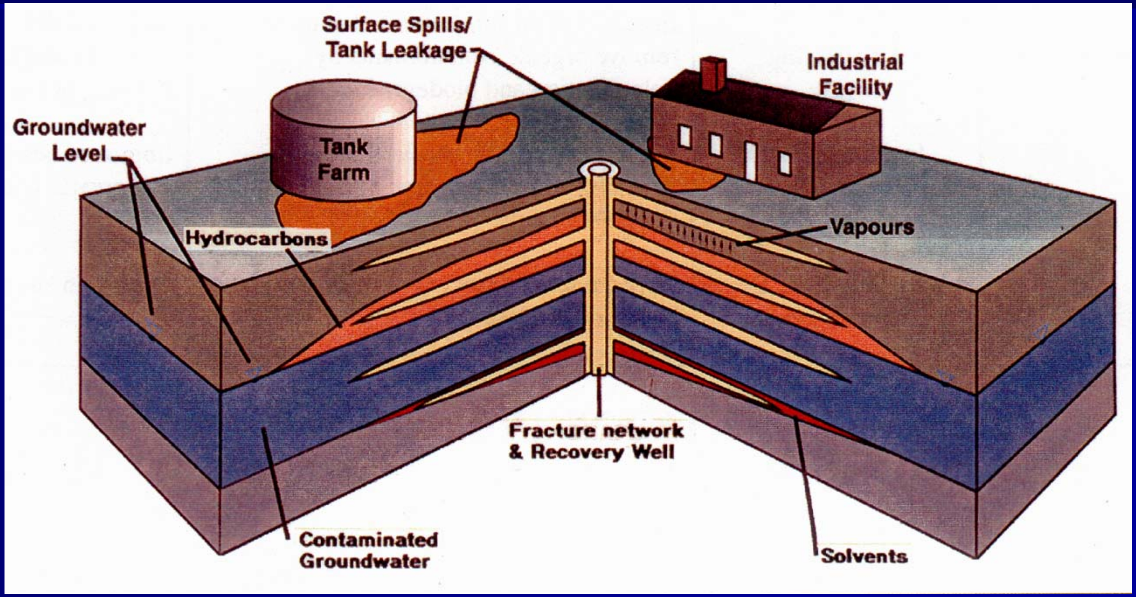
FRAC RITE ENVIRONMENTAL LTD.

ACHIEVING SUCCESSFUL *IN SITU* REMEDIATION OF PETROLEUM IMPACTED CLAYS USING PERMEABLE TREATMENT PATHWAYS EMPLACED BY HYDRAULIC FRACTURING

Outline

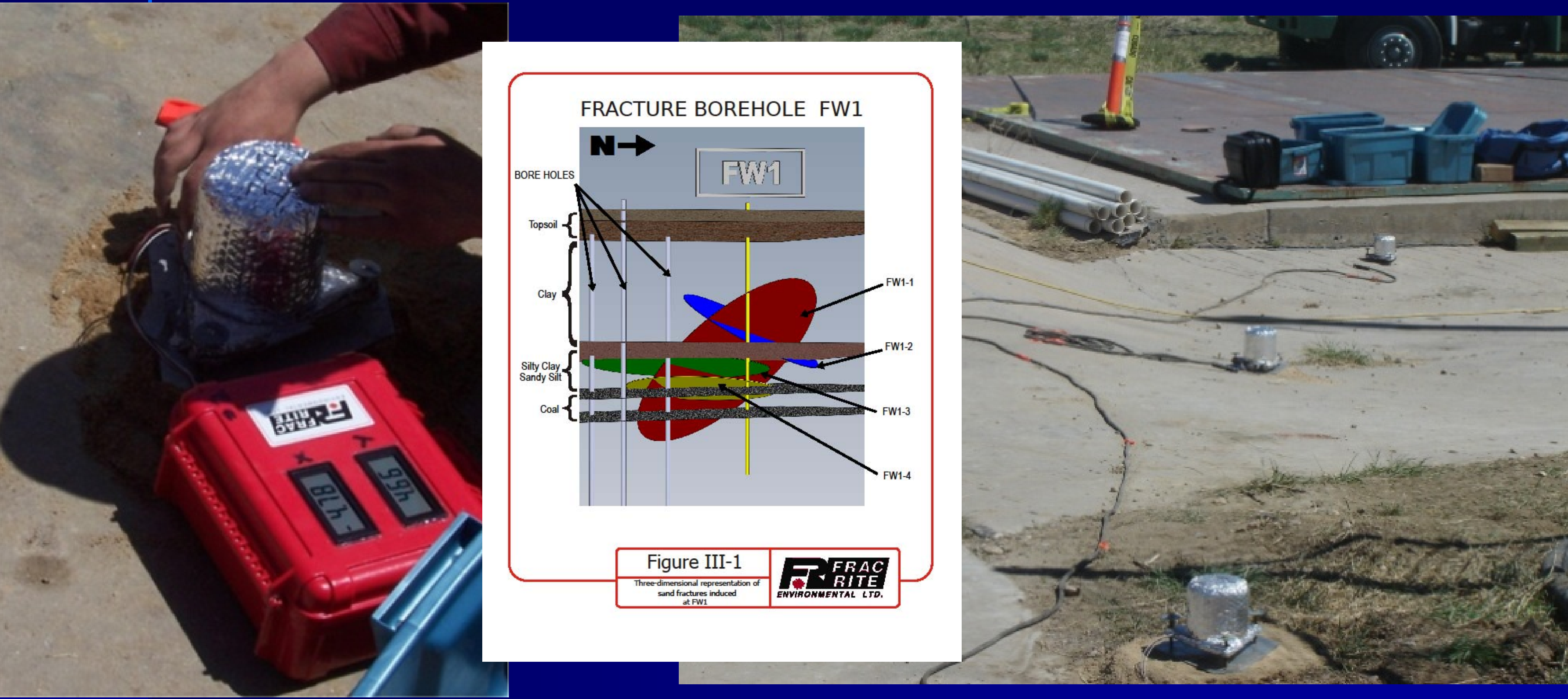
- Fracturing and validation by 3D mapping
- Site background and objectives
- Remedial program and design
- Fracture mapping results
- Initial soil quality results
- Lessons learned

What is Fracturing?



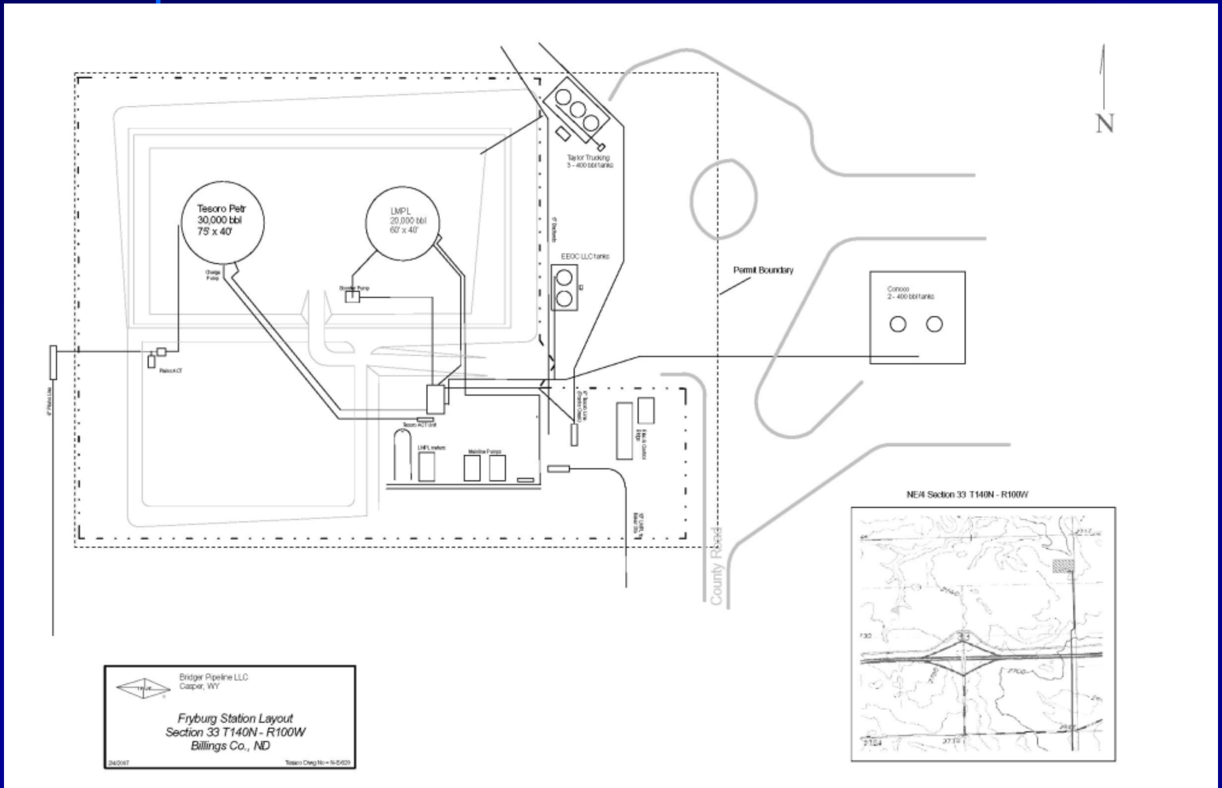
- Fracturing is a process in which fluid is applied to a soil or rock mass until failure of the soil or rock occurs, which results in a tensile parting (i.e. fracture)

Validating Amendment Distribution using Tiltmeters



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

Project Background



- U.S. Forest Service site leased to midstream oilfield transfer company
- Operational tank storage facility and transfer station lease
- Gasoline and fuel oil impacts from operational surface spills and leaks
- Contamination in the facility pad and nearby pasture

Unique Site Challenges

- Contamination in unsaturated zone
- Active facility
- Remote site
- Space constraints
- Unusual geology

Remedial Objectives

1. Treat light and heavy end petroleum hydrocarbons to meet NDDH action level (TPH less than 100 ppm)
2. Clean-up in a relatively short time frame
3. No disruption to on-going operations & tank farm facilities

Remedial Approach

- Emplace highly permeable sand fractures
- Inoculate sand fractures with slow release oxygen compound (calcium peroxide)
- Inject a strong oxidant (stabilized hydrogen peroxide) into these pathways

Reaction Kinetics

- Hydrogen peroxide oxidation

  $2OH^{\cdot} + 2H^{+} + 2e^{-} \rightarrow 2H_2O \quad E^o = 2.76v$

  $H_2O_2 + 2H^{+} + 2e^{-} \rightarrow 2H_2O \quad E^o = 1.77v$

  $HO_2^{-} + H_2O + 2e^{-} \rightarrow 3OH^{-} \quad E^o = 0.88v$

- Hydroxyl Radical Formation

  $H_2O_2 + Fe^{+2} \rightarrow Fe^{+3} + OH^{\cdot} + OH-$

  $2O_3 + 3H_2O_2 \rightarrow 4O_2 + 2OH^{\cdot} + 2H_2O$

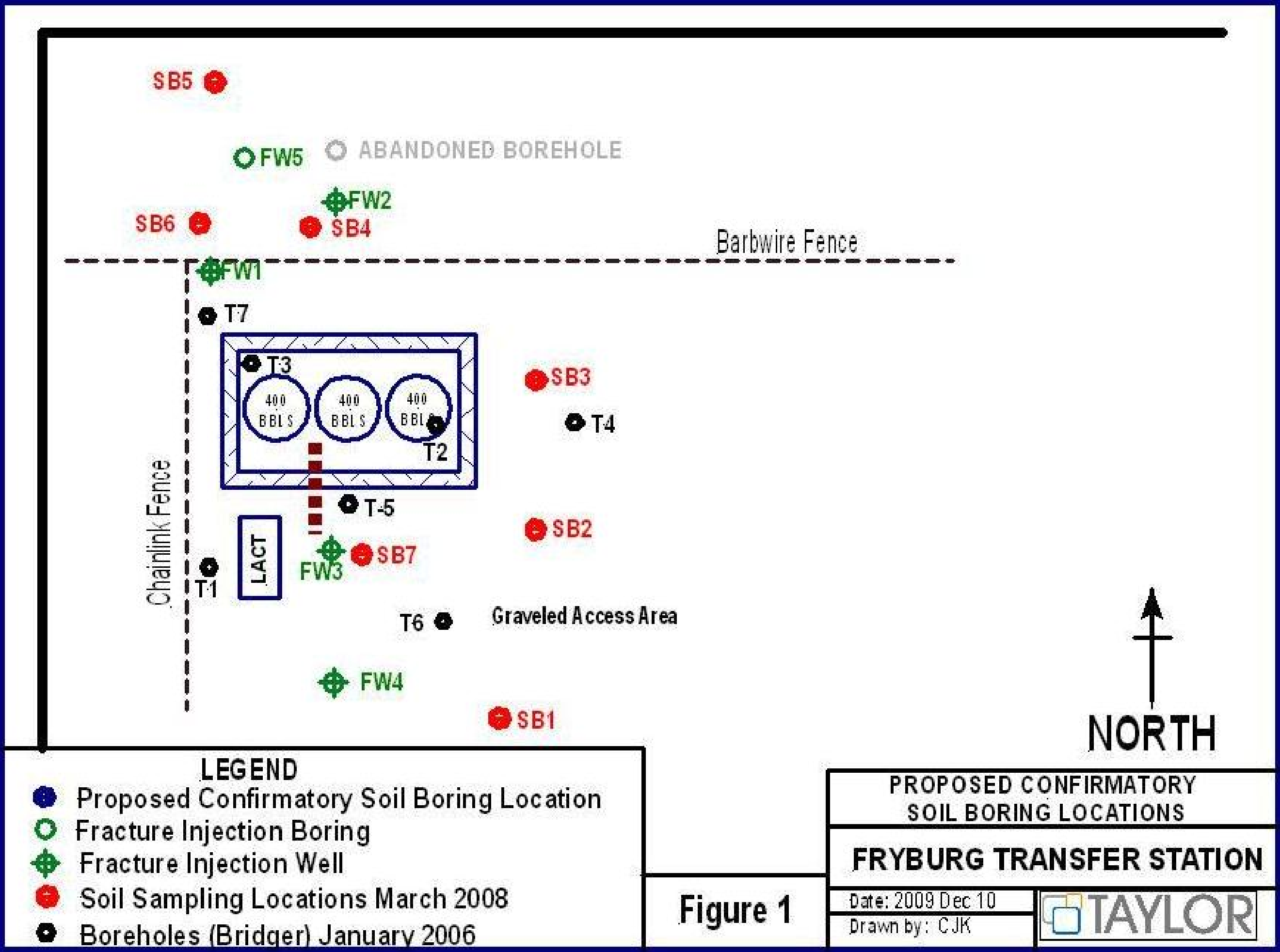
- Calcium peroxide oxidation

  $CaO_2 + 2H_2O + 2e^{-} \rightarrow Ca(OH)_2 + 2OH^{-} \quad E^o = 0.9v$

  $CaO_2 + H_2O \rightarrow \frac{1}{2}O_2 + Ca(OH)_2$

R.A. Brown, 2003

Field Program



- Five fracture boreholes
- Target fracture depths:
  - 7 to 13 ft bgs in pasture
  - 7 to 17 ft bgs on facility pad

  (@ 2 ft increments)

Sand and Calcium Peroxide Emplacement

- A total of 25,110 lbs of silica sand and 1,870 lbs of calcium peroxide was emplaced
- Covered an approximate area of 11,000 ft^2
- Fracturing completed in three work days

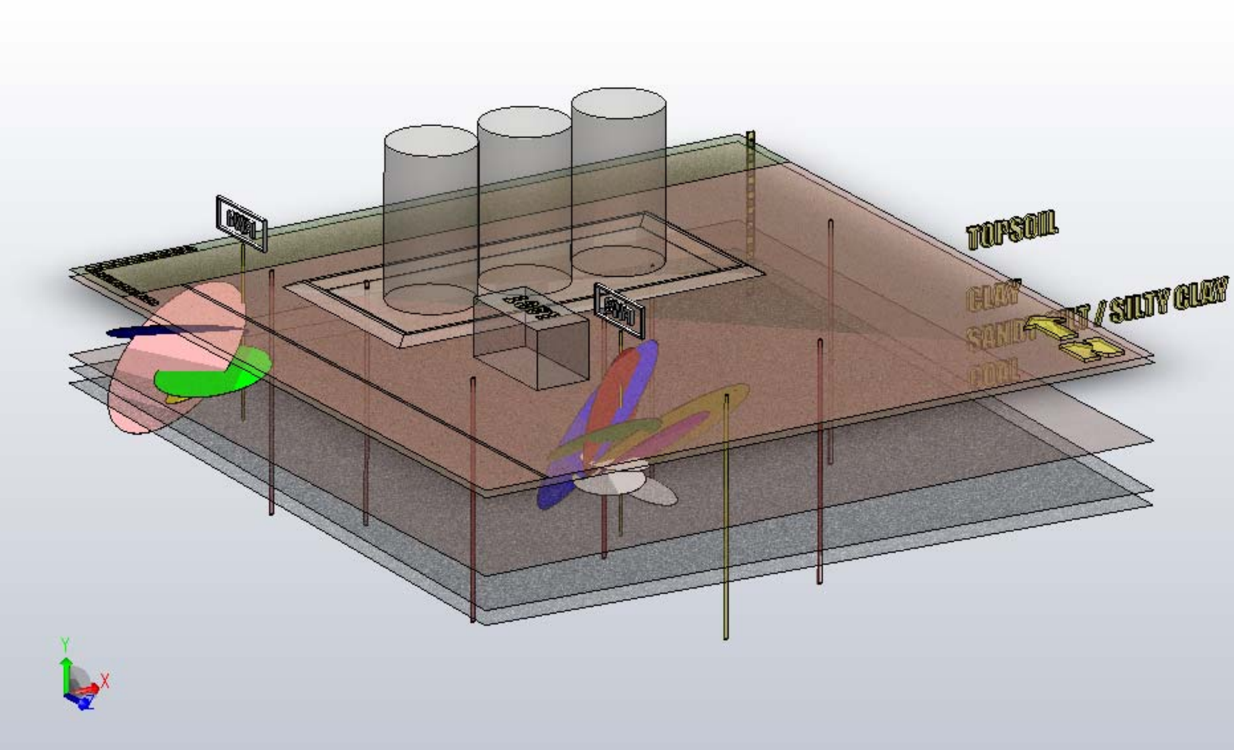
Hydrogen Peroxide Injection

- Four fracture boreholes were completed as injection wells
- Approximately 1,641 gal of hydrogen peroxide were injected
- Injections completed in 24 hours

Sand and Oxidant Distribution

Borehole Number	Frac Sand	Calcium Peroxide	Hydrogen Peroxide
FW1	8,000 lbs	550 lbs	815 gal
FW2	4,000 lbs	330 lbs	250 gal
FW3	5,185 lbs	330 lbs	250 gal
FW4	6,425 lbs	495 lbs	325 gal
FW5	1,500 lbs	165 lbs	-

Fracture Mapping



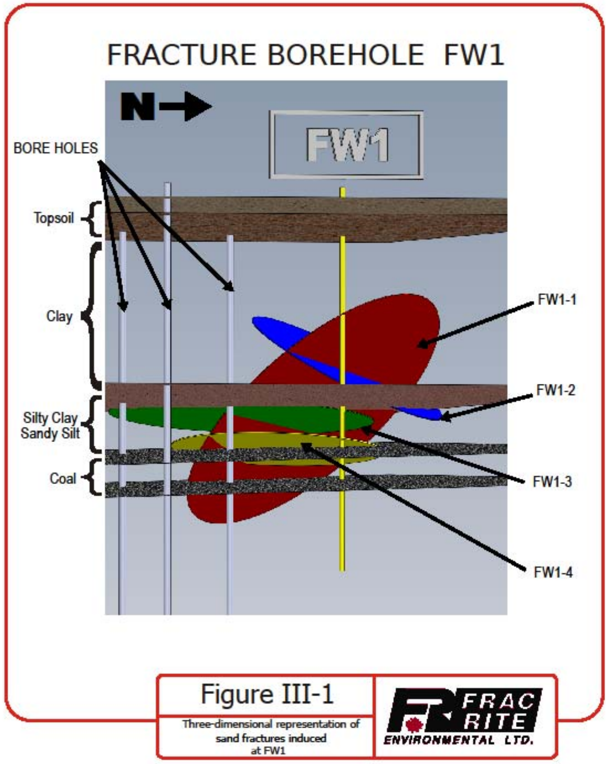


Figure III-1
Three-dimensional representation of sand fractures induced at FW1

Statistical Summary of Fracture Analysis

Fracture I.D.	No. of Fractures	Fracture Classification	% of Total Fractures
FW1-3, FW3-5, FW3-6, FW3-7	4	Nearly Horizontal	34
FW1-4	1	Slightly Ascending	8
FW1-1, FW1-2, FW3-2b, FW3-3, FW3-4	5	Moderately Ascending	42
FW3-2a	1	Strongly Ascending	8
FW3-1	1	Nearly Vertical	8

First Confirmatory Soil Sampling

Background Sampling (March, 2008)

- FW1 – TPH 31,000 ppm
- FW2 – TPH 56 ppm
- FW3 – TPH 27 ppm
- FW4 – TPH 36 ppm

Confirmatory Sampling (February, 2010)

- FW1 – All below m.d.l.
- FW2 – TPH 33 ppm
- FW3 – TPH 2,100 ppm
- FW4 – All below m.d.l.

- Cleanup achieved at all areas of the site except around FW3
- Subsequent discovery of pipeline leak near FW3

Second Confirmatory Soil Sampling

- October, 2010 sampling
  - Laboratory analysis results are pending
  - FW1, FW2, and FW4 appear to be clean
  - FW3 appears to be more heavily contaminated due to recent pipeline leak

Discussion

- Clean up of the contamination present in the unsaturated zone was achieved
- Some hydrocarbons were discovered in sand fractures one year later
  - Contaminants are in the treatable area
- Tiltmeter geophysics provides information about the location of the fractures

Lessons Learned

- Advanced in situ technologies can successfully remediate sites with unique and challenging characteristics
- If this approach is used at an active facility there must be on-going monitoring and remediation if necessary
- Fractures and injection well infrastructure allow for multiple treatments of future releases/spills

Acknowledgements

Our thanks to:

- U.S. Forest Service
- Taylor Transfer Services, LLC.
- Western Plains Consulting, Inc
- Oxy Teknologies
- Braun Intertec
- Eco Scan, Inc.