The Application of In Situ Chemical Oxidation (ISCO) in Fractured Bedrock using Geophysical Aided Design

Presented by Susanne Borchert

Annual FRTR Meeting, Nov. 9 2010

Federal Remediation Technologies Roundtable

CH2MHILL

Acknowledgements:

- Craig Sprinkle, Amanda Struse, and Steve Glennie - CH2M HILL
- Fred Paillet at Univ. of Arkansas (formerly USGS)

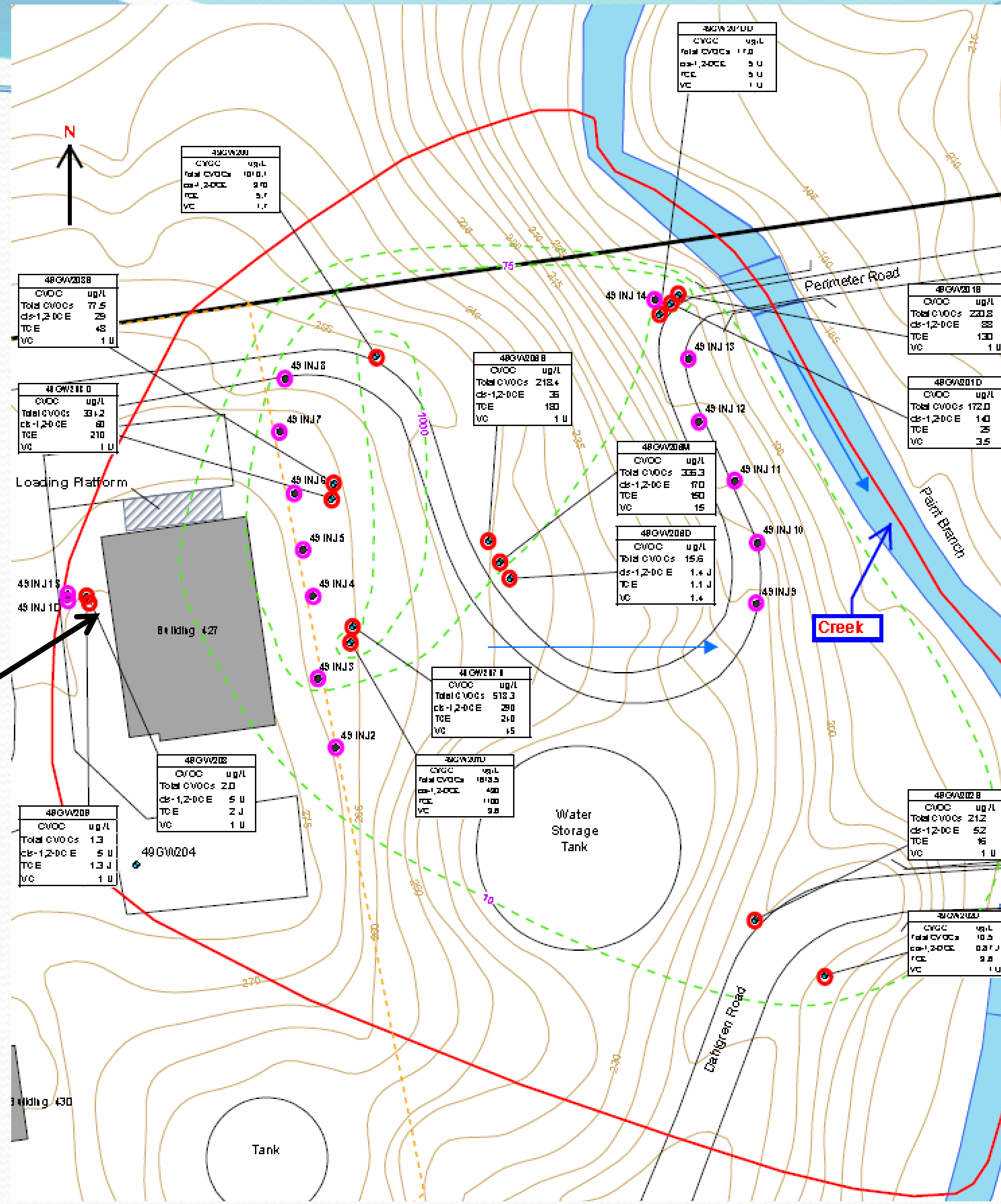
Presentation Overview

- Present case studies highlighting the **bedrock characterization elements used in ISCO designs**
- Show how results were used to
  - a) determine oxidant quantity (dosage)
  - b) assess ISCO delivery approach
- Discuss lessons learned

Background of Maryland Site

- Piedmont bedrock– garnet-bearing schist and quartzite to 150 feet below ground surface (ft bgs)
- Contaminants (µg/L): TCE =4,400, cis-DCE =1,100, VC = 81
- Groundwater table near source is in bedrock (56 ft bgs), extends into saprolite in downgradient direction (8 ft bgs) near creek to east
- i_h= 0.1 to 0.4 ft/ft; complex i_v - mostly downward near source, slightly upward by creek
- k in bedrock 0.36 ft/day; in saprolite 0.14 to 1.01 ft/day

Plan View

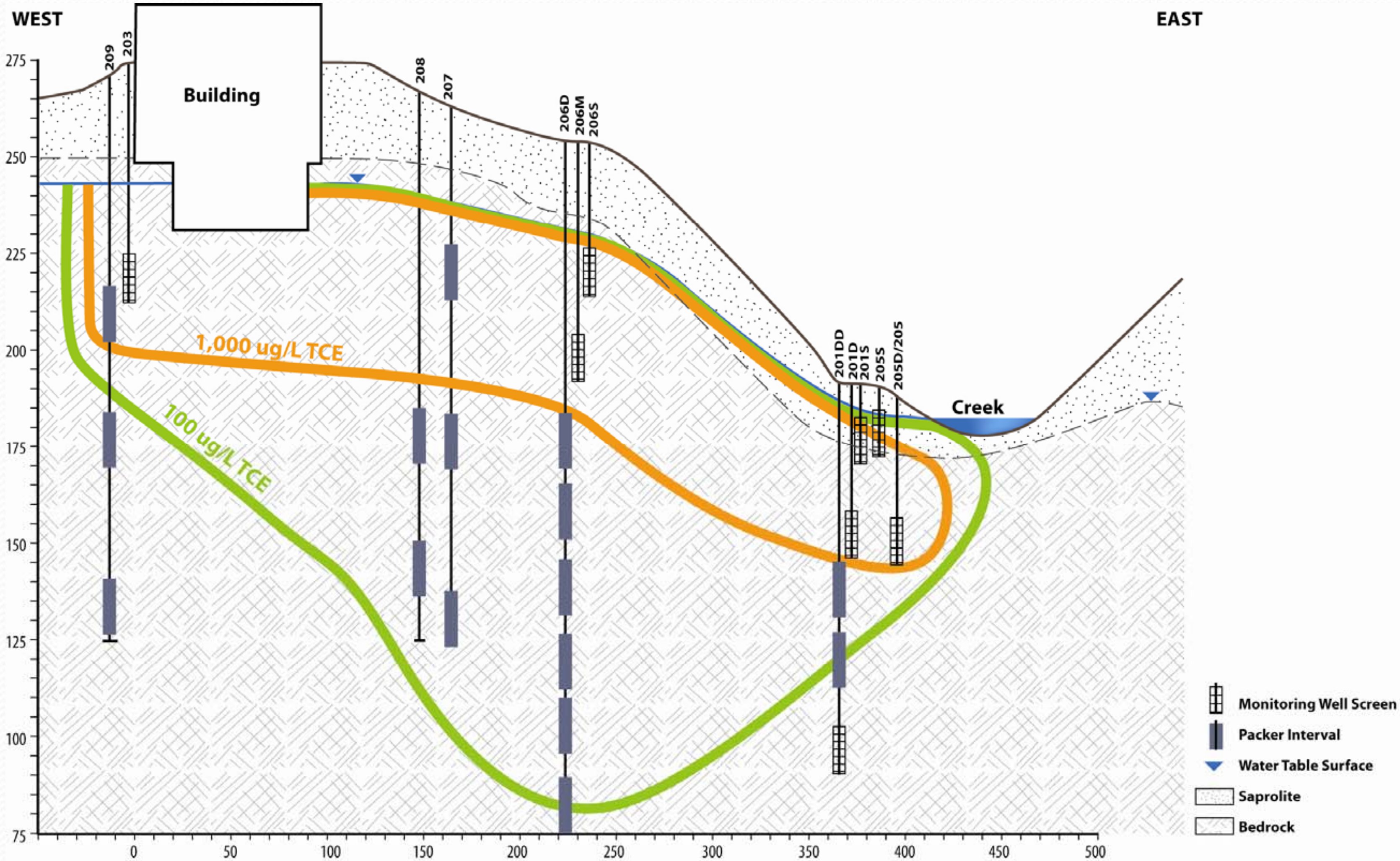


Source (Dry Well)

red=MWs

lilac=IWs

Cross-Section



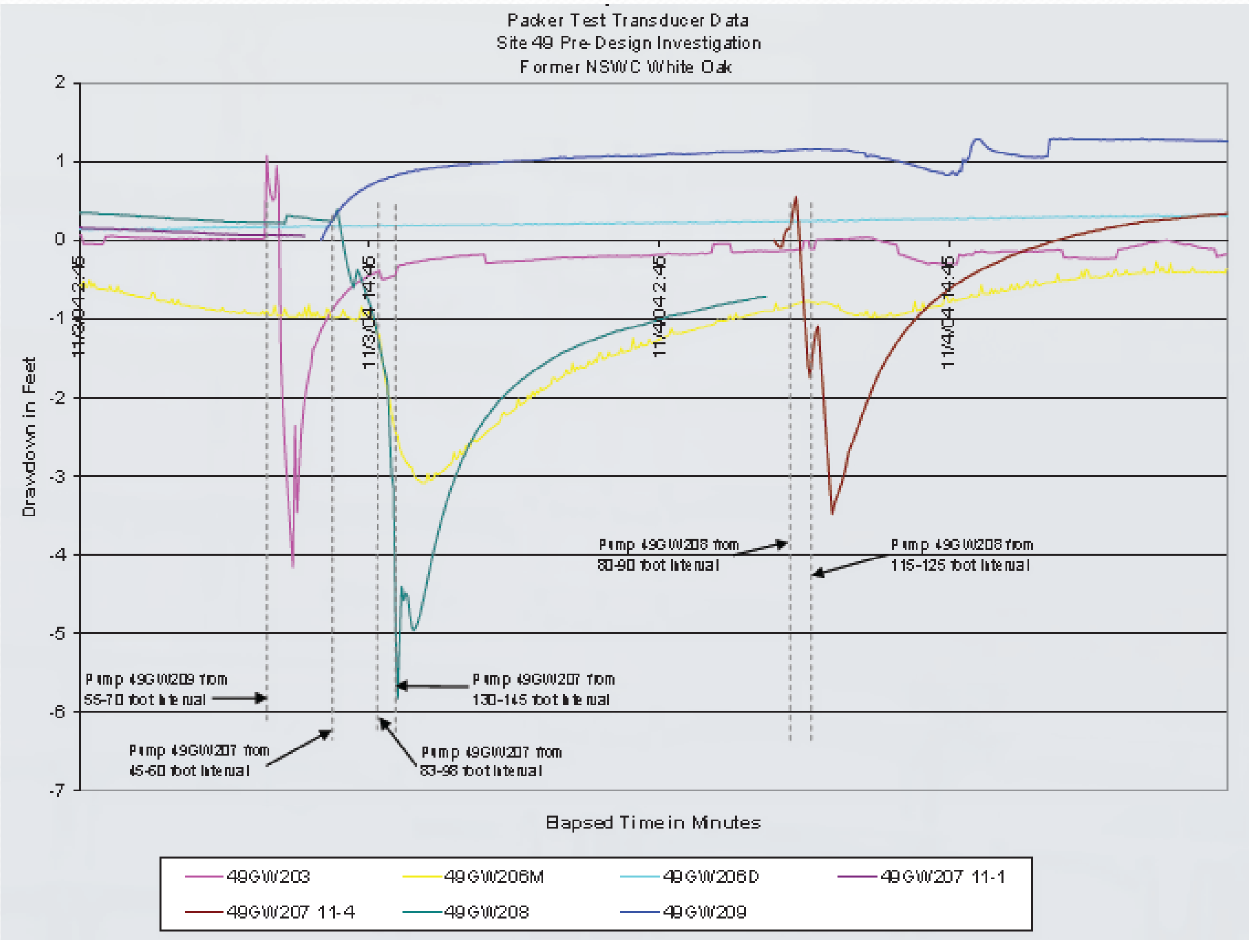
Field Tests Conducted in Bedrock

- Wells sampled for VOCs including using isolated profiling with packers
- Hydraulic connectivity testing in open boreholes
- Borehole caliper, optical televiewer, heat-pulse flow meter and fluid resistivity
  - Borehole fracture aperture were analyzed according to the **Paillet ranking method** due to their importance for the ISCO design – as they **determine the quantity and distribution of groundwater in the bedrock matrix**

Well ID	Total # of Fractures	Paillet Ranking				
		1	2	3	4	5
		----------------------------------> Increase in fracture opening				
GW207	13	12	1	-	-	-
GW208	5	5	-	-	-	-
GW209	7	7	-	-	-	-

(Note – Total oxidant demand [TOD] tests not conducted on bedrock sample/core. Bedrock oxidant demand is assumed to be negligible since contact in fractures is less than in unconsolidated matrix)

Hydraulic Connectivity Test Result



Boreholes pairs showing hydraulic connection:

- 209-203
- 206-207
- 207-208

ISCO Oxidant Demand Design

Initial ISCO design (inject and drift approach):

- Groundwater volume requiring treatment
  - Average width of fracture openings per linear borehole foot
  - Areal extent to treat
- Only used stoichiometric demand of VOCs for dosage
  - assume oxidant demand of bedrock is negligible
  - safety factor of 3 to increase longevity/persistence of permanganate
- 120 to 480 gallons of 5% by weight Na-permanganate per injection well;
- 2,480 total gallons oxidant solution and 1,360 pounds permanganate
  - Individualized per IW depending on inches of open fractures and treatment area (pore volume)

Optimization after installed and characterized 15 injection boreholes:

- 40 to 125 gal of 8% by weight Na-permanganate , with 70 to 200 gallons chase water
- 1,365 total gallons oxidant plus 2,220 gallons chase water and 1,100 pounds permanganate (average 3 gallons per minute injection)

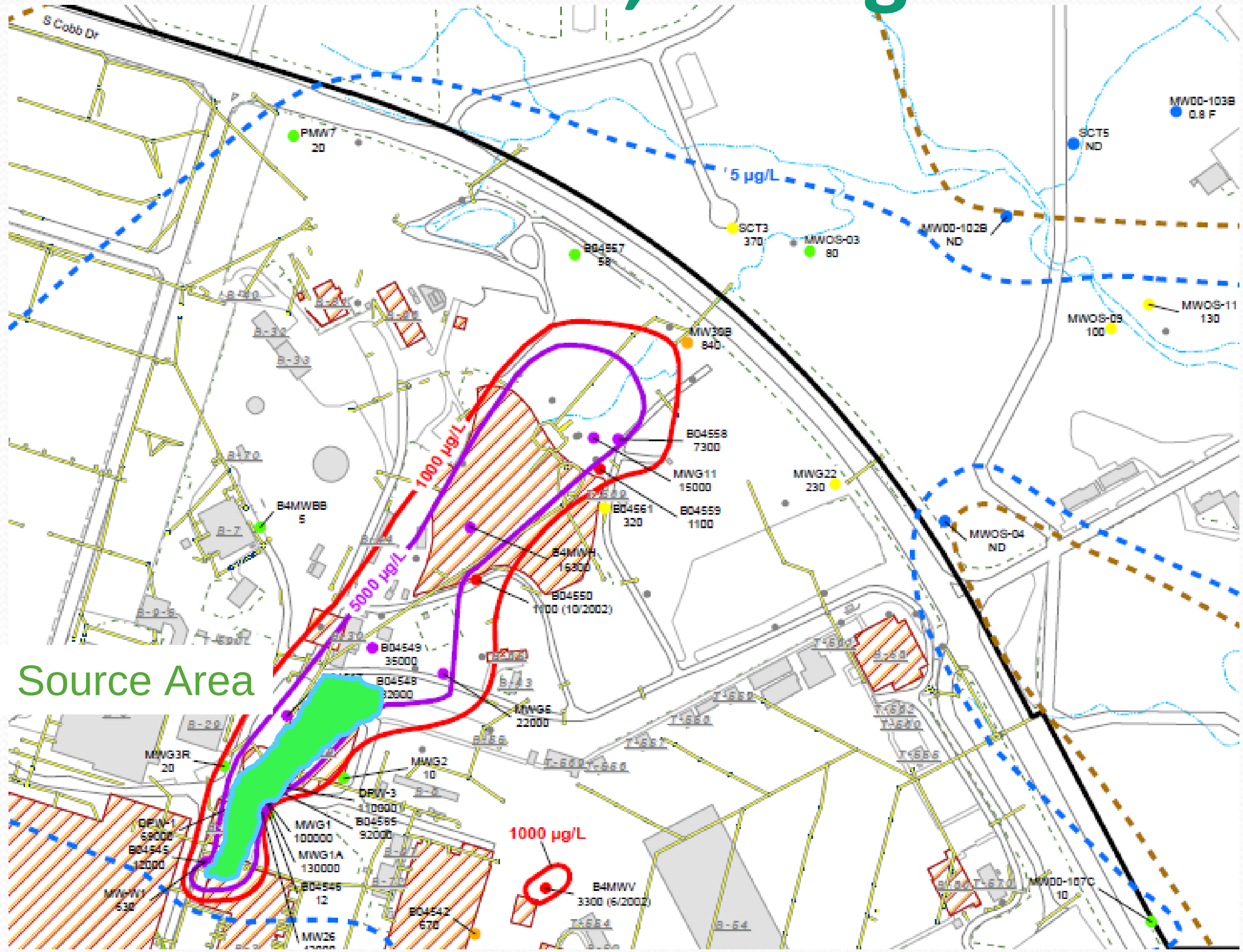
(reduced permanganate solution to <60% of fractured bedrock pore volume)

Effectiveness Overview

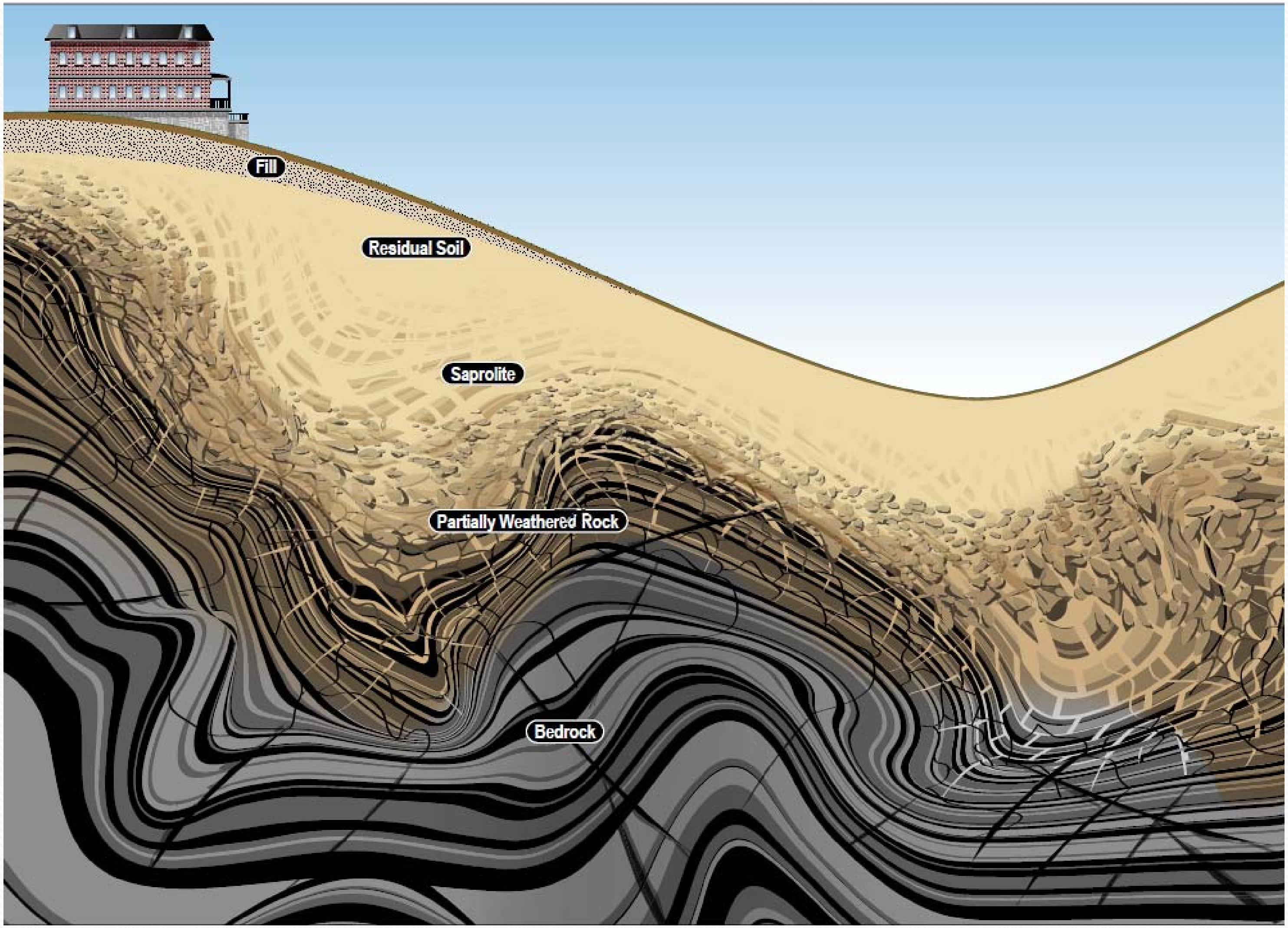
- Permanganate longevity less than 1 year except one well
- Overall areal extent of plume decreased
- TCE decreased initially, rebounded slightly after second year
- cis-DCE and VC decreased slightly
- Configuration of VOC concentration contours showed spotty reductions

Lesson learned: Would be beneficial to test connectivity of injection wells to monitoring wells prior to application

Site in Marietta, Georgia



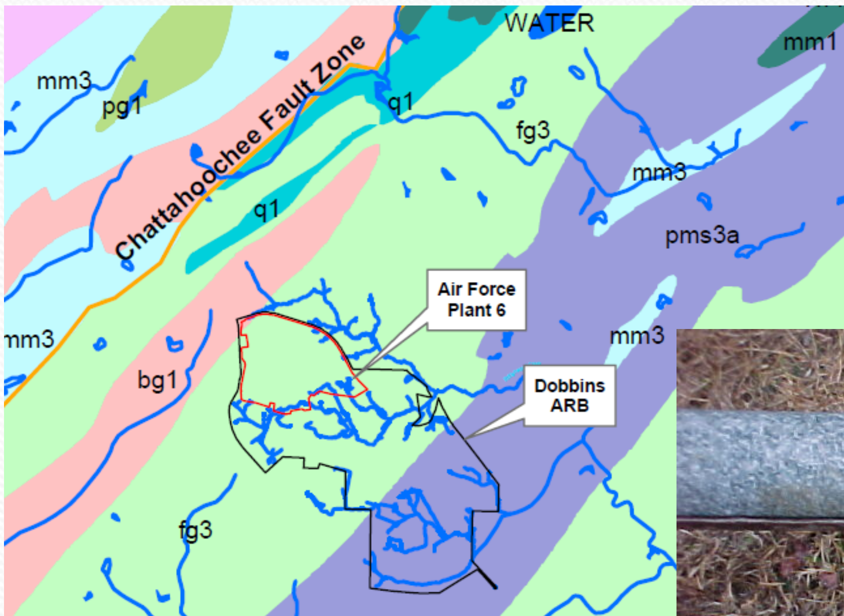
Lithology Model

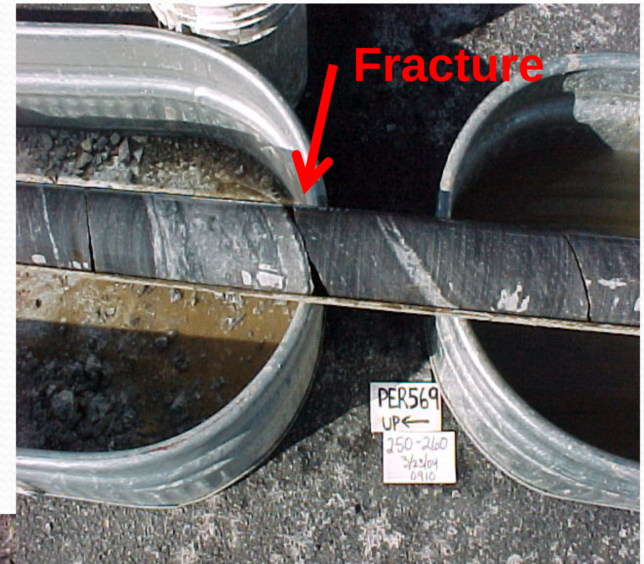


Field Characterization Methods

- Test borings
  - Soil and rock cores (field descriptions)
  - Field and lab tests (Sudan IV dye, FLUTe™ liners, chemical analyses, rock quality designation – RQD)
- Wells
  - Water level measurements to predict horizontal and vertical flow
  - Water samples to define horizontal and vertical plume extent
  - Borehole logs (caliper, acoustic and video televiewer, heat pulse flow meter, electrical resistivity, gamma)
  - Aquifer tests

Bedrock is biotite gneiss, micaschist, and granite





Borehole Logging Results

- Bedrock had no water bearing fractures below 250 ft bgs
- Nearly all water conducting fractures parallel to rock fabric or foliation
  - One water-producing fracture per 100 ft (low count!)
  - Poor vertical interconnection of fractures (pulse heat flow meter, substantial heads between fractures in same borehole)
- Fracture porosity <0.01% of bedrock

Conclusion: although high TCE concentrations in fractures (>100,000 μg/L TCE) migrating in few, and horizontally isolated fractures - not much TCE mass in bedrock (probably <5%)

ISCO Design and Results

Strategy: address zones with highest TCE mass, use technologies that will show results in <3 years

- ISCO in PWR within "source area", to also treat TCE in fractured bedrock
- PWR and bedrock assumed to have no oxidant demand
- Used K-permanganate (more cost effective) and mixed in 4% solution
- Pilot test showed anisotropy in injection radius; estimated volume of PWR
- Injected about 16,000 gallons in 32 injection wells (one pore volume)

Implementation started in late 2008. Results to date:

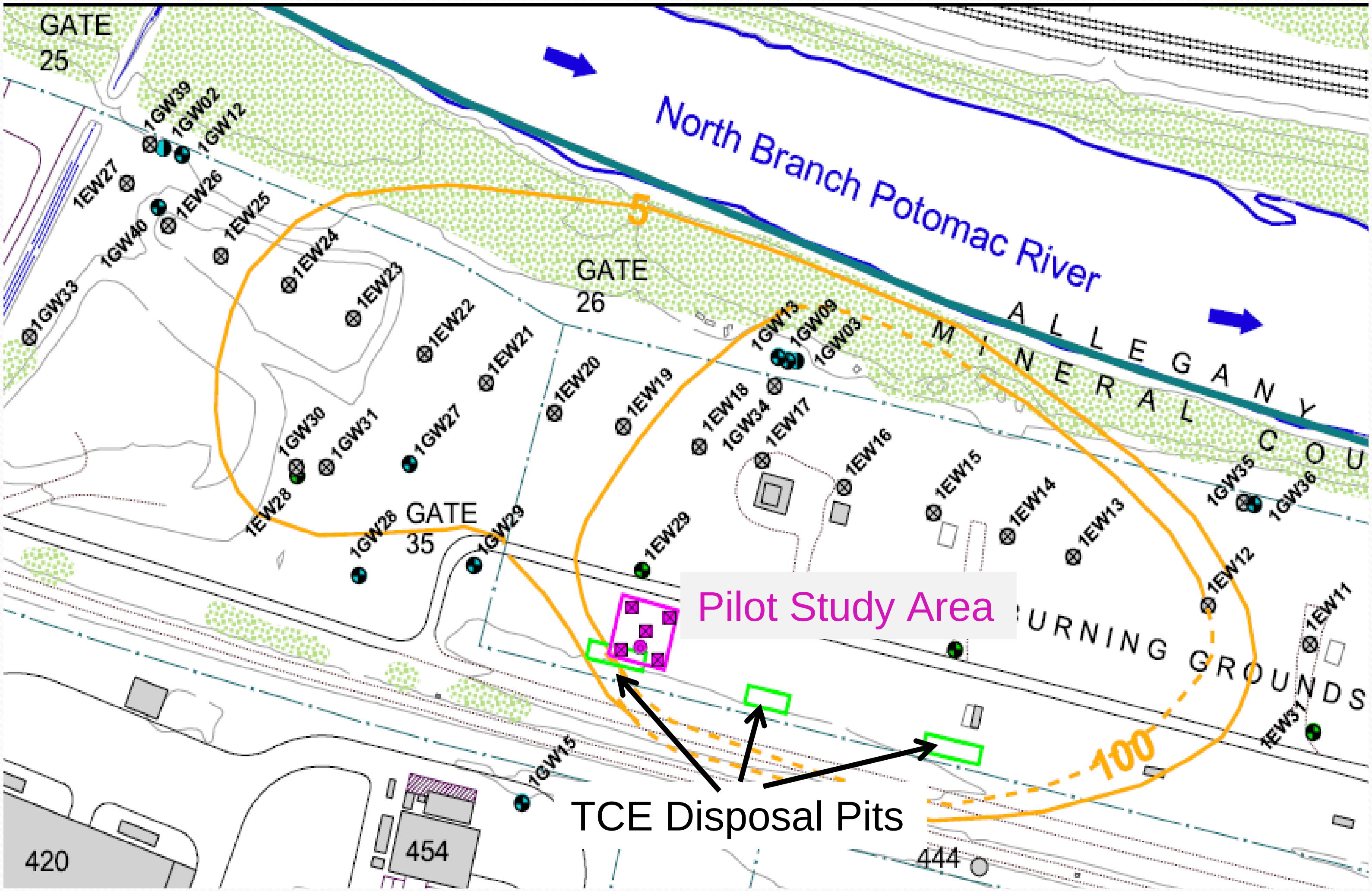
- Eliminated 100,000 µg/L plume in "source area" bedrock
- PWR 10,000 µg/L plume reduced by 68%
- PWR 100,000 µg/L plume reduced by 80%

ISCO Mix Area

Background of West Virginia Site

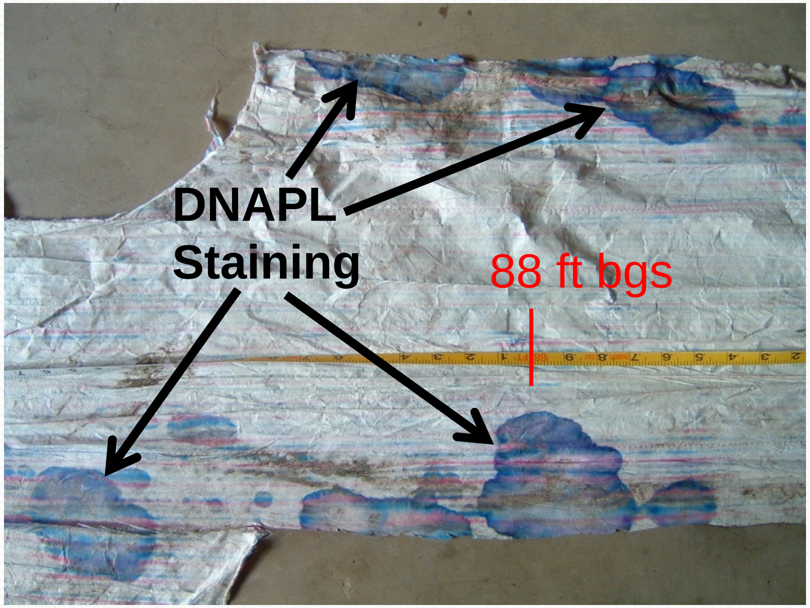
- Site was research and production facility for solid propellants
- Approximately 1,000 pounds per month of TCE were disposed in three unlined pits between 1970 and 1978
- Fill and alluvium underlain by fractured shale bedrock
- Natural groundwater flow is toward NE (to North Branch Potomac River)
- Current groundwater extraction system captures contaminated groundwater before entering river
- Pilot study performed in solvent disposal pit area of Site 1 to evaluate ISCO's ability to reduce VOC mass in fractured bedrock aquifer

Plan View


GATE 25
North Branch Potomac River
GATE 26
GATE 35
ALLEGANY
MINERAL
COU
BURNING GROUNDS
Pilot Study Area
TCE Disposal Pits
5
100
1GW39
1GW02
1GW12
1EW27
1EW26
1EW25
1GW40
1EW24
1EW23
1GW33
1EW22
1EW21
1EW20
1EW19
1EW18
1GW34
1EW17
1GW13
1GW09
1GW03
1EW16
1EW15
1EW14
1EW13
1EW12
1EW11
1GW35
1GW36
1GW30
1GW31
1GW27
1EW28
1GW28
1GW29
1EW29
1GW15
1EW31
420
454
444

Site Characterization

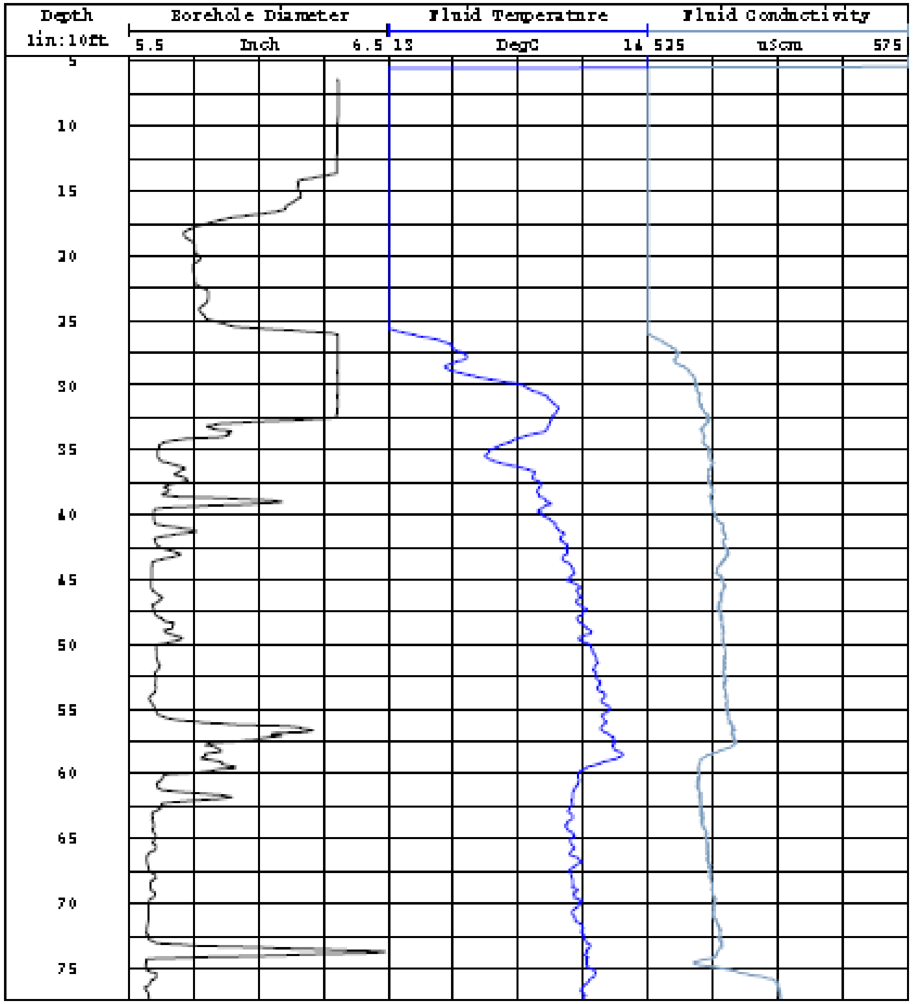
- Limited down-hole geophysics on monitoring and injection wells (caliper log, fluid temperature log, fluid conductivity log)
- FLUTe™ liners to verify the presence and location of DNAPL in fractures
- Collect and analyze borehole groundwater samples using low flow techniques (vs. packers)



Geophysical Results

- Caliper log
- Fluid temperature log
- Fluid conductivity log

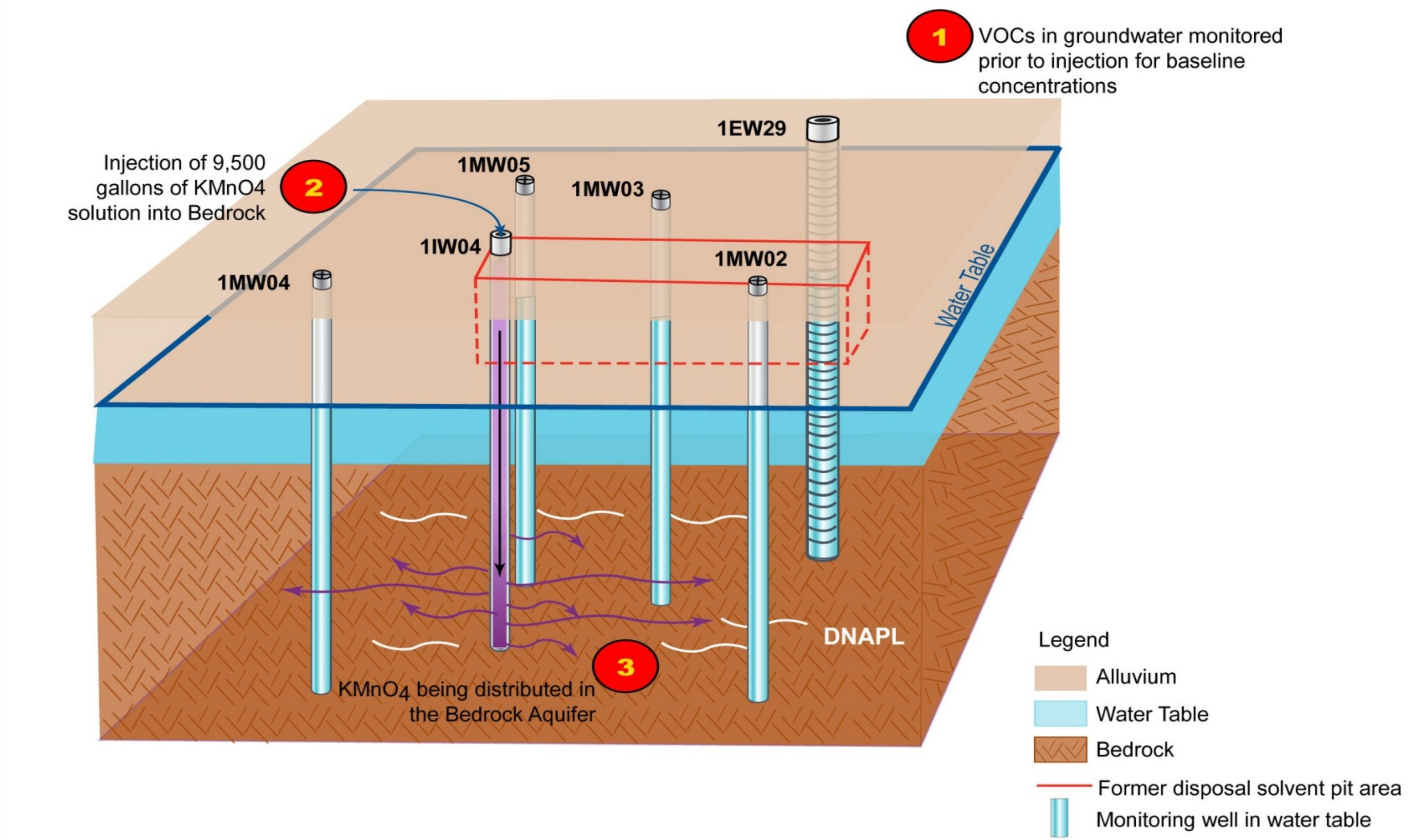
- Shale has extensive horizontal fractures that are also pretty well connected vertically; relatively high bedrock porosity



ISCO Pilot Study Design

- Goal: TCE mass reduction, flux reduction downgradient
- Oxidant selected: potassium permanganate ($KMnO_4$)
  - Wanted to avoid oxidants that need catalyst, mixing in situ
- 3,200 lbs of K-permanganate mixed with water, 9,500 gallons 3% by weight solution
- 6,300 gal gravity fed at 9 to 12 gpm, 3,200 gallons injected with low pressure at 12 to 14 gpm
  - Observed almost immediate impact on surrounding wells
  - Displacement not critical issue during pilot study: small treatment area, high porosity, groundwater extraction system

Pilot Study Layout



NOTE: Wells installed approximately 90' below ground surface.

Pilot Study Results

- Downgradient extraction well had K-permanganate shortly after injection; was turned off for pilot study duration

Sampling Event	Maximum TCE	Average TCE
Baseline	110,000	28,500
3 Week	100	12
6 Week	190	45
3 Month	14,000	4,100
5 Month	13,000	4,500

Pilot Study Conclusions

- Total VOCs decreased 84% in the bedrock aquifer
- Based on vertical ORP trends in boreholes, permanganate evenly distributed
- Rebound observed, likely caused by
  - Migration of alluvium and upgradient dissolved phase VOCs
  - Continued dissolution of DNAPL
- Higher dose permanganate may persist longer and oxidize more mass before rebound occurs
- ISCO may be more effective if the extraction system shutdown to increase permanganate residence time

Lessons Learned

- Characterization tests that end up **most** useful at any given site are unpredictable, need multiple lines of evidence to shape conceptual site model for ISCO design and delivery
  - Televiewer and hydraulic connectivity tests in MD
  - Caliper, televiewer, and heat pulse flow meter in GA
  - FLUTe™ liners, caliper, fluid temperature and conductivity in WV
- To mitigate plume displacement by oxidant solution, use small injection volumes (fraction of estimated pore volume).
  - Don't underestimate transport distance of low volume of injectant in fractures/lineaments – monitor potential surfacing
- During ISCO injection in open borehole extending beyond treatment zone, consider placing packer below lowest impacted, water-bearing fracture
  - Enhances use of oxidant to destroy contaminants in open fractures