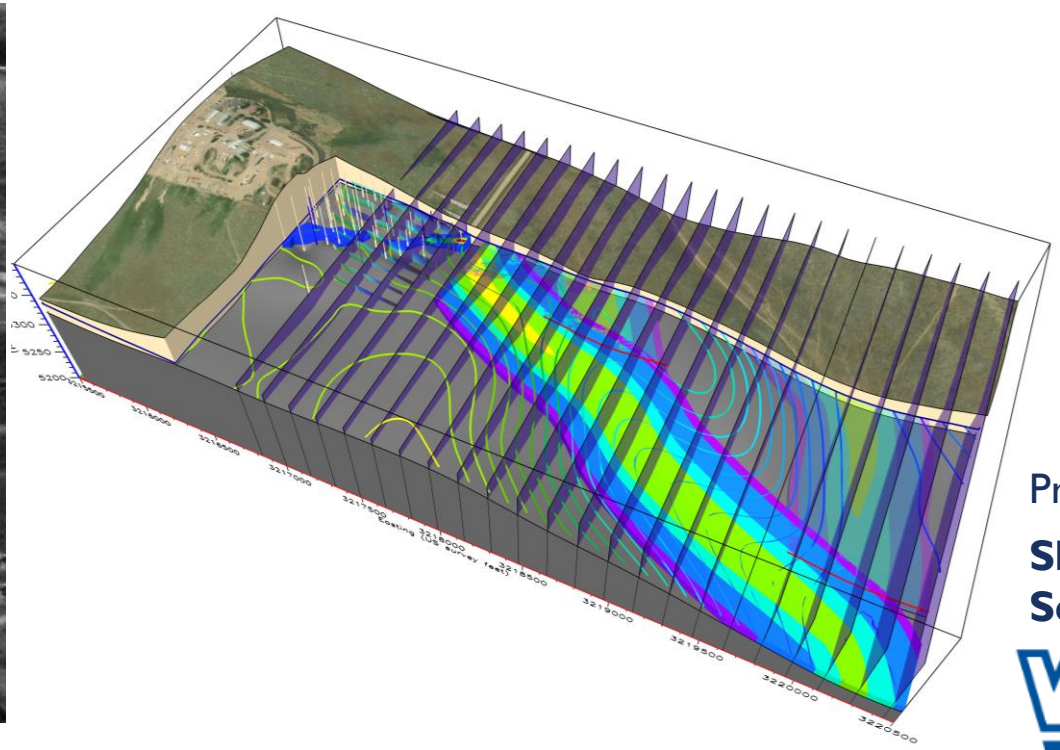


Presented by:

Shaun Cwick, P.G.
Senior Geoscientist

F.E. Warren AFB, Former Atlas "E" Missile Site 11, Nunn, Colorado

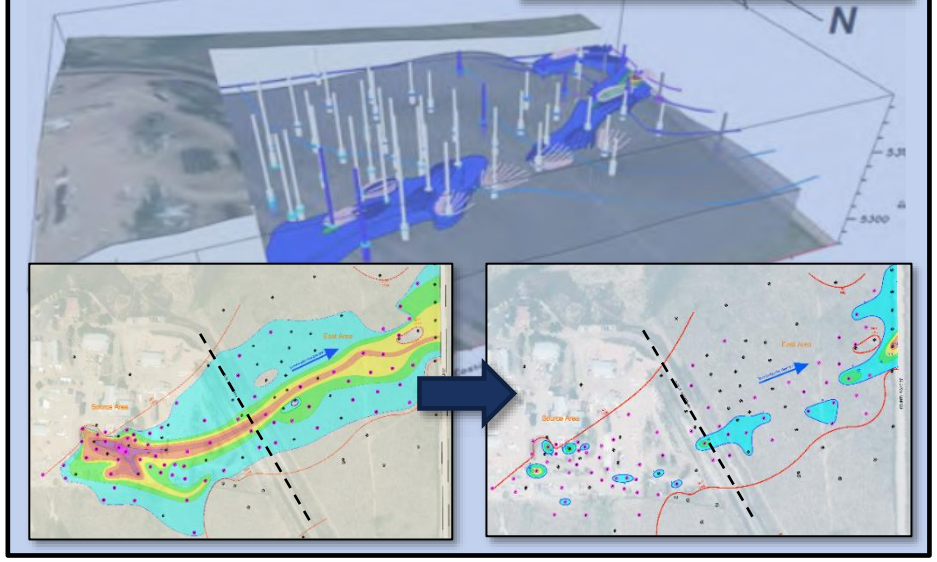
Case Study: Using Adaptive Management to Balance Changes in the CSM, Applicable Regulations, and Newly Identified Stakeholders

F.E. WARREN AFB, FORMER ATLAS "E" MISSILE SITE 11, NUNN, CO

Project & Presentation Outline

REMEDIATION

- 12M gal treated via ISCO recirculation
- 99% TCE mass reduction in source area
- 90% TCE mass reduction in off-site area

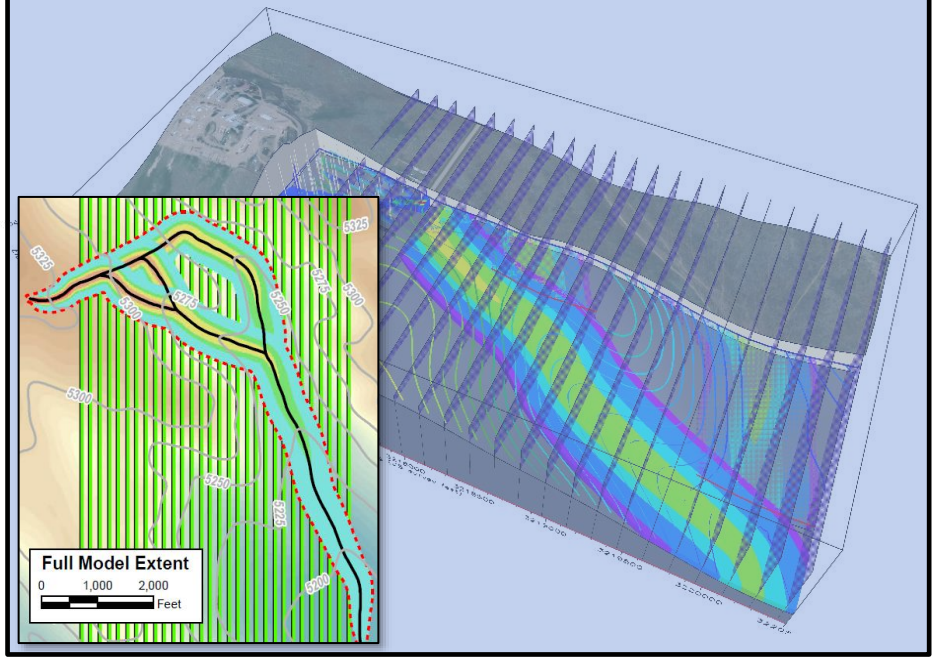


Weston Solutions, Inc.
2011 – Present

- Site Investigation
- RI / FS
- Proposed Plan
- ROD / DD
- Bench- and Field-Scale Testing
- Remedial Design & Construction
- Remedial Action
- Response Complete

INVESTIGATION

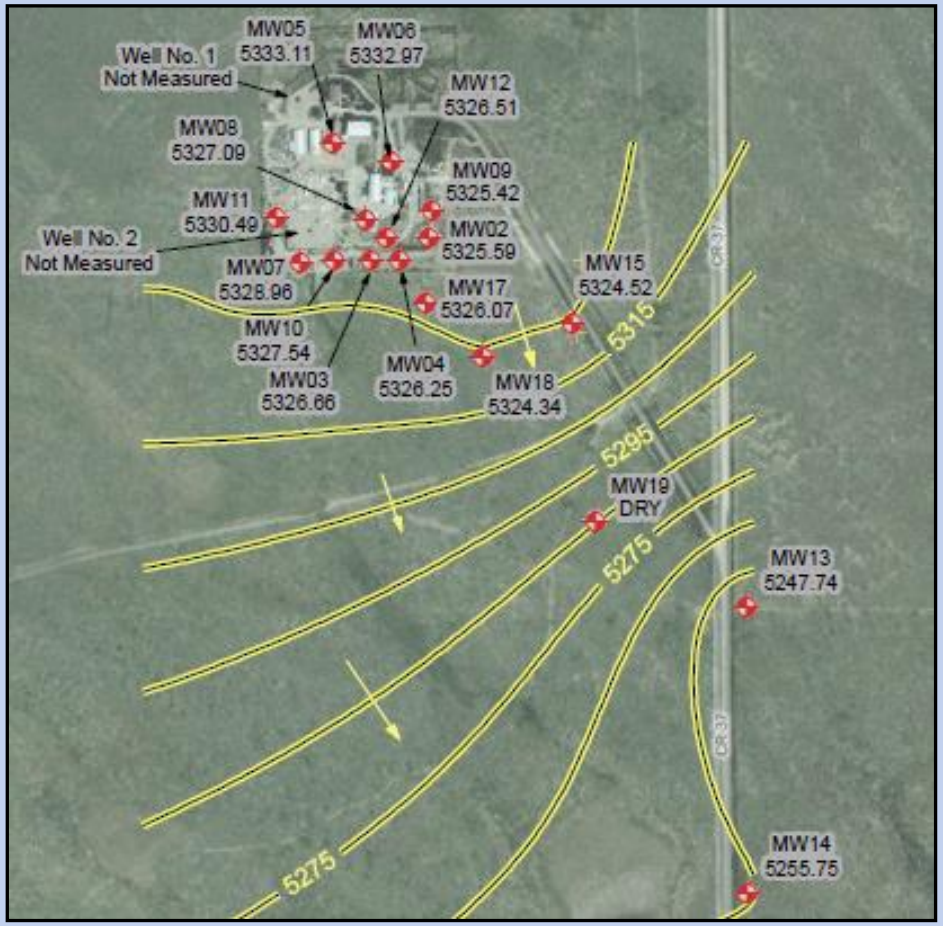
- 125 wells installed
- 4D modeling
- Seismic Refraction survey (2016)
- Helicopter AEM survey (2021)



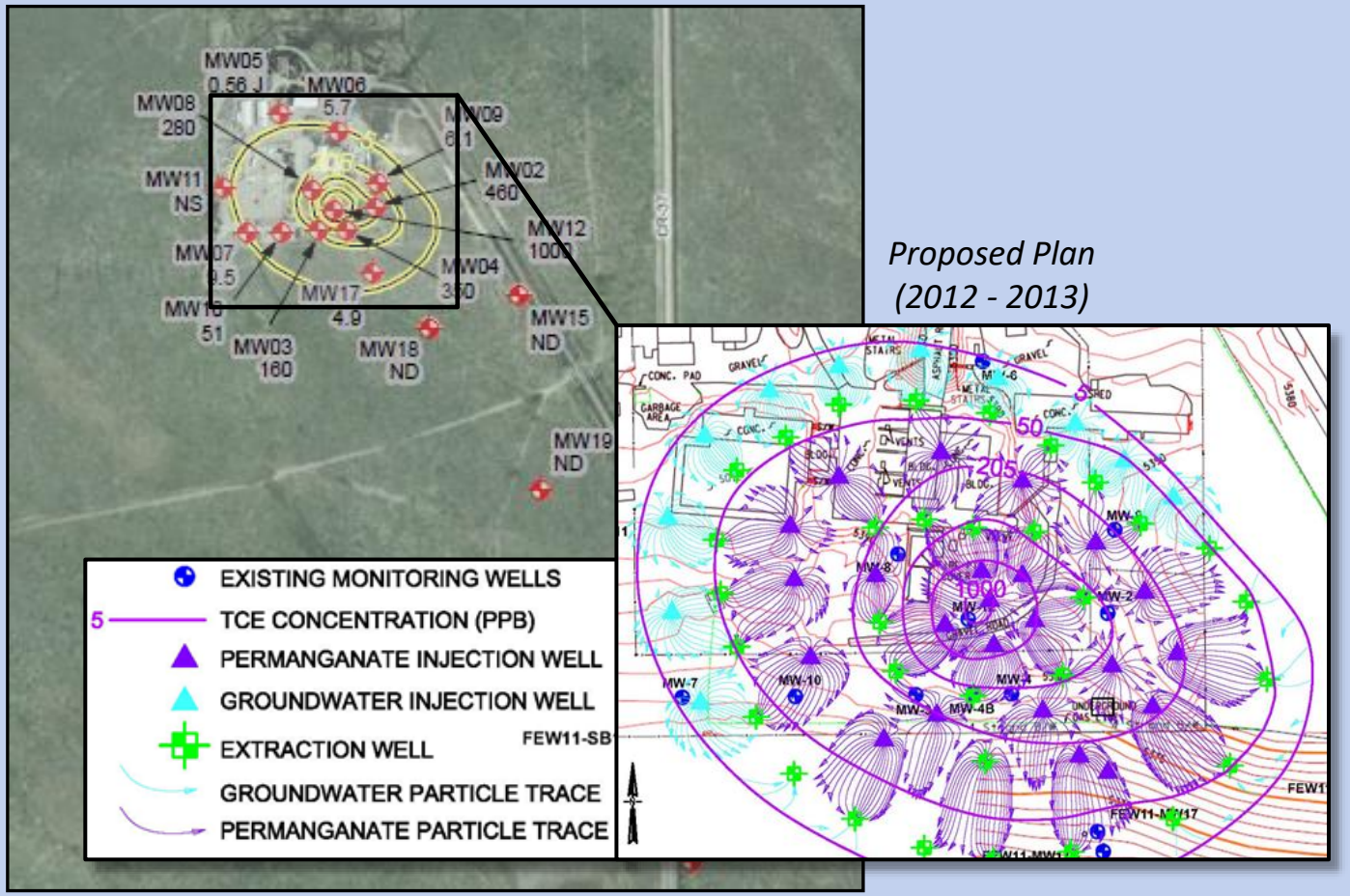
REMEDIATION

Remedial Investigation to Proposed Plan

Potentiometric Surface Map (2005)



TCE Isoconcentration Map (2005)

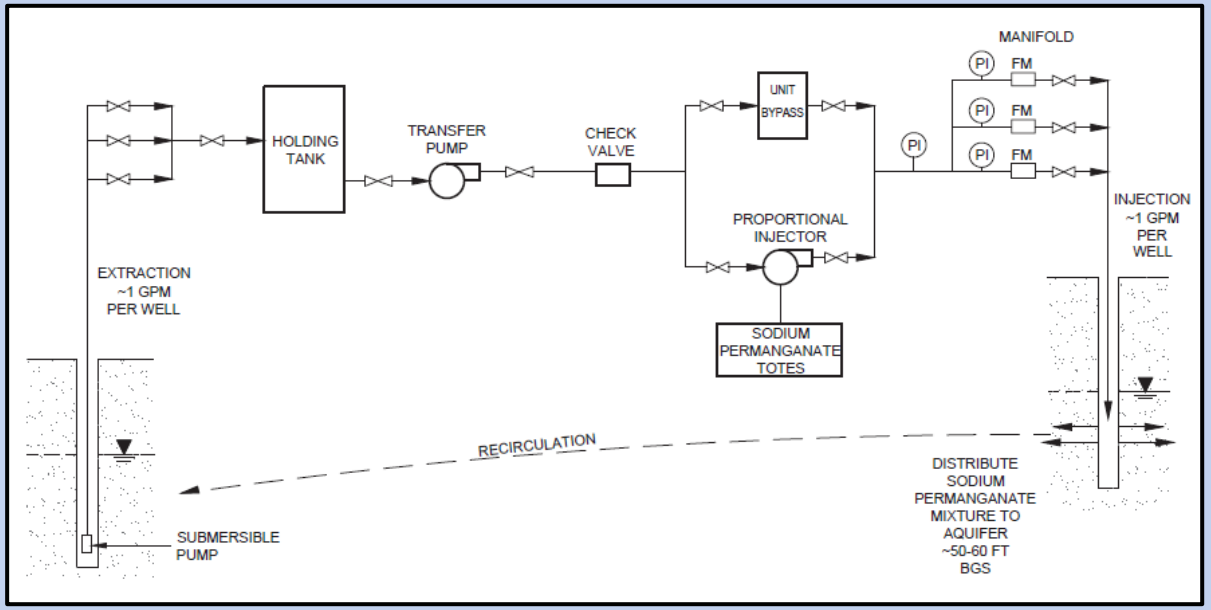


Proposed Plan (2012 - 2013)

REMEDIATION

Proposed Plan to Pilot Study

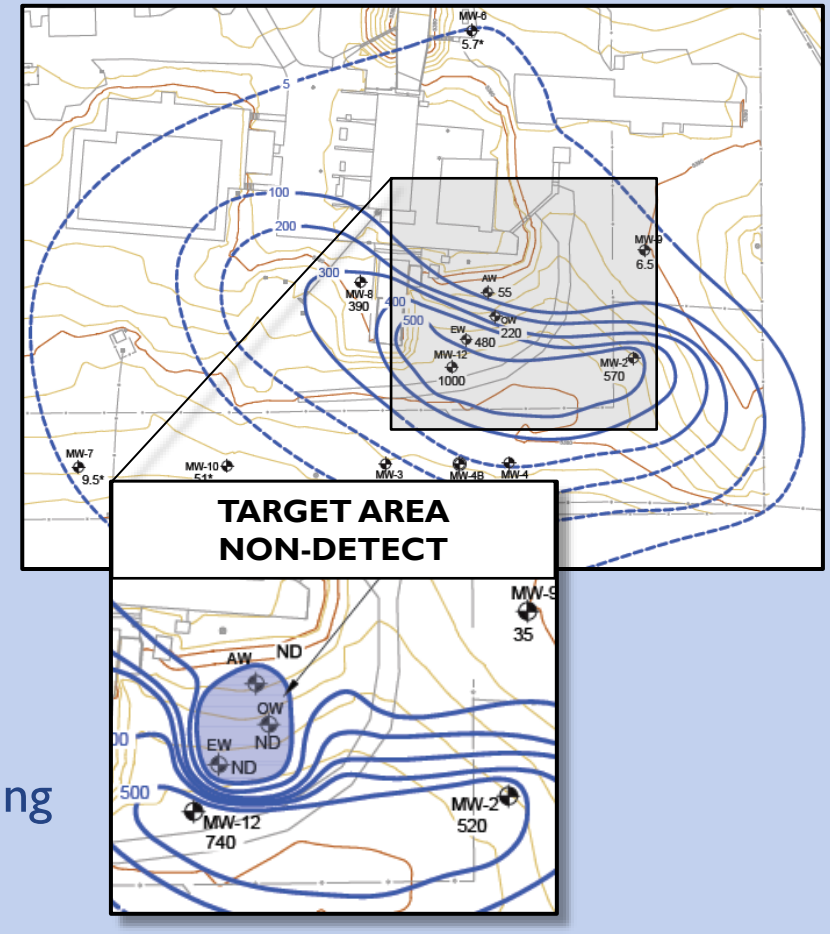
ISCO Recirculation Process Flow Diagram



Bench-Scale Column Test for NaMnO4

0.00%
1.25%
3.75%
7.50%
15.00%
25.00%

Pre-Pilot Study (2012-Q2) & Post-Pilot Study (2012-Q3)



Benefits of Recirculation:

1. Induce GW gradient
2. More rapidly distribute the oxidant
3. Limit plume distribution
4. Reduce rebound via flushing

REMEDIATION

Remedial Action to Response Complete (Source Area)

FUDS Requirements (2011-2020):

- 5-year review process
- Response Complete flexibility (extent practicable vs. MCL)

Response Complete Demonstrated (2019):

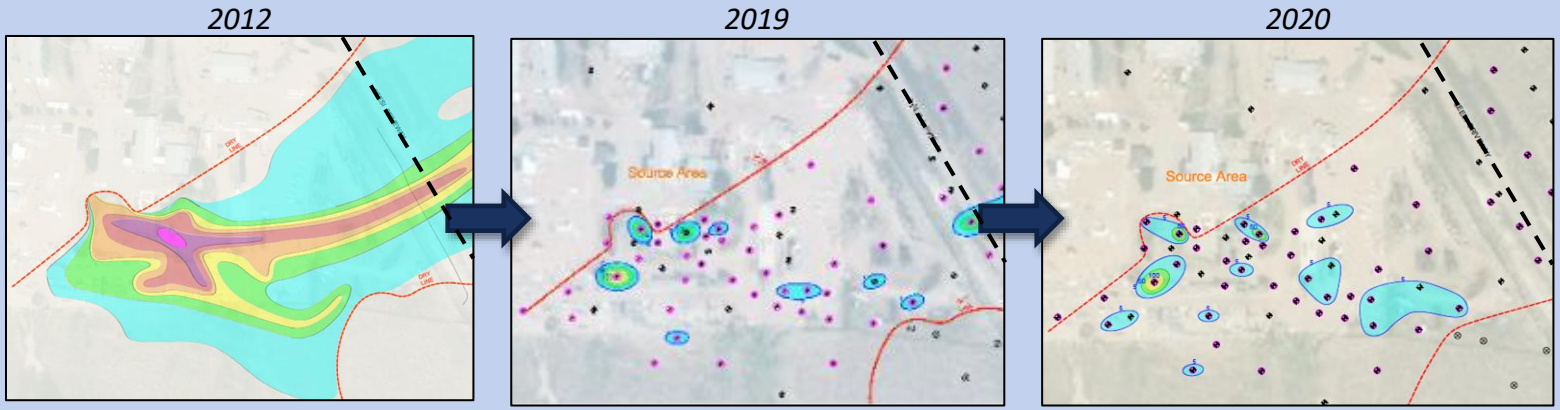
1. 7.7M gal treated in 2.5M gal pore vol
2. 99% mass reduction
3. 6 quarters with diminishing rebound (demonstrating asymptotic conditions)
4. 50 of 50 wells decreasing, stable, or no trend

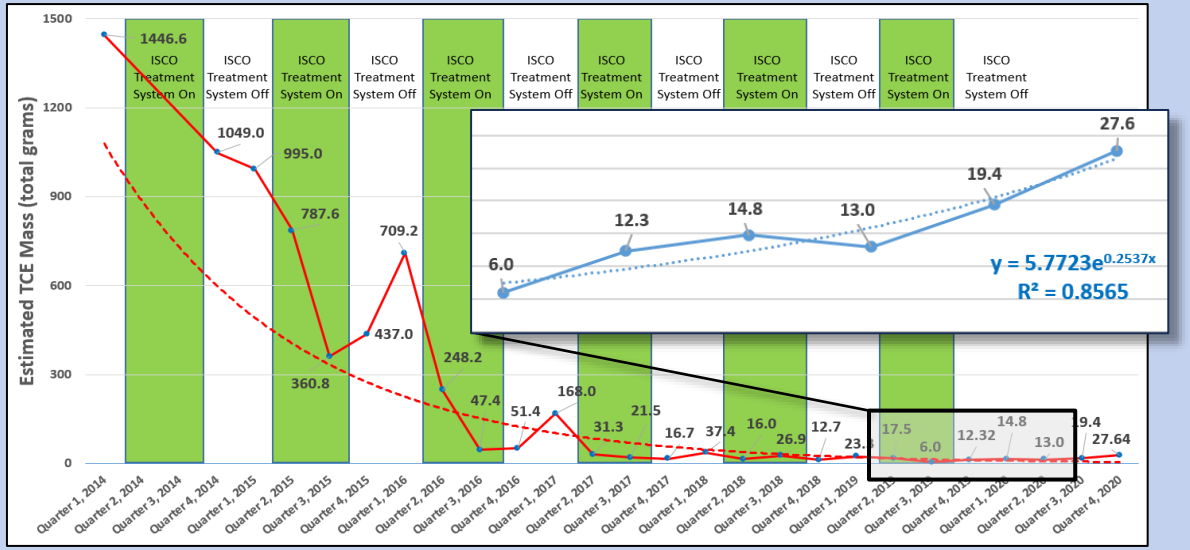
Rebound (2020-2021):

- Near direct source:
  - TCE back diffusion and/or desorption from soils
- Isolated areas:
  - Incomplete reagent distro and/or incomplete reactions

Addressing Rebound (2021-2022):

1. Pursue Conditional Closure
2. Continue Optimized LTM
3. Additional RA-Os
4. Focused Supplemental Investigation





COLORADO REGULATORY CHANGES

Structuring an Effective Exit Strategy

New CDPHE Policy for Conditional Closure of Low-Threat Sites with Residual Ground Water Contamination

POLICY BACKGROUND

- Established Oct. 2014
- Mechanism for closing low-risk sites
  - *7 Lines of Evidence & 10 Policy Conditions*
- 5 sites closed to date

POLICY BENEFITS

- Eliminates routine monitoring & reporting
- Reduces waste & cleanup costs
- Reduces regulatory oversight costs

POLICY CONSIDERATIONS

- Can require institutional controls
- Does not preclude legal damages pursued by private parties
- Can be reopened by CDPHE if new information warrants

Former Atlas "E" Missile Site 11, Nunn, Colorado

FULFILLED REQUIREMENTS

Line of Evidence #1 – Characterization of site.

Line of Evidence #2 – Remediation of source areas.

- ☑ Policy Condition #1

Line of Evidence #3 – Evaluation of exposure pathways.

- ☑ Policy Condition #6
- ☑ Policy Condition #7
- ☑ Policy Condition #8
- ☑ Policy Condition #9

PARTIALLY FULFILLED REQUIREMENTS

Line of Evidence #4 – Demonstration of natural attenuation processes.

- ☒ Policy Condition #2
- ☒ Policy Condition #3
- ☒ Policy Condition #5

UNFULFILLED REQUIREMENTS

Line of Evidence #5 – Estimation of the timeframe for achieving remediation goals.

- ☒ Policy Condition #4

Line of Evidence #6 – Ability to enact, implement, & maintain institutional controls.

- ☒ Policy Condition #10

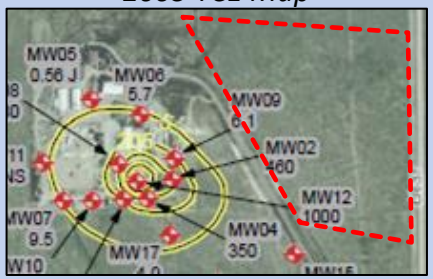
Line of Evidence #7 – Applicability of an ACL.

- ☒ Policy Condition #10

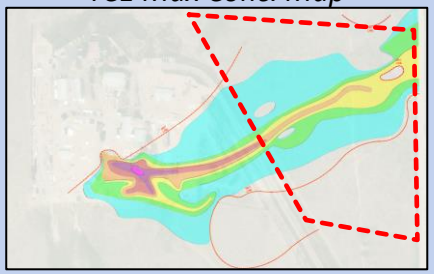
SUPPLEMENTAL INVESTIGATION

2016 Seismic Refraction Survey

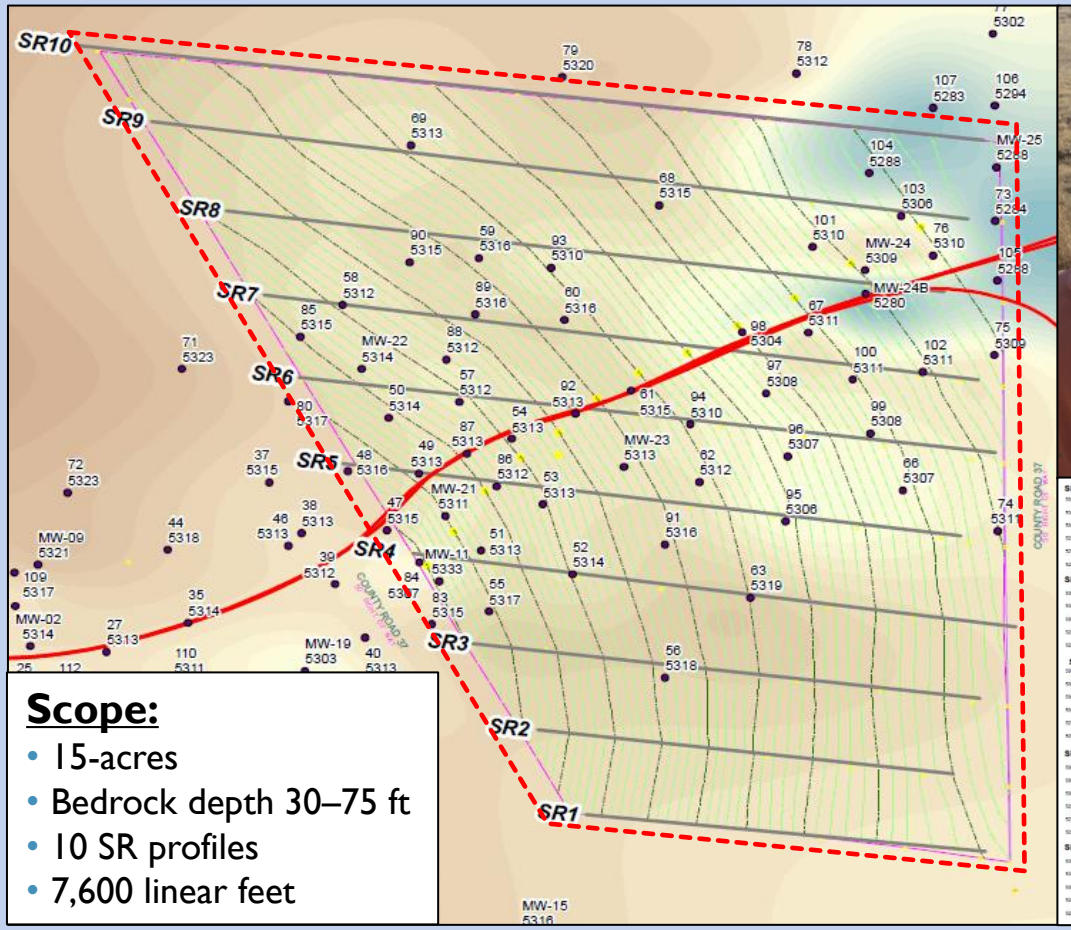
2005 TCE Map

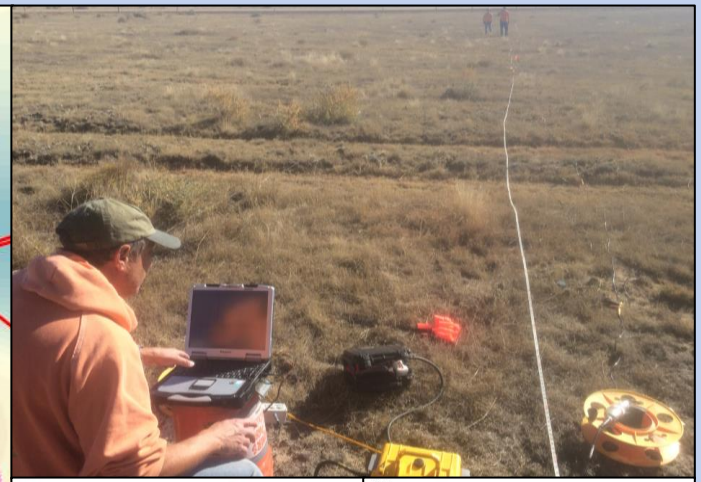


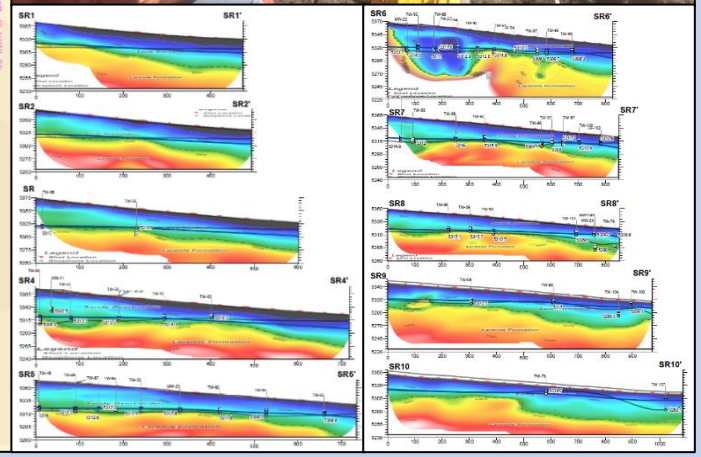
TCE Max Conc. Map



A minimally-invasive approach to bedrock topography characterization





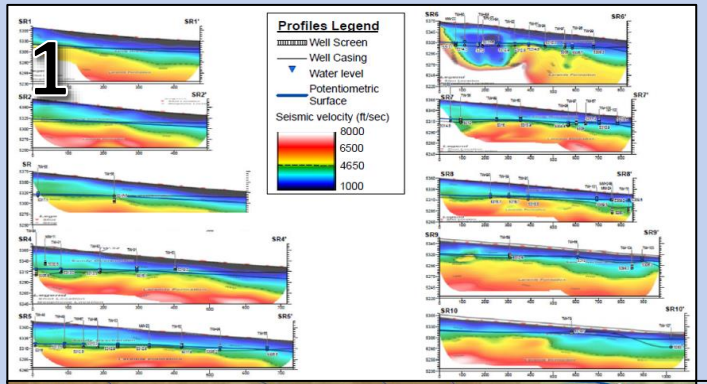


Scope:

- 15-acres
- Bedrock depth 30–75 ft
- 10 SR profiles
- 7,600 linear feet

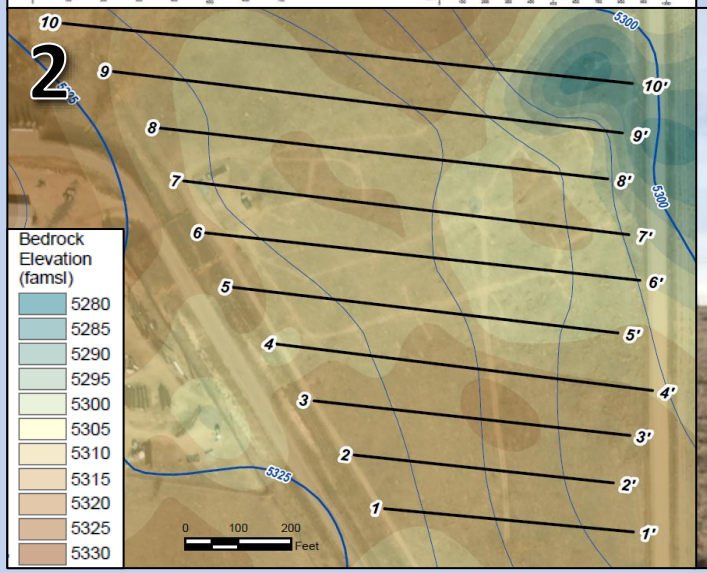
SUPPLEMENTAL INVESTIGATION

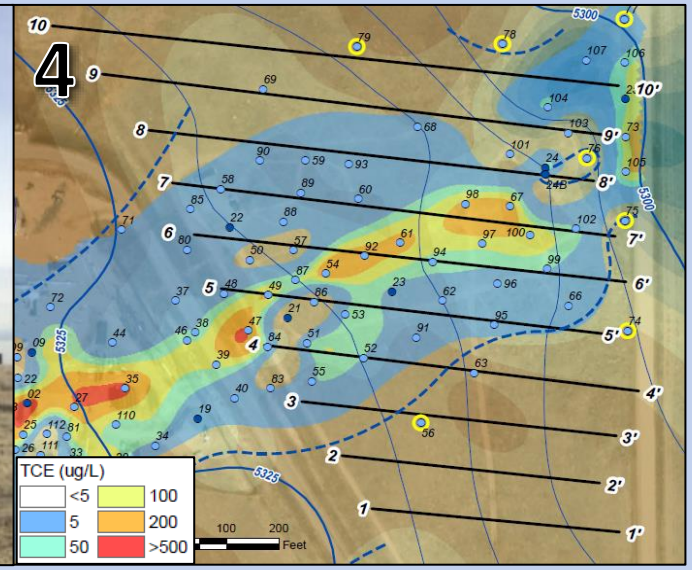
2016 Seismic Refraction Survey



Data Revealed:

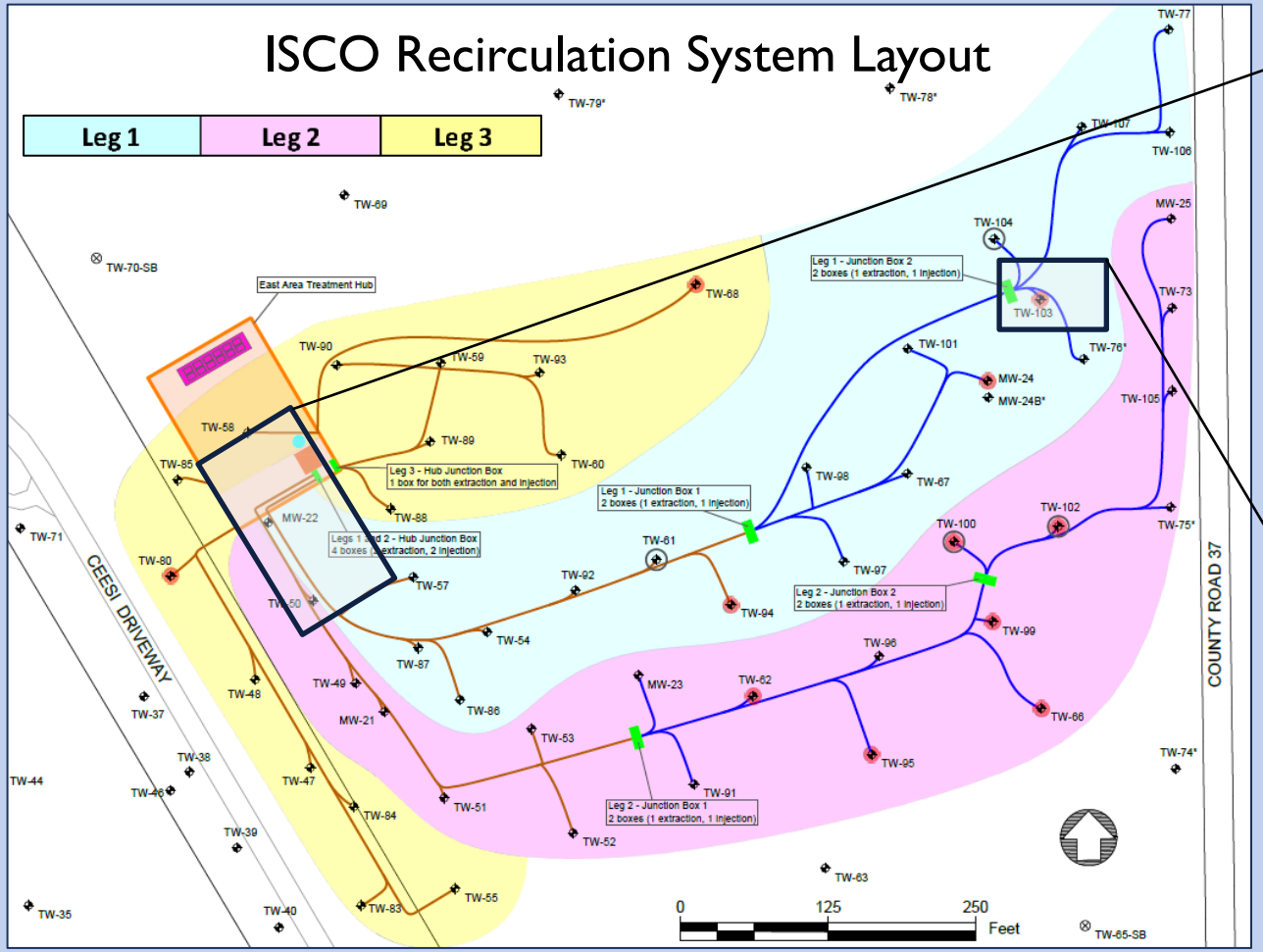
- Bedrock slope to east-northeast
- Bedrock features controlling GW flow beyond existing well network
- Dry areas to north & south
- Bedrock features later determined to be water-bearing fractures in the shale





REMEDIATION PART II

2018 Design & Construction (Expanded Work Area)



REMEDIATION PART II

2018 Construction Complete (Expanded Work Area)

Treatment System Control Shed

Air Compressors

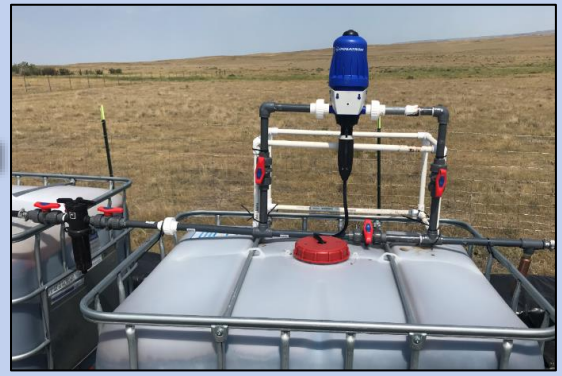
Extraction Well

Holding Tank

Groundwater Transfer Pump

Sodium Permanganate Totes

Proportional Injector



Injection Well Cap

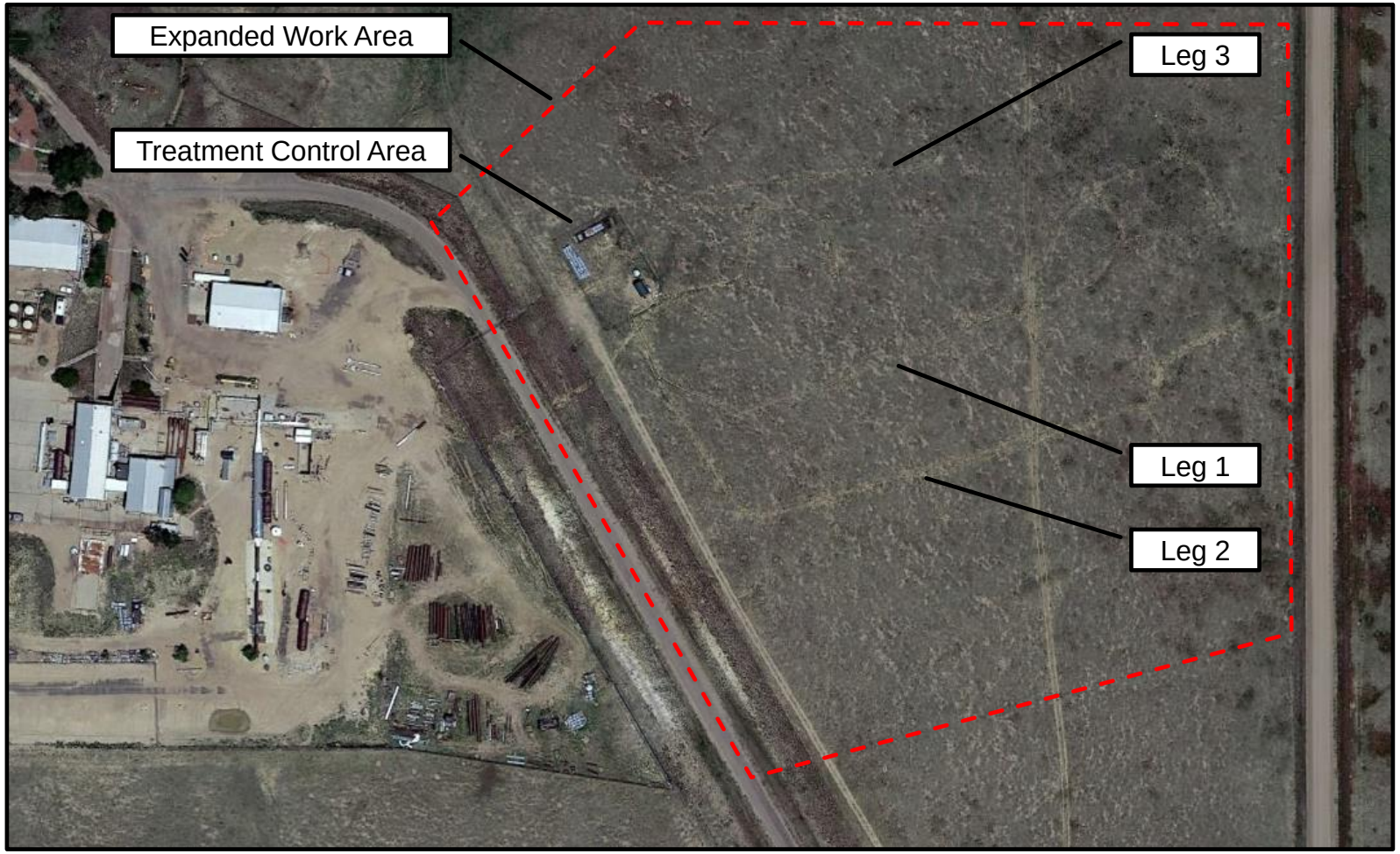
REMEDIATION PART II
2018 – 2021 Operations (Expanded Work Area)

BENEFITS

- Minimally invasive
- No impact to owner's operations
- Autonomous system operates 16 of 65 treatment wells concurrently
- Reduced O&M costs

RESULTS

- 4.2M gal treated in 2.8M gal pore volume
- 85% reduced TCE area
- 90% reduced TCE mass



REMEDIATION
Lessons Learned

Design Strengths:

- Recirculation:
  - Enhanced flushing, induced gradient, etc.
- 2011 Model Simulations:
  - Radial flow model via MODFLOW / MODPATH
- 2020 Model Simulations:
  - MODFLOW / MODPATH / MT3D
  - Delineation of unknown extent

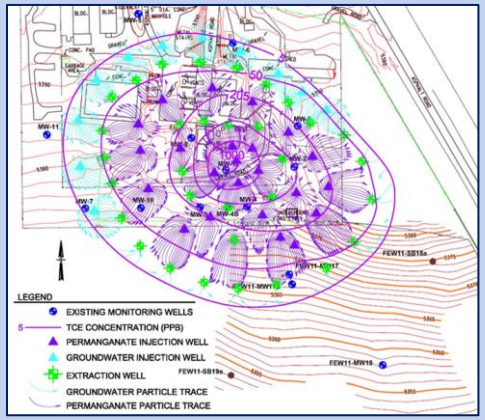
Design Issues:

- Injection: well fouling & pore clogging
- Extraction: ozonation & sunlight reactions cracking elastomers

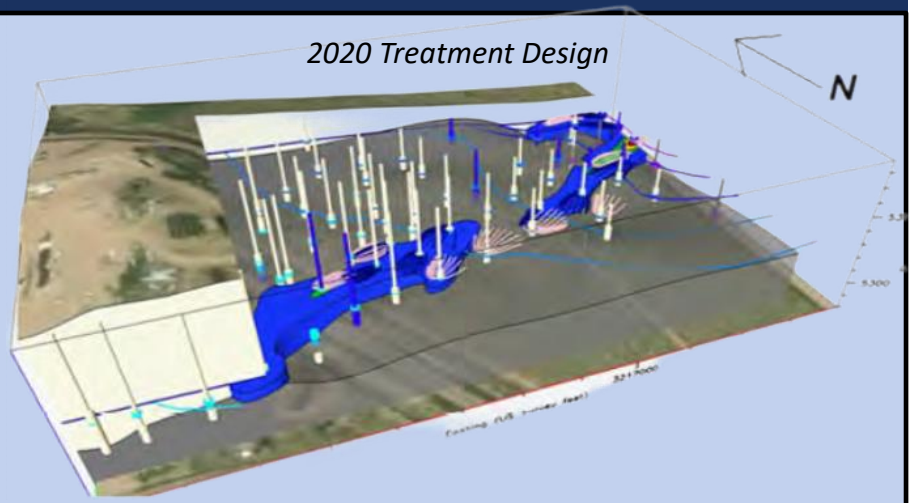
Regulatory and Program Changes:

- FUDS Response Complete (RC) flexibility
- CDPHE Policy on Conditional Closure of Low-Threat Sites

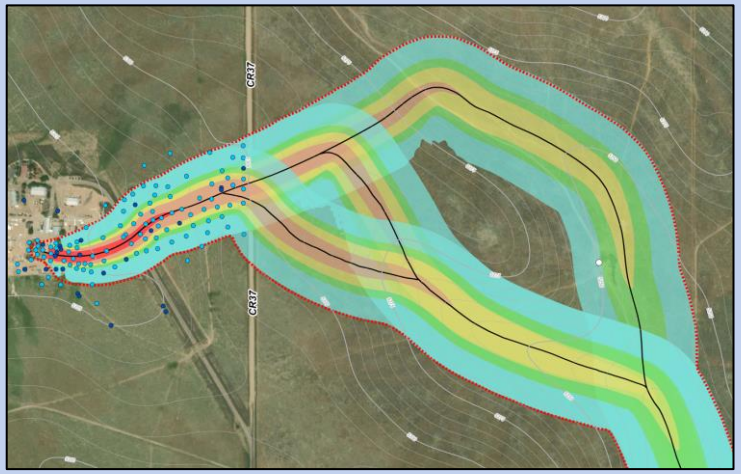
2011 Treatment Design



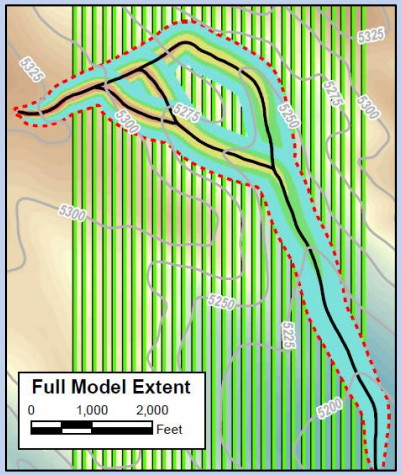
2020 Treatment Design



2020 Delineation Design



2020 Delineation Design



SUPPLEMENTAL INVESTIGATION PART II

2020 Groundwater Modeling

Data Input

- 139 wells with analytical results
- 10 SR profiles (7,600 linear ft)
- Public data (well logs, regional bedrock contour, and GW flow data)
- USGS 10-m resolution DEM data

Data Processing

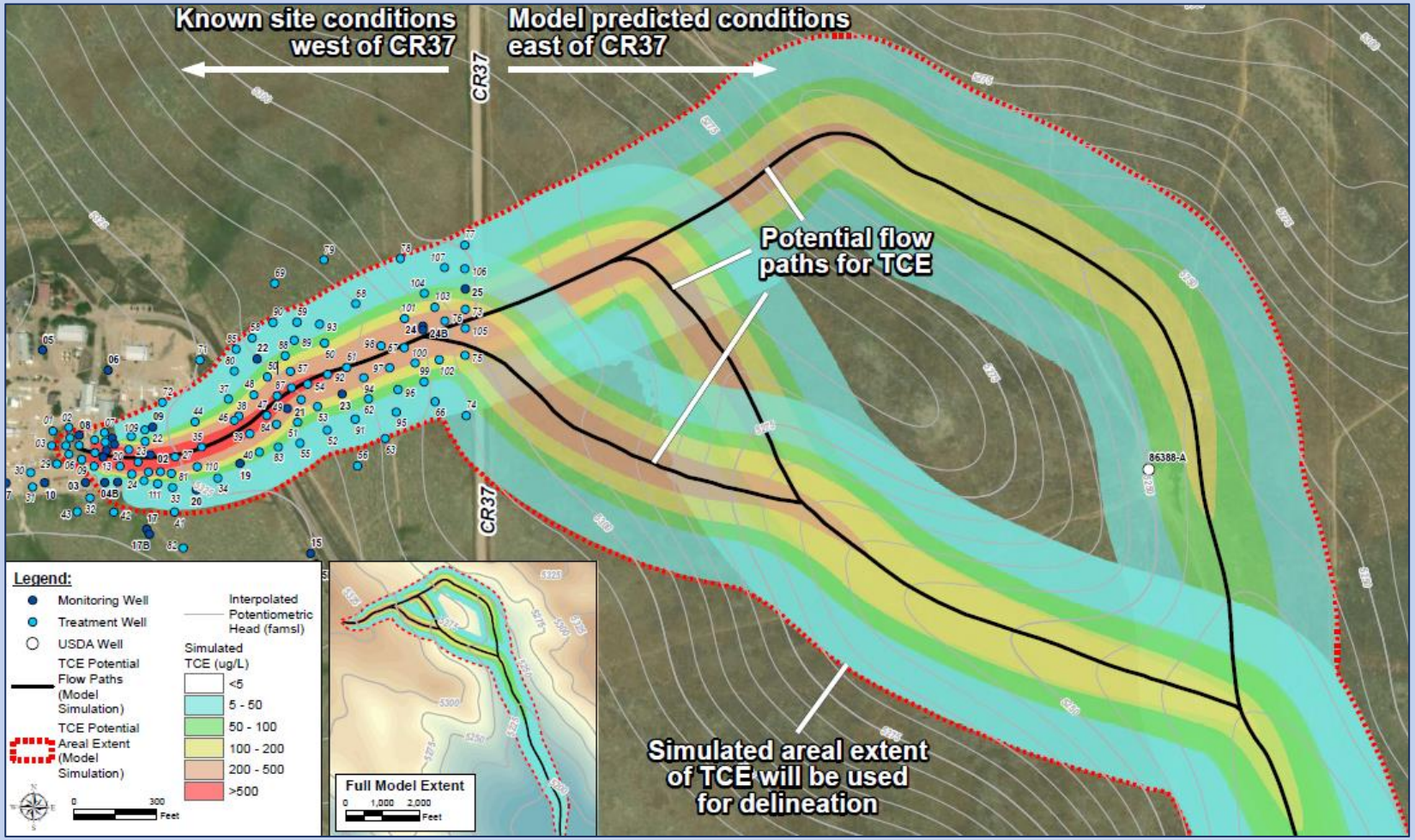
- EarthVision® geologic software
- 3D advective-dispersive groundwater chem transport code

Data Output

- Off-site bedrock topography
- Off-site potentiometric surface

Conclusion

- Three potential paths ID'd w/ TCE 1-linear mile beyond known extent

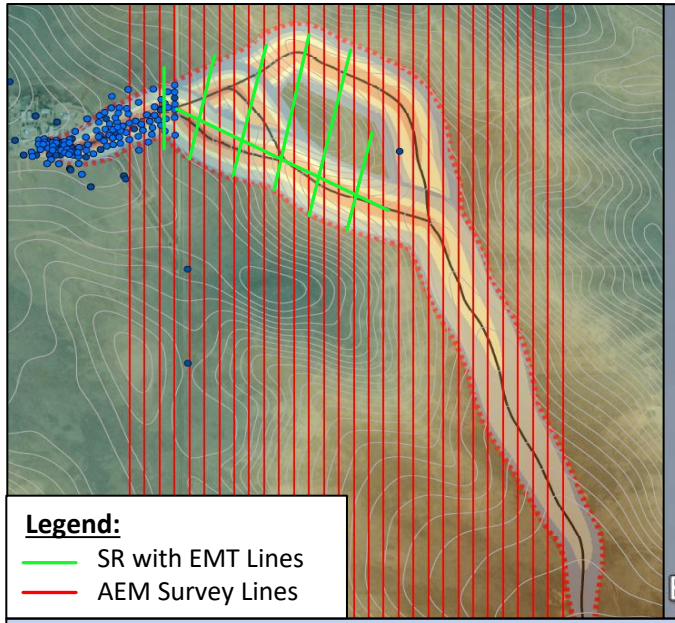


SUPPLEMENTAL INVESTIGATION PART II

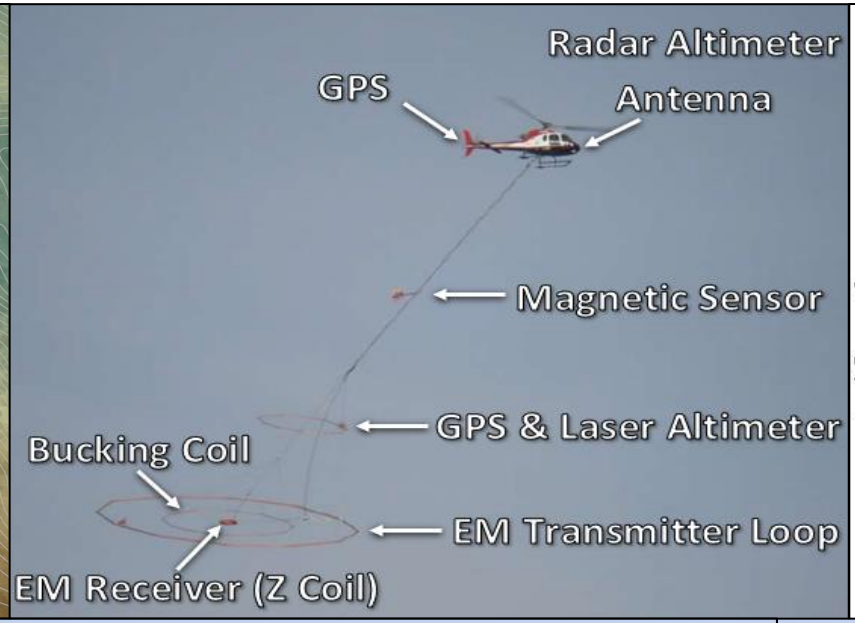
2021 Airborne Electromagnetic (AEM) Survey

A non-invasive approach capable of complete bedrock topography characterization

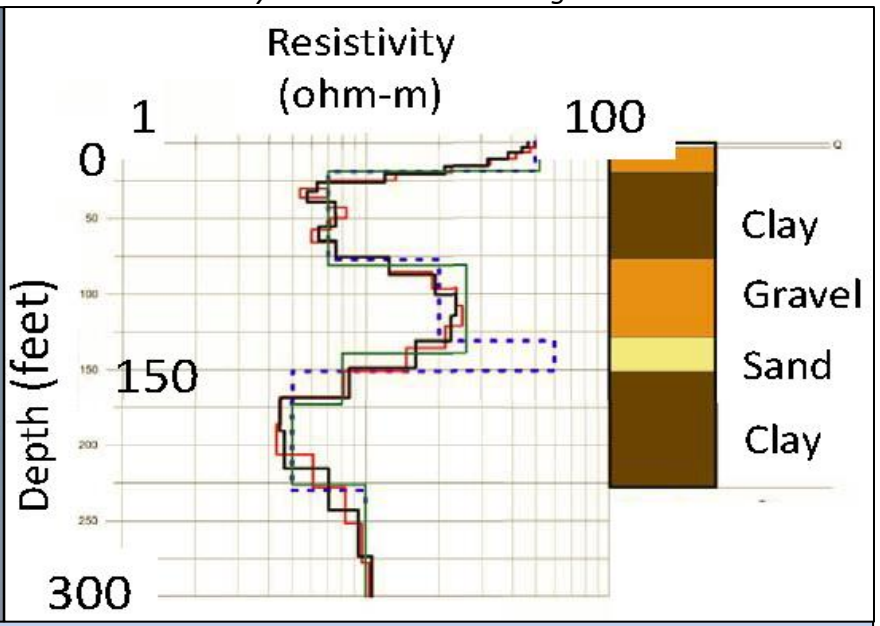
Simulated TCE Areal Extents



VTEM™ ET system in flight.



AEM Survey 1D Forward Modelling via VTEM™ ET



Cost Comparison

800-acre AEM vs. 70-acre SR+EMT survey:

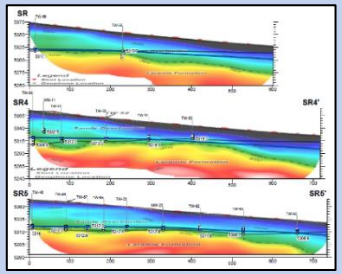
1) Higher resolution
2) Cover entire simulated TCE impacted area
3) Ultimately leads to the completion of the overall delineation objective
4) No Right-of-Entry required!

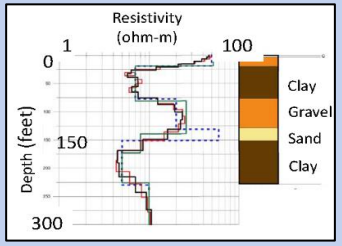
Data Acquisition

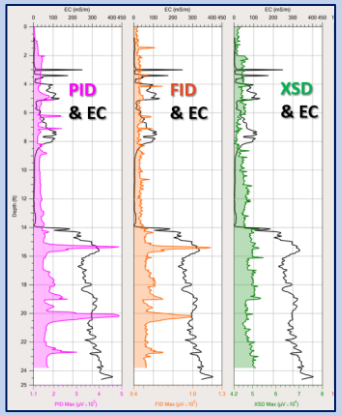
- 800-acre AEM survey area
- Speeds of 50-60 mph
- Altitude of 180 ft (receiver at 100 ft)
- Recorded rate of 10 readings per second
- Data points recorded every 6-10 ft

SUPPLEMENTAL INVESTIGATIONS

Lessons Learned & Moving Forward







Seismic Refraction Survey (2016):

- Minimally invasive
- Aided in selection of well locations

Airborne Electromagnetic Survey (2021):

- Non-invasive
- Cost comparable: 800-acre AEM vs. 70-acre SR / EMT
- Ultimate selling point to USDA allowing USACE to perform the additional delineation

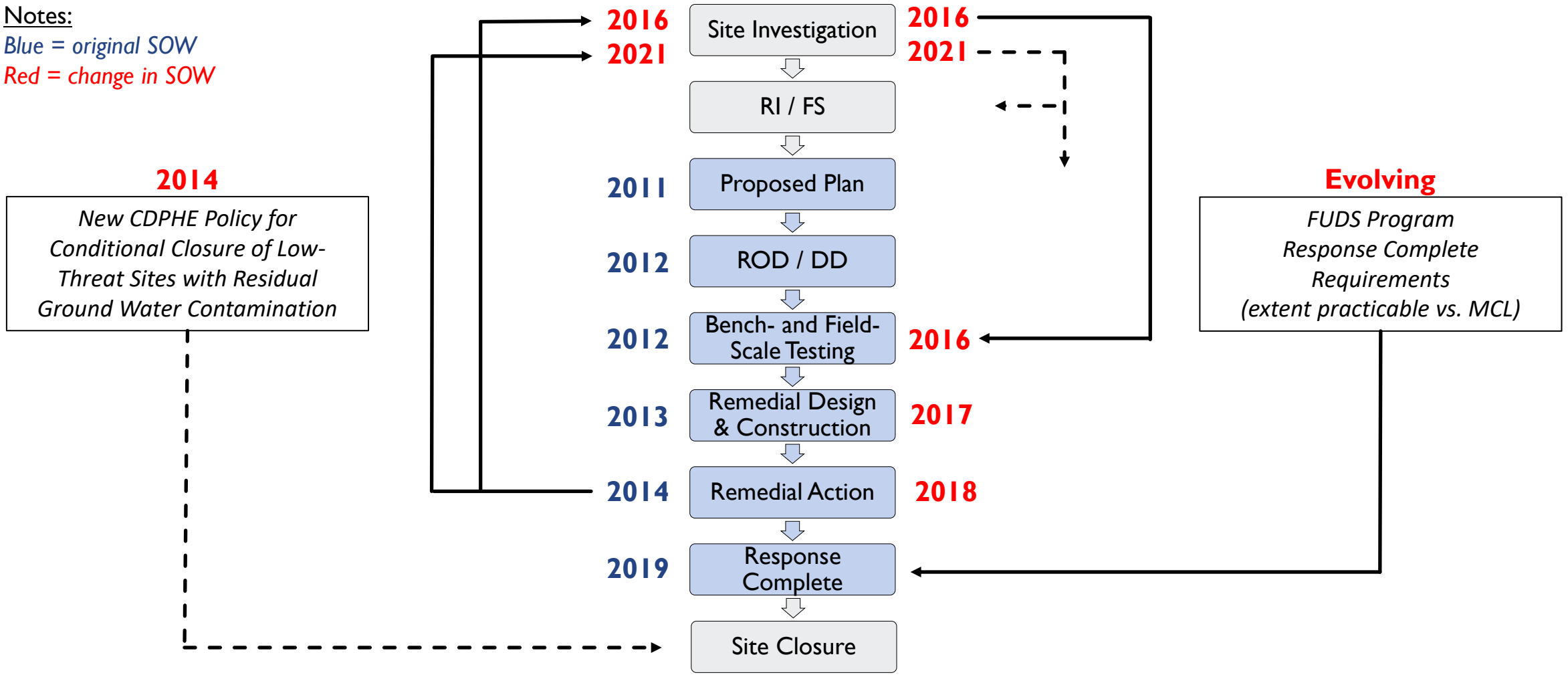
Discussions on Source Area Supplemental Investigation (2022):

- Reason for rebound after >3X pore volume treated
- In-situ vertical profiling of vadose zone, saturated zone, and clay/shale aquitard
  - Temporary borings may be allowed in areas where well installs have historically been denied

ADAPTIVE SITE MANAGEMENT

Weston Solutions, Inc. (2011 – Present)

Notes:
Blue = original SOW
Red = change in SOW



THANK YOU FOR YOUR SUPPORT!

Company: Weston Solutions, Inc.

Client: U.S. Army Corps of Engineers – Omaha District

Event: Colorado Environmental Management Society