ENVIRONMENTAL FRACTURING TO ACHIEVE SUSTAINABLE REMEDIATION IN DIFFICULT LITHOLOGIES

FRAC RITE ENVIRONMENTAL LTD.

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Who is Frac Rite?

- Environmental service company providing ***advanced in situ*** remediation and engineering services using technologies modified from the Petroleum, Geotechnical, and Water Treatment Industries
- Key personnel are professionals from environmental consulting, geotechnical services, and oil and gas service industry
- Privately held - incorporated in 1995
- Based in Calgary, Canada with offices in Burlington, Canada (Toterra); Dallas, Texas (Frac Rite Remediation); and Rotterdam, Netherlands (Groundcontrol)
- International Projects: N.America, Europe, Asia, Africa

Presentation Outline

- Environmental Fracturing: What is it and how is it used?
- In situ Remediation: Key concepts for doing it right
- Fractures as Treatment Pathways
- **Case Study:** Hydrocarbon Remediation in shallow clays
- **Case Study:** Chlorinated solvent remediation in deep bedrock
- Conclusions
- Implications for achieving Sustainable Remediation

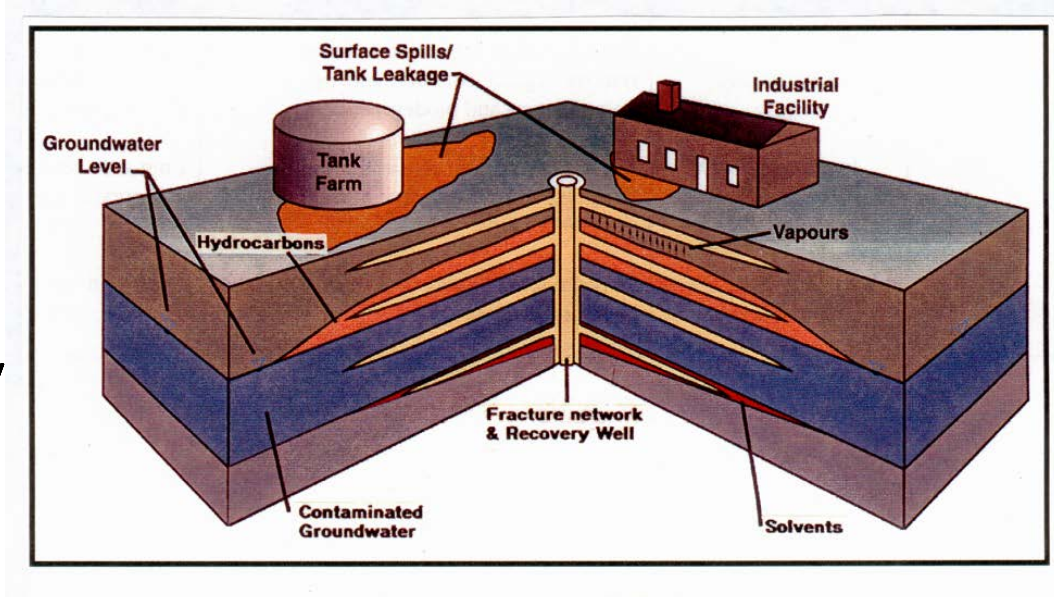
Environmental Fracturing for enhanced *in situ* Remediation

Environmental 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).

WHY DO IT?

Because it *increases*:

- soil permeability
- area of treatment/recovery
- contact with contaminants*



… *and facilitates*

- co-delivery and/or multiple injections of treatment reagents

Evolution of Environmental Fracturing

In Canada – adapted and modified from research into fracturing of oil sands (Golder Associates) in late 1980s

In the U.S.A. – from research into environmental applications for hydraulic fracturing at University of Cincinnati and New Jersey Institute of Technology in late 1980s - studies sponsored by US EPA

Commercial "environmental" fracturing services for in situ remediation of contaminated sites available since 1993 in North America:

- Refineries and Tank Farms
- Gas Plants and Battery Sites
- Pipeline ROWs
- Bulk Fuel Plants
- Former Flare Pit sites
- Retail Gasoline Stations
- Dry cleaner sites
- Grain Terminals
- Landfills
- Industrial Manufacturing Sites
- Brownfield redevelopment properties

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Field set up for Environmental Fracturing

- Mobile mixing and pumping unit
- Specialized downhole fracture tooling
- Drilling Equipment
- Data Acquisition System (Pressure, Rate vs. Time)
- Geophysical Fracture Mapping Equipment

- Environmental Fracture Fluid:

Potable water and biodegradable polysaccharide (i.e .sugar based) guar polymer (non toxic) and silica sand

Critical Elements for successful In Situ Remediation

DELIVERY + TREATMENT

DRILLING METHOD / TOOLING

EMPLACMENT TECHNIQUE

GEOLOGY

TREATMENT KINETICS / CHEMISTRY

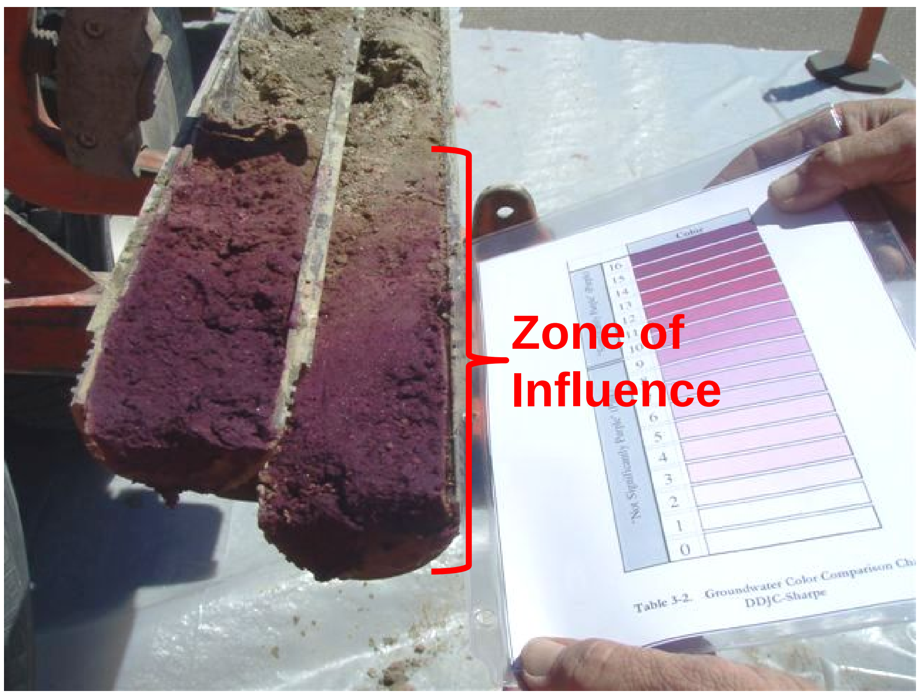
CONTAMINANT TYPE and DISTRIBUTION

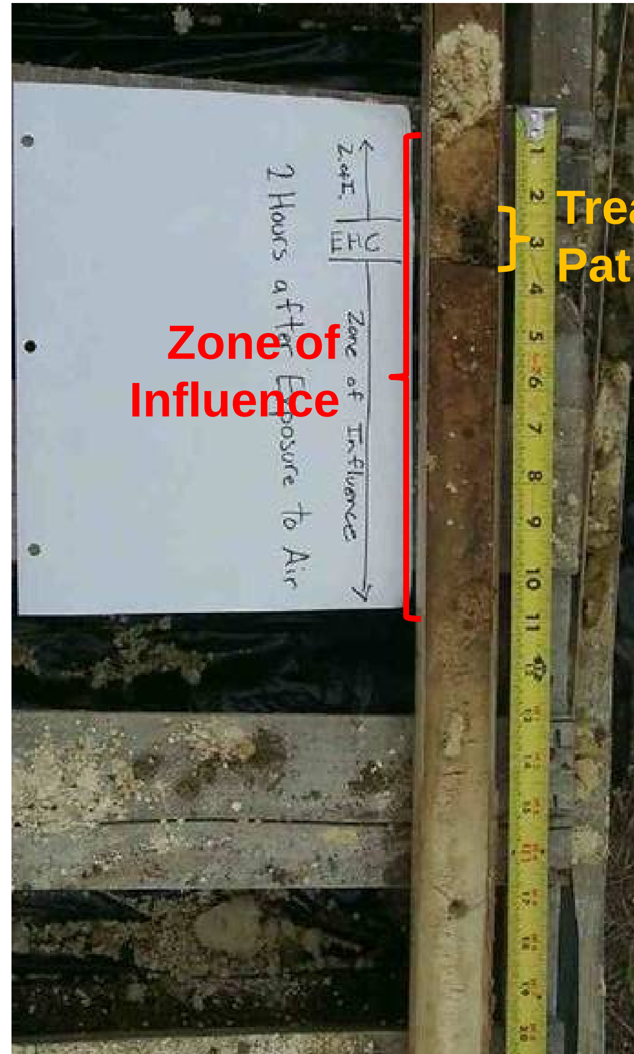
Treatment Pathways Exposed

Narrowly spaced, highly permeable treatment pathways in low permeability soils

Fracture-Emplacement of Treatment Ammendments

Upon injection into (or co-emplacement with) the permeable treatment network, amendments radiate out from the pathway, creating a zone of influence many times the thickness of the pathway.





Case Study: Industrial Property Remediation using Frac-enhanced Chemox

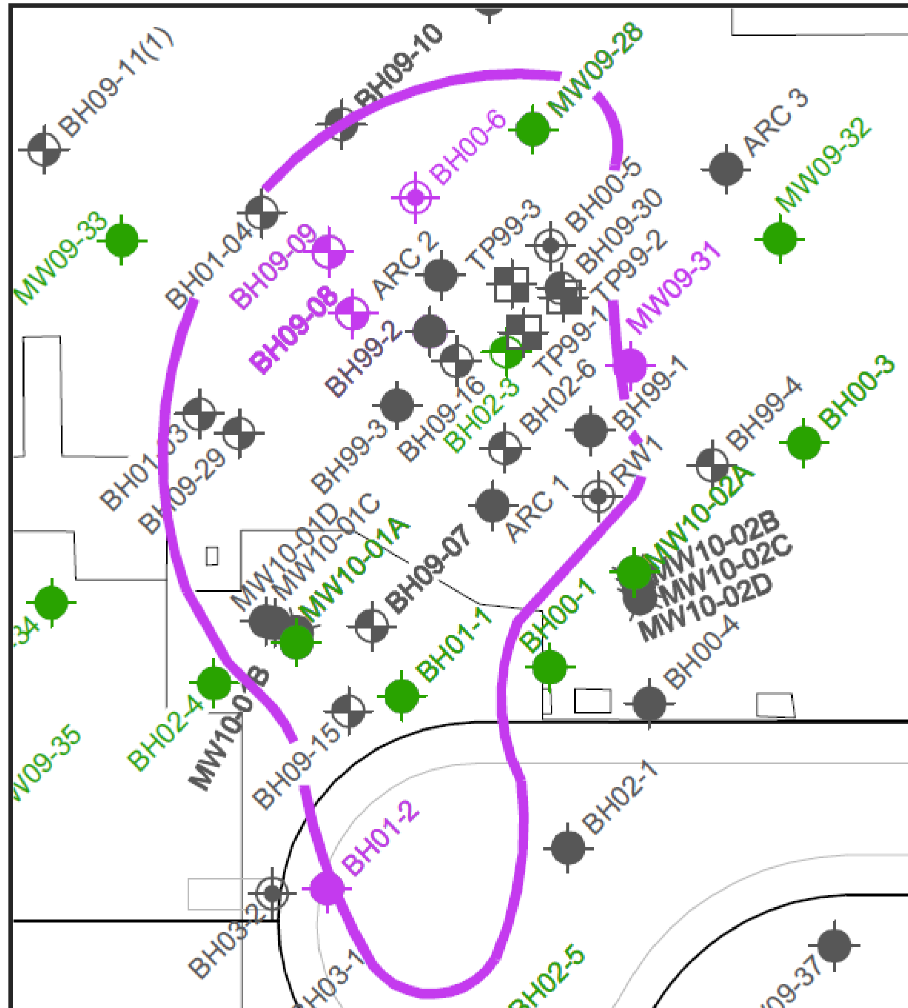
- Has been operated as a wood products manufacturing facility since the early 1980's
- Gasoline tank onsite
- Site surroundings
  - North: chemical company
  - West: food distribution facility
  - East & South: wood products manufacturer

Previous Work / Recommendations

- In 1999 a gasoline underground storage tank (UST) was decommissioned
- From 2000 to 2005: operation of a high vacuum multi-phase extraction system
- May 2010 soil excavation was recommended
- August 2010 application & approval for Tier 2 criteria to reduce area of excavation

Conceptual Site Model

- Has been an active industrial manufacturing facility since 1981
- COCs are refined PHCs from a gasoline tank
- Soil on-site is fine grained (clays)
- Site specific AESRD Tier 2 Criteria values approved in August 2010
- Tier 2 delineation prior to remediation:
  - Soil plume volume 5,530 m³ over an area of 1,725 m²
  - Groundwater plume 2,900 m²



Challenges & Objectives

CHALLENGES

- Active facility with significant site traffic
- Off-site impacts
- Remediation timeline relatively short
- Low permeability clays (10^{-9} m/s)

OBJECTIVES

- Remediate on-site plume to Tier 2 guidelines by Summer 2012
- Use several integrated technologies to expedite remediation
- Apply for remediation certificate and achieve site closure

Initial Approach to Remediation

- Environmental fracturing to enhance bulk permeability of fine grained soils (120 fracs)
- Incorporate surfactant into fracture slurry to increase availability of sorbed PHCs
- Install 30 dedicated injection wells into FBHs
- Inject chemical oxidants through fracture network to oxidize PHCs

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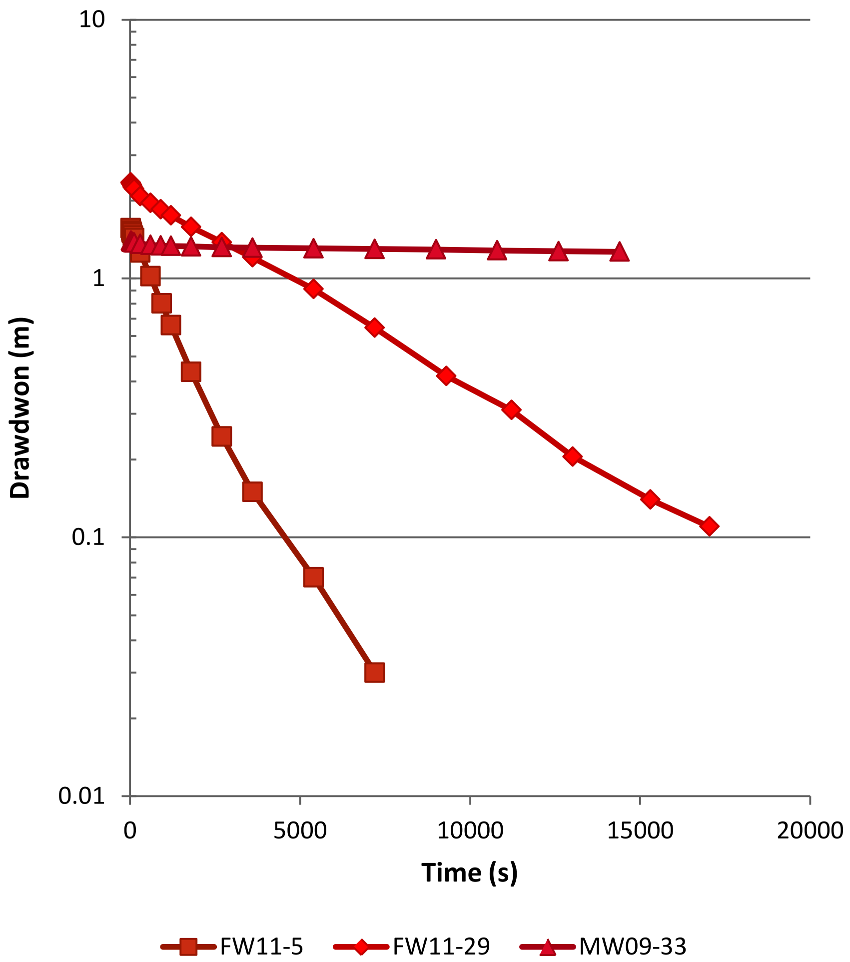
Initial Remedial Treatment

2011 Month	Oxidant / Proppant	Volume
June – July	Sand & Surfactant	106,000 L & 600 L
July	Sodium Persulfate & Hydrogen Peroxide	20,800 L & 7,250 L
September	Sodium Persulfate & Hydrogen Peroxide	9,300 L & 29,500 L
December (Off-site)	Calcium Peroxide & Hydrogen Peroxide	5,000 L & 5,000 L

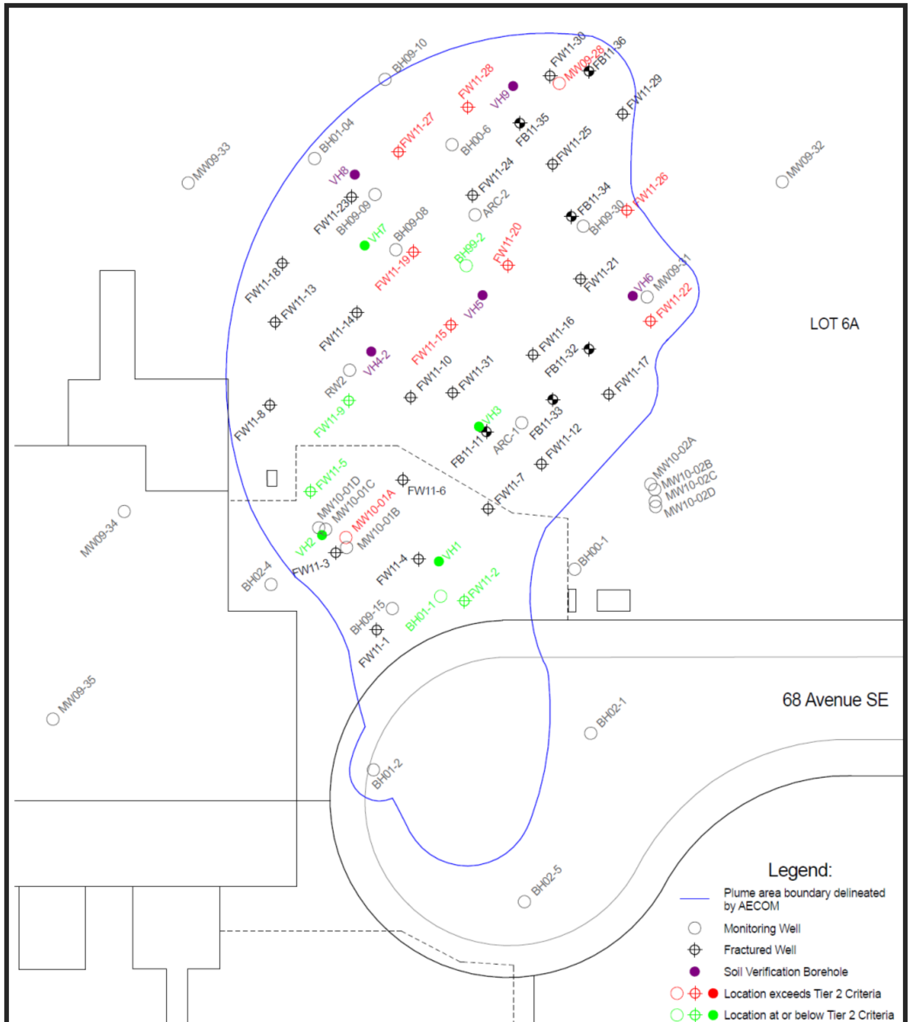
Hydraulic Conductivity Test

- Rising head tests conducted on two fractured wells and one monitoring well (Bouwer & Rice)

Well I.D.	Hydraulic Conductivity Estimate (m/s)
MW09-33	1.8×10^{-9}
FW11-5	2.6×10^{-7}
FW11-29	5.5×10^{-8}



Initial Results (2011)



2011 Year End Results (after 6 months)

- South end of on-site plume below Tier 2 Criteria
  - However, one groundwater well was above criteria
- Overall four of nine soil locations below criteria
- Off-site conditions not yet verified

Optimized Treatment (2012)

Additional oxidant emplacement:

- January 2012 (18,500L sodium persulfate & 6,000L calcium peroxide)
- March 2012 (10 potassium persulfate treatment canisters)
- April 2012 (30,500L hydrogen peroxide & 4,000L calcium peroxide)
- August 2012 (500L sodium persulfate)
  - To treat the groundwater only

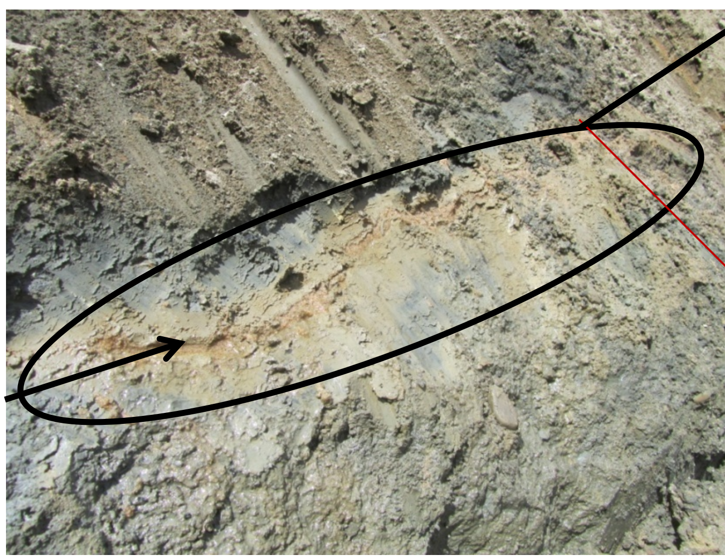
Limited Excavation (2012)

- A “hot spot” area was located on the east side of the plume
- A total of 900 tonnes of contaminated soil was disposed (<10% of total) in an area of 15 x 15 m and 1.5 to 3.5 m bgs
- Work completed during April 2012

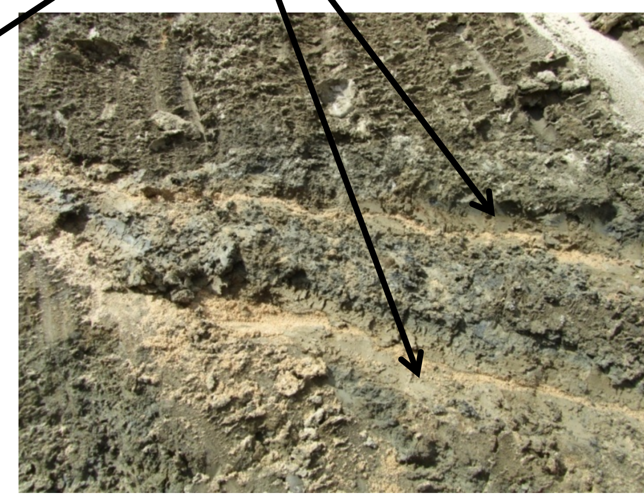
Fractures as Treatment Pathways

Sand-filled permeable treatment pathway in clay (2 cm thick)

Horizontal permeable treatment pathways in low permeability soils



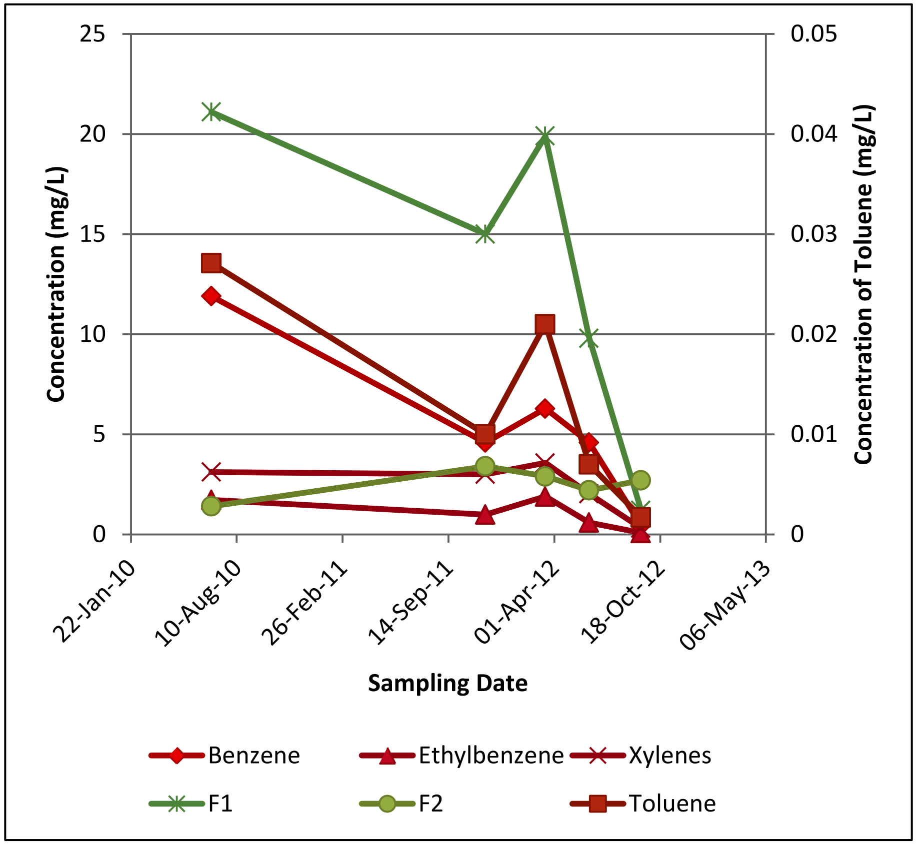
Brown-coloured oxidation front through contaminated soil



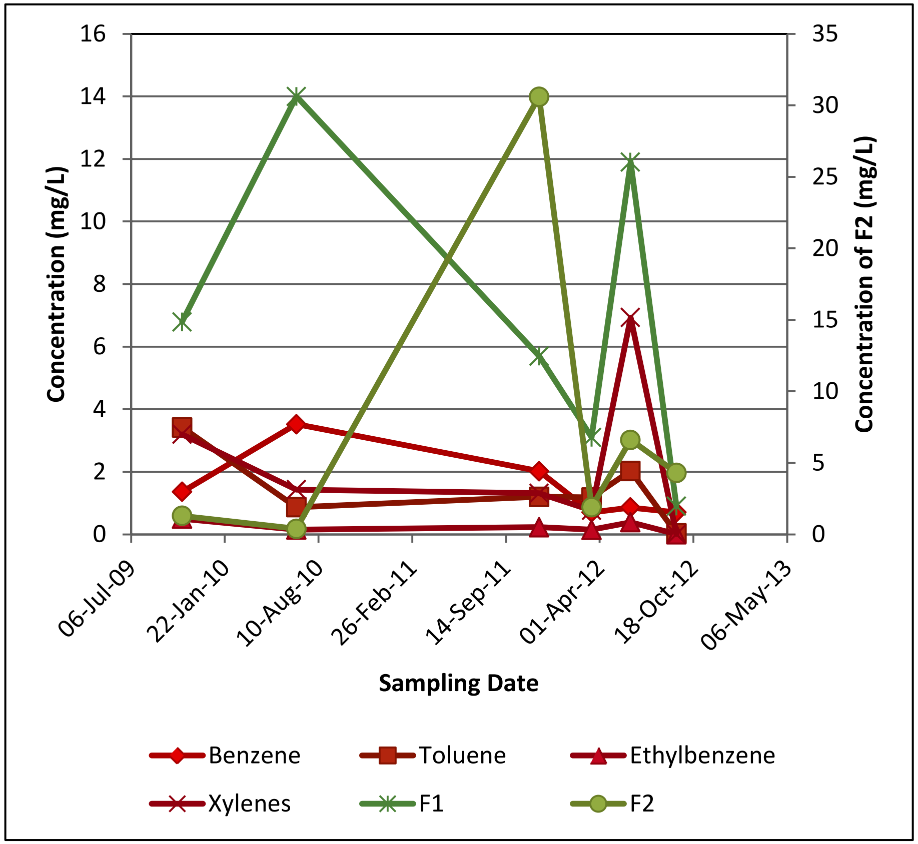
Groundwater Quality Summary

- Groundwater results 15 months after commencing remedial work

Groundwater Analysis MW10-01A



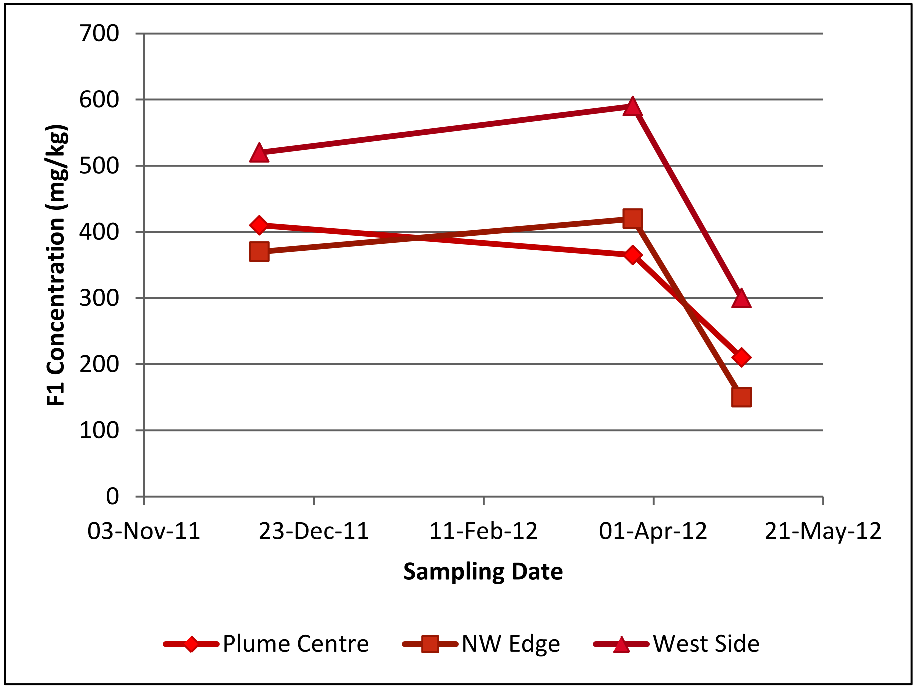
Groundwater Analysis MW09-28



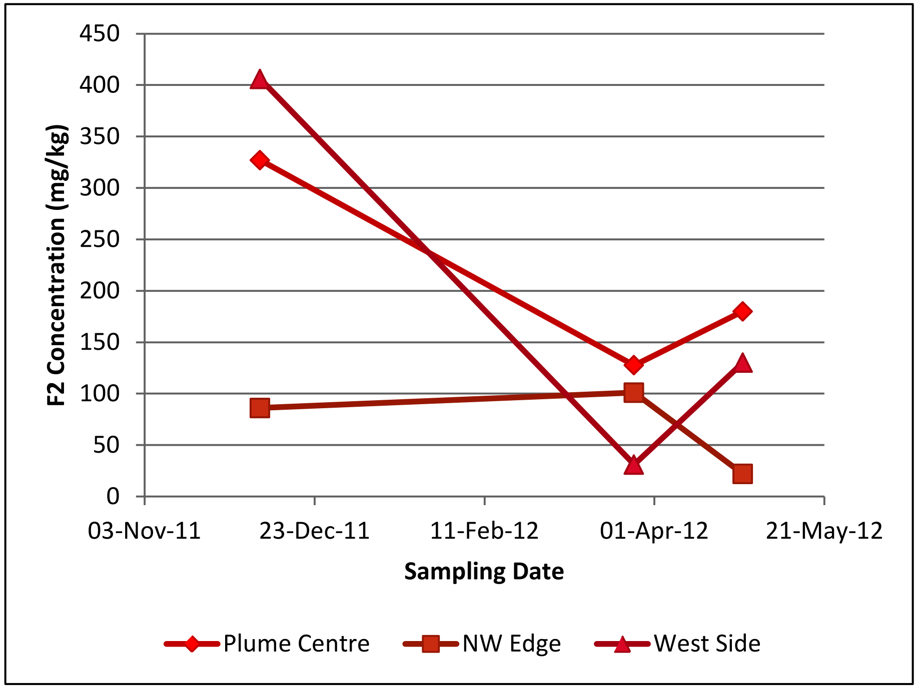
Soil Quality Summary

- All soil samples were below criteria in April 2012
  - 10 months after commencement of remediation
- F1 criteria is 320 mg/kg, and F2 criteria is 260 mg/kg

F1 Hydrocarbon Fractions



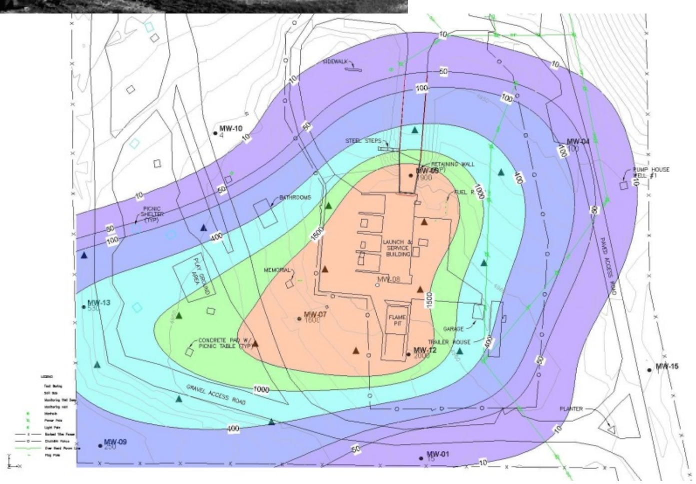
F2 Hydrocarbon Fractions



Summary

- An integrated, in situ remedial approach using environmental fracturing and chemical oxidation, with a limited excavation of a "hot spot", was implemented
- On-site soil Tier 2 criteria achieved within expected timeframe of 1 year
- Minor F2 fraction rebound in groundwater – used multiple treatments to deal with diminishing "rebound" effects
- Total cost to site owner: $650,000 to date vs. $1.5M D&D
- Bank refinancing of the property was made possible
- Very little disruption to business operations during remediation and no loss of business revenue.
- Off site verification drilling confirmed compliance with Tier 2 criteria; Long term GW sampling program in progress

Environmental Fracturing to Remediate TCE contamination in a bedrock aquifer



- 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

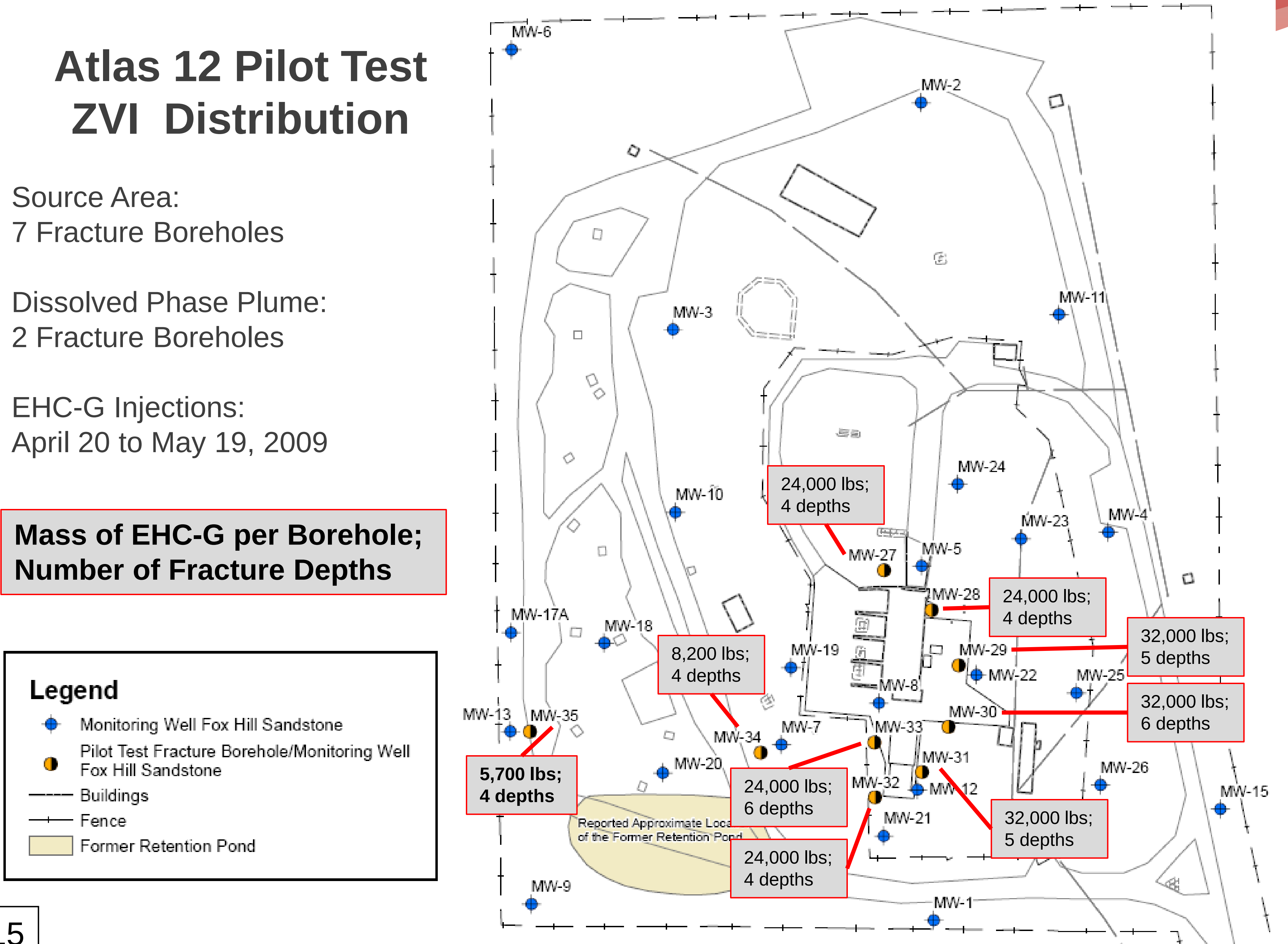
Atlas 12 Pilot Test ZVI Distribution

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



Fracture Mapping using Tiltmeter Geophysics

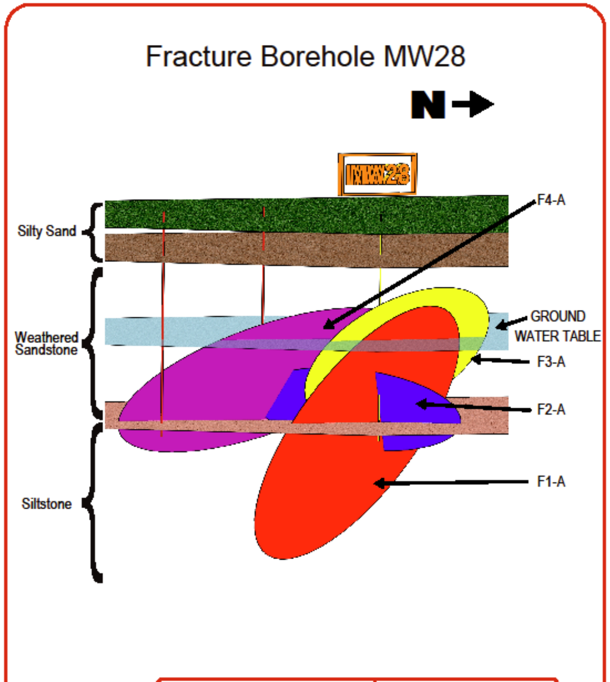
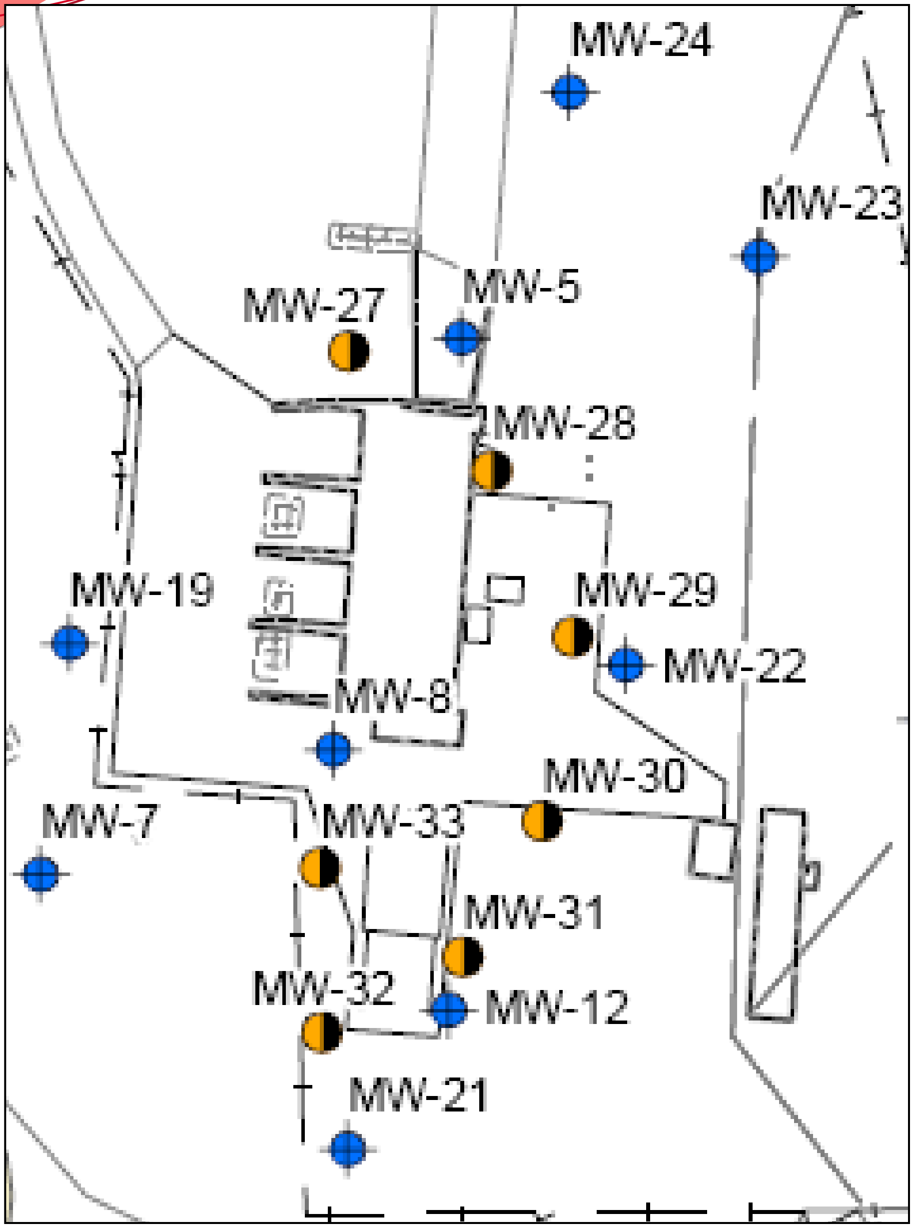


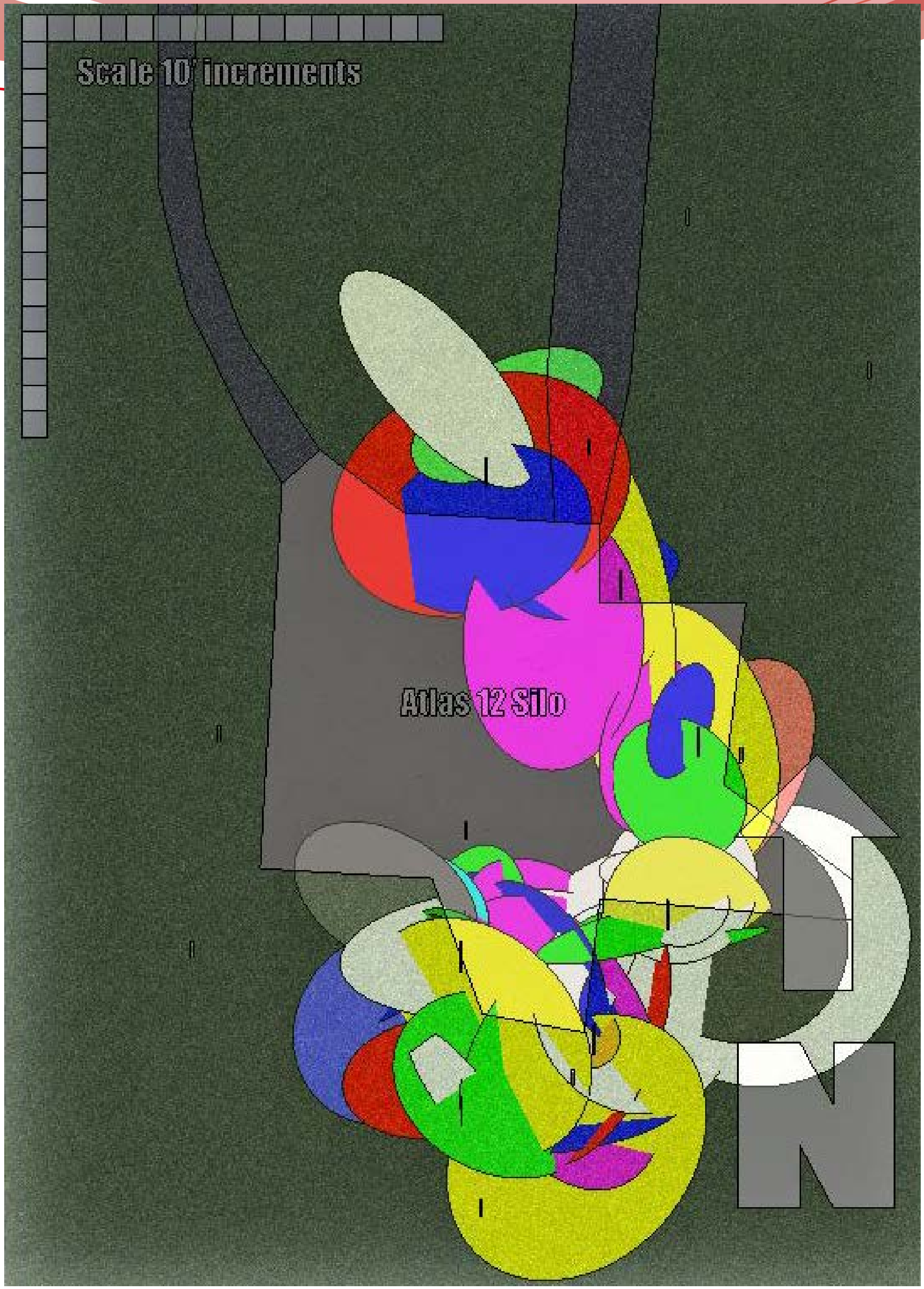
Figure IV-2
Three-dimensional representation of EHC-G distribution in bedrock at MW28

- 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 of ZVI fracs

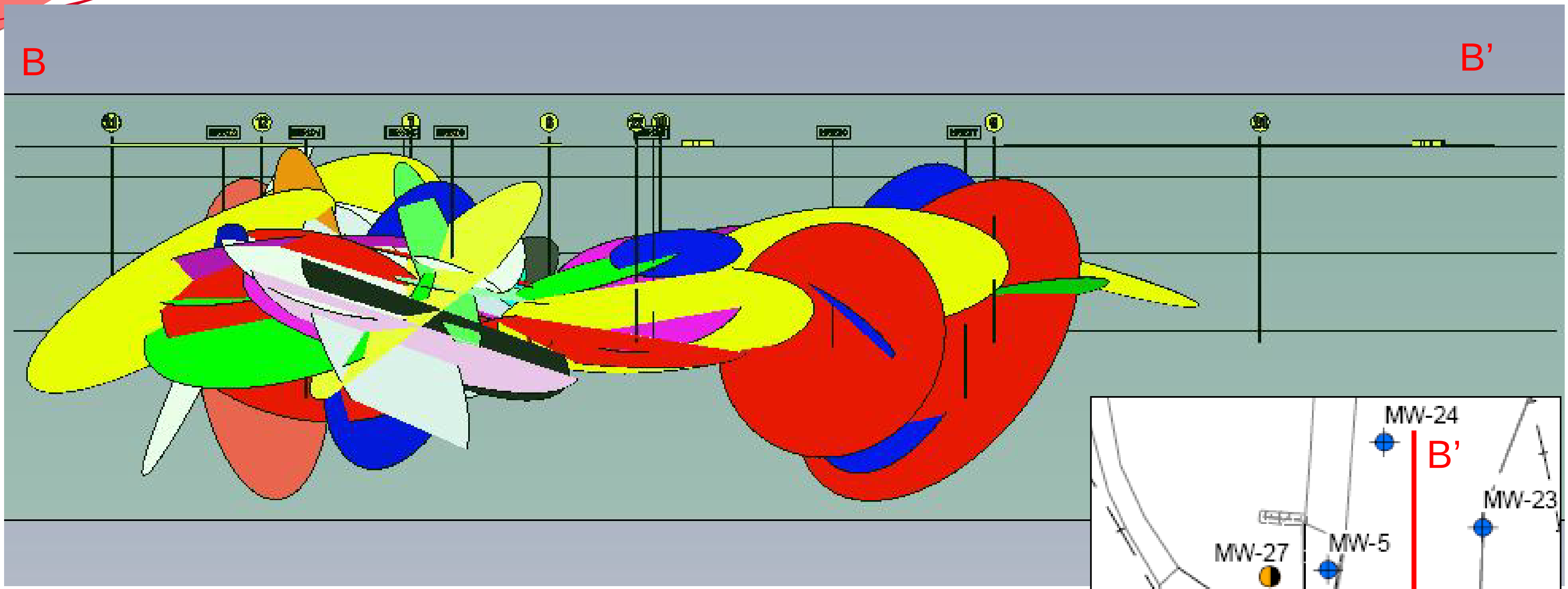
Conducted for 7 boreholes in source area



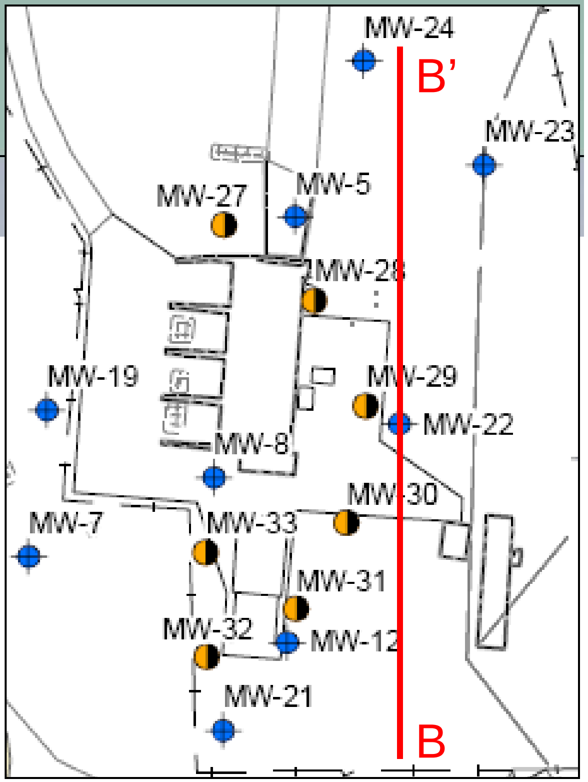


Fracture Mapping of ZVI fracs

From MW-22 looking west



North-South extent of continuous ZVI/C coverage is approximately 450 ft, effectively comprising a treatment barrier



TCE Treatment Perfomance after 21 months

- **Source Area**:

Pre-treatment TCE levels - >2000 to 4,000 ug/L

After 12 months – less than 40 ug/L except at 2 wells

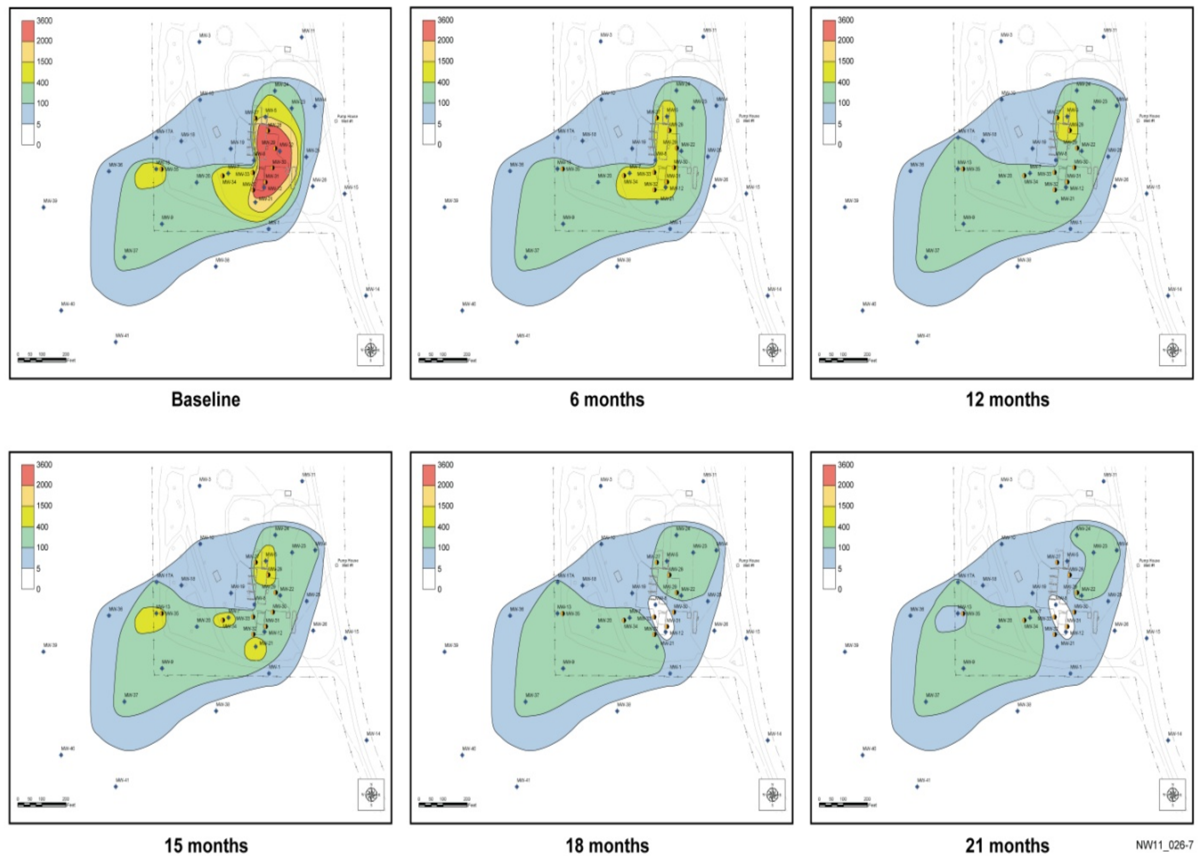
After 21 months – less than 10 ug/L generally

- **Dissolved Plume Area**:

Pre-treatment TCE levels - 500 to 700 ug/L

- After 21 months – 200 to 400 ug/L

Atlas 12 Post-Pilot Test TCE Concentration Changes



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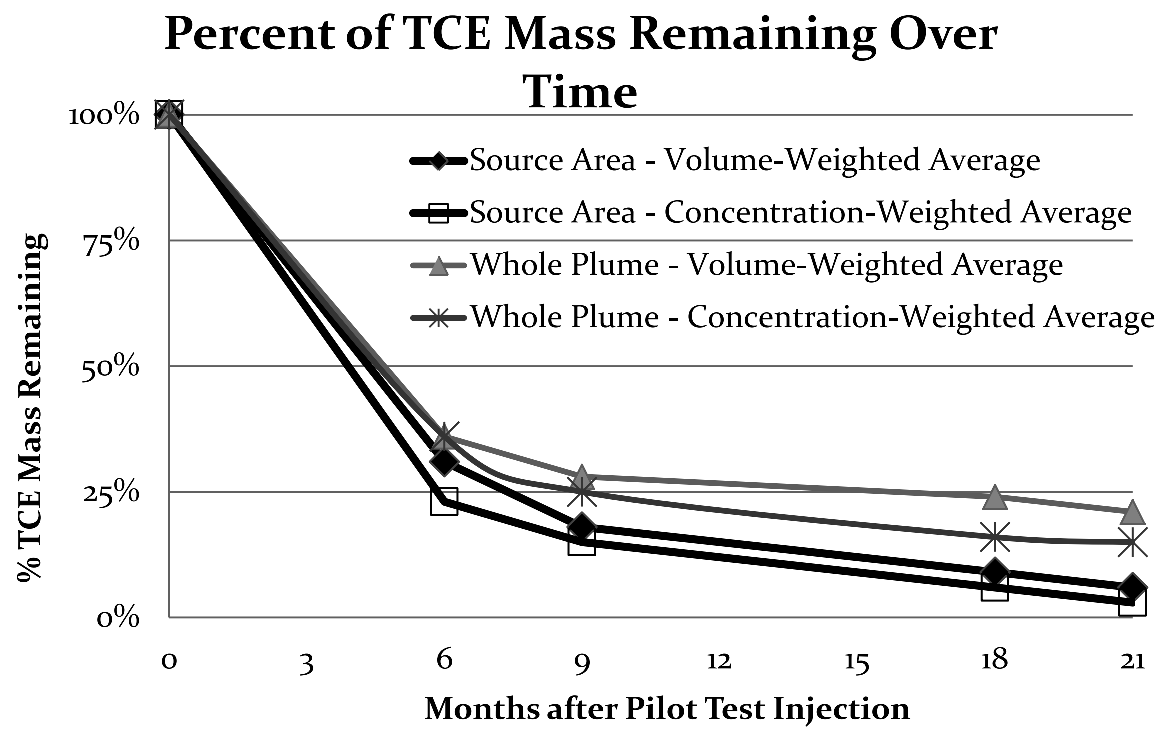
21 Month Performance Evaluation

- 94% of Source Area below RMC of 100 ppb TCE
- 82% of Dissolved Plume Area below TCE RMCs
- Phase 2 ZVI Injection of another 40 tons ZVI completed in August 2011, TCE is ND to 100 ug/L
- Treatment cost equivalent: $8 per ton
- Approach in now the model for USACE missile site clean-ups **(Journal of Remediation, Spring, 2012).**
- Phase 3: unrestricted land use – Sept. 2013



Implications for Remediation

Environmental Fracturing and Injection techniques coupled with innovative treatment and verification technologies can overcome traditional limitations to *in situ* remediation:

- Cost effectively,
- Non-disruptively,
- Synergistically,
- Verifiably, and
- Sustainably

These are key drivers in the growth of advanced *in situ* remediation technologies within the environmental market.

Thank You!

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