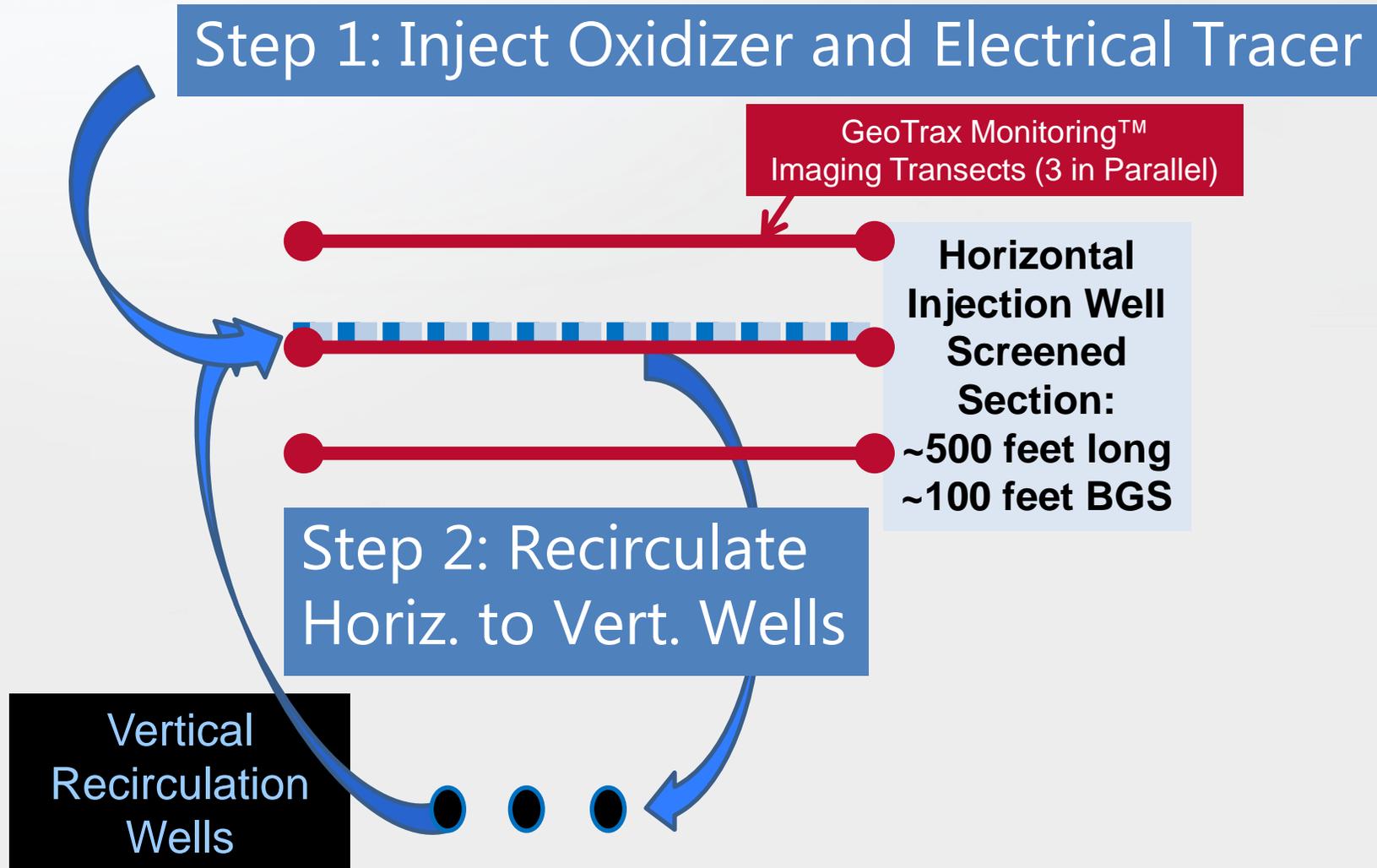


Remediation Layout

- 3 GeoTrax Survey™ Transects
- ~2.5m Resolution
- 275 m (902 feet) on ground surface
- 56 m (**184 feet**) of Imaging Depth



Plan View of Injection Geometry

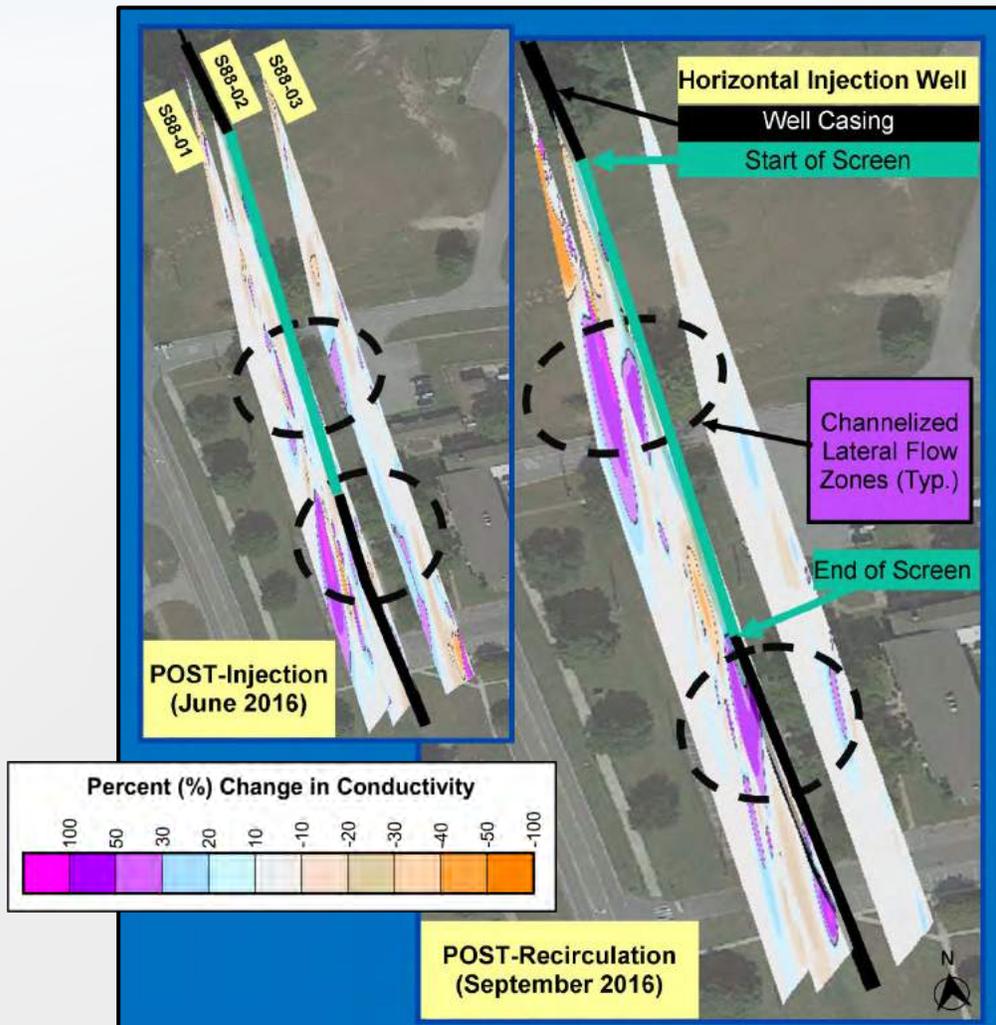


Temporal Imaging Datasets

- 3 Static Imaging Events
 - Pre-Injection (October 2014)
 - Post-Injection (June 2016)
 - Post-Recirculation (September 2016)
- **Yielded 2 Temporal Datasets**
 - **Injection – 20 months** (Oct 2014 – Jun 2016)
 - **Recirculation – 3 months** (Jun 2016 – Sep 2016)

Channelized Lateral Flow Indicated

Post-Injection & Post Recirculation 2D Imagery

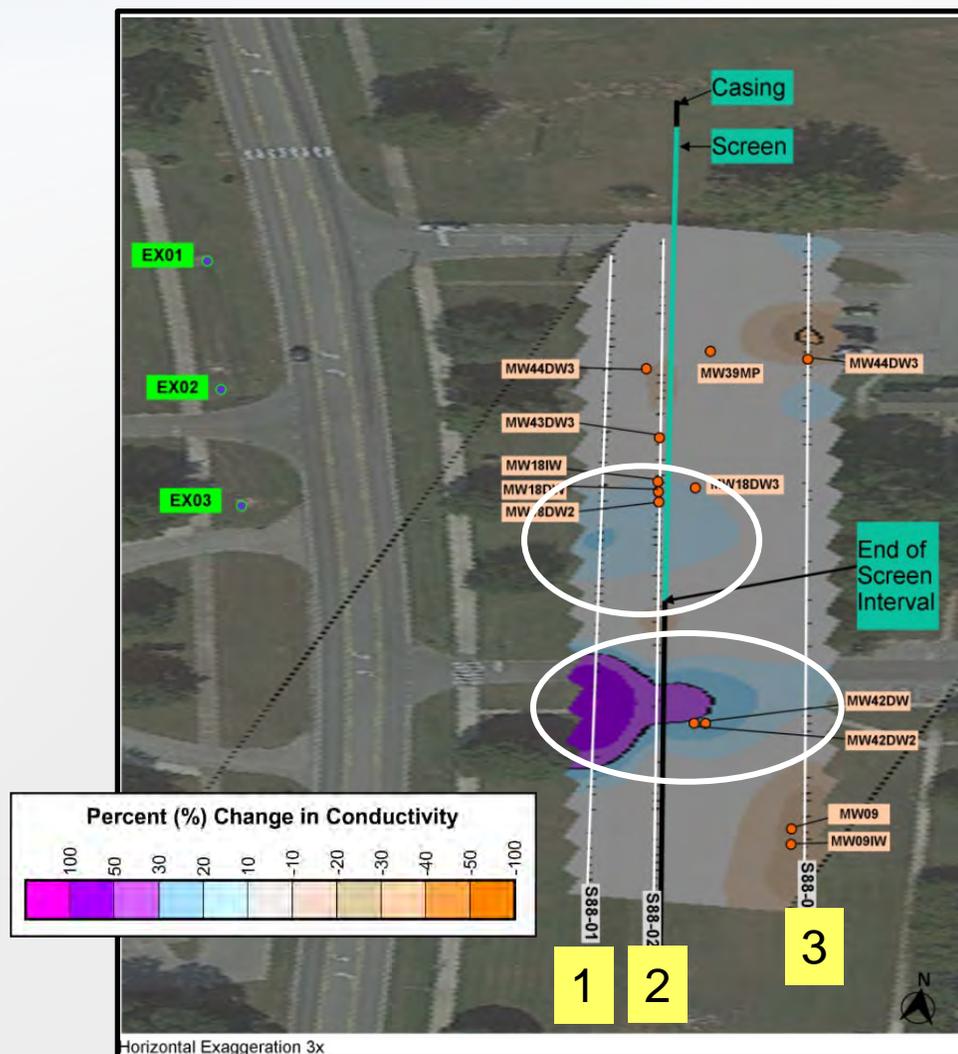


- 2 channelized zones (purple)
- Oriented E-W
- One in screened interval; other past screened interval to south
- Consistent across both temporal data sets



Channelized Lateral Flow Indicated

Post-Injection Data Elevation Slice ~100' BGS



- Channelized lateral flow
- Channel feature south of screened interval has largest changes
- Significant changes observed on Line 1
- Smaller changes on Line 2 for channel feature

GEOTRAX MONITORING

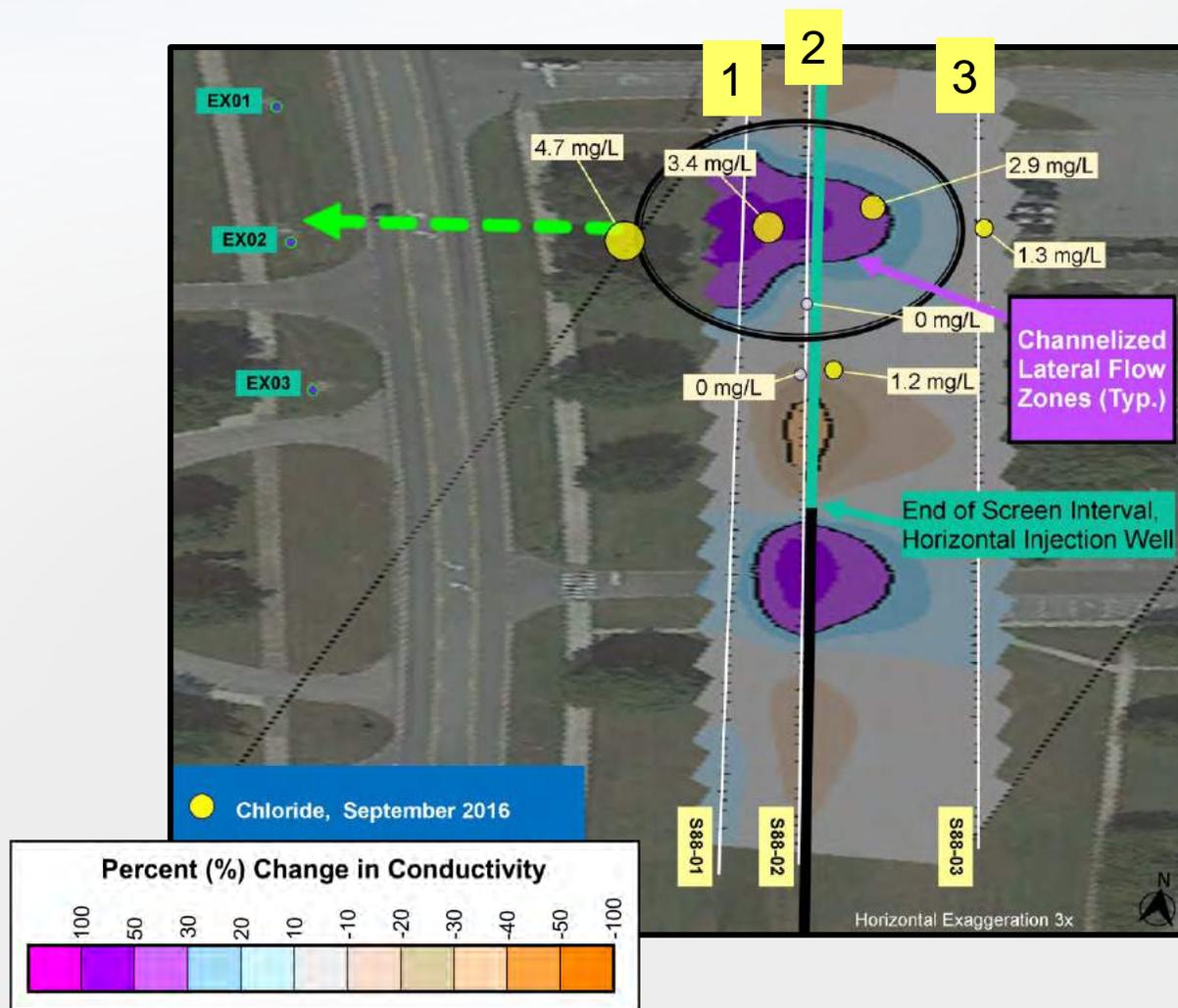
Long-Term Data. Lasting Returns.



Powered by Aestus, LLC

Channelized Lateral Flow & Chloride

Post-Recirculation Data Elevation Slice ~100' BGS

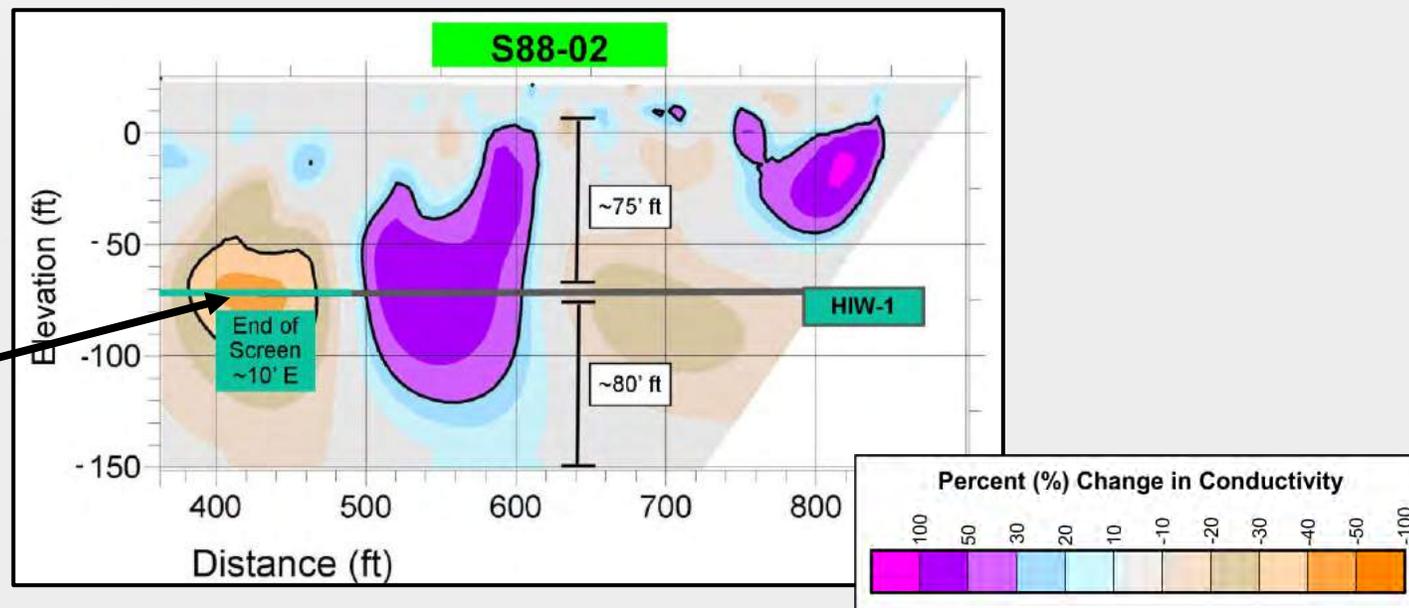


- Discharge at injection well spreading west toward recirculation wells
- Chloride higher in purple zones; confirms treatment



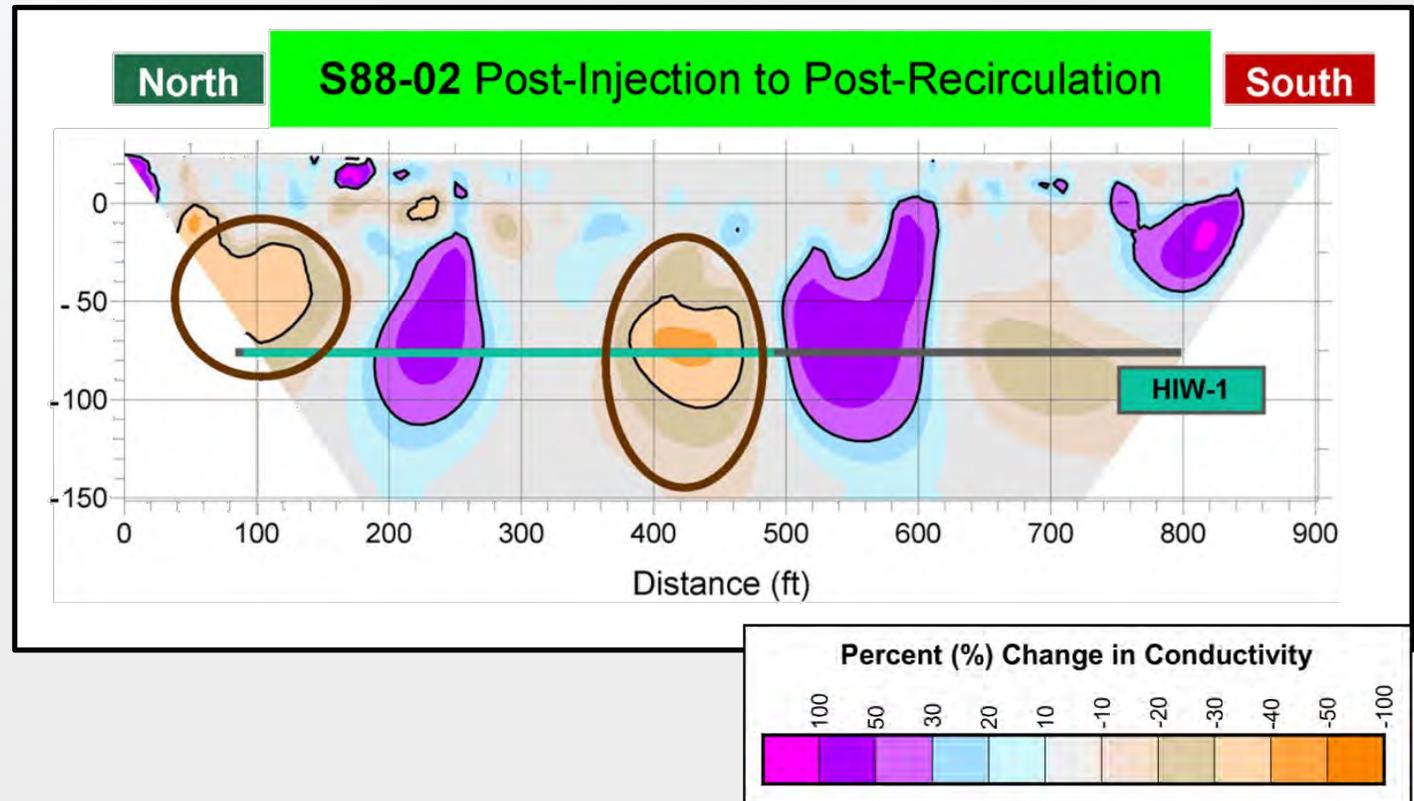
Vertical Migration

- During injection and recirculation, vertical changes observed beyond the expected ~15-20 ft design radius of influence
- Changes in resistivity of sediments caused different magnitude of resistivity changes



Why are some areas more resistive?

These may be due to precipitation of MnO_2 due to injectate



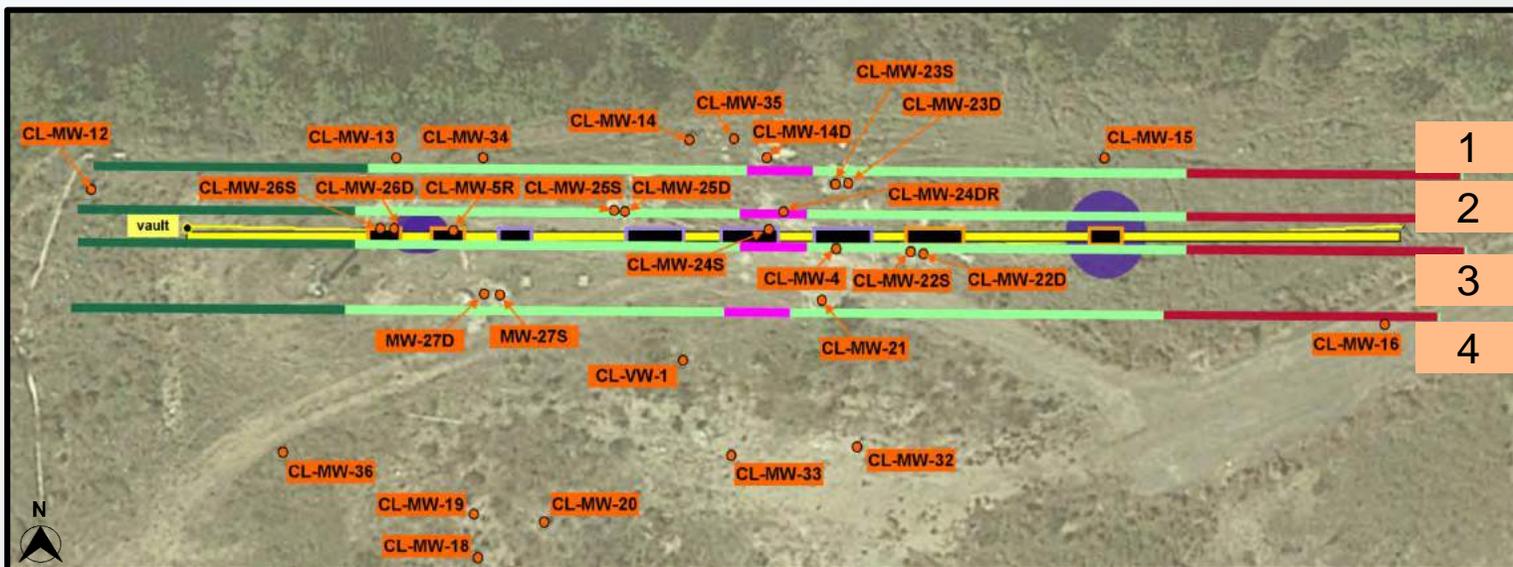
Distribution of Injectate not Predictable, but Observable

Case 2: Segmented Well Site

Segmented horizontal well
without pumping controls



Horizontal Segmented Injection Well

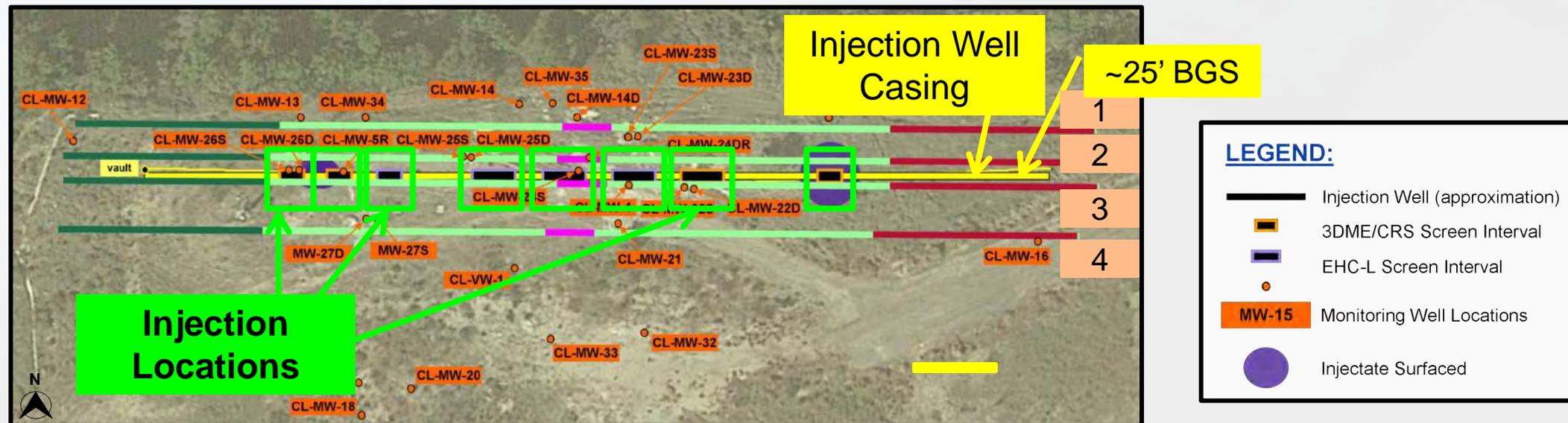


LEGEND:

- Injection Well (approximation)
- 3DME/CRS Screen Interval
- EHC-L Screen Interval
- MW-15 Monitoring Well Locations
- Injectate Surfaced

- 4 GeoTrax Survey™ Transects
- ~1.25 m Resolution
- 138 m (451 feet) on ground surface
- 28 m (**90 feet**) imaging depth

Injection Geometry and Imaging Setup



- ENRx Vertebrae™ segmented horizontal well installed @ 25 feet bgs
- 2 transects each N and S of well
- 8 injection locations (900-1000 gal in each)
- 2 different injection compounds used

Temporal Imaging Datasets

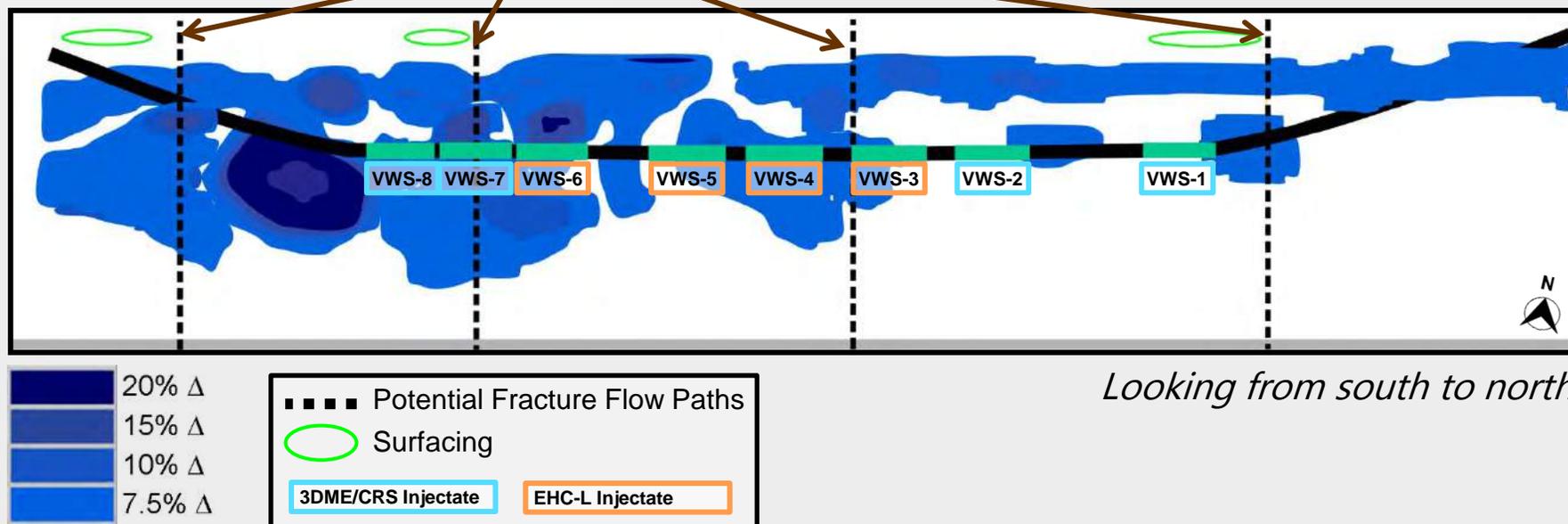
- 2 imaging events
 - Pre-Injection (March 6-8, 2019)
 - › Injection March 16-26, 2019
 - Post-Injection (March 28-29, 2019)

- **Yielded 1 Temporal Dataset**

3D Distribution of Injectate (Profile View)

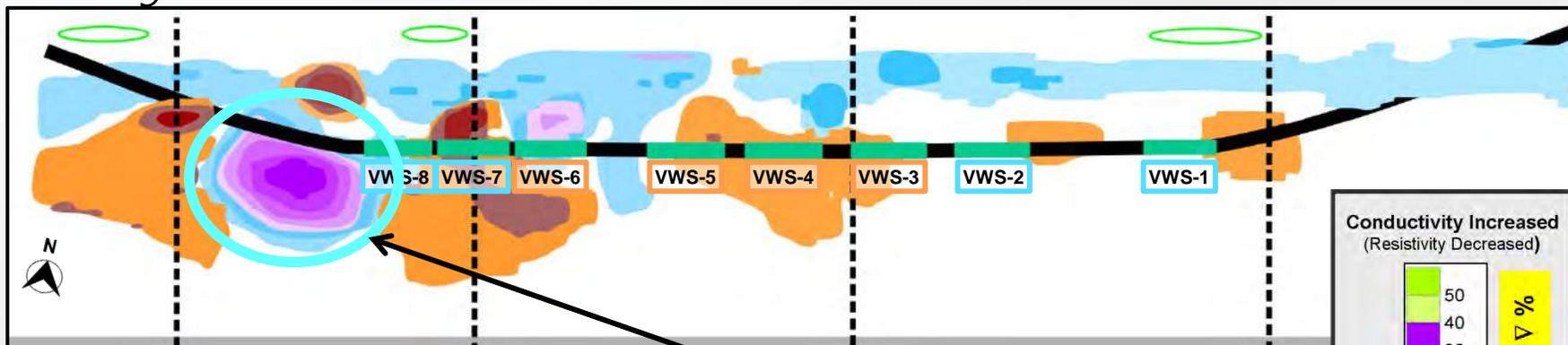
Apparent distribution of injectate:

- within ~15' of well screens
- in screens proximal to well head, poorer in distal portions of well
- in interpreted fracture zones

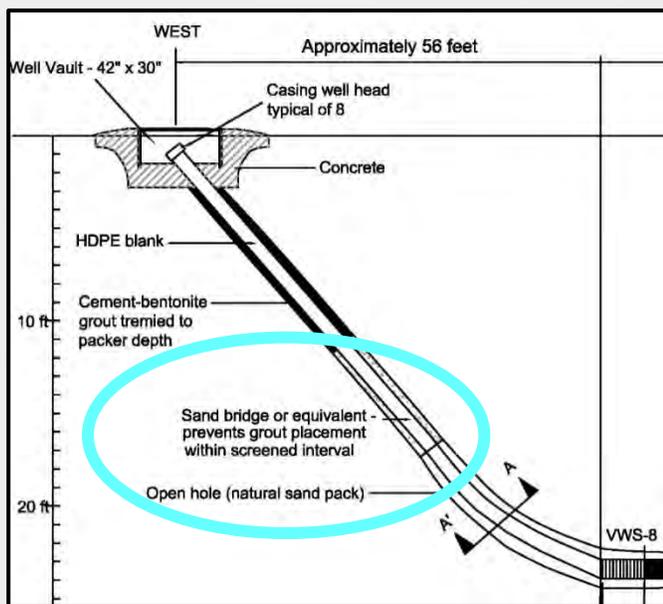


Conductive Anomaly (Profile View)

Looking from south to north

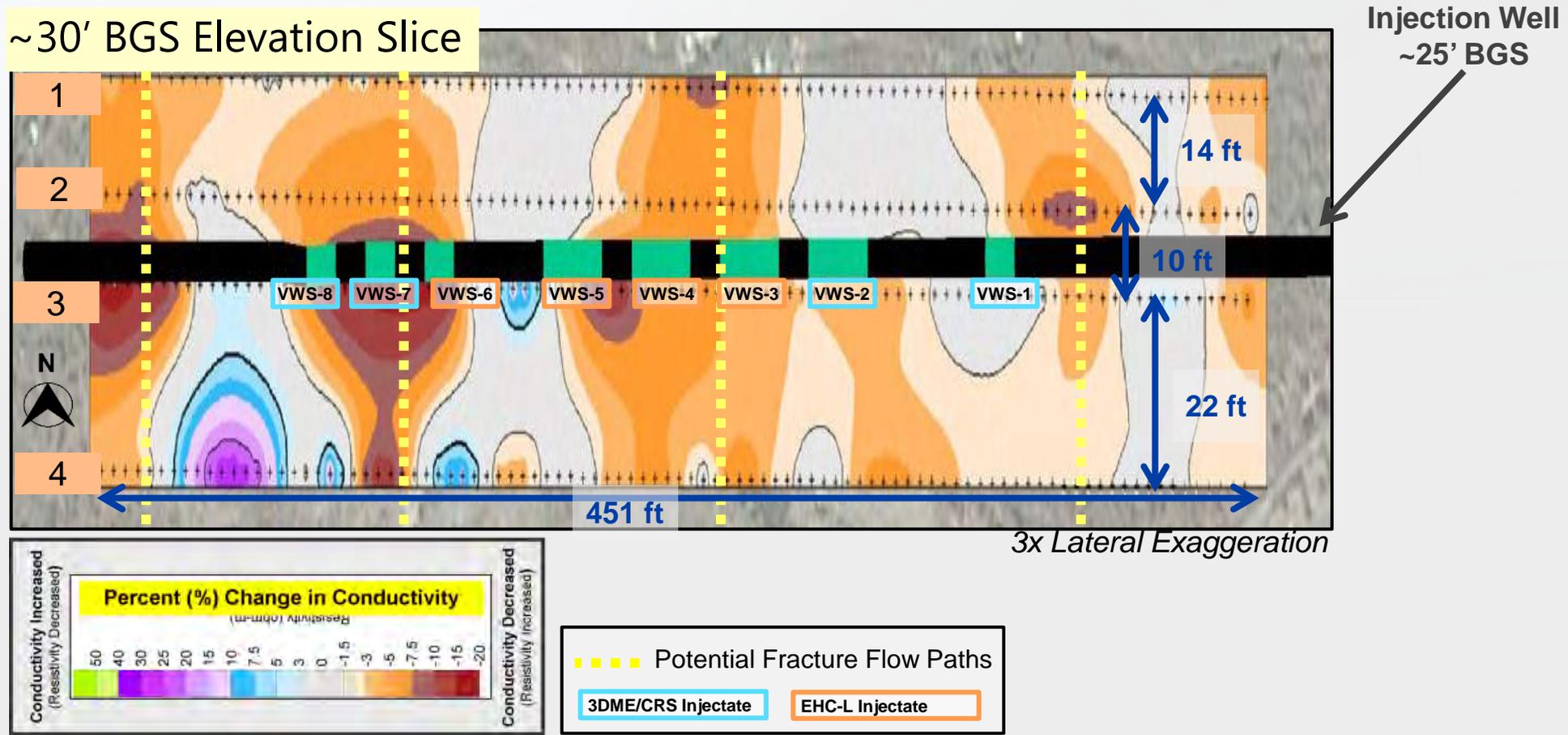


highly fractured zone full of fluid confirmed by drilling

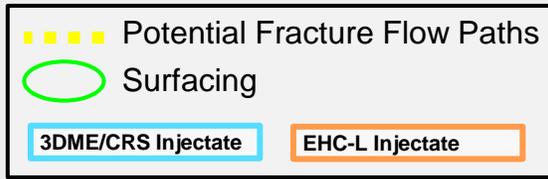
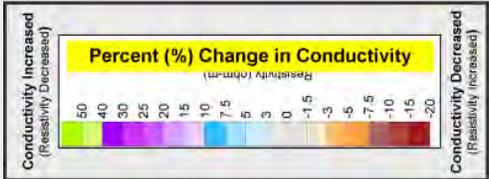
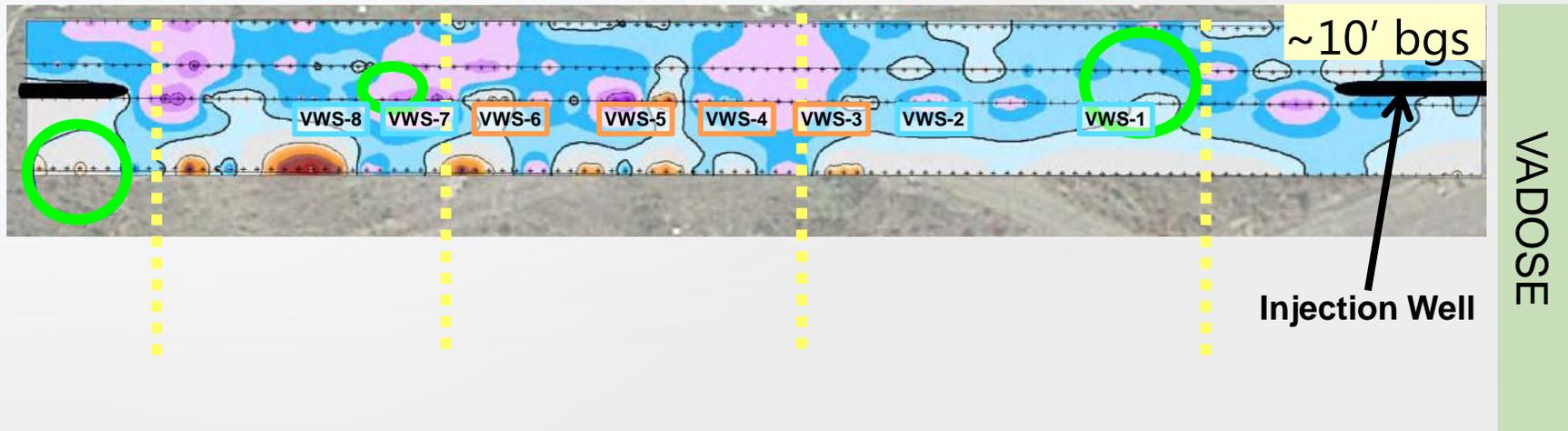


- ■ ■ Potential Fracture Flow Paths
- Surfacing
- 3DME/CRS Injectate
- EHC-L Injectate

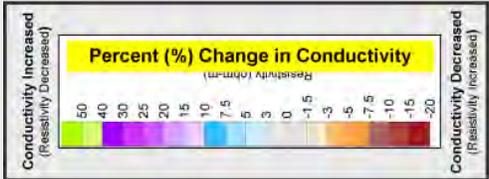
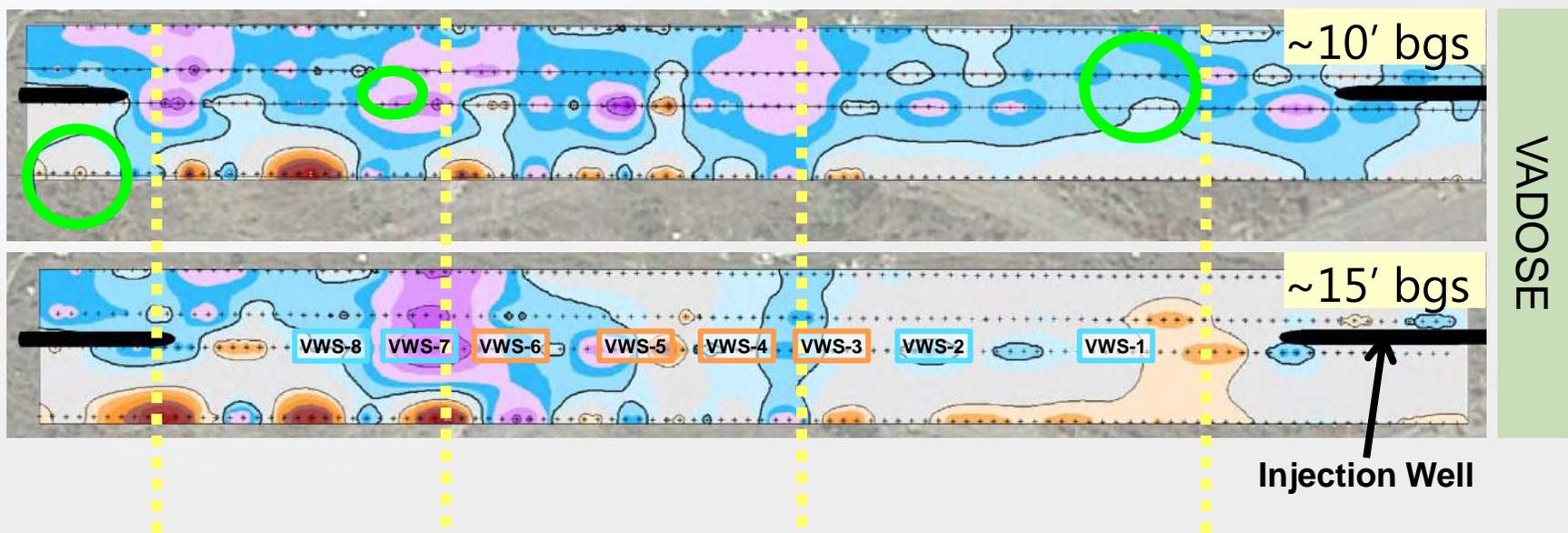
Horizontal Distribution (Plan View)



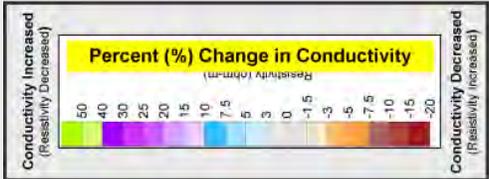
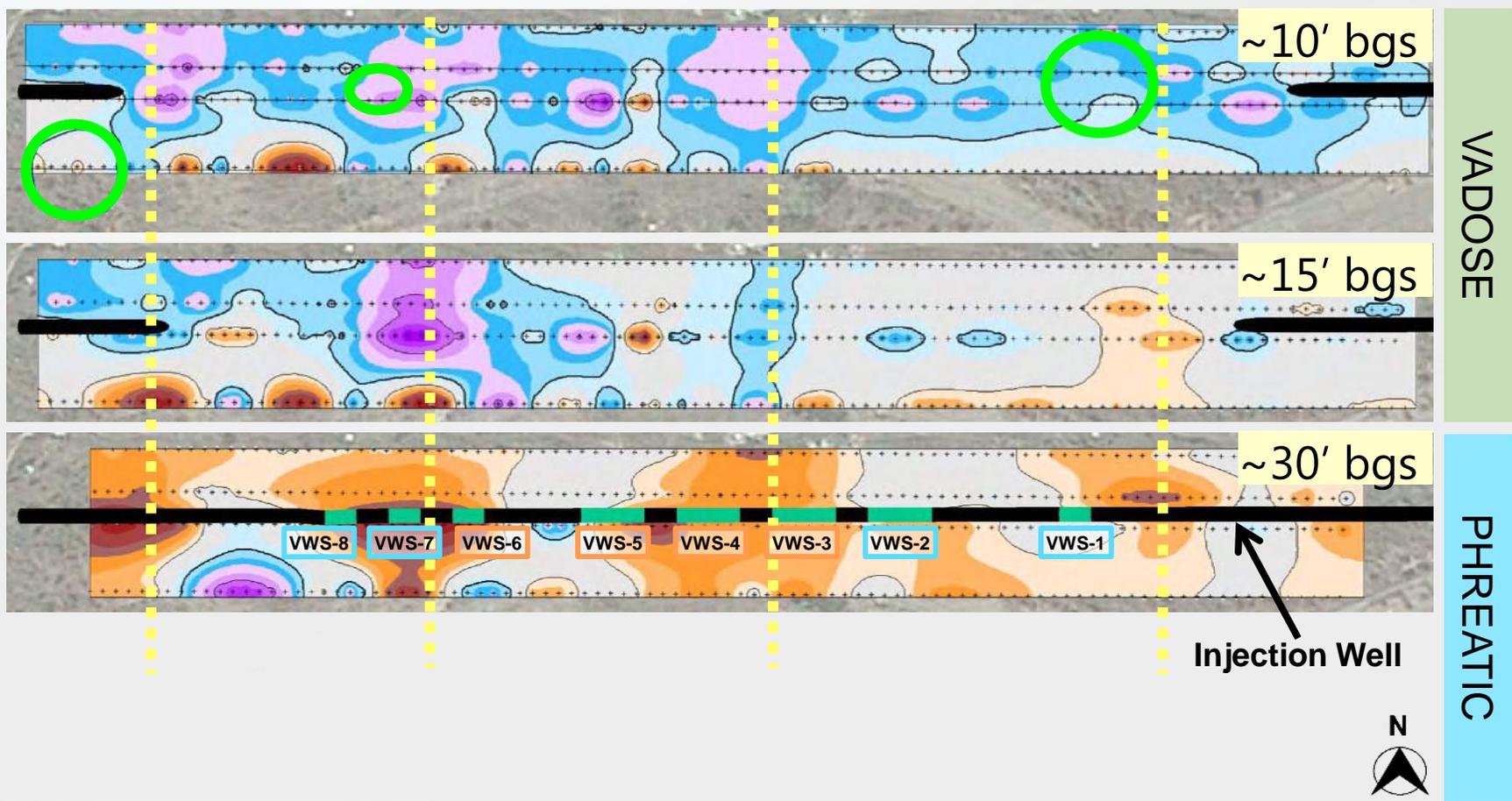
Vertical Distribution (Plan View Elevation Slice)



Vertical Distribution (Plan View Elevation Slices)

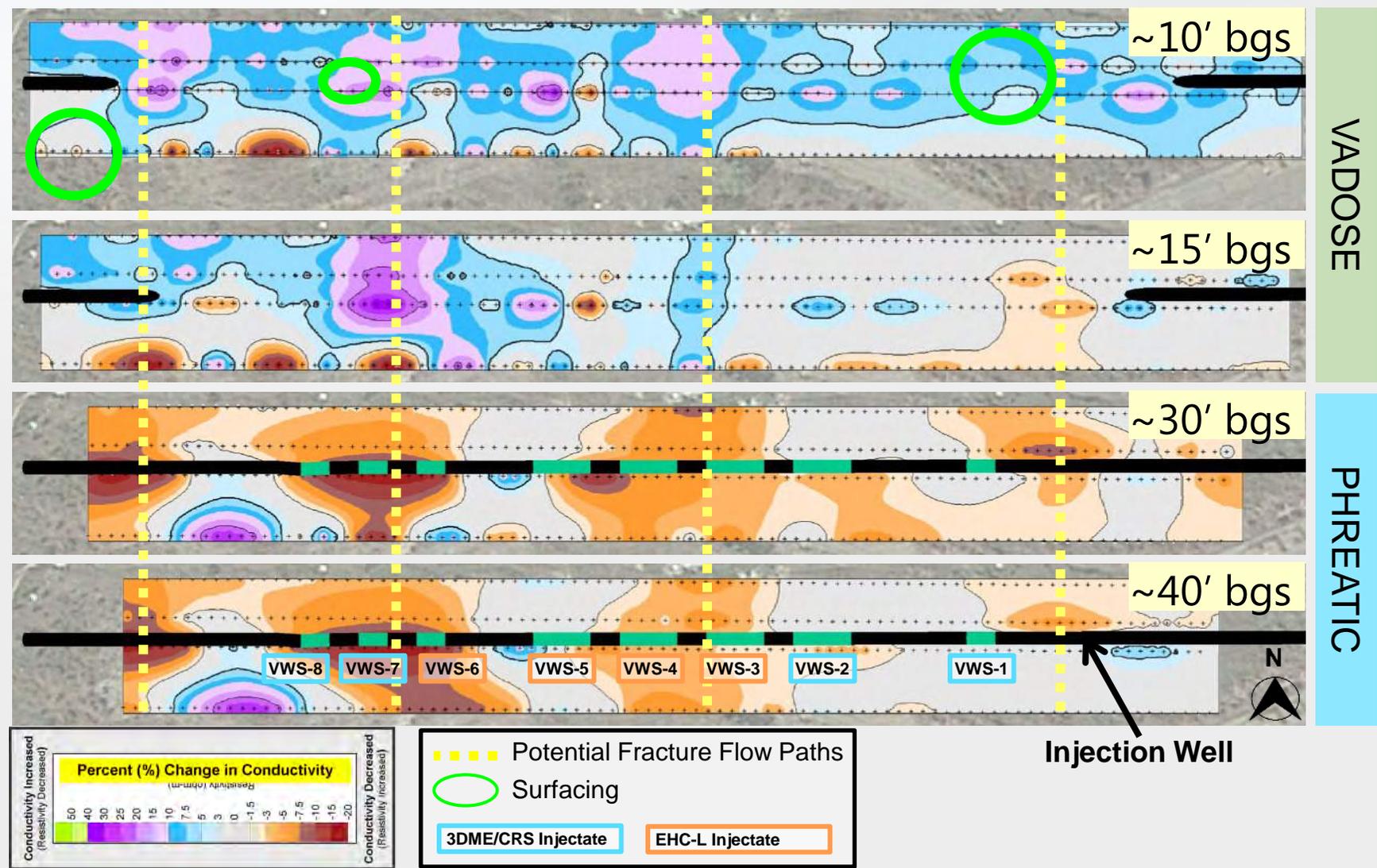


Vertical Distribution (Plan View Elevation Slices)



- Yellow dashed line: Potential Fracture Flow Paths
- Green circle: Surfacing
- Blue box: 3DME/CRS Injectate
- Orange box: EHC-L Injectate

Vertical Distribution (Plan View Elevation Slices)



Lessons Learned

- Fluids will not inject uniformly into “homogeneous” aquifers
- ...even if you don't watch

- Recirculation aids in distributing injectate
- TERI (GeoTrax Monitoring™) can
 - Identify flowpaths prior to injections to maximize injectate efficacy
 - Monitor/confirm distribution post-injection

Research Facility for Horizontal Wells

OK State Uni Experimental Segmented Well



QUESTIONS?

Thank you for your time!

Todd Halihan

halihan@aestusllc.com
405-612-2713

Stuart McDonald

swm@aestusllc.com
303-717-8893



www.aestusllc.com