Delineation of a Potentially TCE-Impacted Aquifer via Airborne Electromagnetic Geophysical Survey

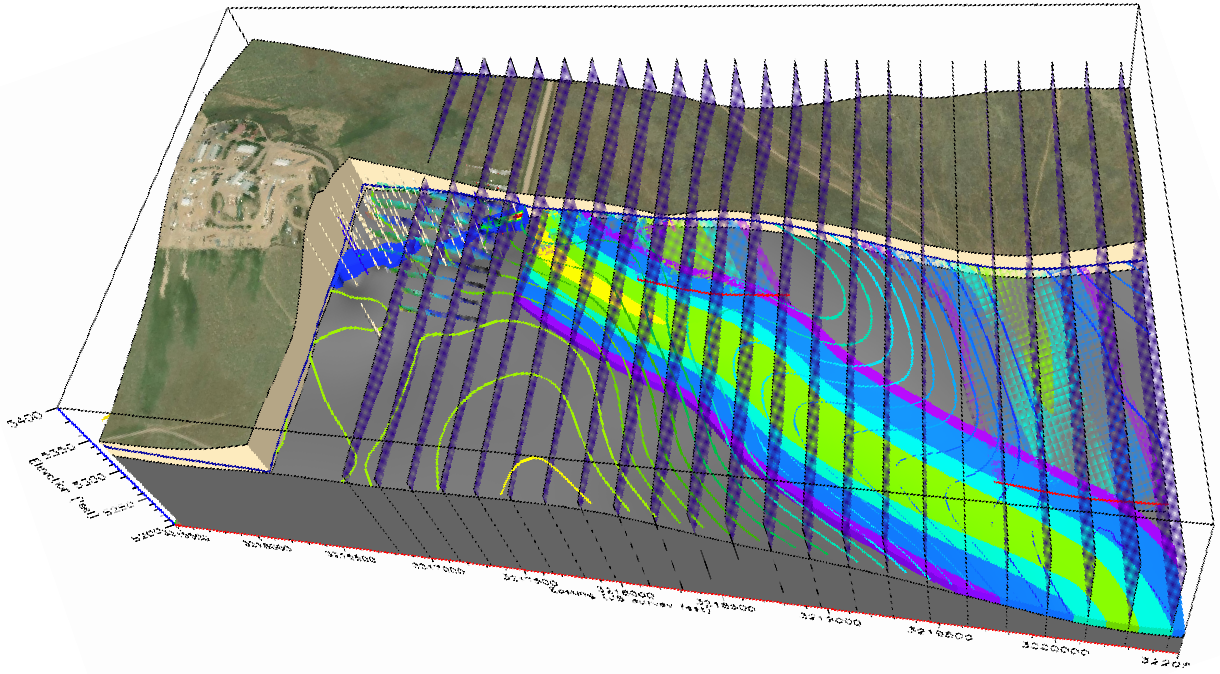
No boots on the ground

F.E. Warren AFB, Former Atlas “E” Missile Site 11, Nunn, Colorado
Formerly Used Defense Site (FUDS), USACE-Omaha
2011 – Present

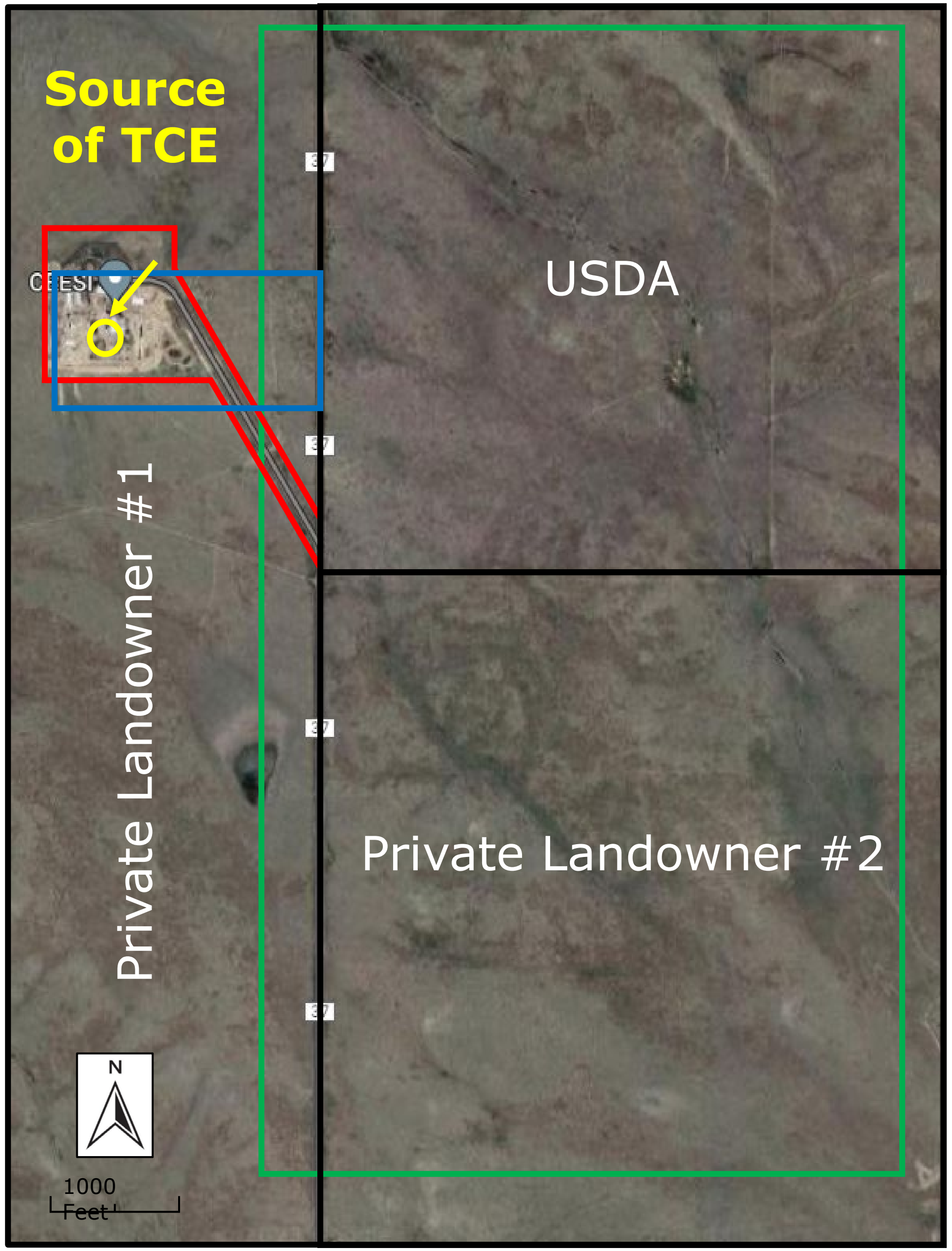
Photo captured by adjacent property owner – facing W-SW

Presentation Overview

- Site Location and brief History
- Onsite Historical TCE Maximum
- In-situ Chemical Oxidant (ISCO) Remediation System Design, Construction, and Performance
- CERCLA Framework
- Why an Airborne Electromagnetic (AEM) Survey?
- What is Airborne Electromagnetics
- AEM Survey Planning
- Initial Survey Results in 2D
- 3D Model from Resistivity Data
- Cross-Sectional Profiles and Interpretation
- Proposed Well Placement
- SkyTEM Overview



Site Location and Brief History

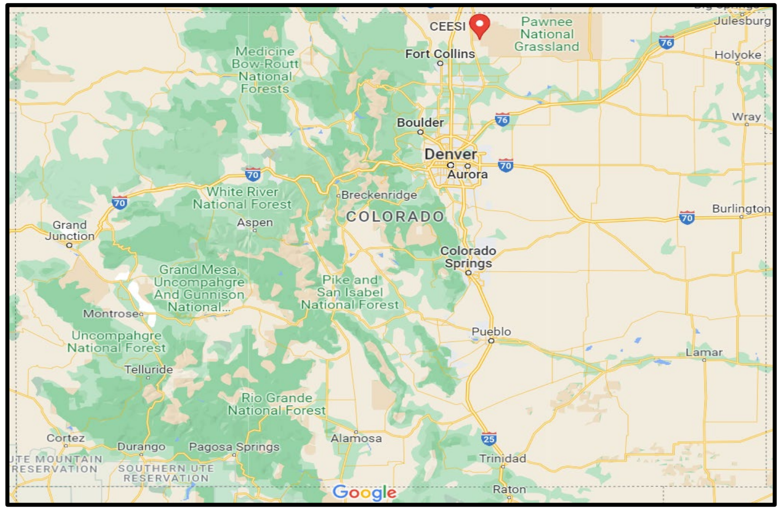


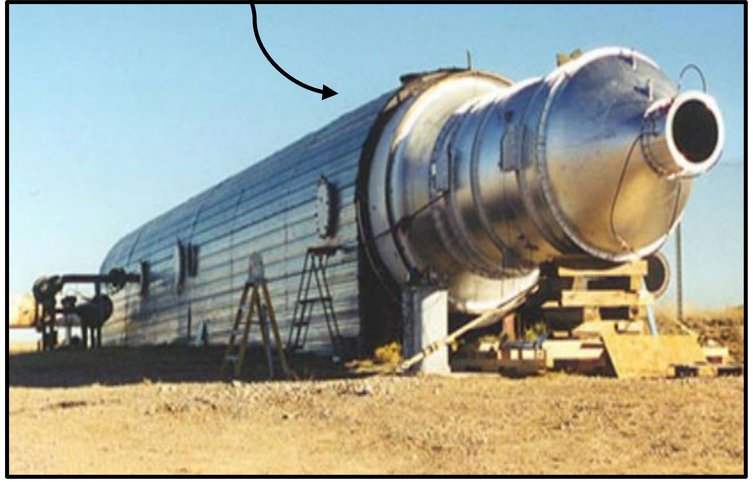
= Extent of the Current 'Onsite Area'

= Colorado Engineering Experiment Station Inc. (CEESI) Property

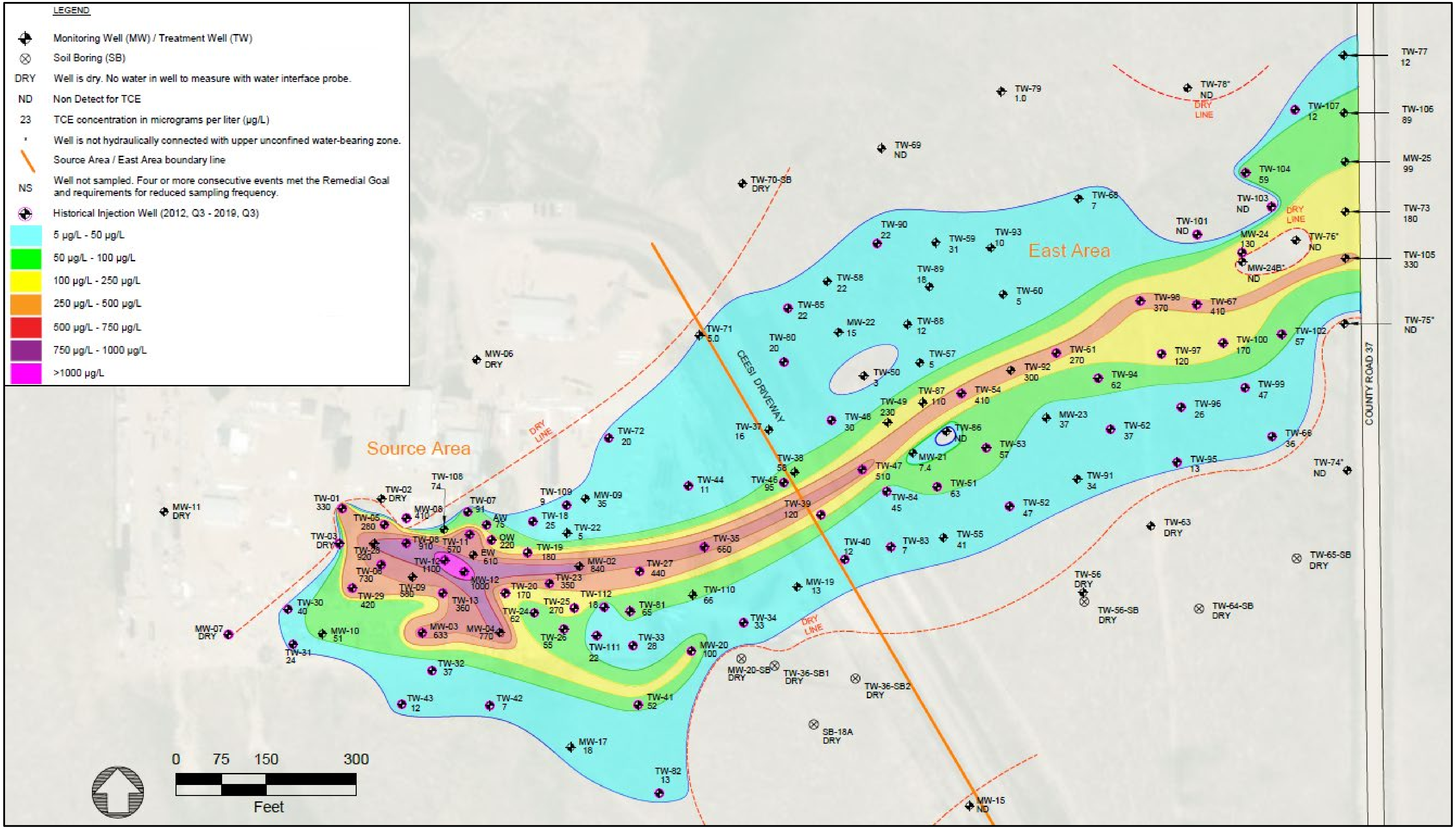
= Private Landowner's and United States Department of Agriculture (USDA) Property

= Airborne Electromagnetic Geophysical Survey Area

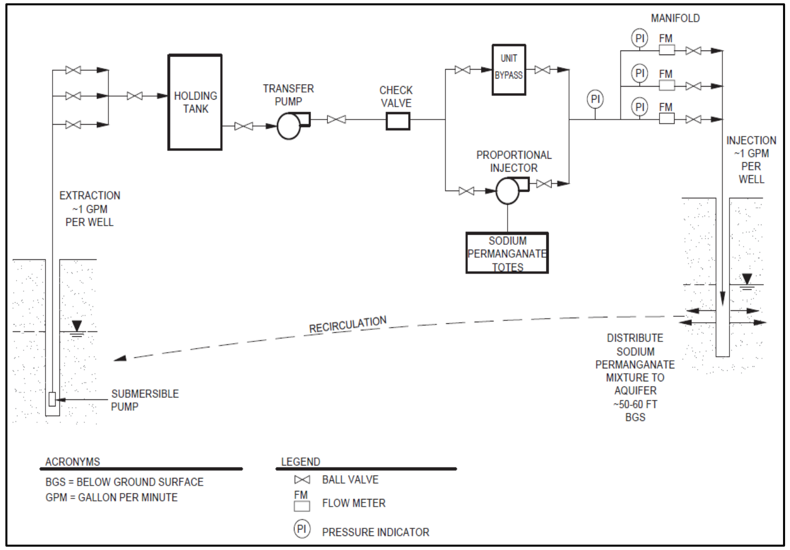




Onsite Historical TCE Maximum



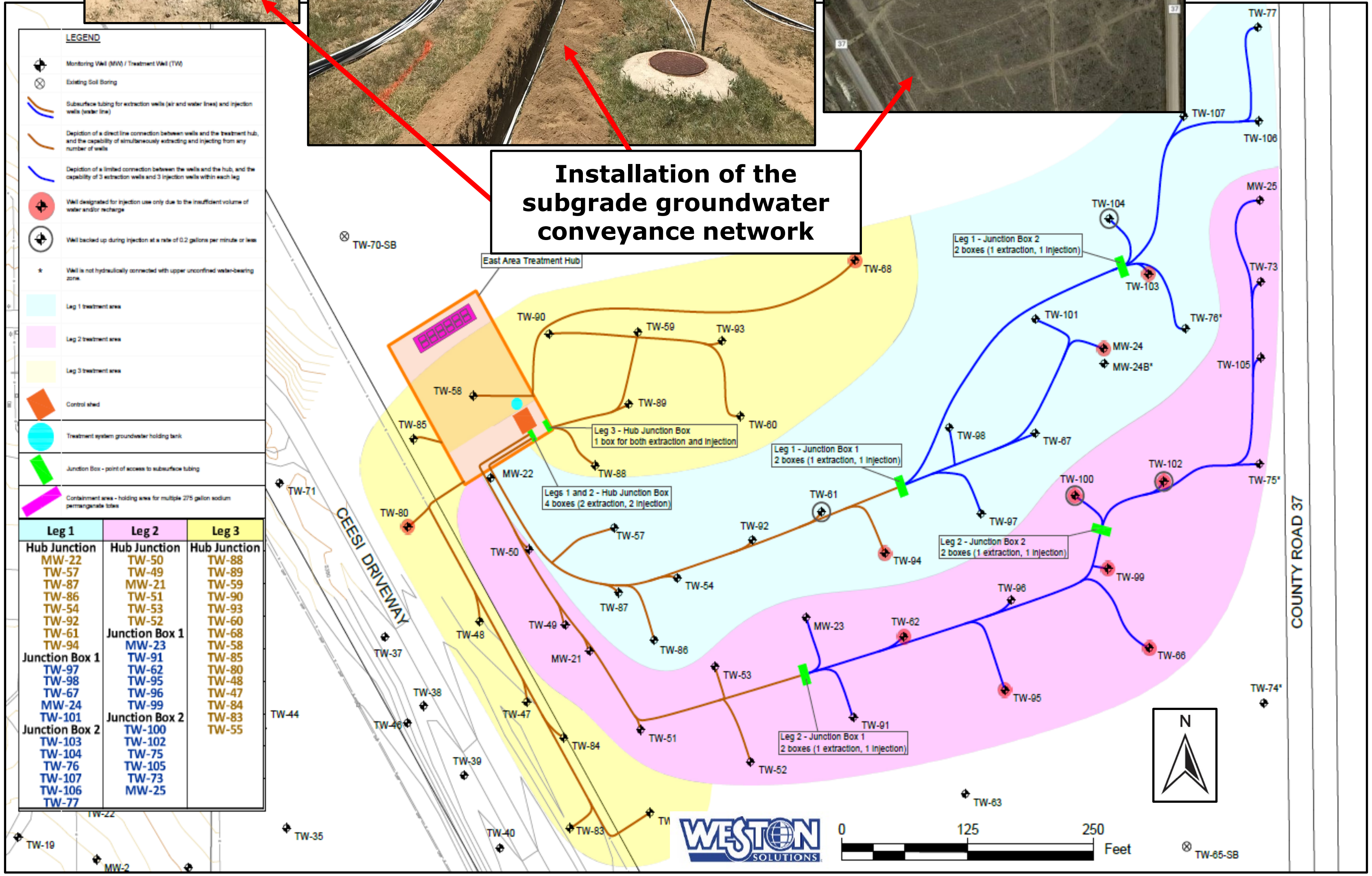
ISCO Remediation System Design and Construction



Recirculation is KEY

- Subgrade tubing network
- All system equipment is housed in one centralized ‘Hub Area’ to preserve land use (cattle grazing)
- Most wells have injection and extraction capabilities
- ‘Closed-loop’ recirculation cells to expedite cleanup goals via increasing the groundwater velocity and dispersion of the remedy
- Persistence of Sodium Permanganate in the TCE-impacted water-bearing zone

Installation of the subgrade groundwater conveyance network

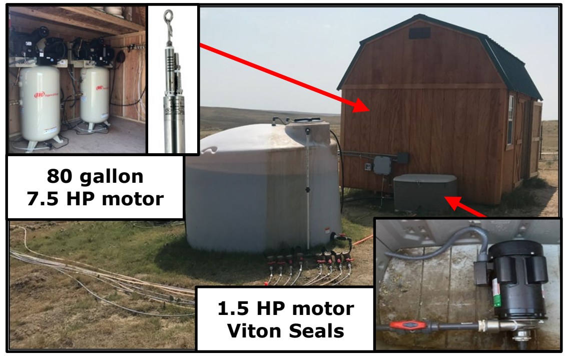


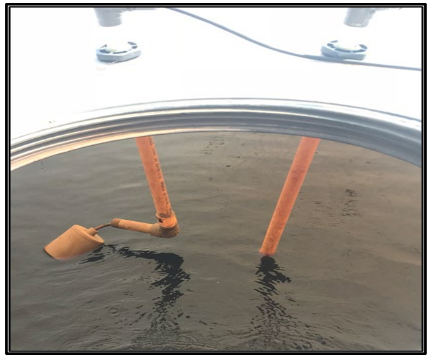
Leg 1	Leg 2	Leg 3
Hub Junction	Hub Junction	Hub Junction
MW-22	TW-50	TW-88
TW-57	TW-49	TW-89
TW-87	MW-21	TW-59
TW-86	TW-51	TW-90
TW-54	TW-53	TW-93
TW-92	TW-52	TW-60
TW-61	Junction Box 1	TW-68
TW-94	MW-23	TW-58
Junction Box 1	TW-91	TW-85
TW-97	TW-62	TW-80
TW-98	TW-95	TW-48
TW-67	TW-96	TW-47
MW-24	TW-99	TW-84
TW-101	Junction Box 2	TW-83
Junction Box 2	TW-100	TW-55
TW-103	TW-102	
TW-104	TW-75	
TW-76	TW-105	
TW-107	TW-73	
TW-106	MW-25	
TW-77		

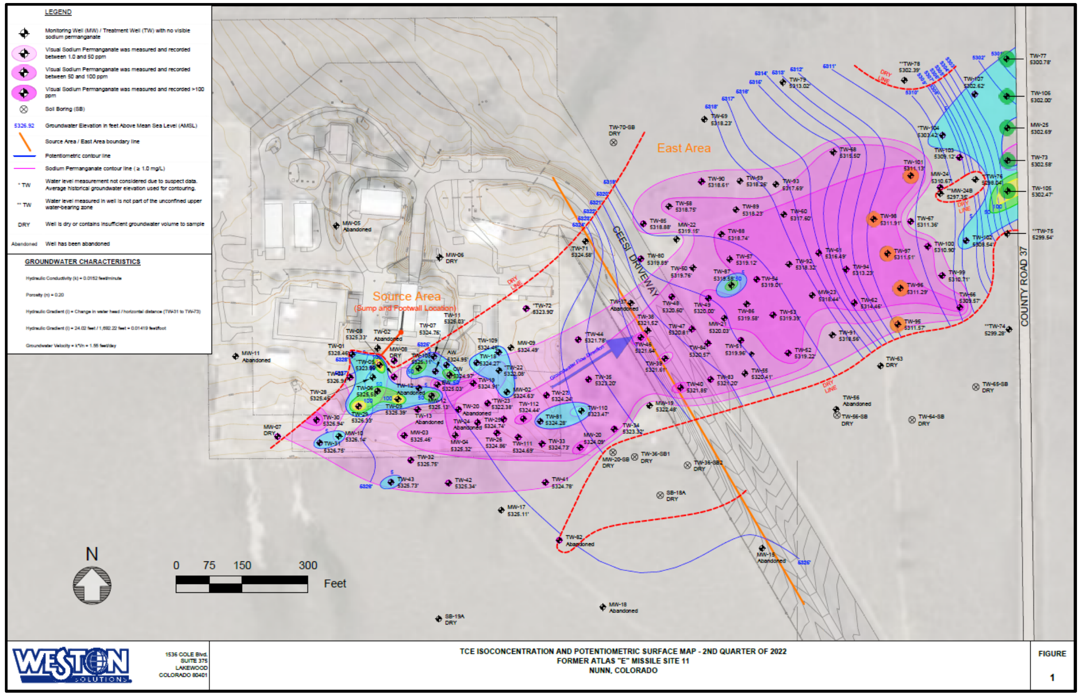
ISCO Remediation Performance

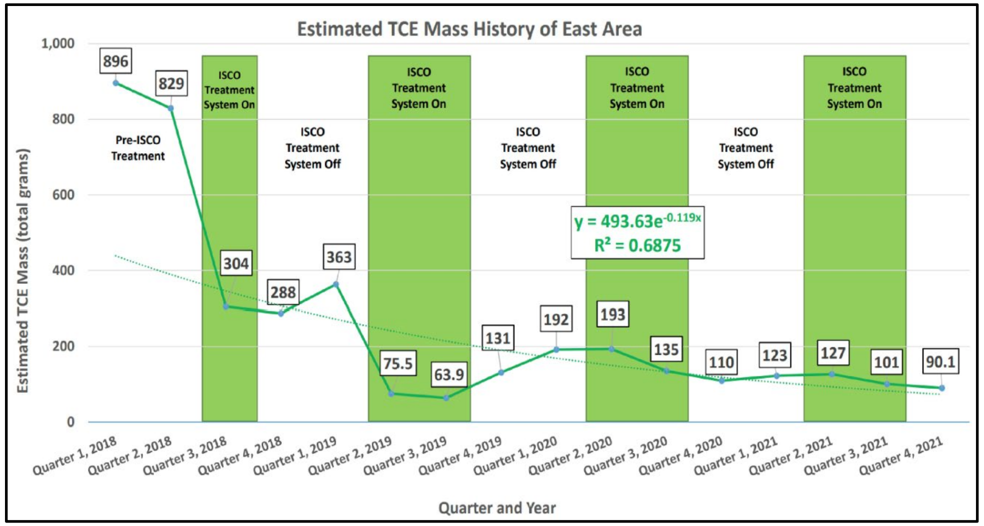
TCE and Sodium Permanganate – It is a contact sport

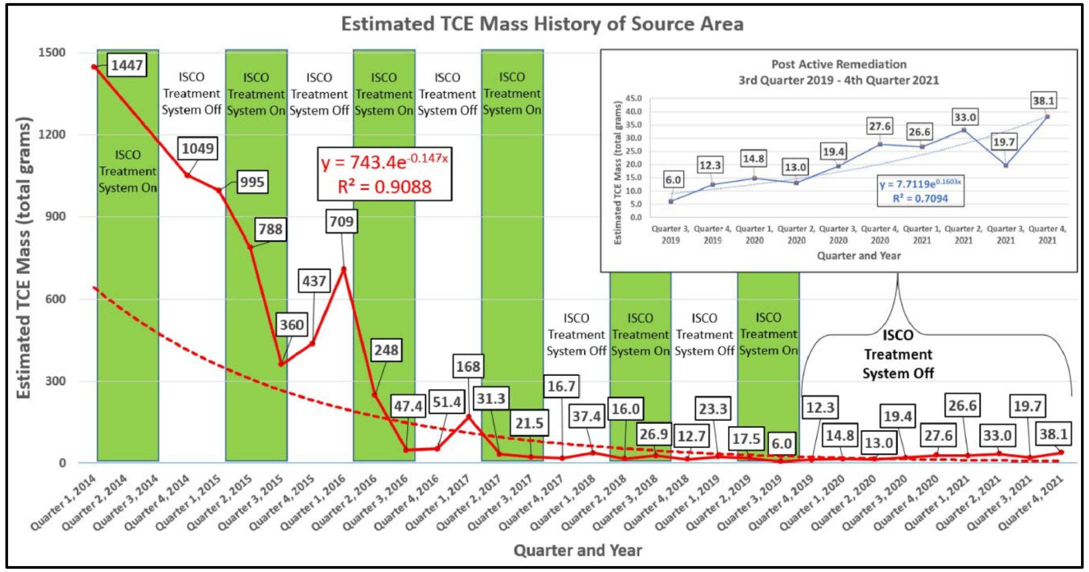
- Implement up to 8 Injection – Extraction well pairs simultaneously
  - Decreased TCE mass in the Source Area by 98%
  - Decreased TCE mass in the Source Area by 84% (still in process)
- Capable to achieve near 100% uptime via automation throughout the field season (May through October in Colorado)
- Requires system O&M only twice/week
- Changes to well pairings and configurations are quick
- Sodium permanganate disperses/diffuses well and is persistent in the groundwater







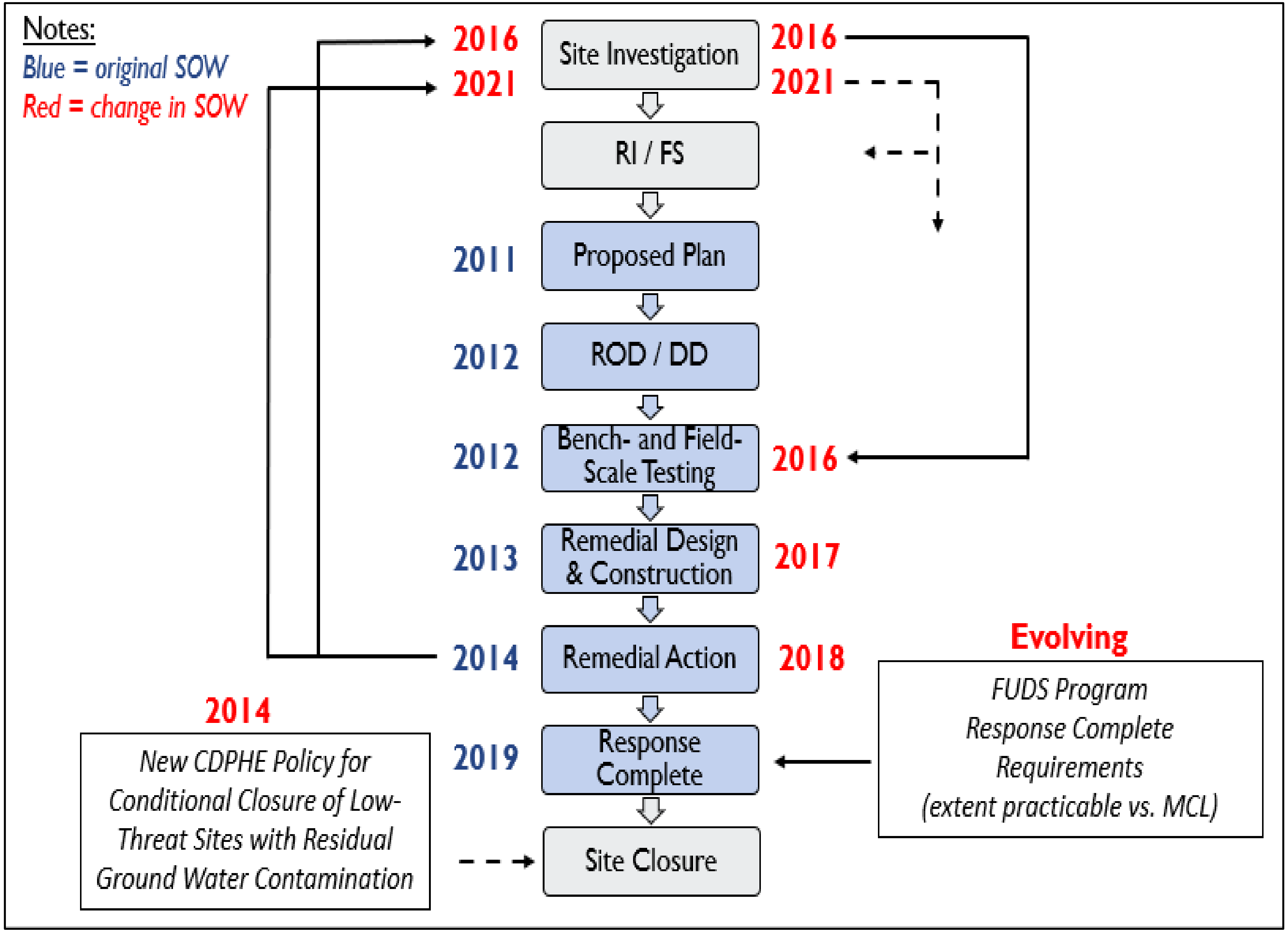




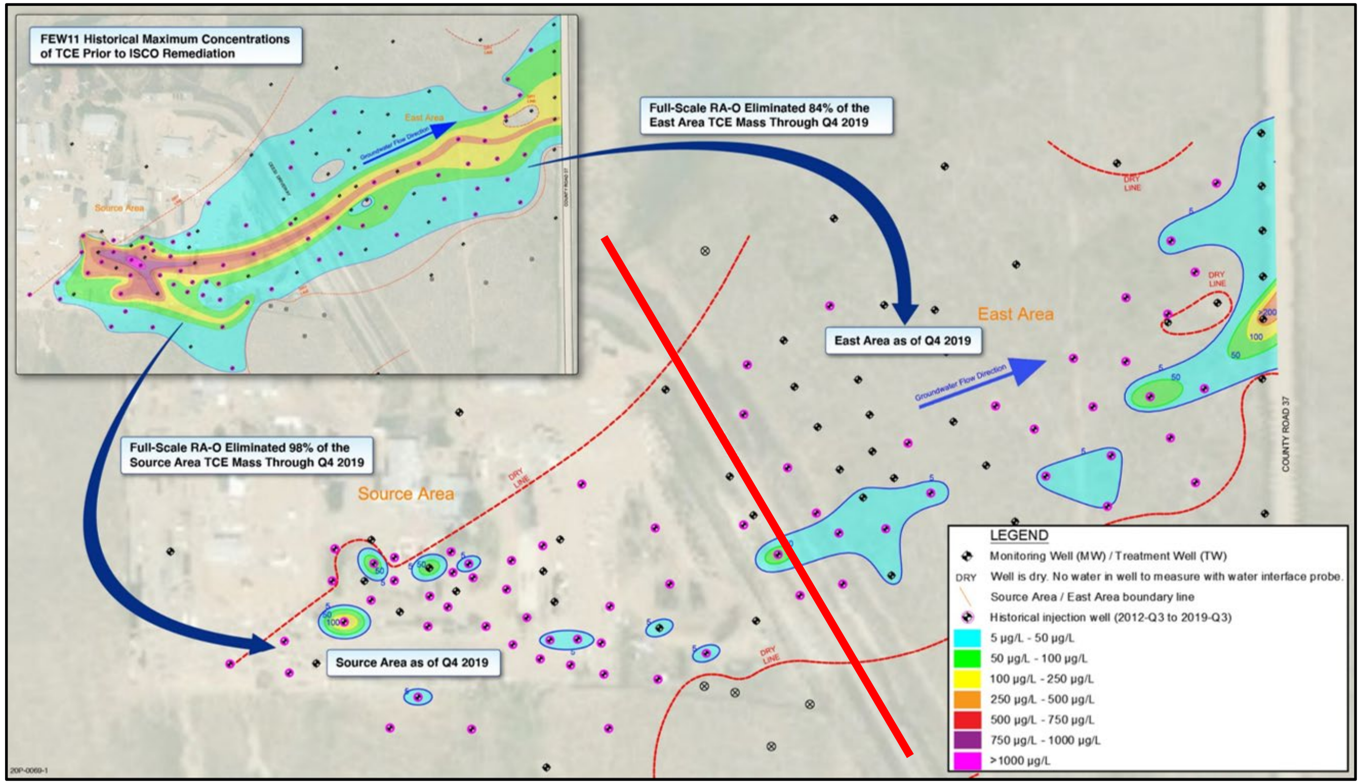
CERCLA Framework

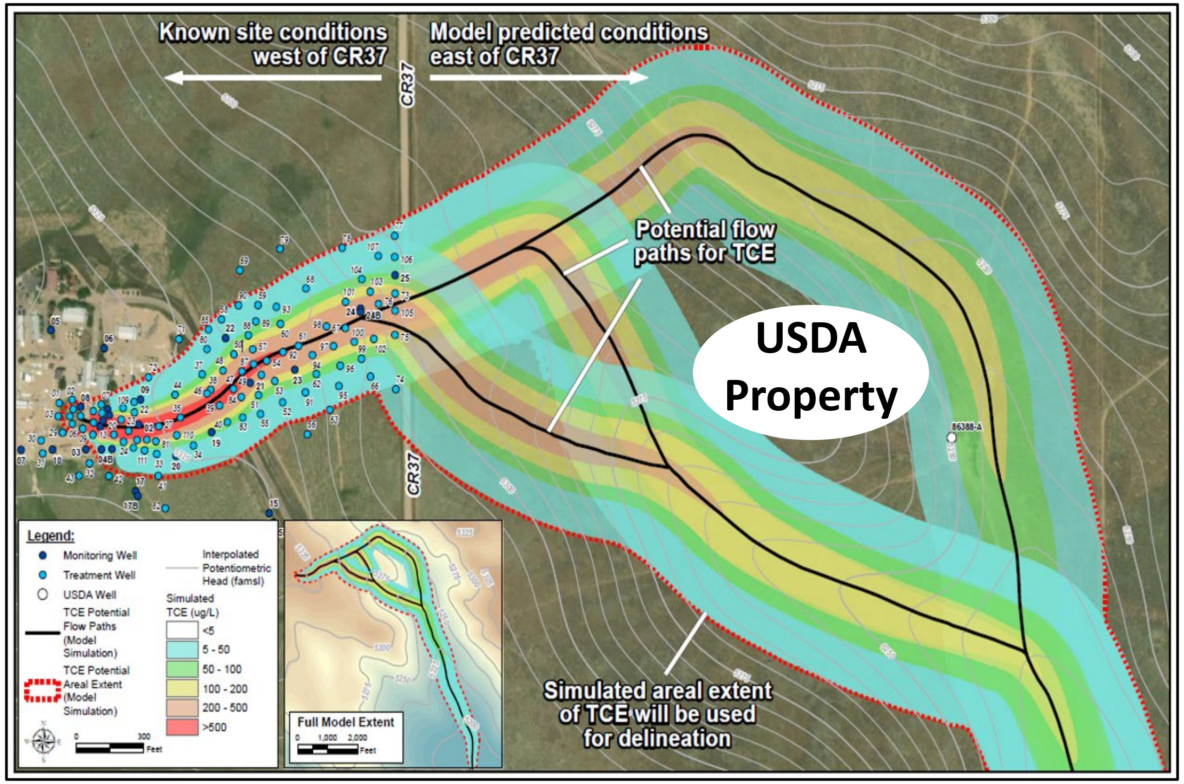
***Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA)**

- The CERCLA framework is set up as a linear process
- The process can easily be 'broken' due to previous steps being not fully complete
- Often, we find that the Investigation phase requires a revisit to better characterize the Site



Why an Airborne Electromagnetic (AEM) Survey?





Updating the Conceptual Site Model (CSM)

- Visual depiction of recent groundwater TCE concentrations across the Site
- Achievement of Response Complete (RC) in the Source Area in 2019
- Delineated the extent of TCE-impacts in the East Area
- Ongoing Remedial Action-Operations (RA-O) in the East Area (2018 to current)

Note the termination of TCE-impacts along County Road 37 (CR37)

- **Based on our current understanding of the Site, where are TCE-impacts most likely to continue beyond CR37?**

Data Input

- Analytical results, lithology, well construction, and water level measurements from 139 soil borings and wells

Data Processing

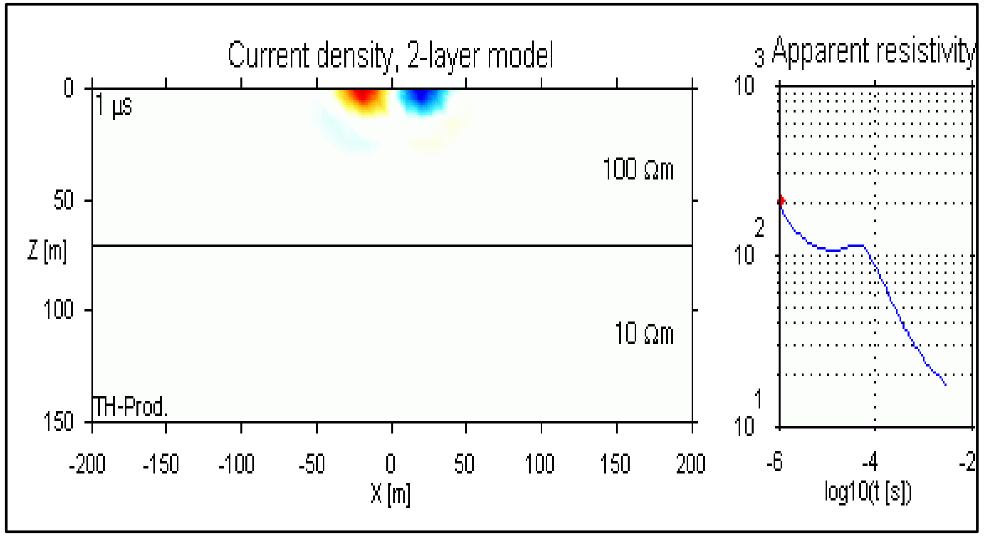
- Data synthesized using EarthVision® (geologic modeling software) and ATRANS (3D advective-dispersive chemical transport code)

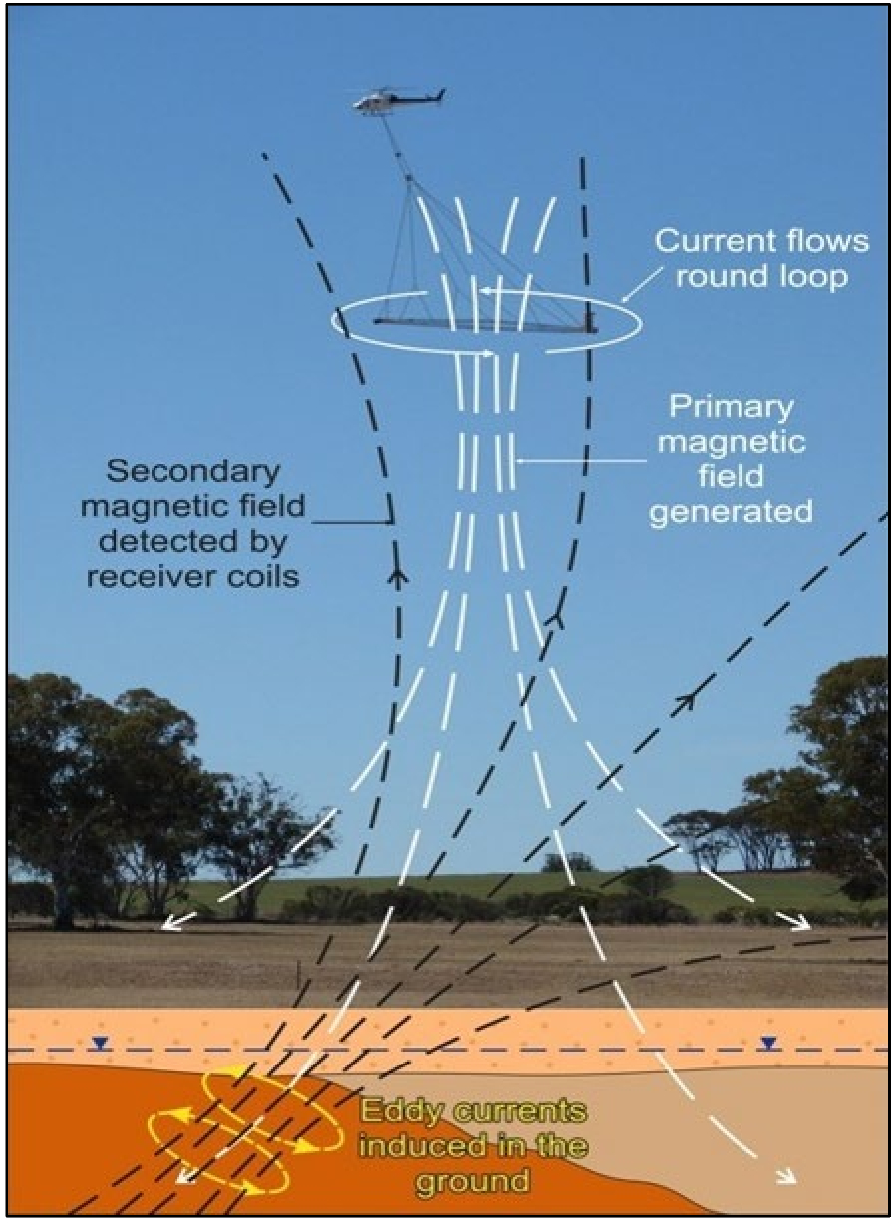
Task 9: Delineate the TCE Plume in the Area East of CR37 (including horizontal and vertical extents):

The chief purpose of the AEM Survey was to collect subsurface data in a noninvasive manner to guide up to six well/boring locations.

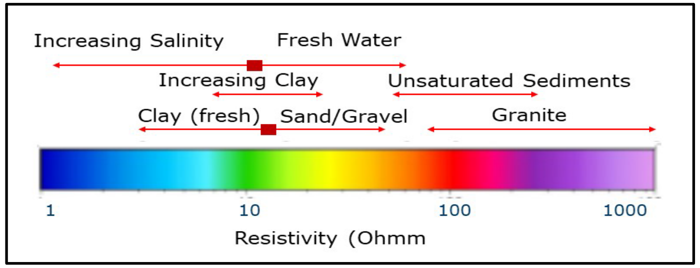
What is Airborne Electromagnetics

- Measure subsurface **electrical properties**
- Depth of investigation **0-500 metres**
- Data inverted into a **conductivity/resistivity model**

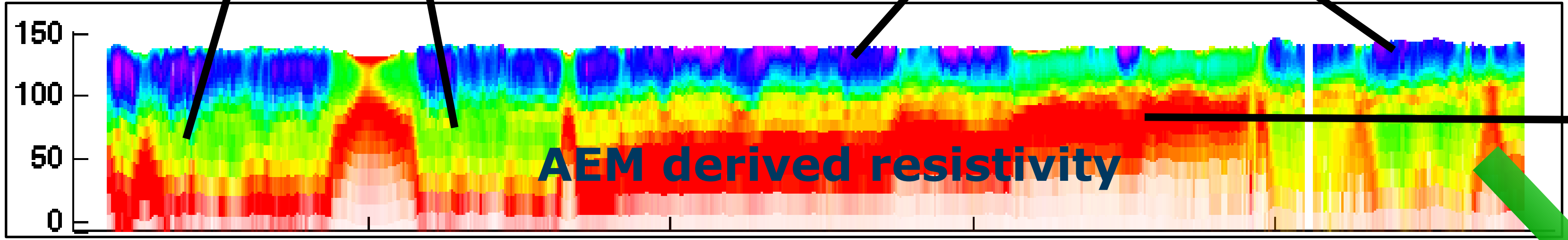




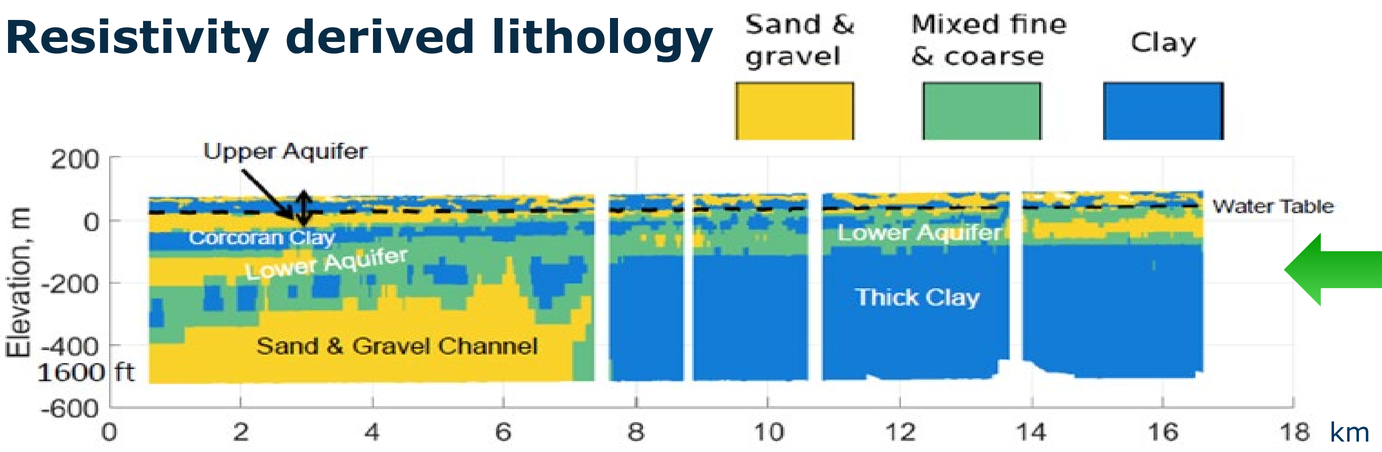
AEM to Lithology



20 miles



Resistivity derived lithology

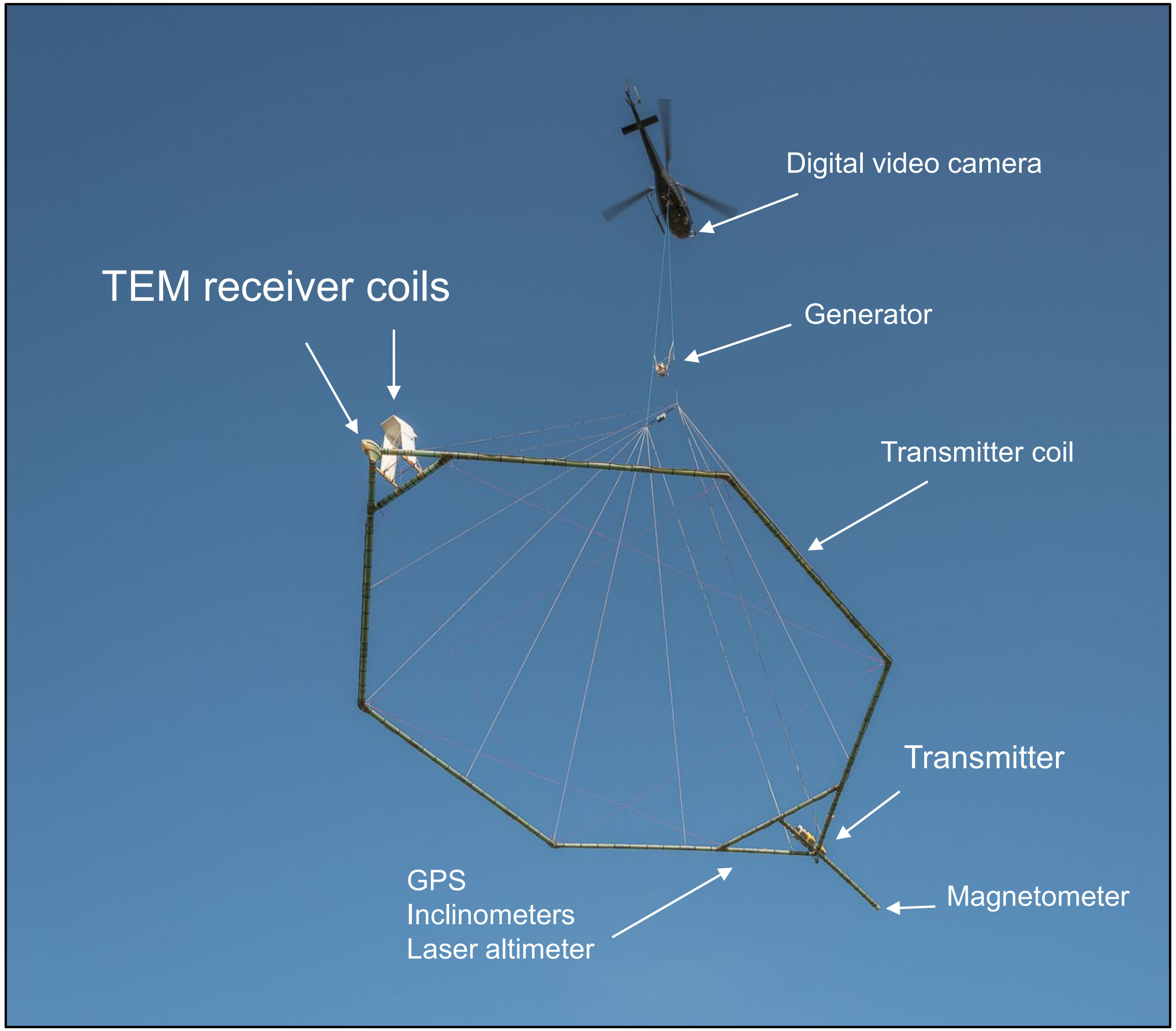


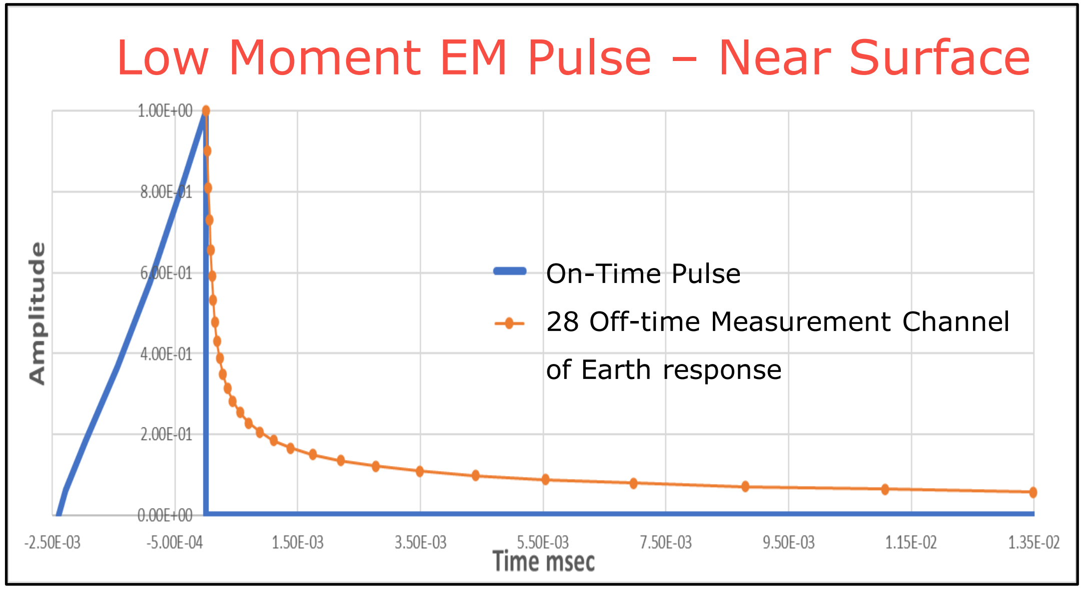
Subsurface mapping with airborne electromagnetics in the Central Valley of California
Dr. Rosemary Knight et al Stanford University

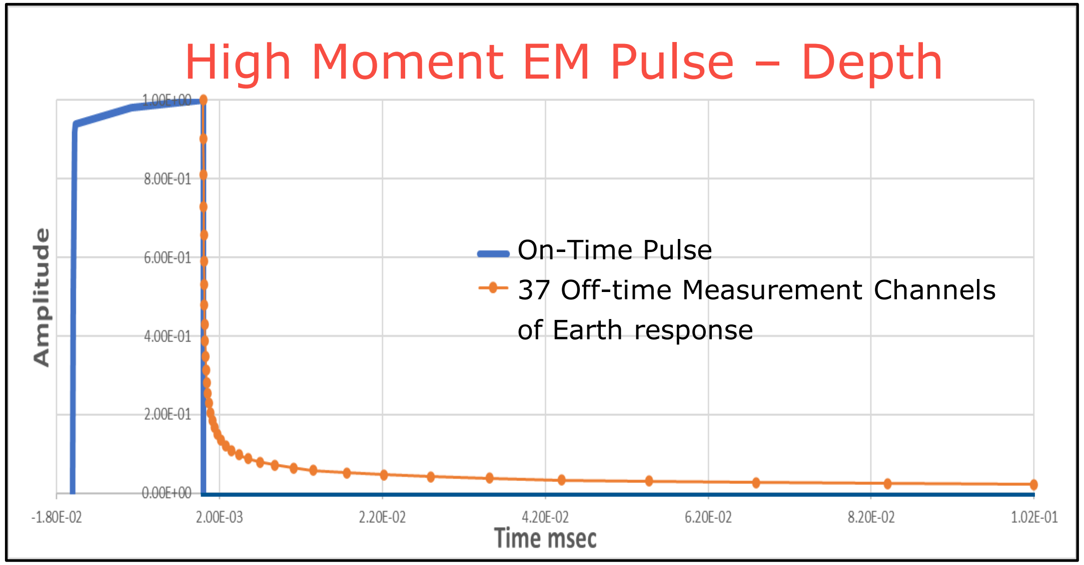
"Geological data gathered from boreholes are an absolutely critical part of study design and implementation, establishing confidence in the interpretation of lithology from resistivity"

Airborne electromagnetic surveys: A quantitative tool for groundwater management
J. Abraham, J.Cannia, B.Minsley USGS
GEM Beijing 2011

SkyTEM304 Configuration







Survey Design: Near Surface Mapping

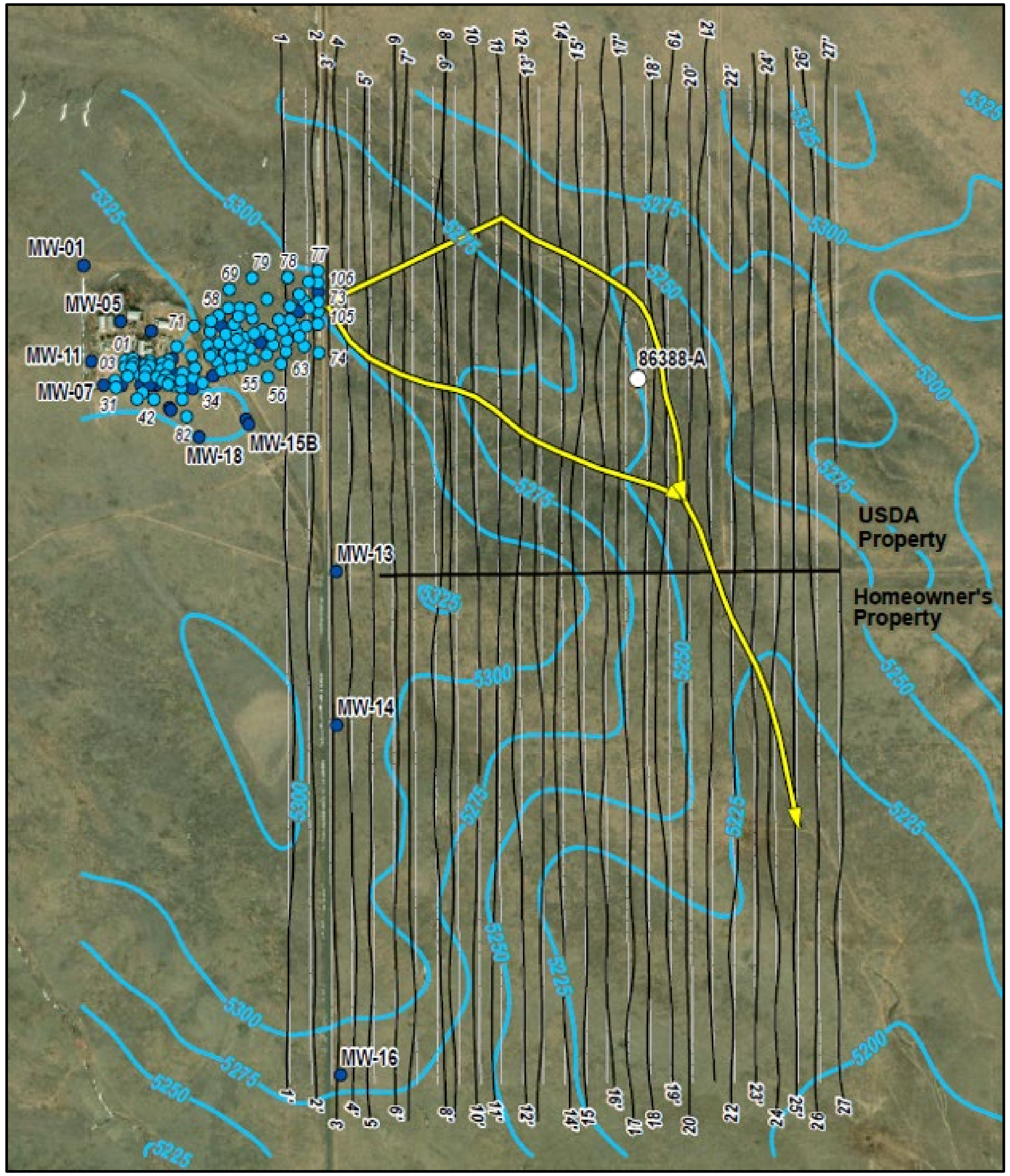
SKYTEM

Operational considerations:

- Understand geological trends
- Distance to base of operations
- FAA and other regulations & restrictions
- Weather

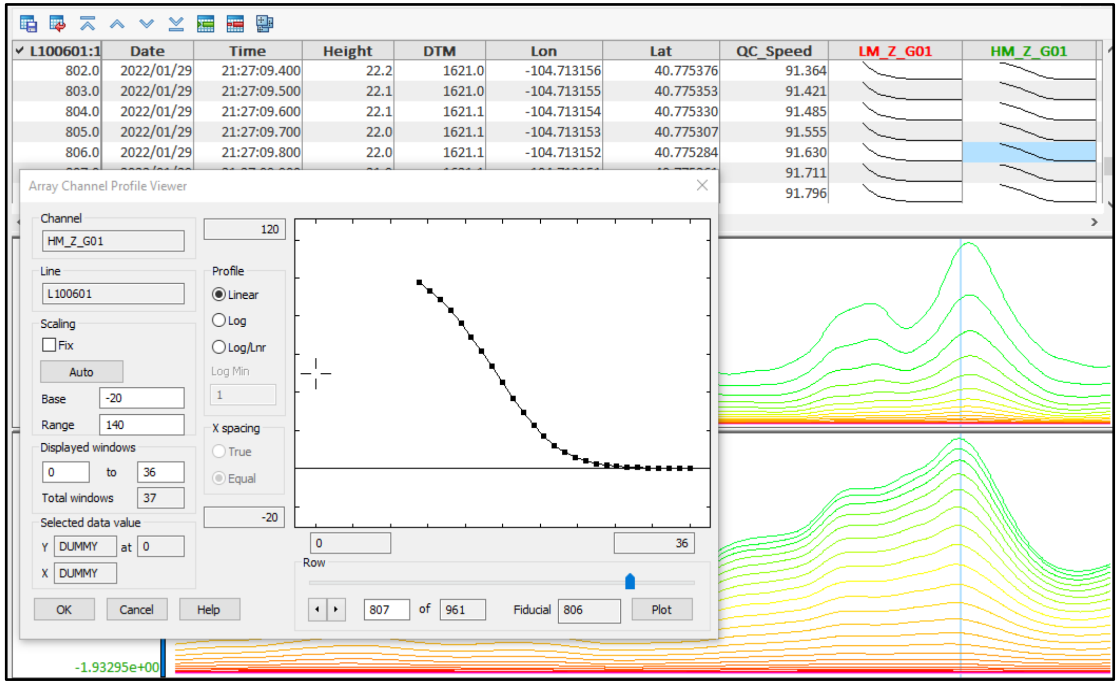
Design outcomes:

- SkyTEM304
- 50m line separation
  - High lateral spatial resolution
- ~35m flying height
  - Safety & Data Quality
- 100 km/h flight speed
  - Safety & Data quality



Survey Statistics

Transects	27
Ave length of transects (km)	2.5
Survey area (acres)	803
Planned vs Flown l-km	63.7 vs 68.5
Data Stations	~30,000
EM Soundings	~60,000
EM data points	~3,000,000
Inverted conductivity data points	~70,000

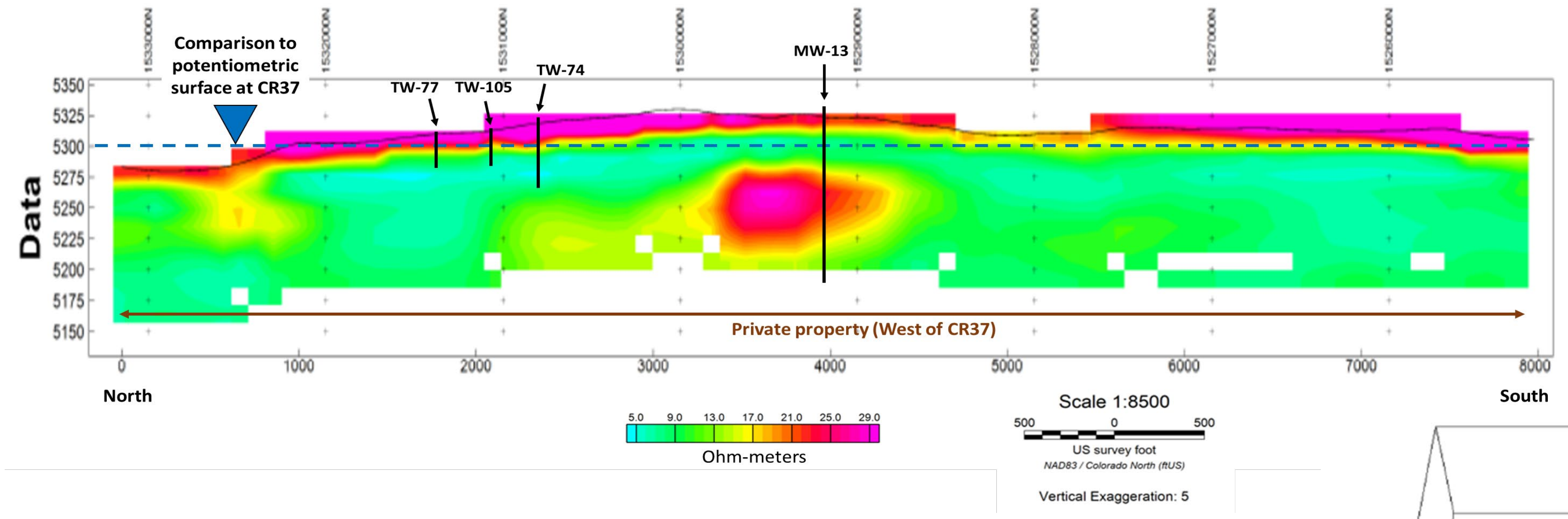


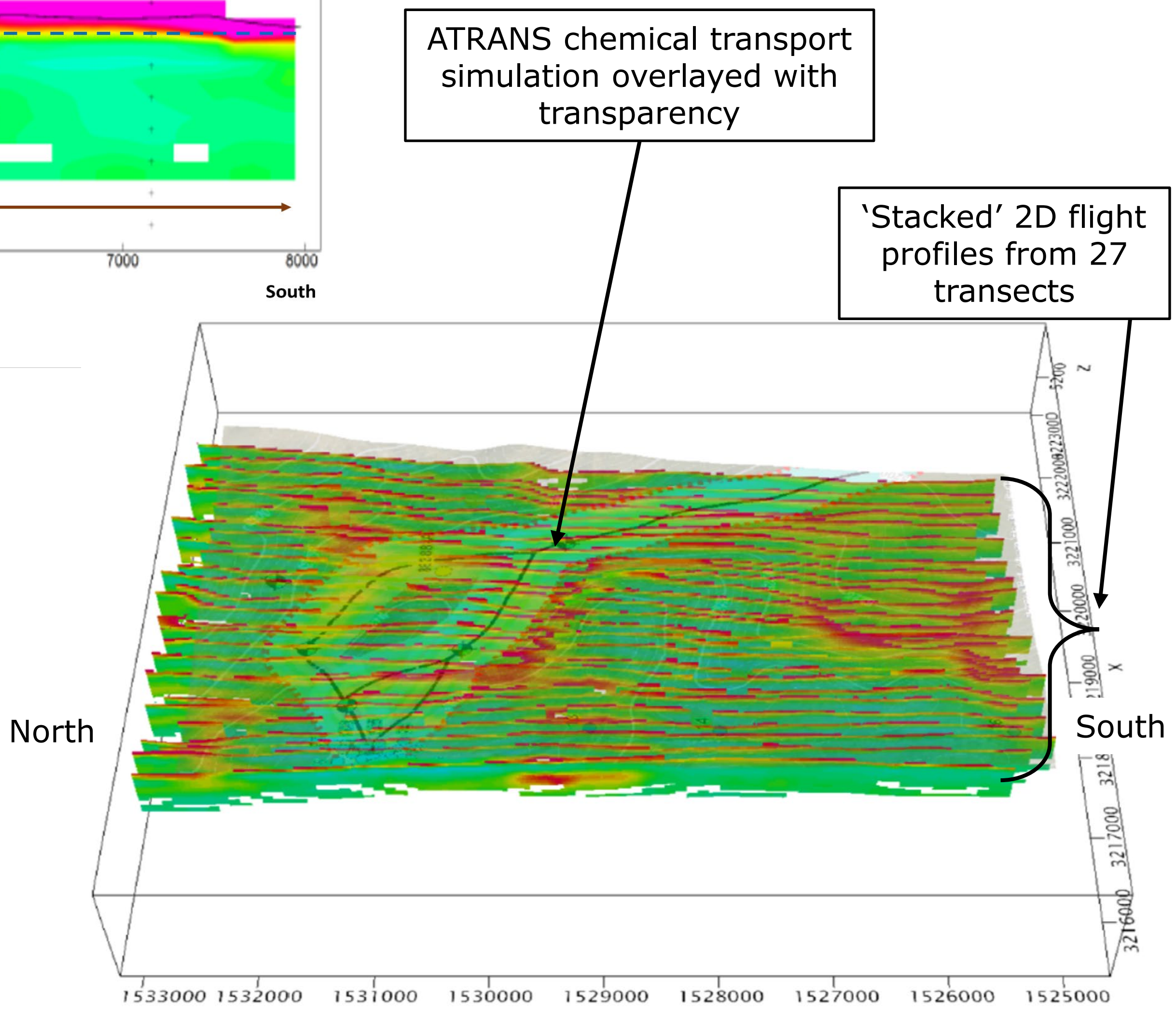
Data Quality Control

- 2-3 pre-production calibration flights
- Pre-flight equipment check
- Field data QC immediately following a flight
  - Proprietary software
- Daily data check by office geophysicist
  - Proprietary and commercial software

INSTRUMENTS	Time/Date	Yes/no/initials
EM		
Date and time on PaPC and Mag PC synchronized with GMT/UTC	20220127	Yes/FL
Data sign on Z coil positive, X-coil negative	20220127	Yes/FL
Signal on X component ~10 times lower than Z	20220127	Yes/FL
Noise scripted - noise ok on both x and z coil	20220127	Yes/FL
Noise on X component ~8 times higher than Z	20220127	Yes/FL
Internal noise test	20220127	Yes/FL
Apparent 0-pos found - Z coil	20220127	Yes/FL
Apparent 0-pos found - X coil	20220127	Yes/FL
The production script is running for 30 minutes	20220127	Yes/FL

Initial Survey Results in 2D

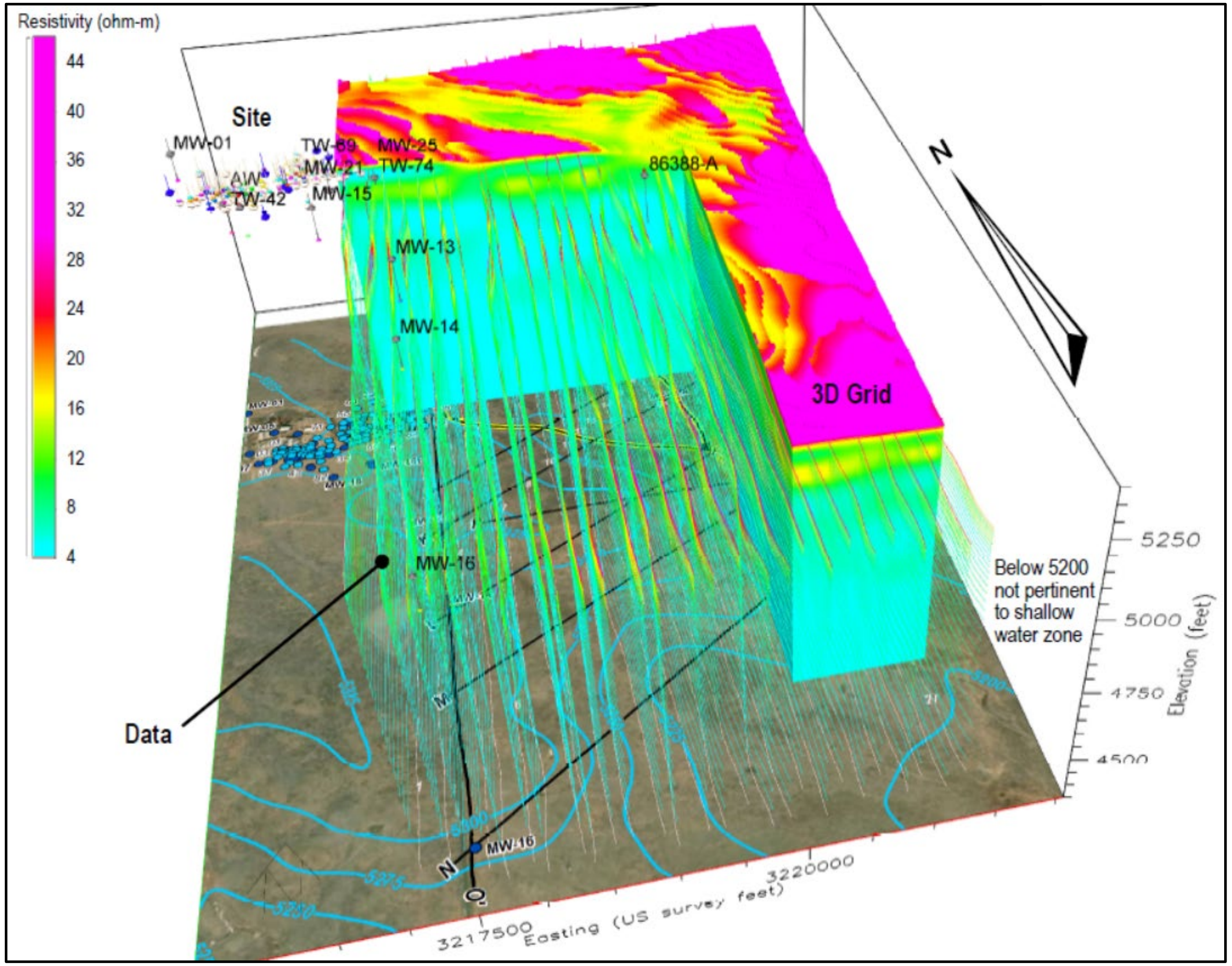


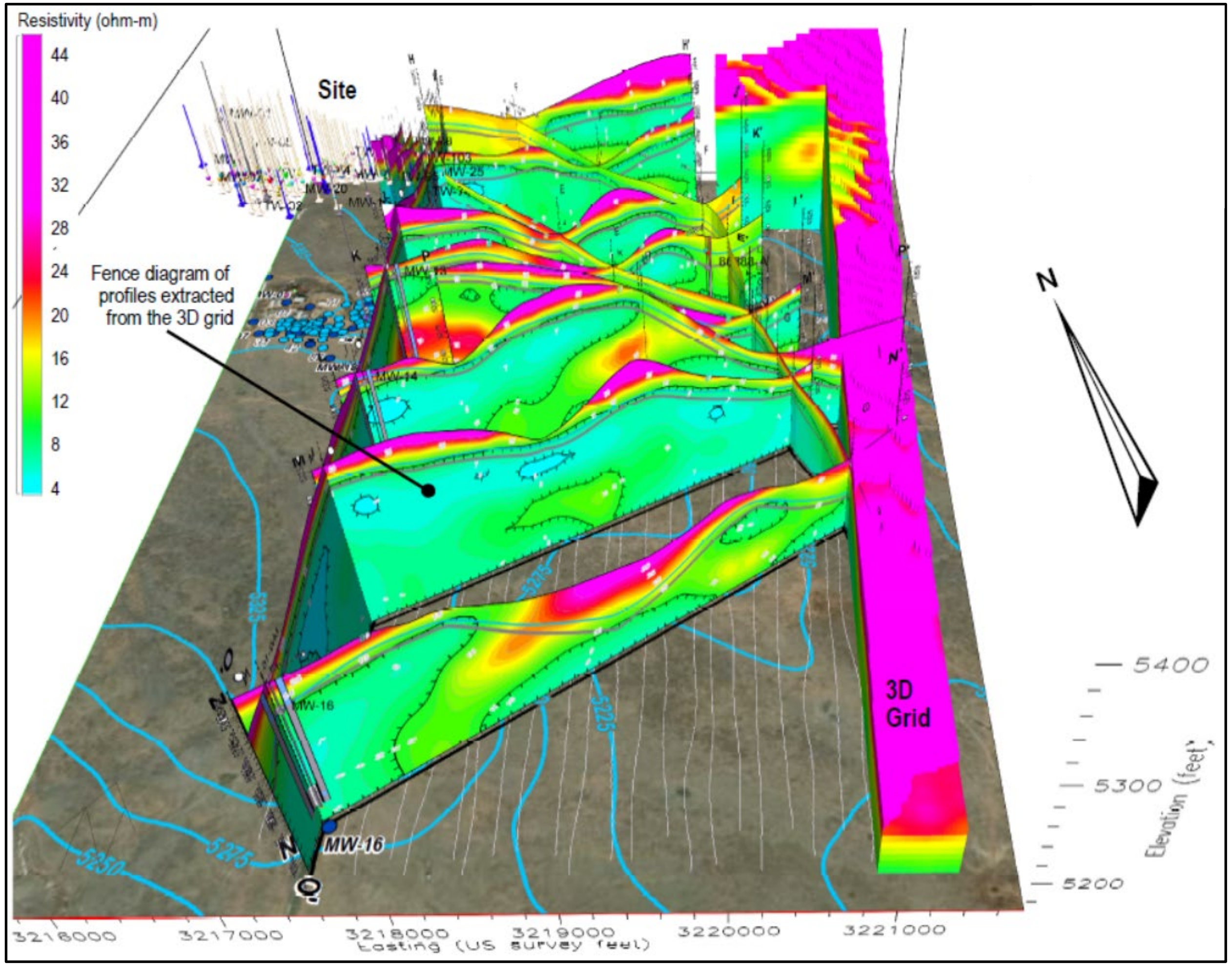


Limitations using Oasis Montaj Software

- North South trending profiles only
- Difficult to follow subsurface features
- Difficult to isolate specific resistivity values/ranges
- Difficult to interpolate between stacked 2D images

3D Model from Resistivity Data

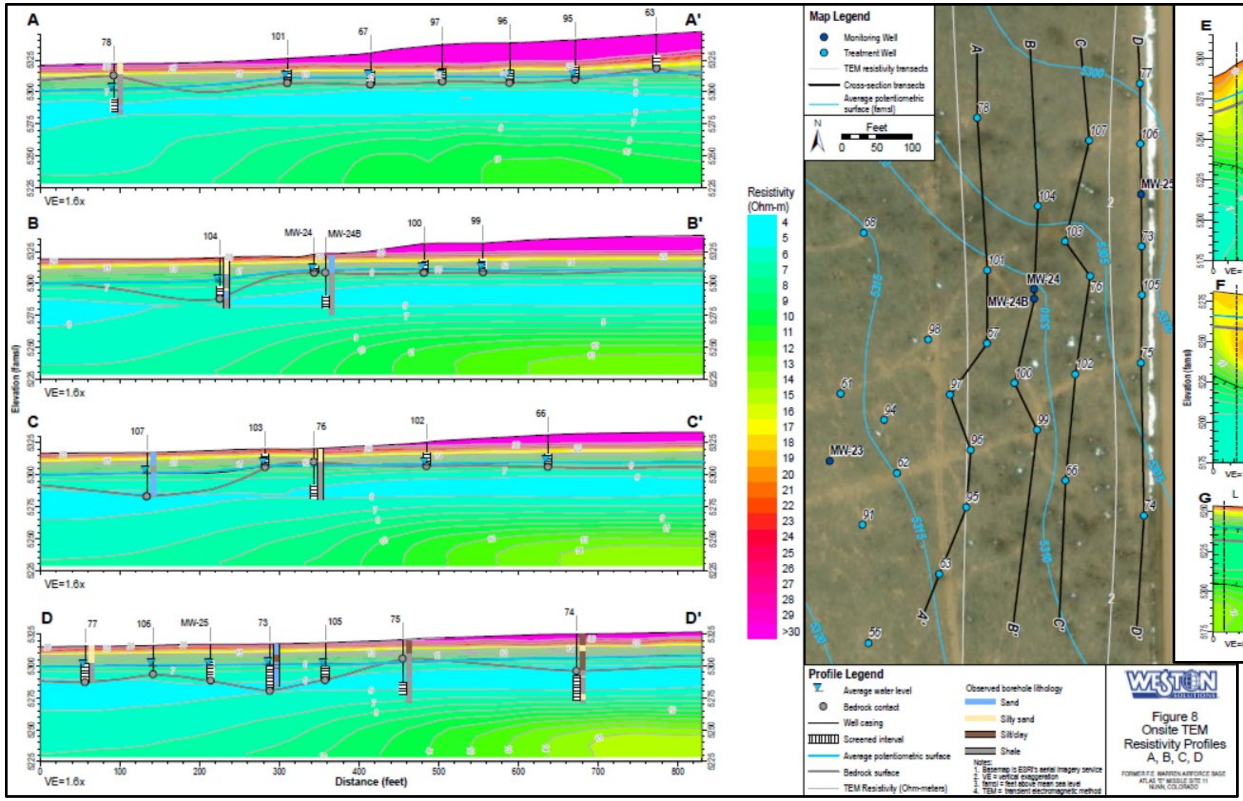


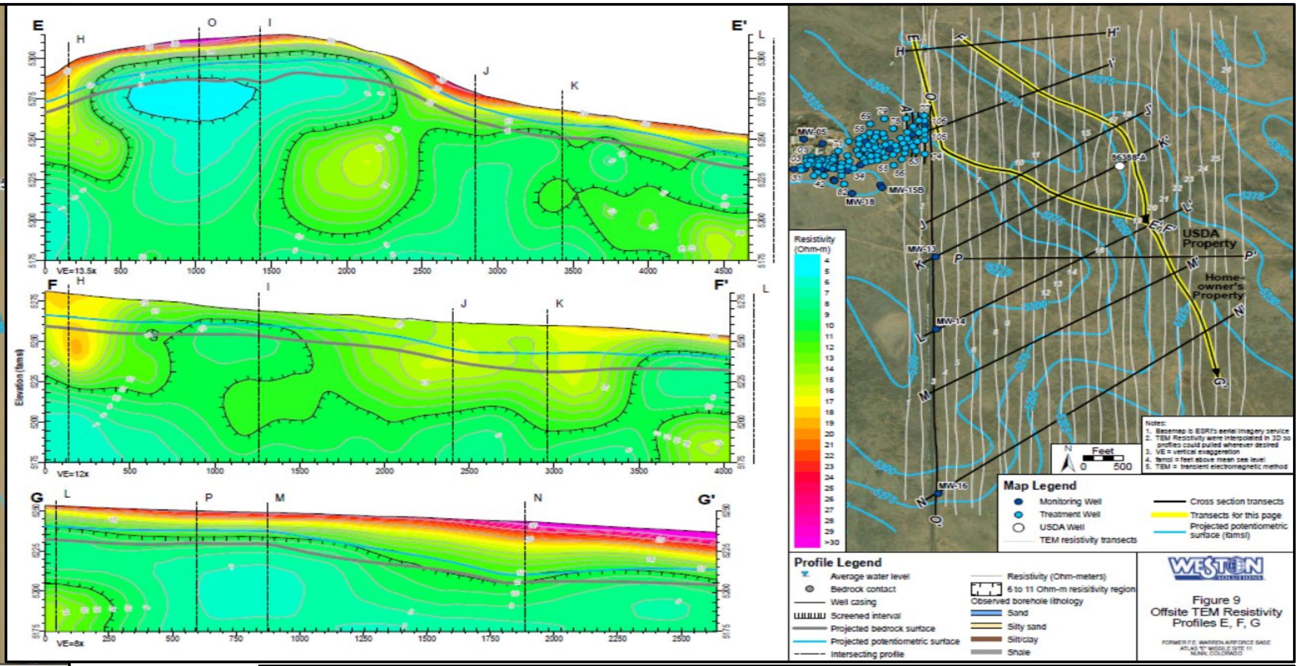


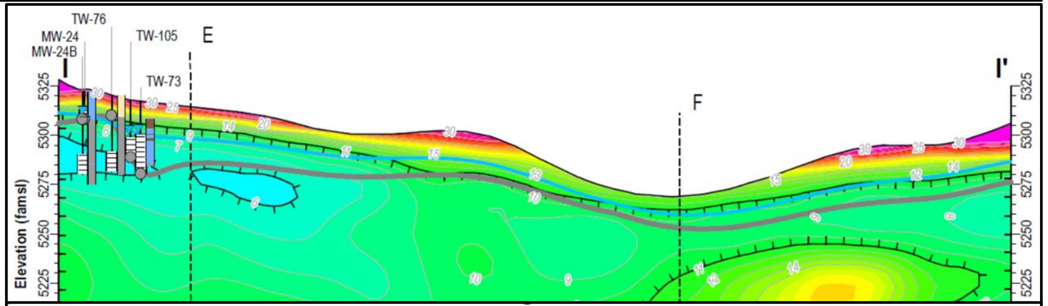
Post-Oasis Montaj Processing

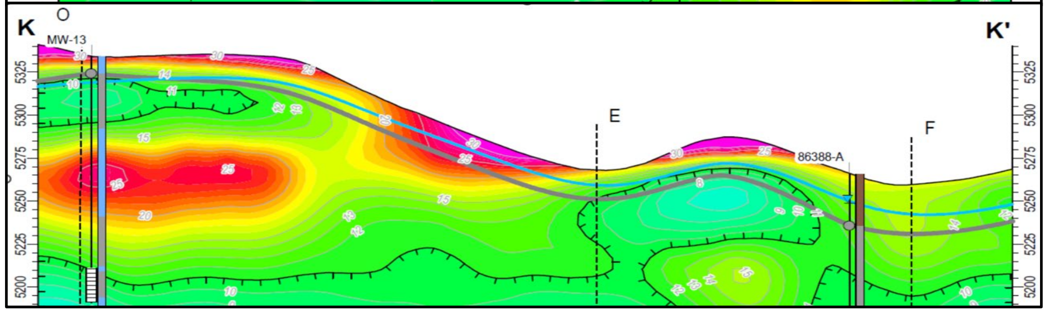
- The 3D grid-interpolation was performed using a minimum tension splining algorithm within the EarthVision 3D geologic modeling suite (Dynamic Graphics, 2023)
- Calibrated (updated) the resistivity model to corroborate with existing 'onsite' boreholes (lithology, saturated zone, etc.)
- Extracted onsite and offsite profiles from the 3D grid to construct this 'Fence Diagram'

Cross-Sectional Profiles and Interpretation









Profiles A, B, C, and D – Wells were used to calibrate AEM data (ground-truthing)

- Comprised of 24 onsite wells (2% of the total AEM Survey Area)

Profiles E, F, and G – Most likely flow path based on AEM Results / 3D Model

- Supports the paleochannel-topographic lows theory

Profile I – Plume centerline extrapolated from onsite to offsite areas

- Highlights where the TCE-impacted water may migrate once offsite

Profile K – Corroboration between high contrasting lithology (shale and sandstone) and AEM results

Together, the interpretation of these profiles indicate the most probable groundwater flow path(s) East of CR37 and verify that the collection of subsurface data is feasible from the air with *no boots on the ground.*

Proposed Well Placement

Overarching Goals for Conducting an Airborne Electromagnetic Geophysical Survey:

1) Collect subsurface data via airborne techniques, '<u>No Boots on the Ground</u>'

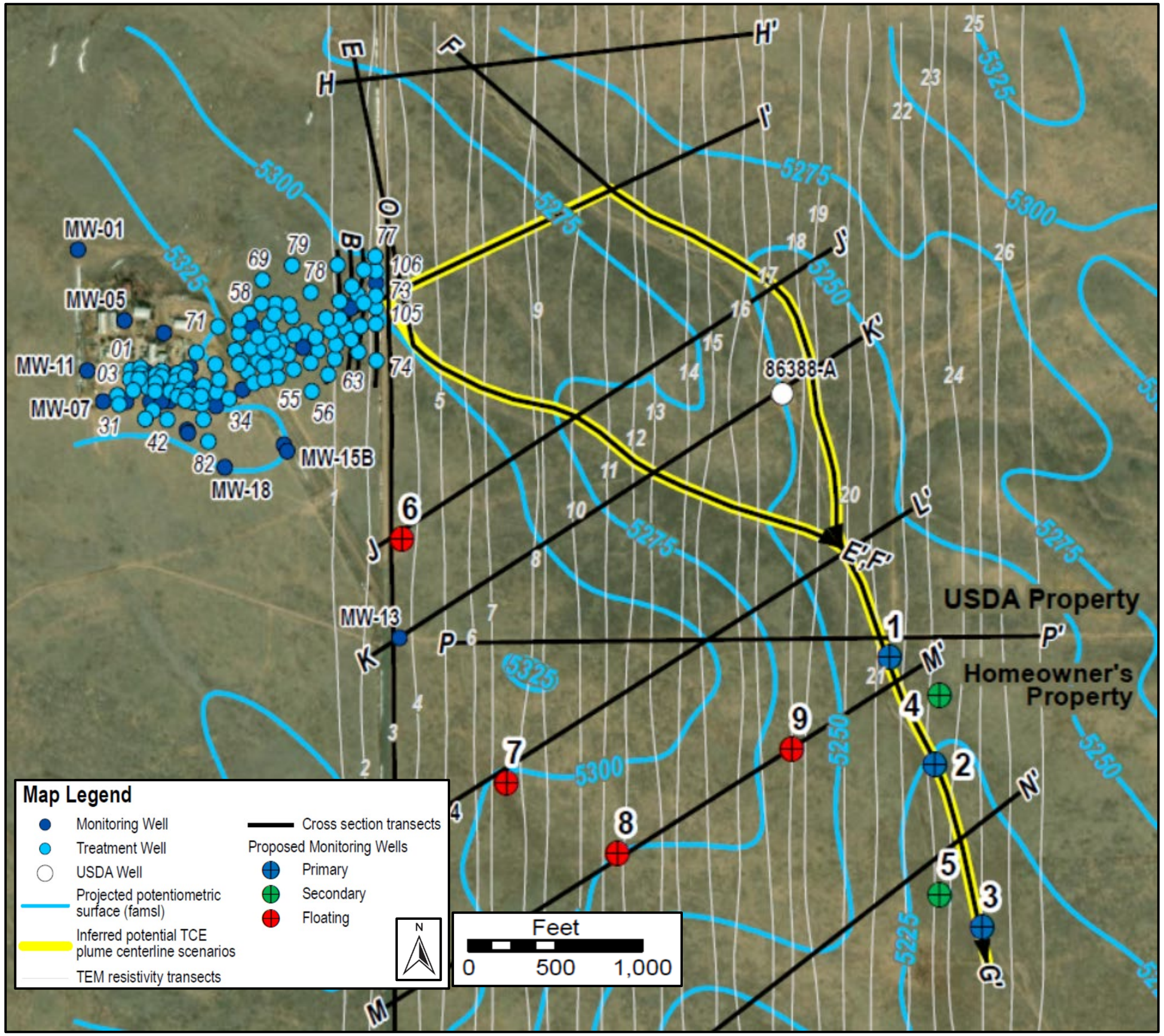
2) Locate potential paleochannels that may act as a groundwater conveyance mechanism for upgradient TCE-impacted groundwater

3) Install up to **6 total wells** with aim to delineate the extent of <u>TCE-impacted</u> groundwater

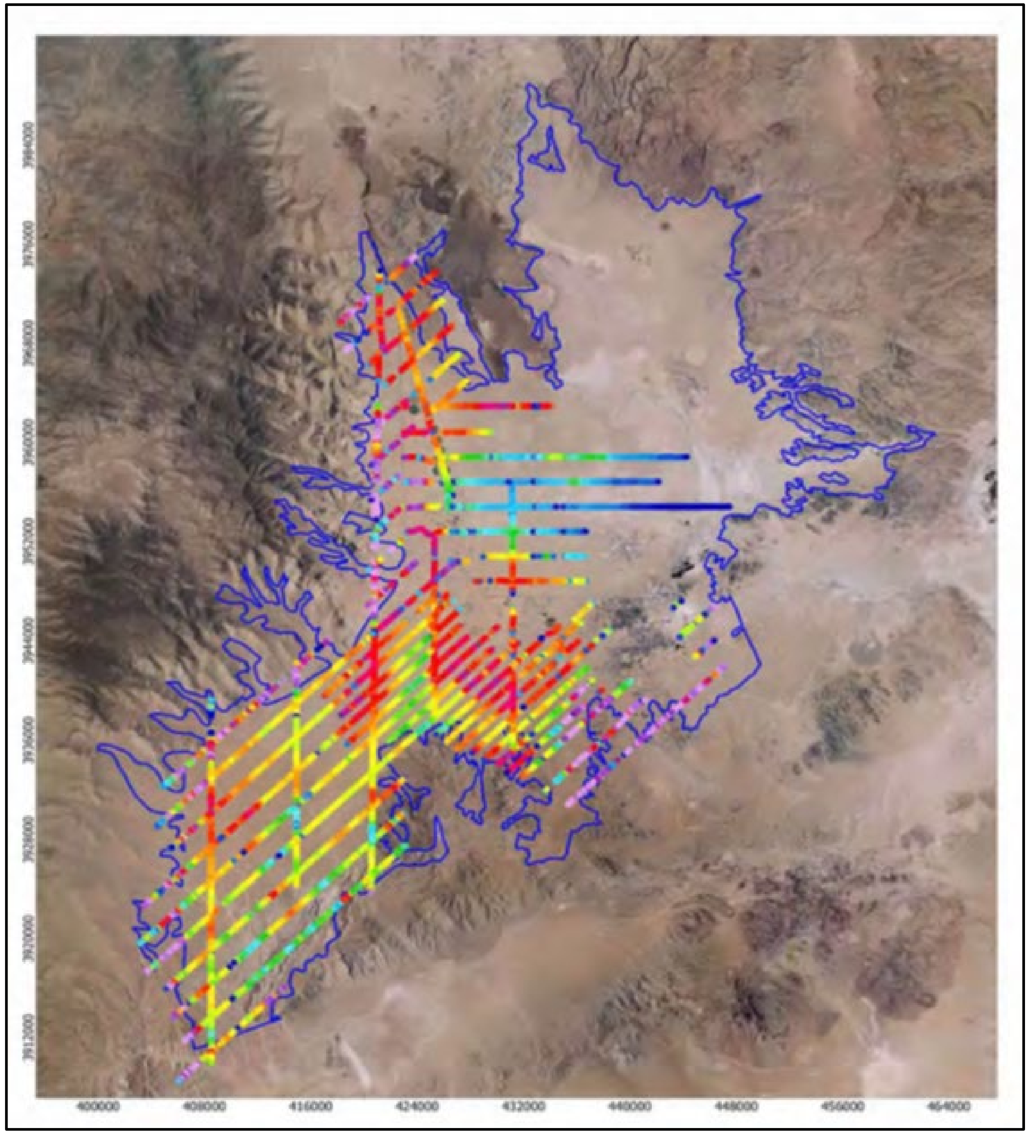
The challenge is that 'Right of Entry' cannot be attained due to a 30-year grassland study that is being carried out on the USDA property that is adjacent to the Site.

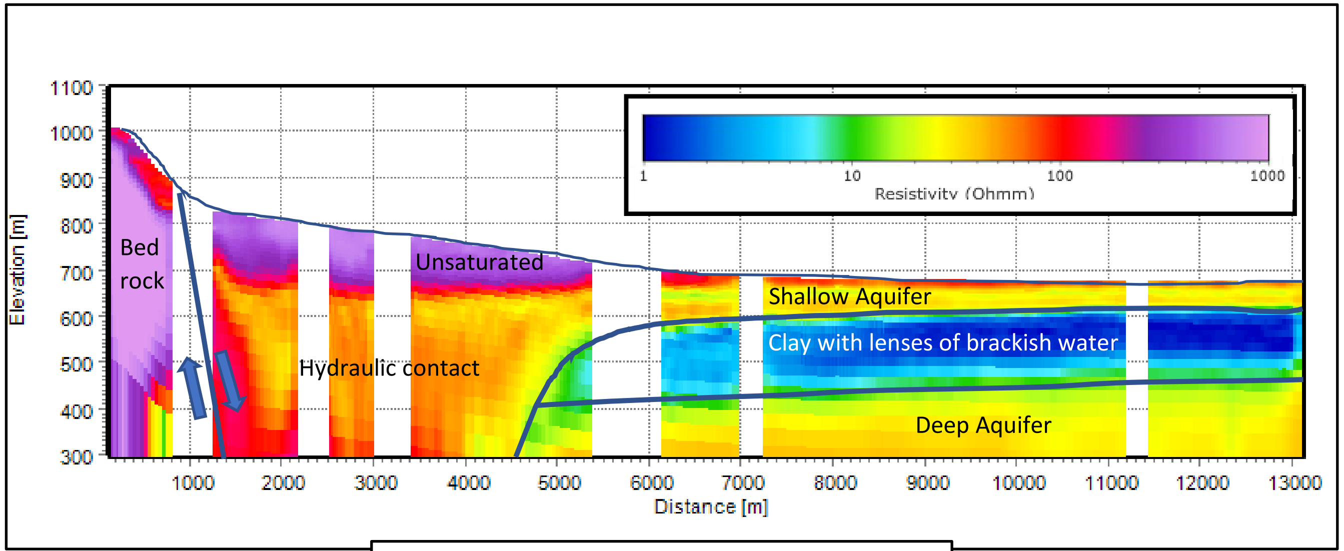
The Weston Team proposed 9 total locations to the South and West of the USDA property where groundwater may be likely:

- **<u>3 Primary locations</u>** along Profile G
- **<u>2 Secondary locations</u>** approximately 200 feet East or West of the Profile G centerline
- **<u>4 floating well locations</u>** that may be adjusted based on findings from Primary and Secondary locations

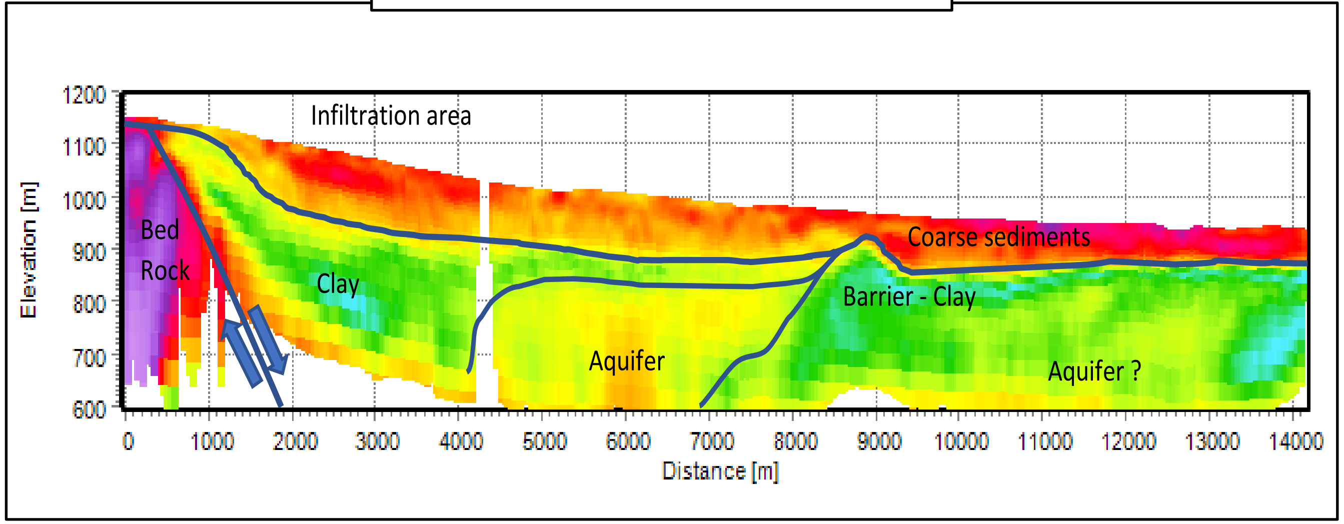


Survey Design Considerations:
Varying Line Direction and Spacing

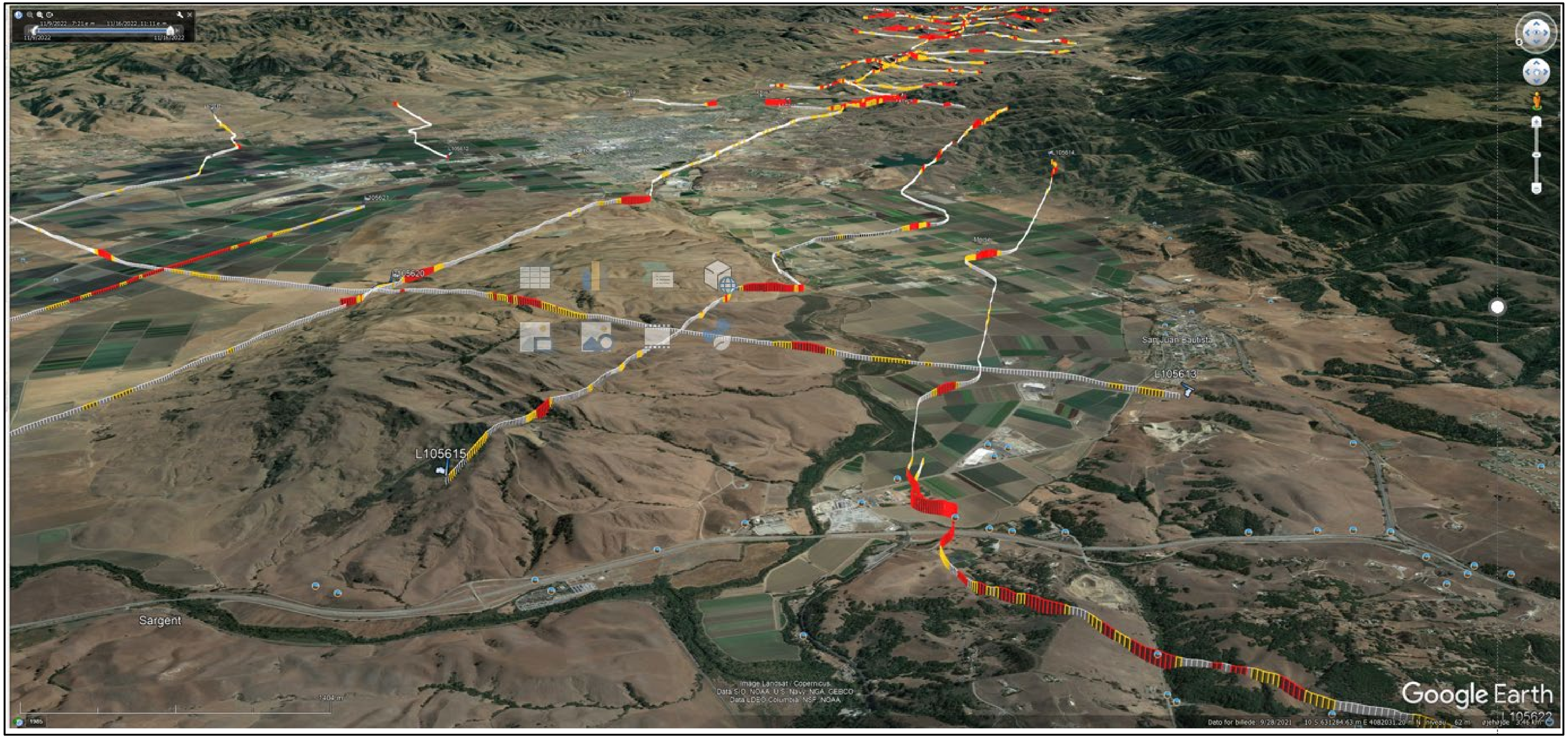




Indian Wells Valley, CA



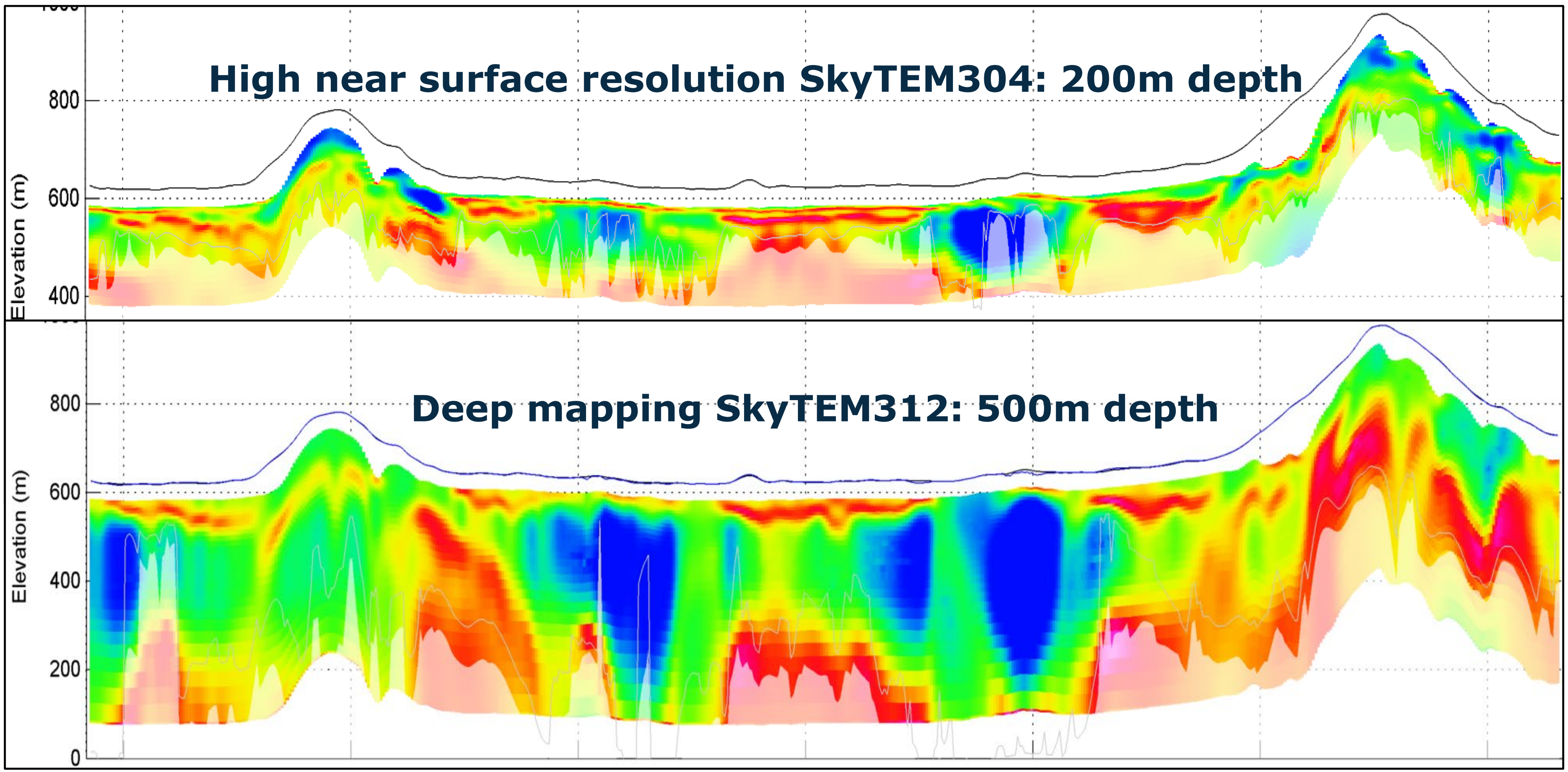
Non-Linear Transects



Data: California Department of Water Resources

Survey Design Considerations:

Shallow vs Deep Mapping Systems



Thank You!

Questions?

"Don't place wells with hope, place with intension"

Special thanks to:

- Molly Maxwell *(United States Army Corps of Engineers)*
- Mark Rothas *(United States Army Corps of Engineers)*
- Tony Briganti *(United States Army Corps of Engineers)*
- Danielle Welch *(Weston Solutions)*
- Jared Johnson *(Weston Solutions)*
- Philip Stearns *(Weston Solutions)*
- Mandy Long *(SkyTEM Canada)*

Photo captured by adjacent property owner – facing E-SE