

# Fracture Emplacement of a Micro-Iron/Carbon Amendment for TCE reduction in a Bedrock Aquifer

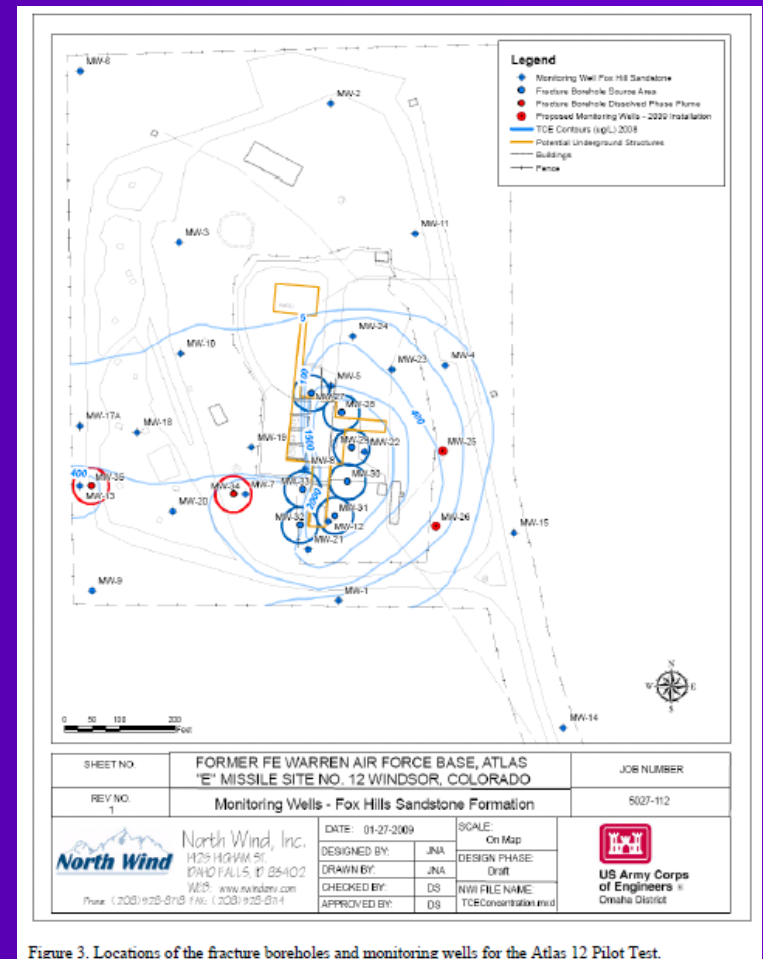


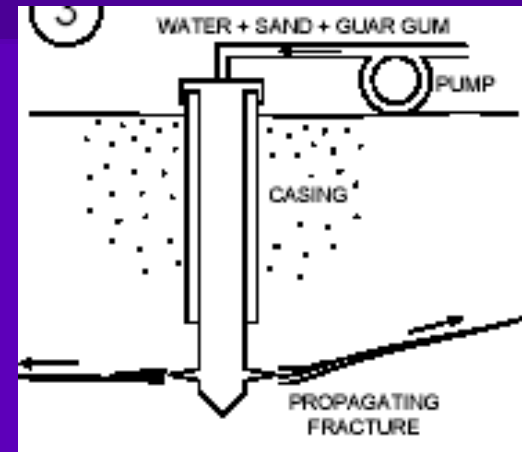
Figure 3. Locations of the fracture boreholes and monitoring wells for the Atlas 12 Pilot Test.

# Outline

- What is Fracturing?
- Site Background and Objectives
- Pilot Program Design
- Emplacement of Treatment Amendment
- Initial Groundwater Quality Results
- Fracture Mapping Results
- Implications for Full Scale Remediation

# What is Fracturing?

- Fracturing is a process in which a fluid is applied to a soil or rock mass until failure of the soil or rock occurs, which results in a tensile parting (i.e. fracture).



# Hydraulic Fracturing for Amendment Placement



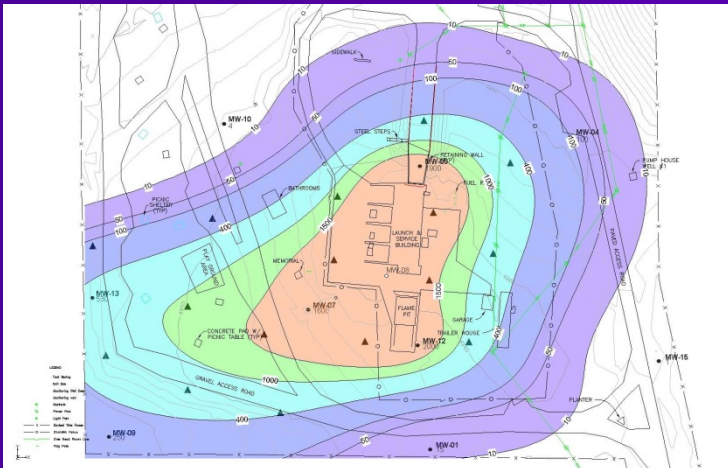
- Mobile mixing tank and pumps
- Fluid Delivery System (gel)
- Drilling equipment
- Downhole Fracturing and Injection tools
- Real time pressure & flow data acquisition
- Fracture mapping equipment & modeling software



# Project Background



- Former USAF "Atlas 12" Missile Site, Colorado
- Operational disposals of TCE (1960-1965) resulted in impacts in underlying sandstone aquifer to 60 ft. depth
- Widespread TCE concentrations in groundwater upwards to 4,000 ug/L



# Pilot Objectives

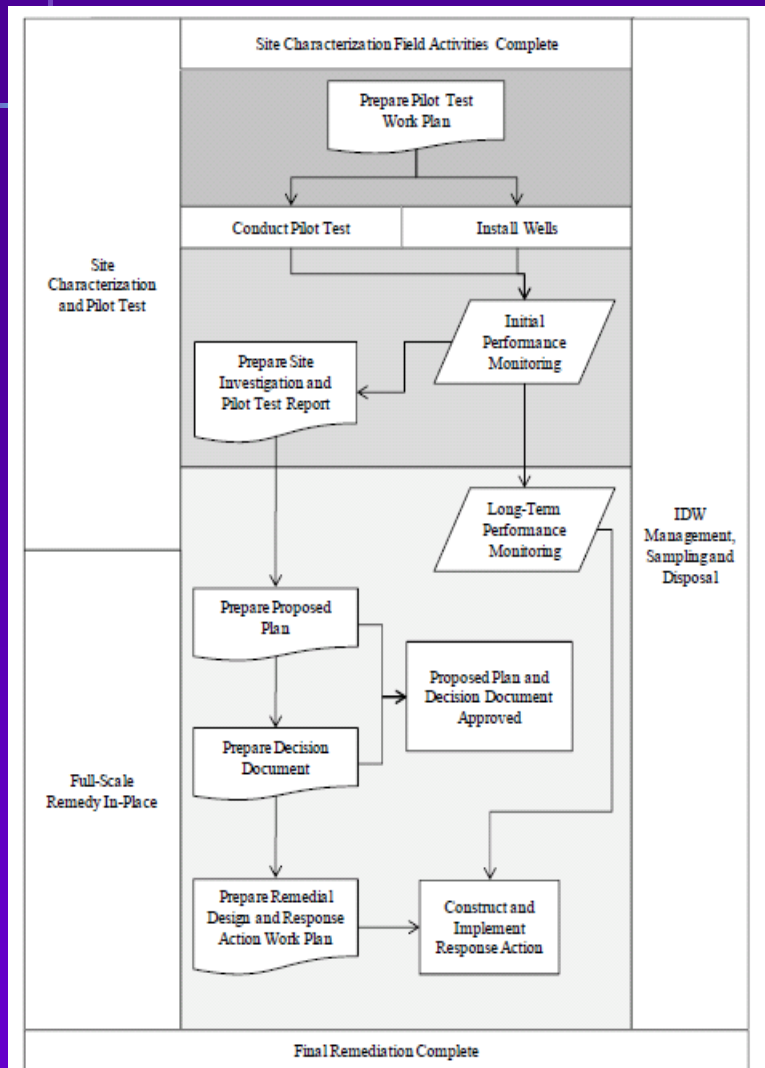


Figure 1. Pilot Test activity flowchart.

Evaluate viability and performance of *in situ* remediation using hydraulic fracturing to:

- enhance permeability of sandstone aquifer
- deliver a micro-iron & carbon amendment into bedrock sediments
- reduce TCE concentrations in groundwater
- USACE mandate for selected technology to meet clean-up objectives within 5 years

# Pilot Project Design

- Additional site characterization & plume delineation (North Wind, Inc)
- Rock coring (Layne Christensen) and laboratory geotechnical strength testing (Golder Associates)
- Micro-iron/carbon (Adventus "EHC-G") amendment application design
- Delivery fluid design & amendment Fracture-Emplacement Protocol (Frac Rite)
- Fracture Mapping and conversion to 3D model (Frac Rite, Eco-Scan)

# Rock Testing Results



Sample tested from  
51 and 66 ft. depth  
– CIU Triaxial Tests

- Peak shear strength: 350 to 876 kPa
- Cohesive Strength: 45 to 75 kPa



# Fracturing and EHC-G Emplacement

- 7 Boreholes in "Source Area" Plume
- 2 Boreholes in "Dissolved Area" Plume
- Fracture-emplacement of EHC-G in zone from 35 ft to 63 ft bgs in bedrock
- Total of 206,000 lb of EHC-G micro-iron delivered at 42 individual fracture depths.



# Atlas 12 Pilot Test EHC-G Distribution

Source Area:  
7 Fracture Boreholes

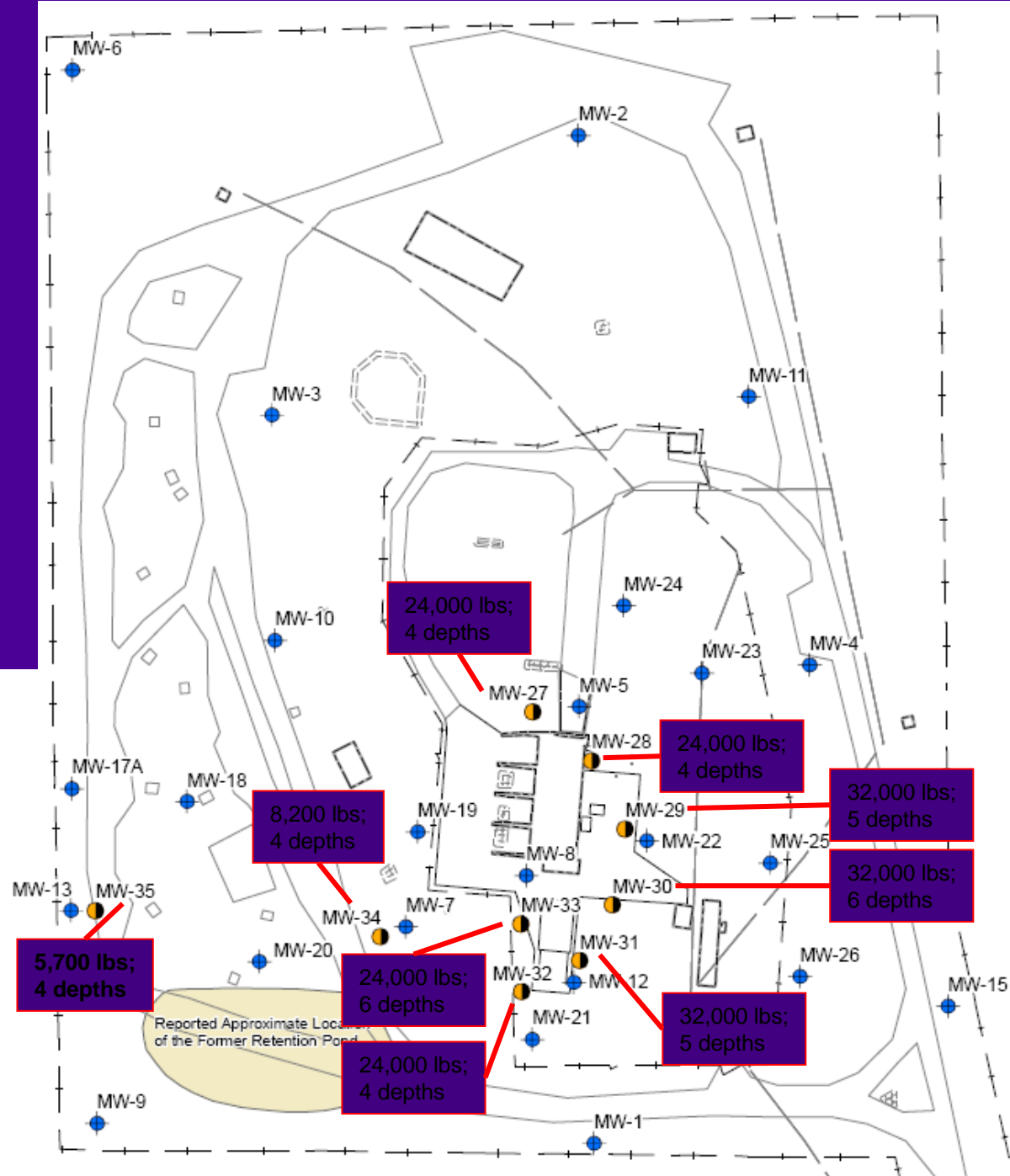
Dissolved Phase Plume:  
2 Fracture Boreholes

EHC-G Injections:  
April 20 to May 19, 2009

**Mass of EHC-G per Borehole;  
Number of Fracture Depths**

## Legend

- Monitoring Well Fox Hill Sandstone
- Pilot Test Fracture Borehole/Monitoring Well Fox Hill Sandstone
- Buildings
- Fence
- Former Retention Pond

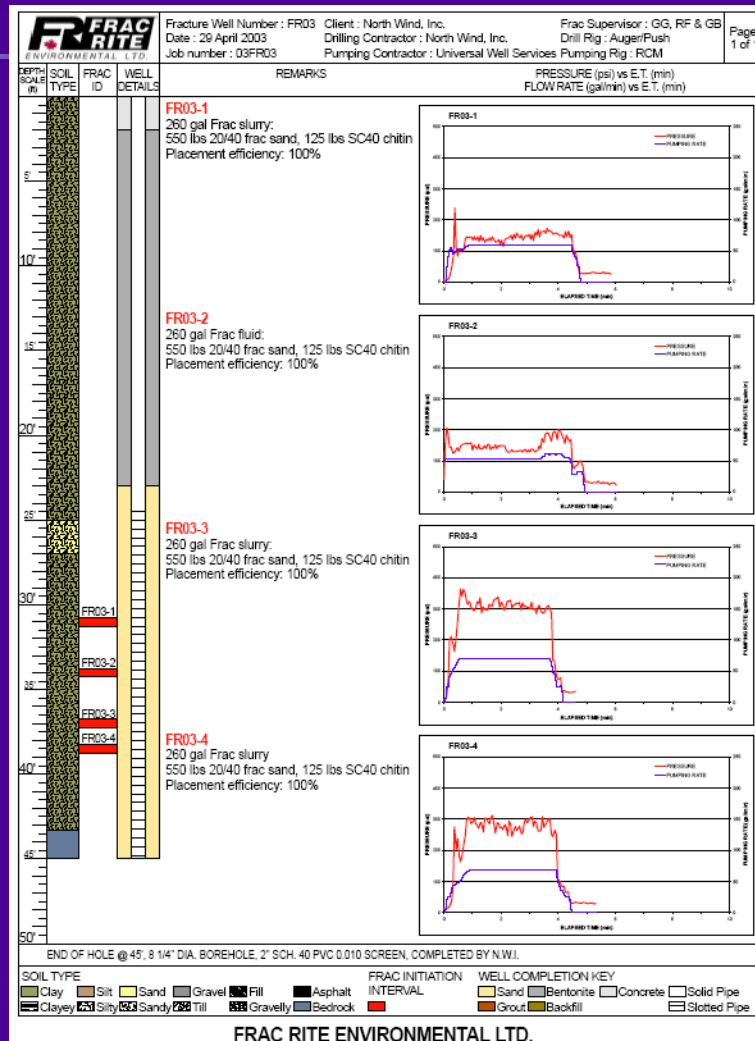


# Fracture-Emplacement





# Fracture Borehole Log



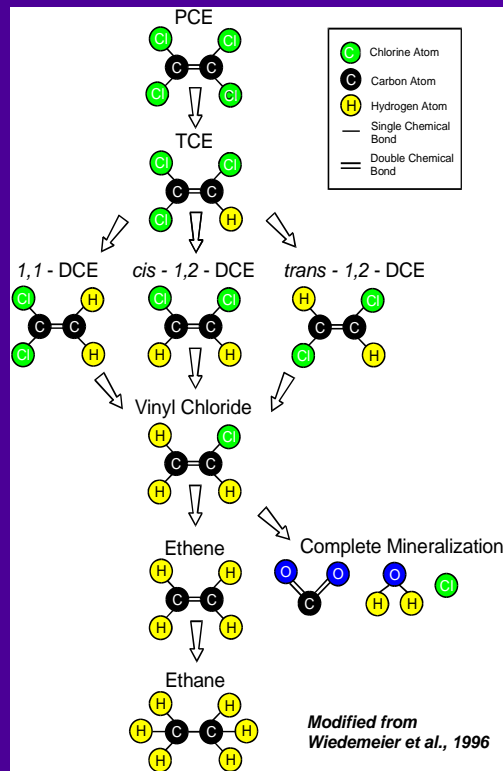
- Pressure vs. time characteristics indicate operational fracture pressures:
- “Break” Pressure – indicates pressure at which bedrock breaks (i.e. fractures)
- “Propagation” Pressure – indicates pressure required to radiate fracture outward from borehole



# Groundwater Monitoring Parameters

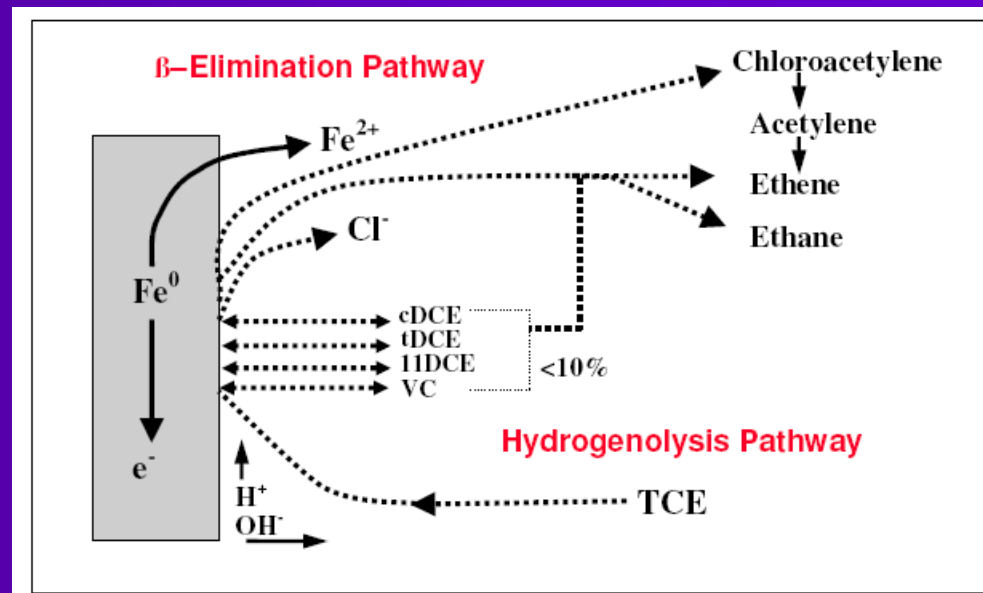
## ARD Parameters

- TOC (total organic carbon)
- Redox Parameters
- TCE and degradation products
- Microbial (*Dehalococcoides* spp.)

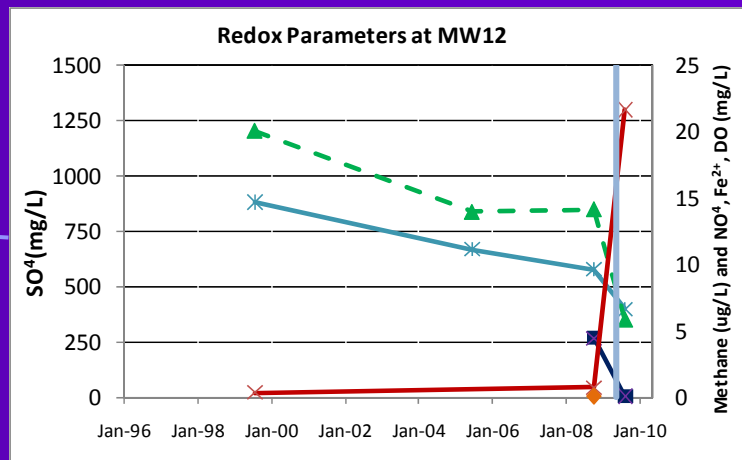
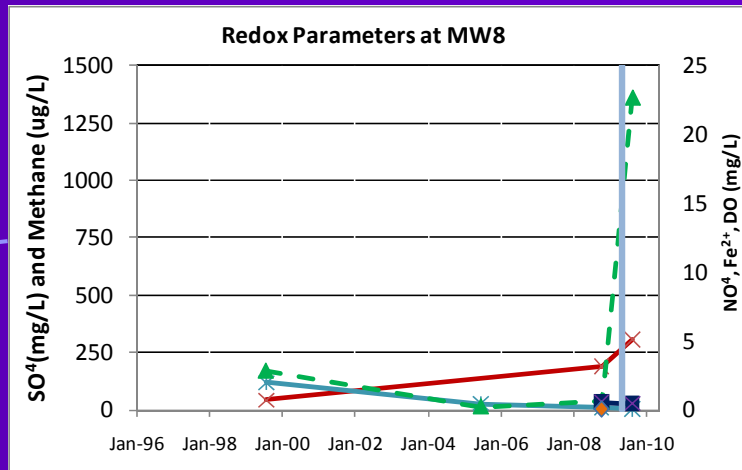
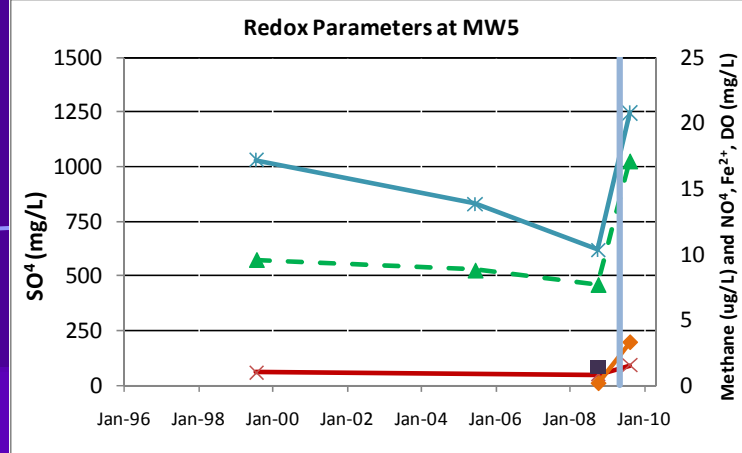
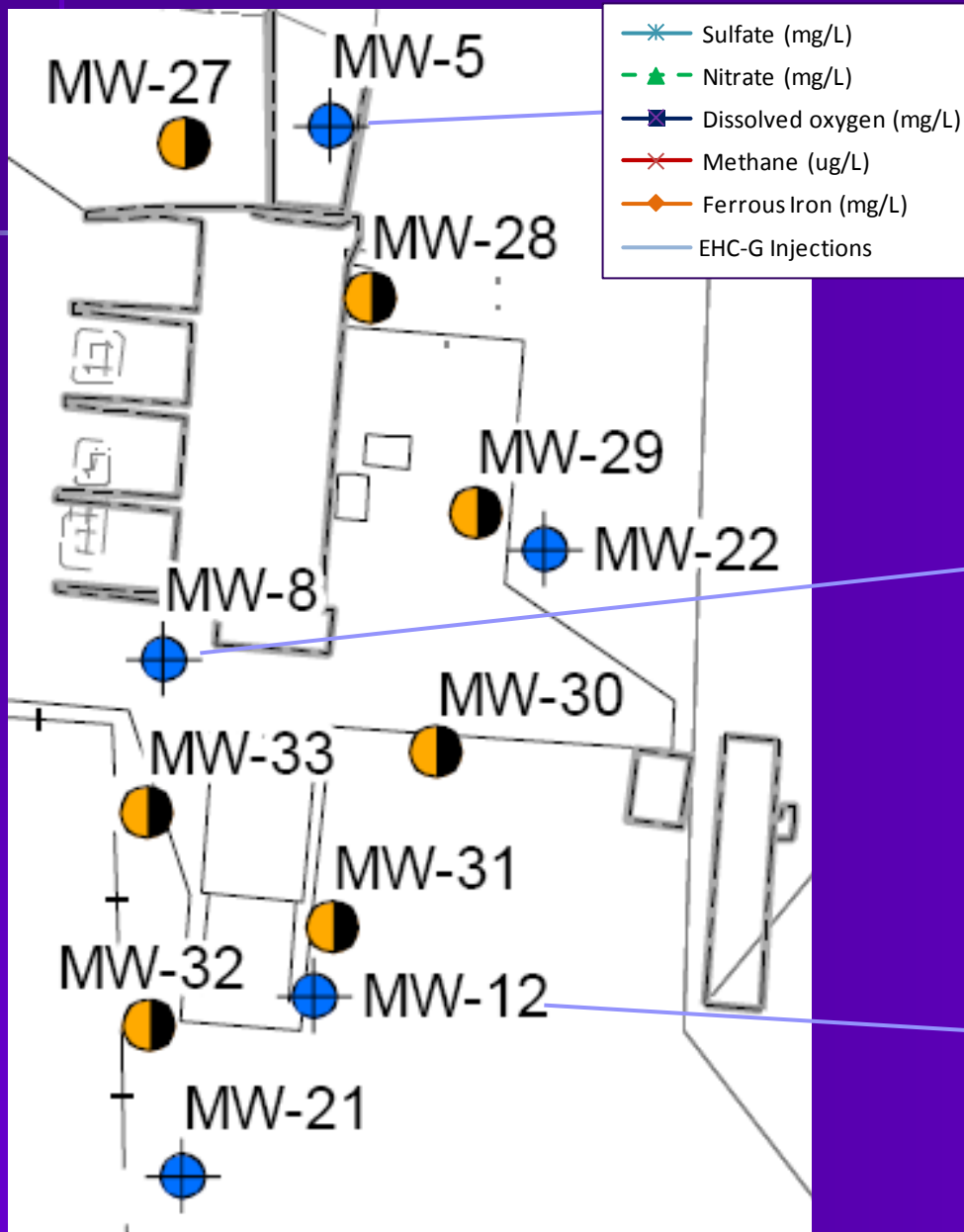


## Chemical Dechlorination Parameters

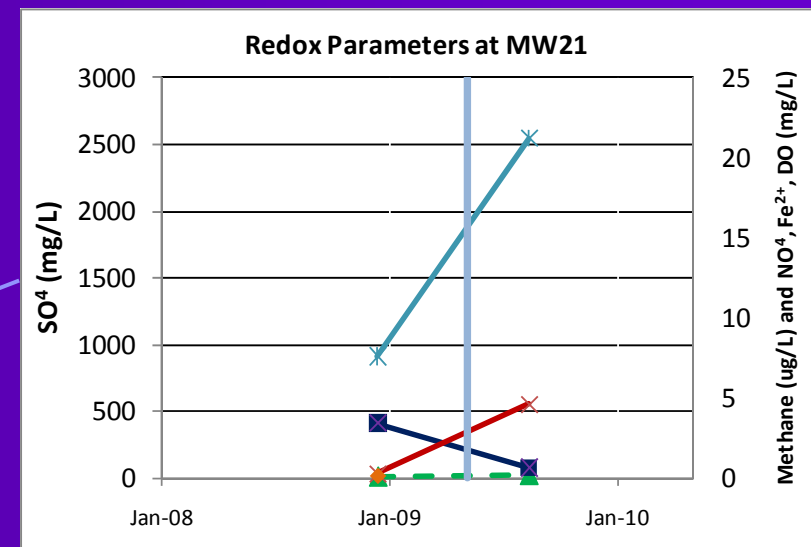
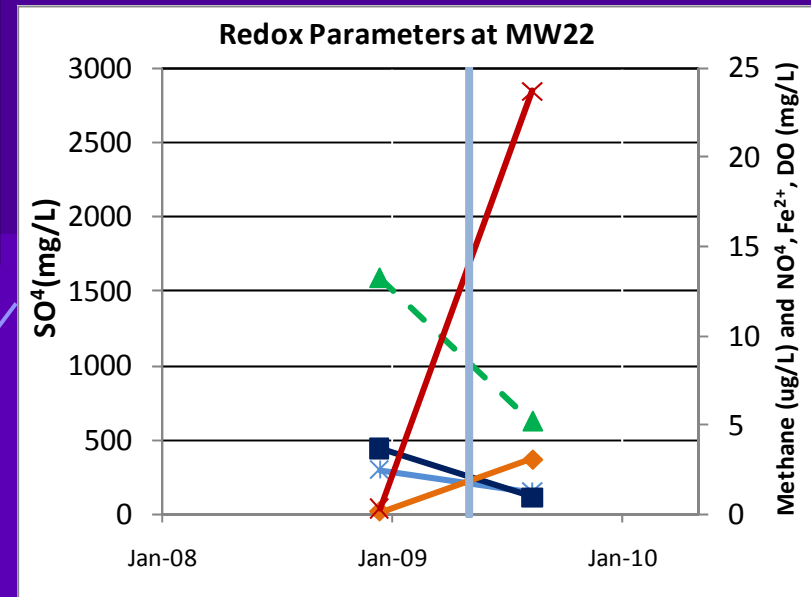
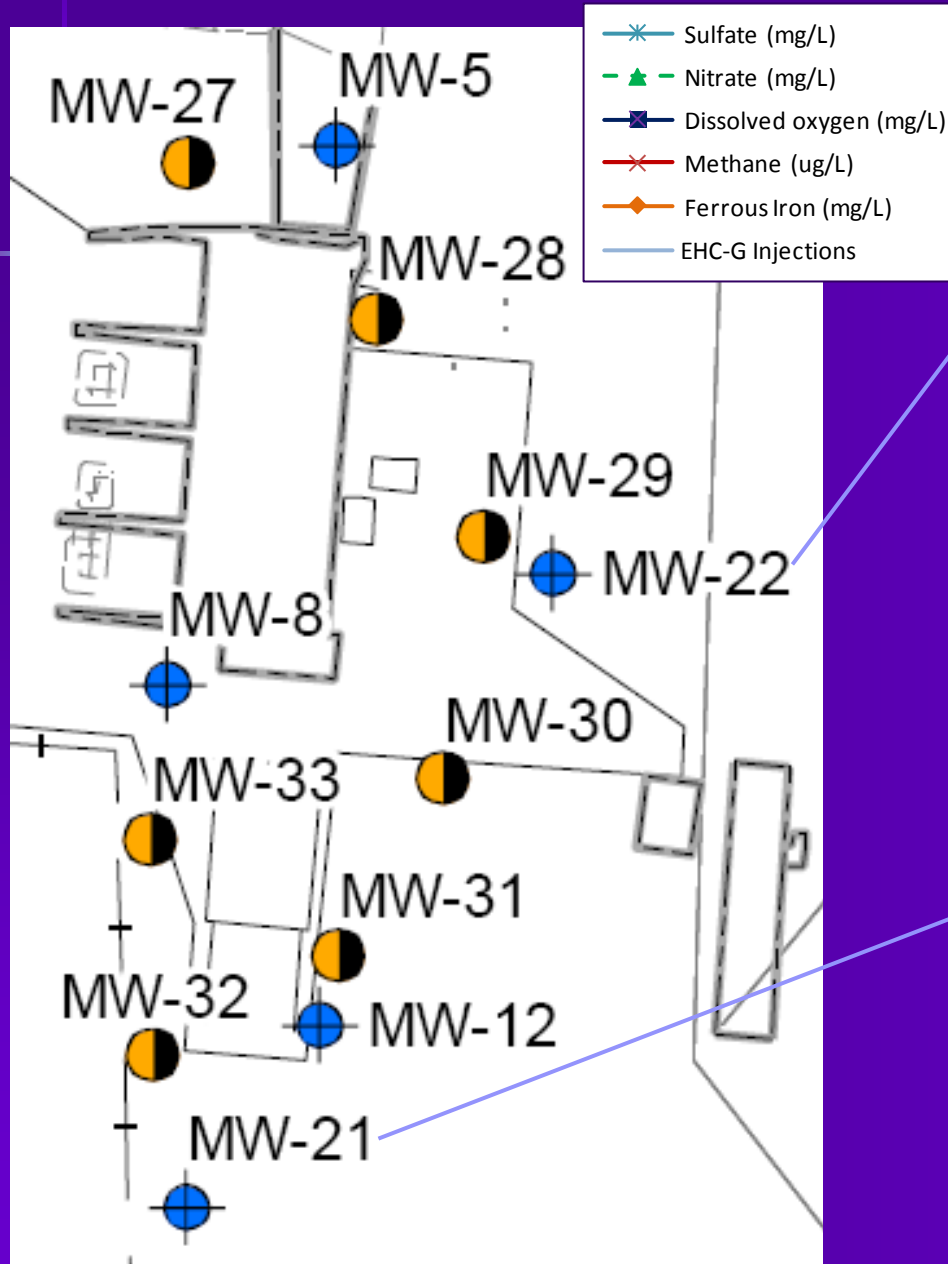
- TCE
- Ethene



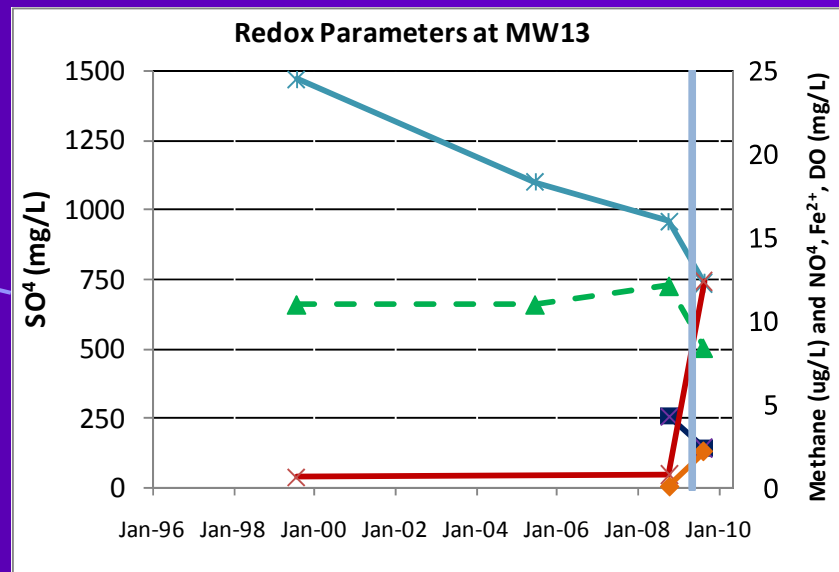
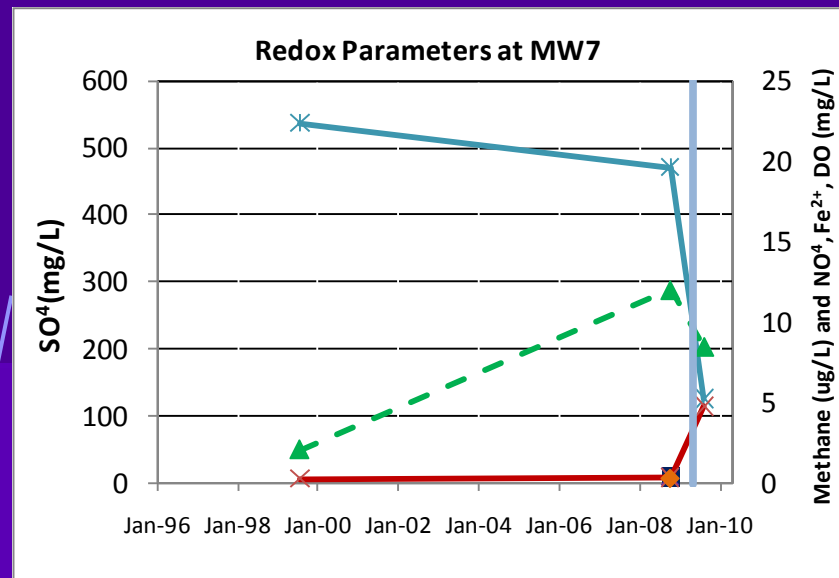
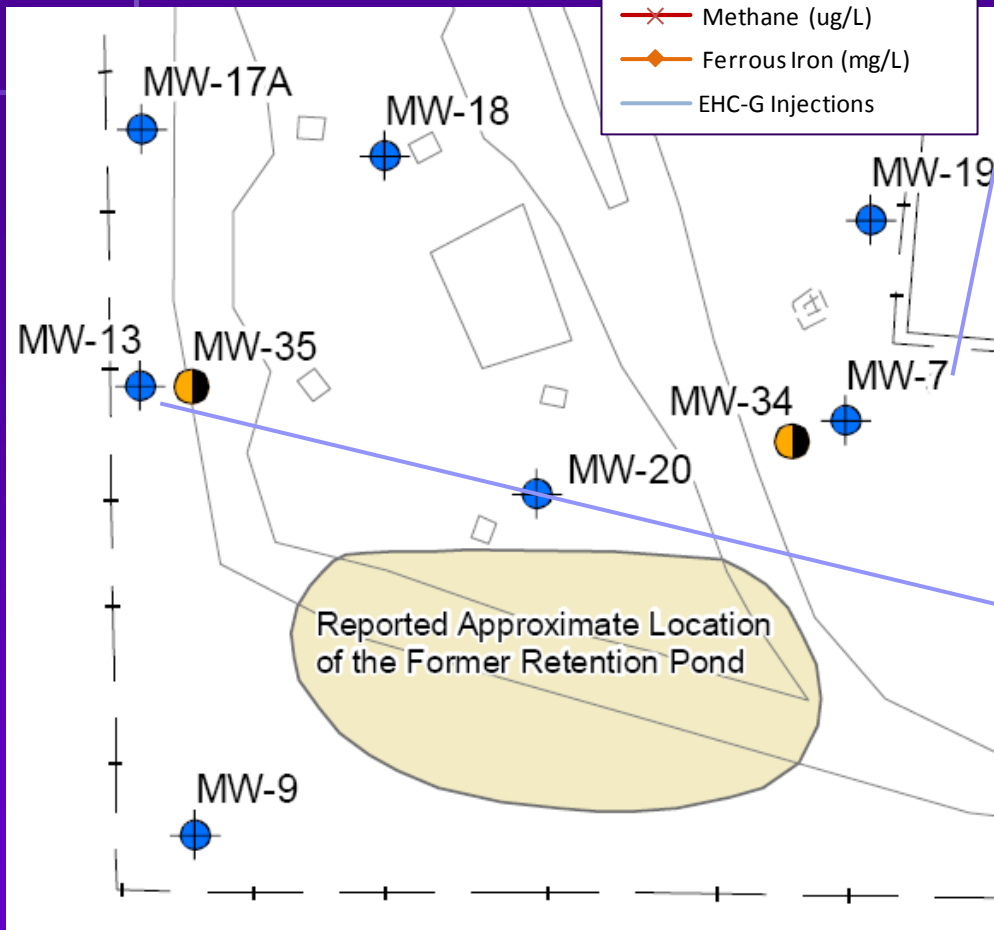
## Source Area: Redox Parameters



# Source Area: Redox Parameters



# Dissolved Phase Plume: Redox Parameters

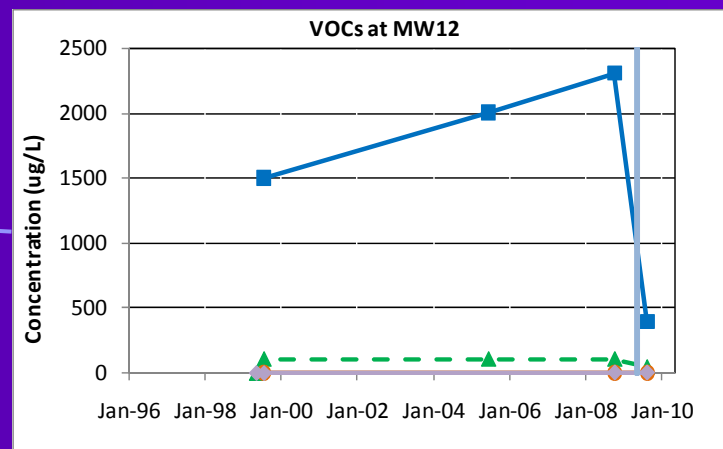
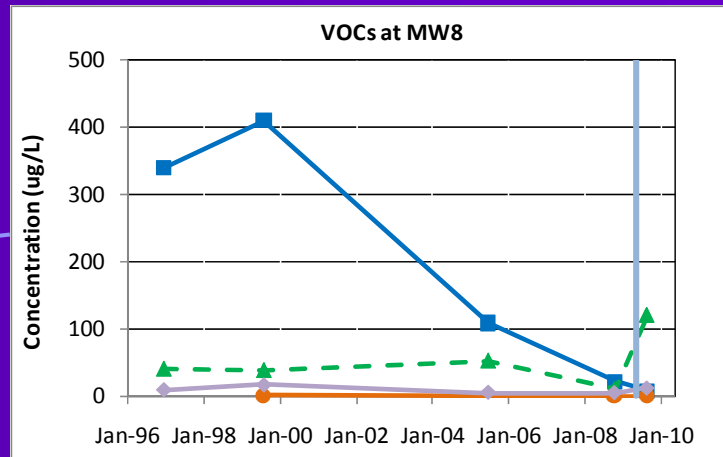
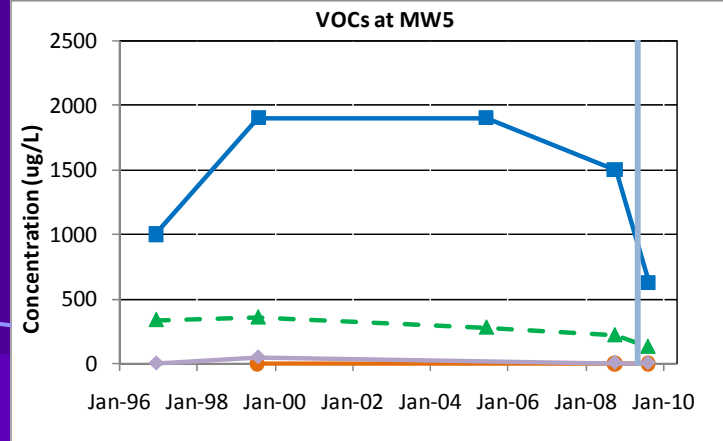
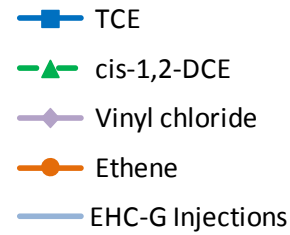
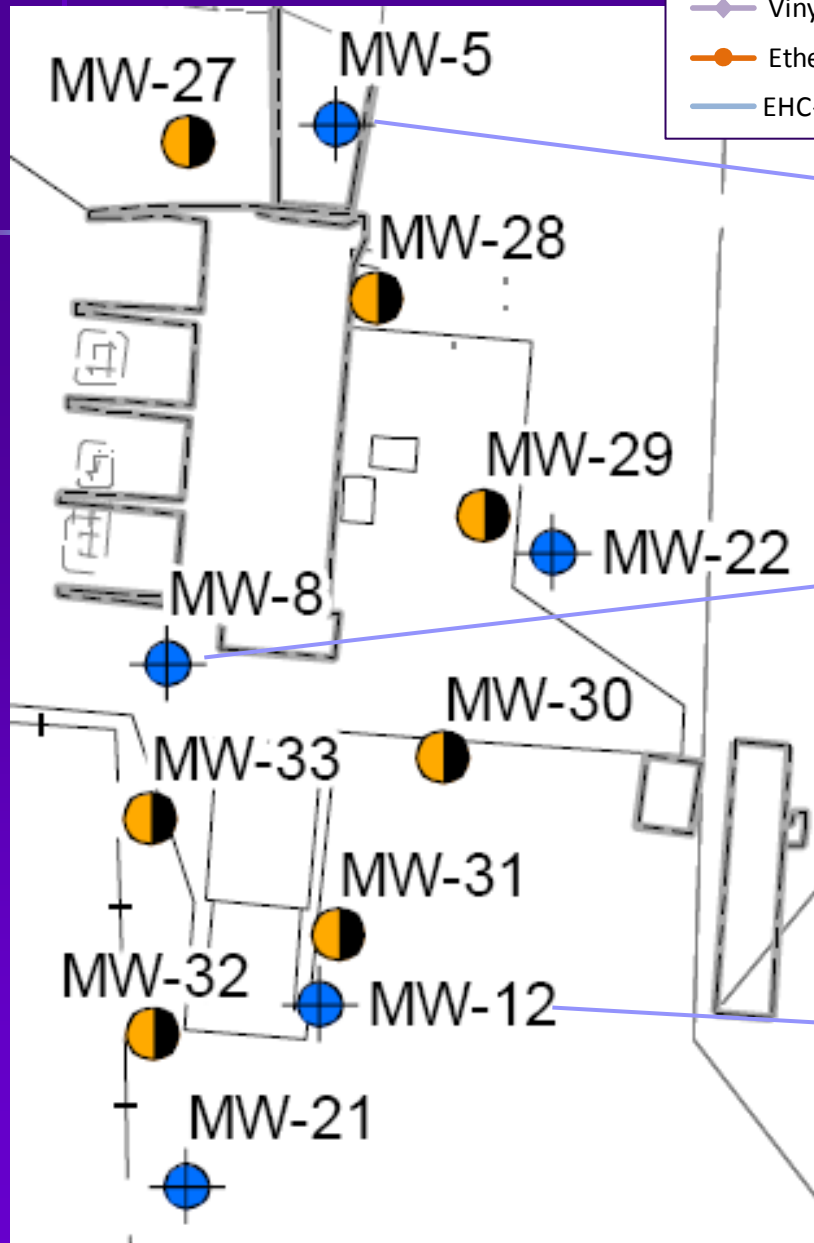


## Redox Summary:

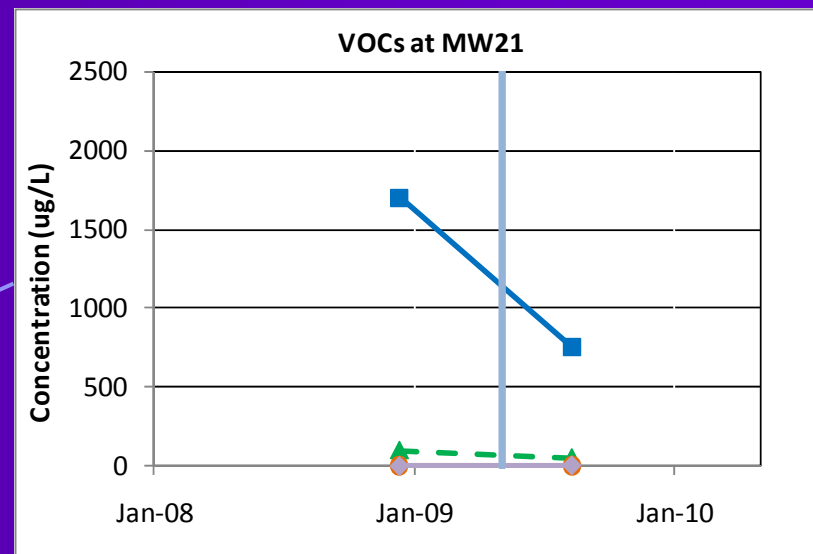
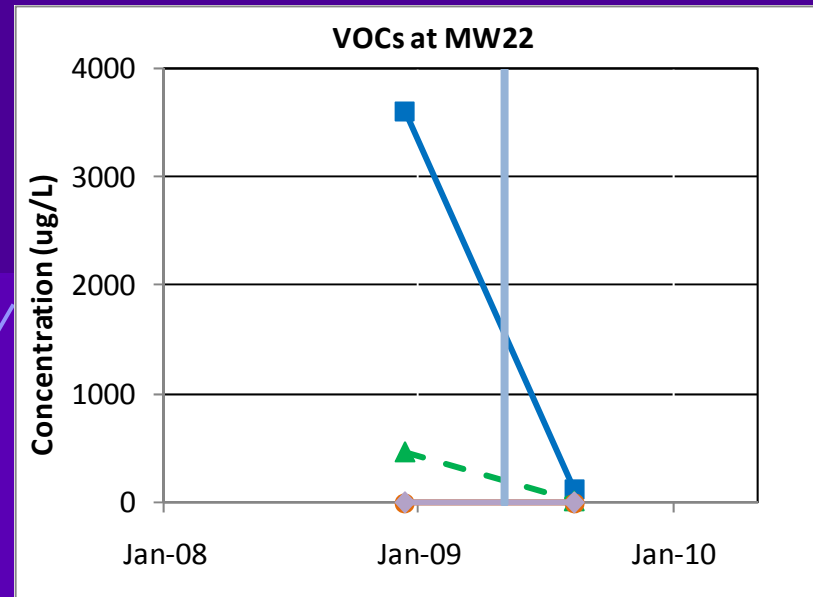
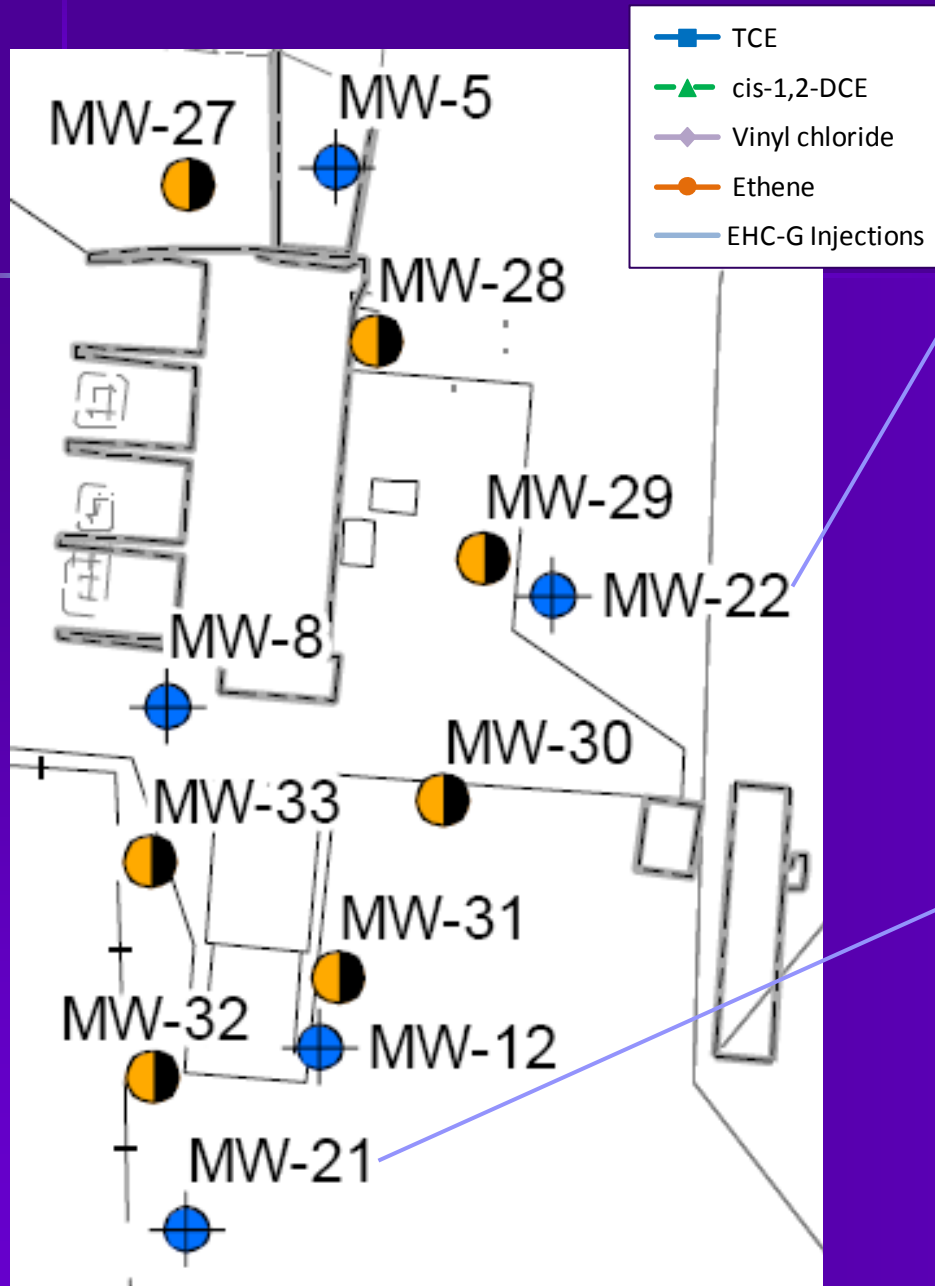
- All wells show some evidence of reducing redox potential (especially depleted oxygen, elevated iron, and methane production; sulfate and nitrate are still present in most wells)



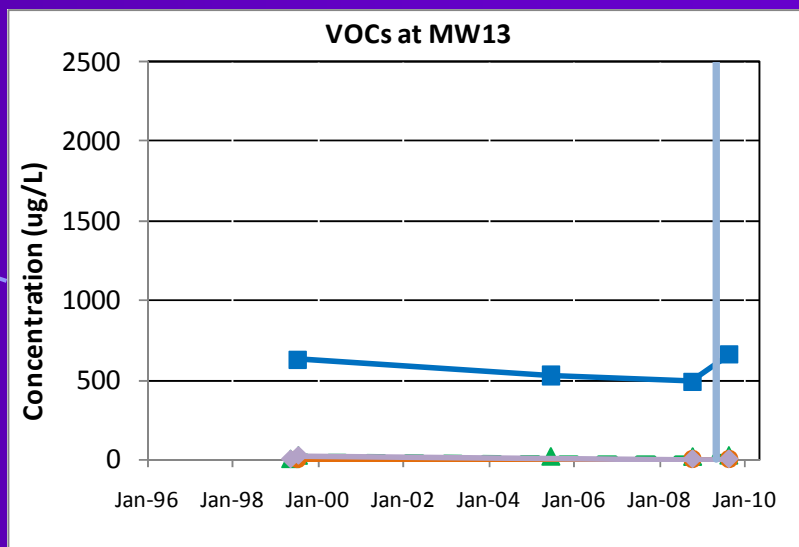
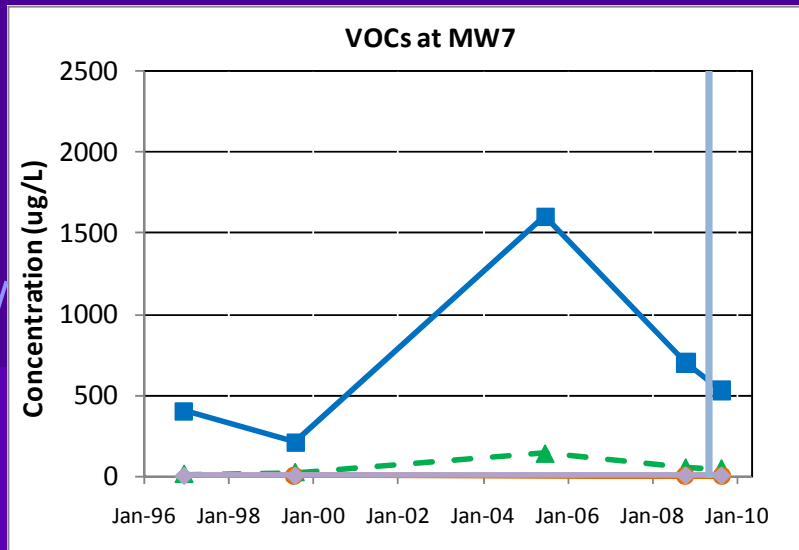
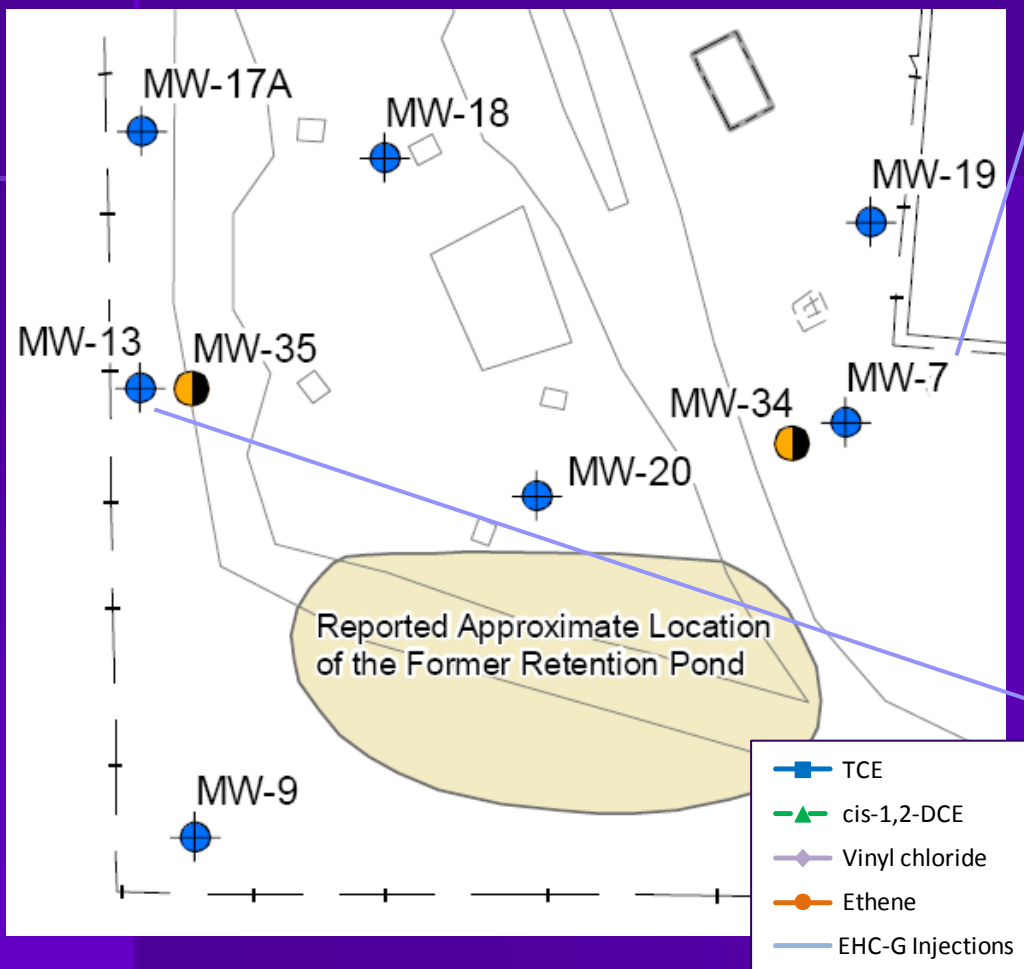
# Source Area: VOCs



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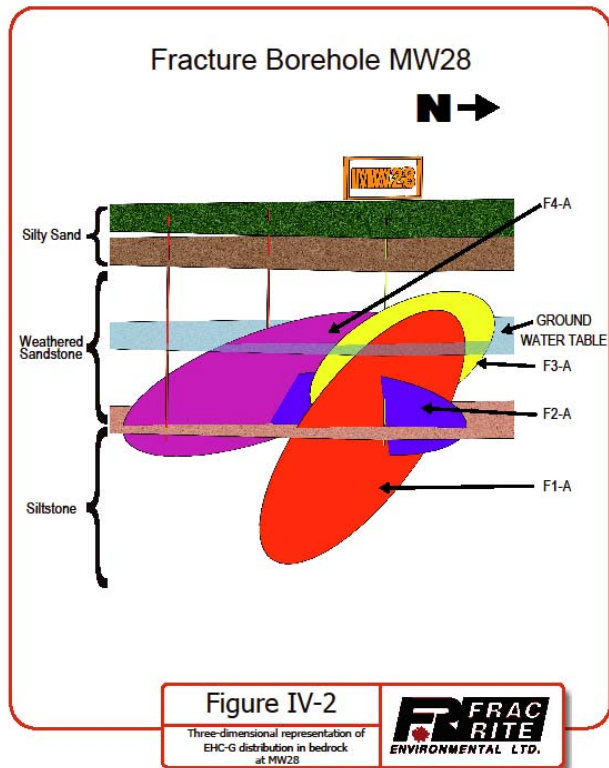
# Dissolved Phase Plume: VOCs



## VOC Summary:

- All source area wells showed TCE reduction; minimal changes in dissolved plume
- cis-DCE increased at MW-8 (~50 to 120 ug/L); no significant changes in vinyl chloride
- Ethene detected at low levels (0.35 to 4.5 ug/L)

# Fracture Mapping using Tiltmeter Geophysics

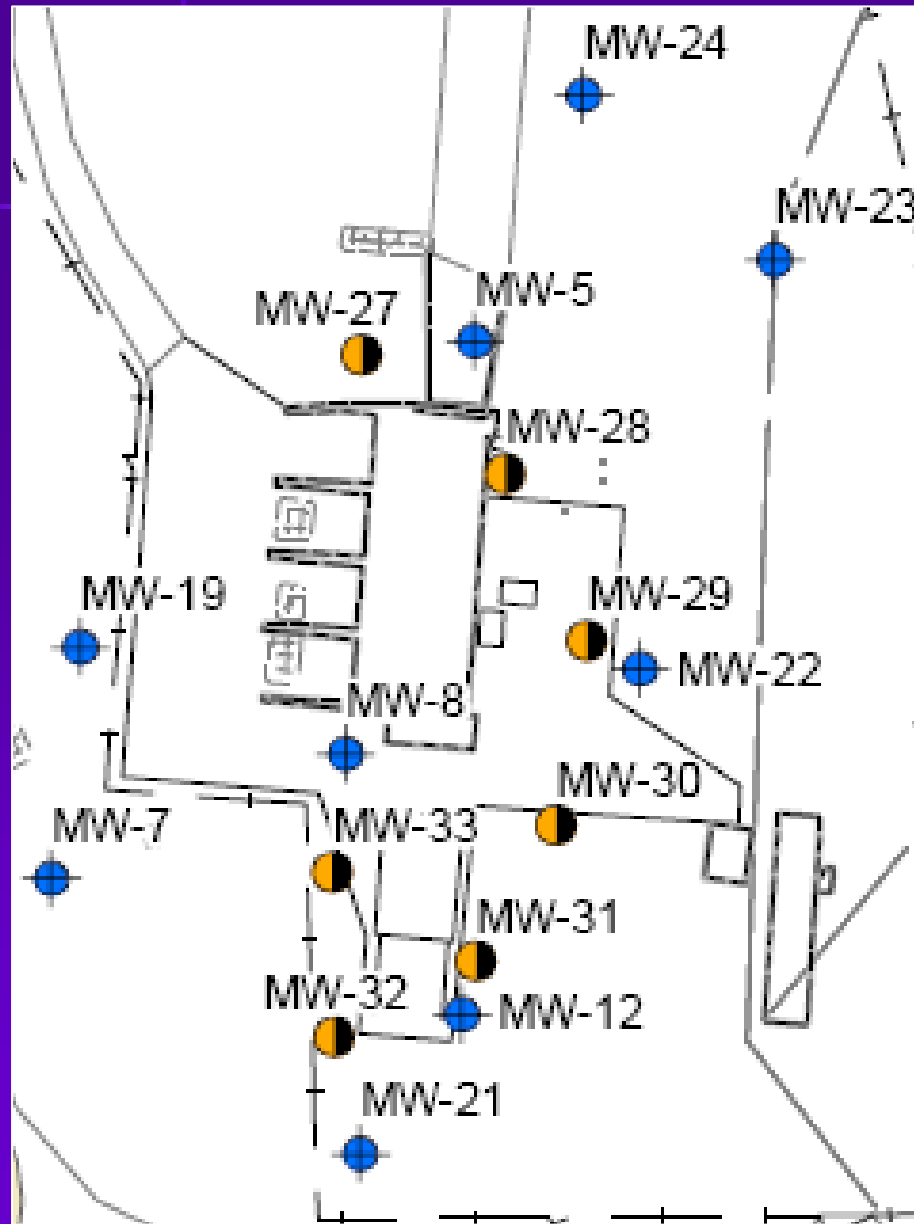


- Tiltmeters are ground surface sensors that detect tilt angle and tilt direction in response to a fracturing or injection event in the subsurface



# Fracture Mapping

Conducted for 7 boreholes in source area

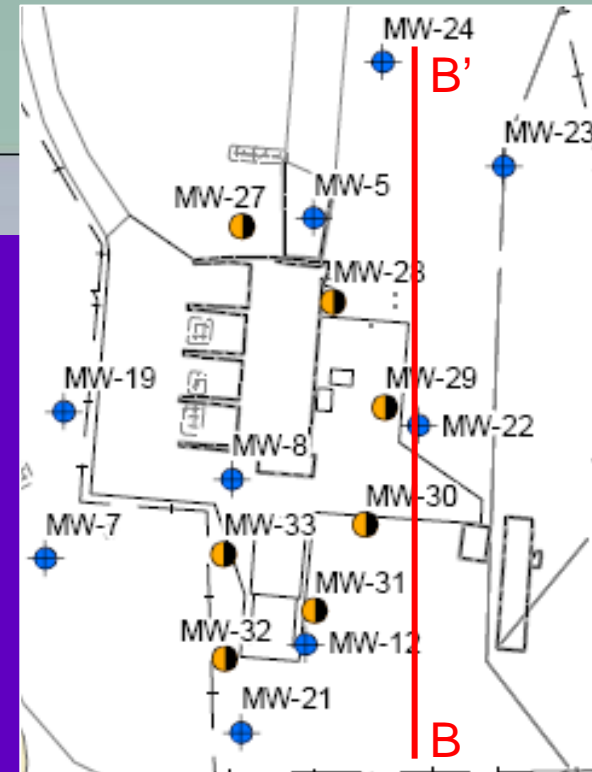
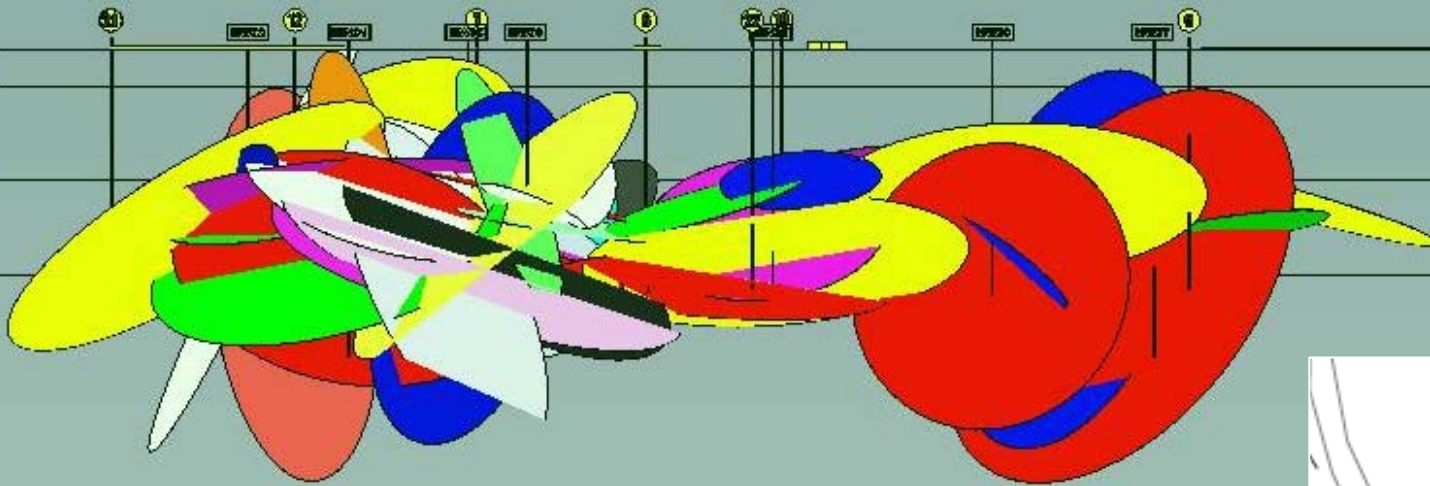


# Fracture Mapping

From MW-22 looking west

B

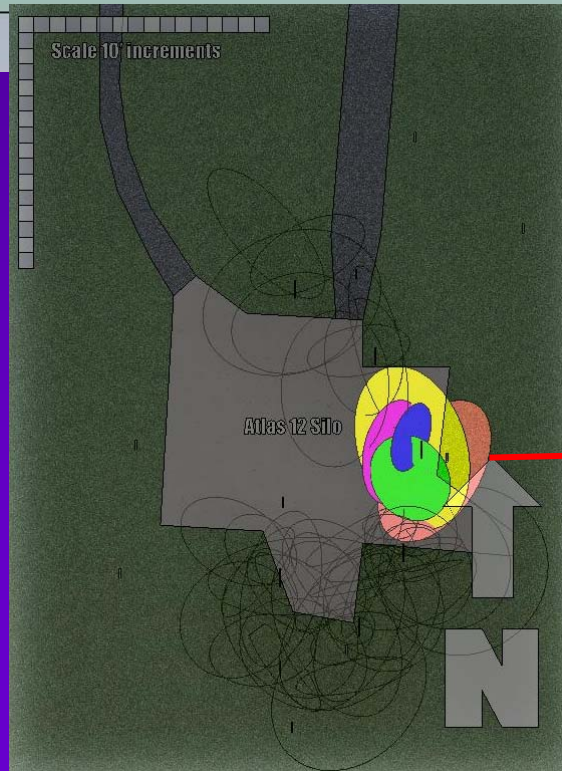
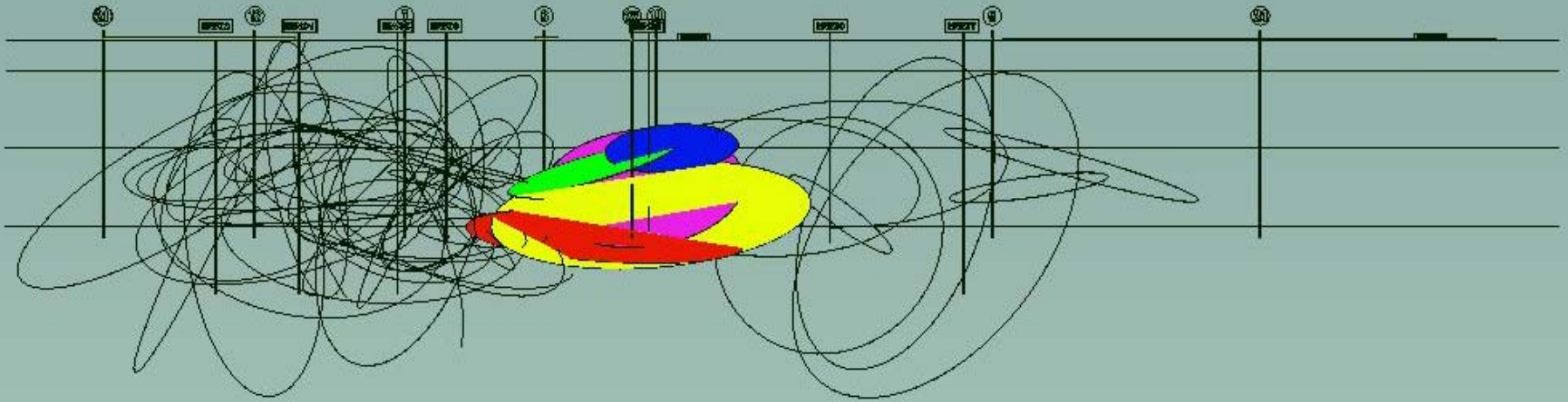
B'



# Fracture Mapping- MW-29

B

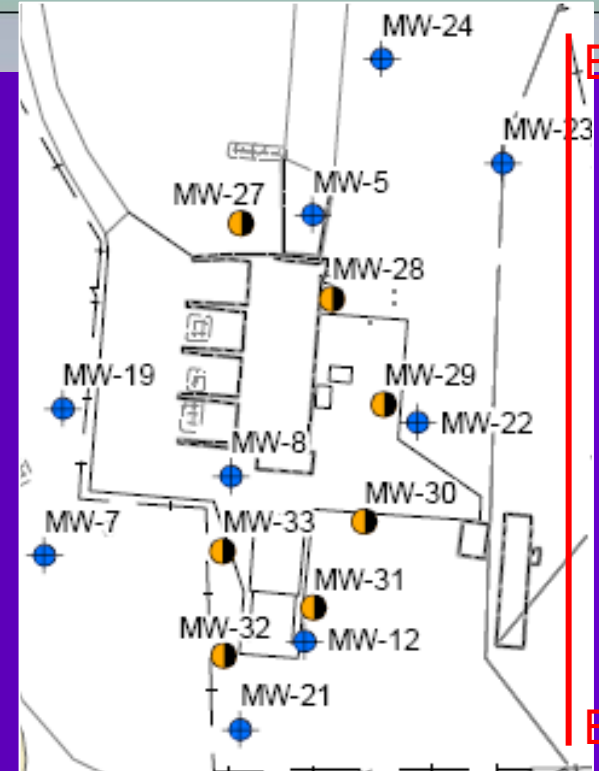
B'



Scale 10' increments

Atlas 12 Silo

32,000 lbs;  
5 depths

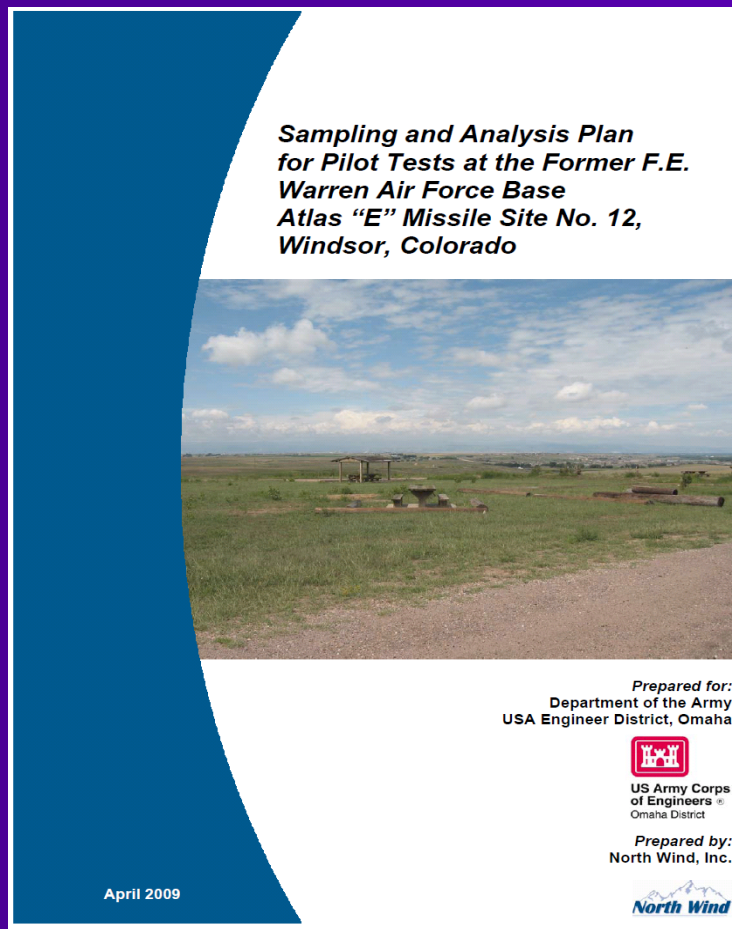


B'

B



# Implications for Full Scale Application



- Massive EHC-G loading can be delivered as fractures
- Widespread EHC-G distribution achieved using few boreholes
- Initial GW quality results show significant decrease in TCE within first 90 days
- 3D Fracture Mapping allows validation of EHC-G distribution
- ISCR appears to be an effective remedial approach
- Passive remediation negates need for capital treatment equipment and O&M costs



# Acknowledgements

## OUR THANKS TO:

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