Treatment of TCE to 30 Meters in Fractured Granite – How to Address a Site When you Cannot Drill and Sample the Rock?

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Site Background

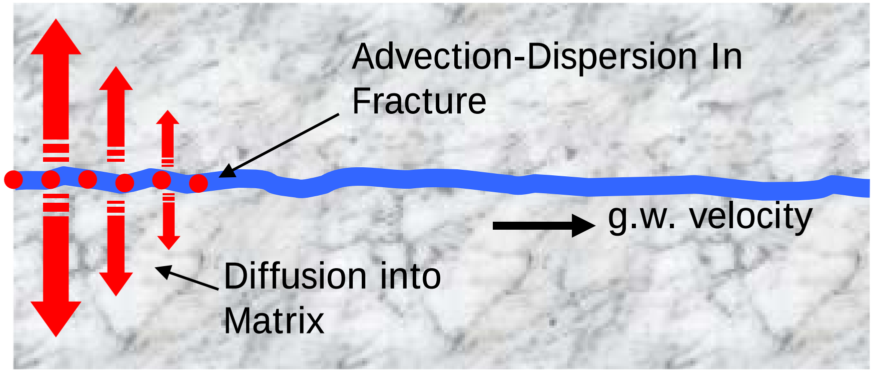
Background:

- Since the 1950's site was used for testing aerospace components.
- About 15 years ago operations at the site were discontinued and since then most structures have been demolished
- TCE is the main contaminant at the site

Main challenges:

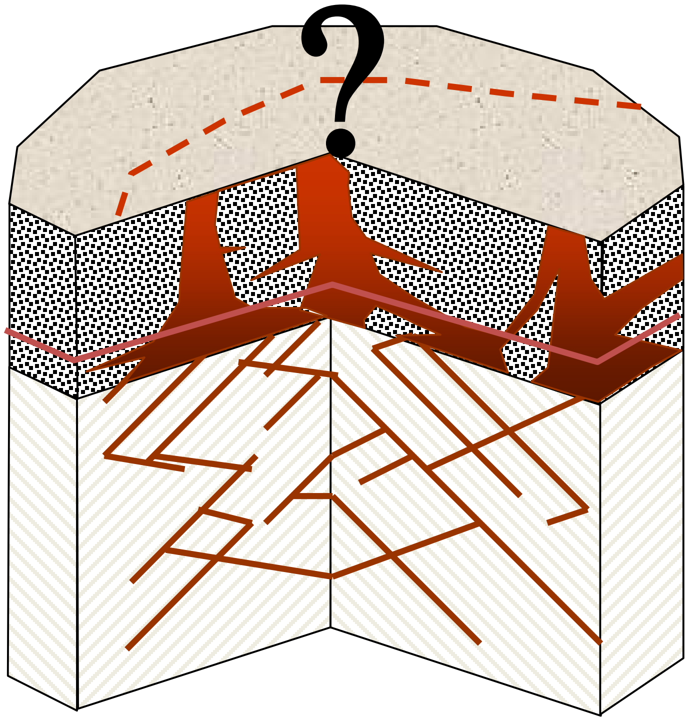
- The exact source zone and treatment volume was still to be refined.
- TCE was present in fractures below the water table.
- The fracture network is complex – vapor recovery was essential.
- A novel method for determining remedial completeness was needed, due to the difficulty of collection of rock samples in the middle of the well-field during operations.

The Challenge: Fractured Rock



COCs present in matrix

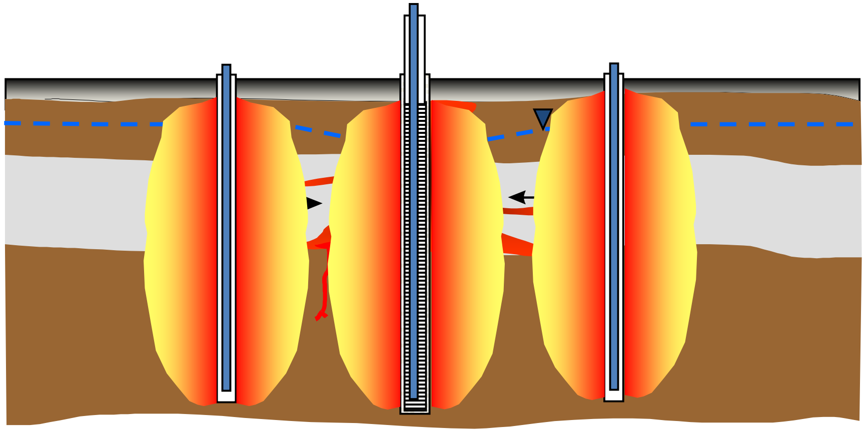
Fracture-dominated flow



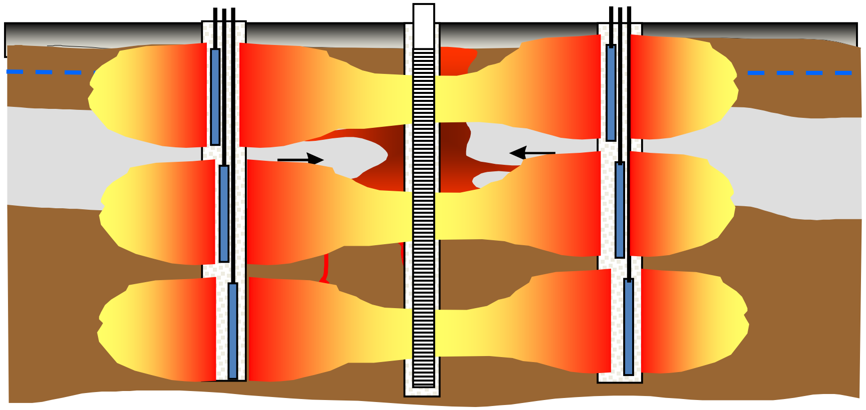
Key for Thermal in Rock

- Determine TTZ in 3 dimensions
- Ensure steam capture
- Match heating technology to site
- Ensure heating
- Adapt sampling to track progress

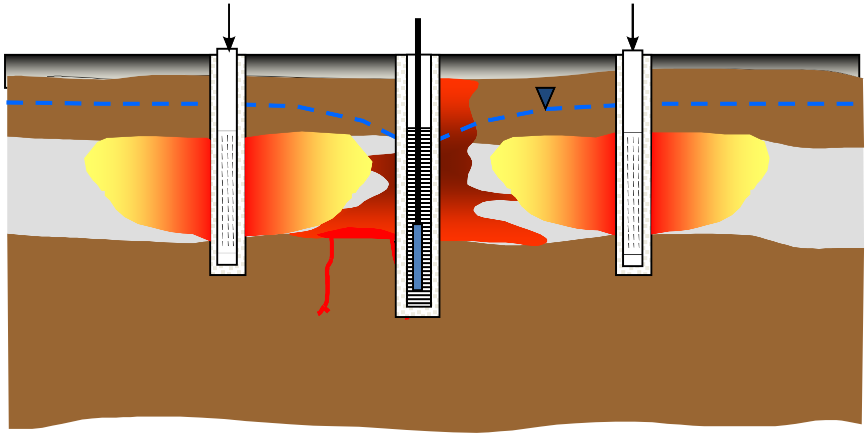
Heating Methods



TCH/ISTD - Heating governed by **thermal conductivity**



ET-DSP/ERH - Heating governed by **electrical conductivity**



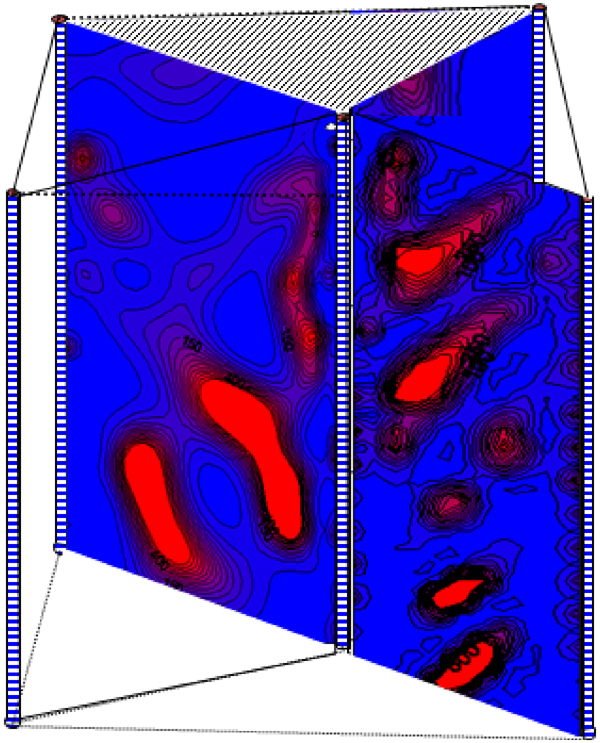
SEE - Heating governed by **hydraulic conductivity**

Limitations for SEE

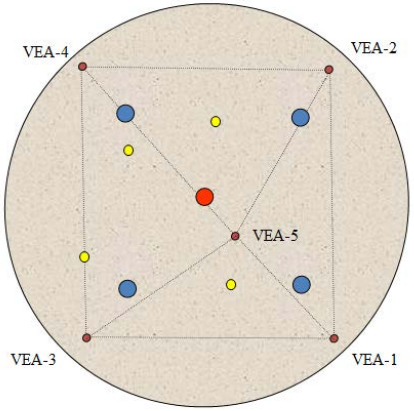
Resistivity low enough for ERH/ET-DSP?

- Steam only travels in fractures
- Fractures may be too small for effective steam migration
- Will not heat volume between fracture zones (competent bedrock)

Edwards AFB, CA. Fractured granite pilot (SteamTech)

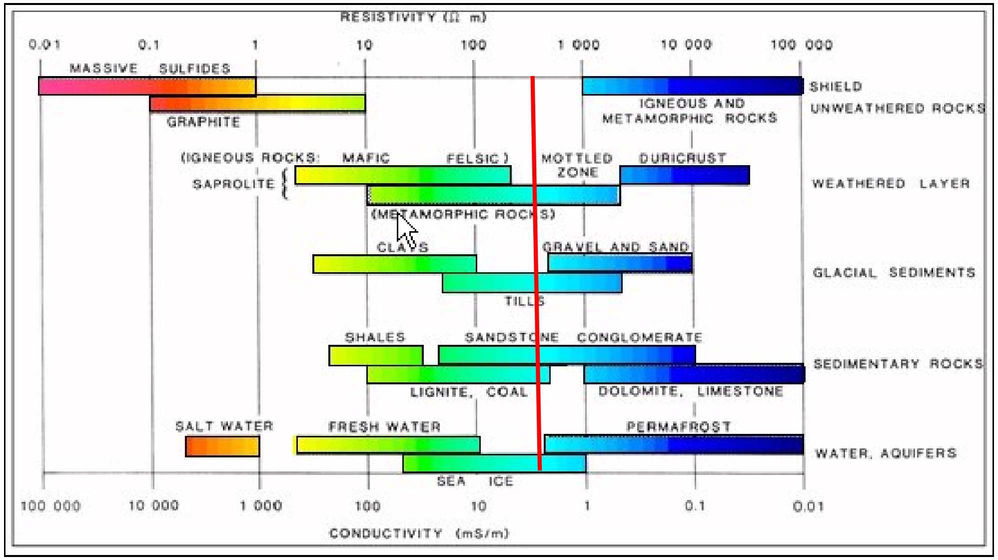


Electrical Resistance Tomography (ERT) data planes during SEE



Limitations for ERH

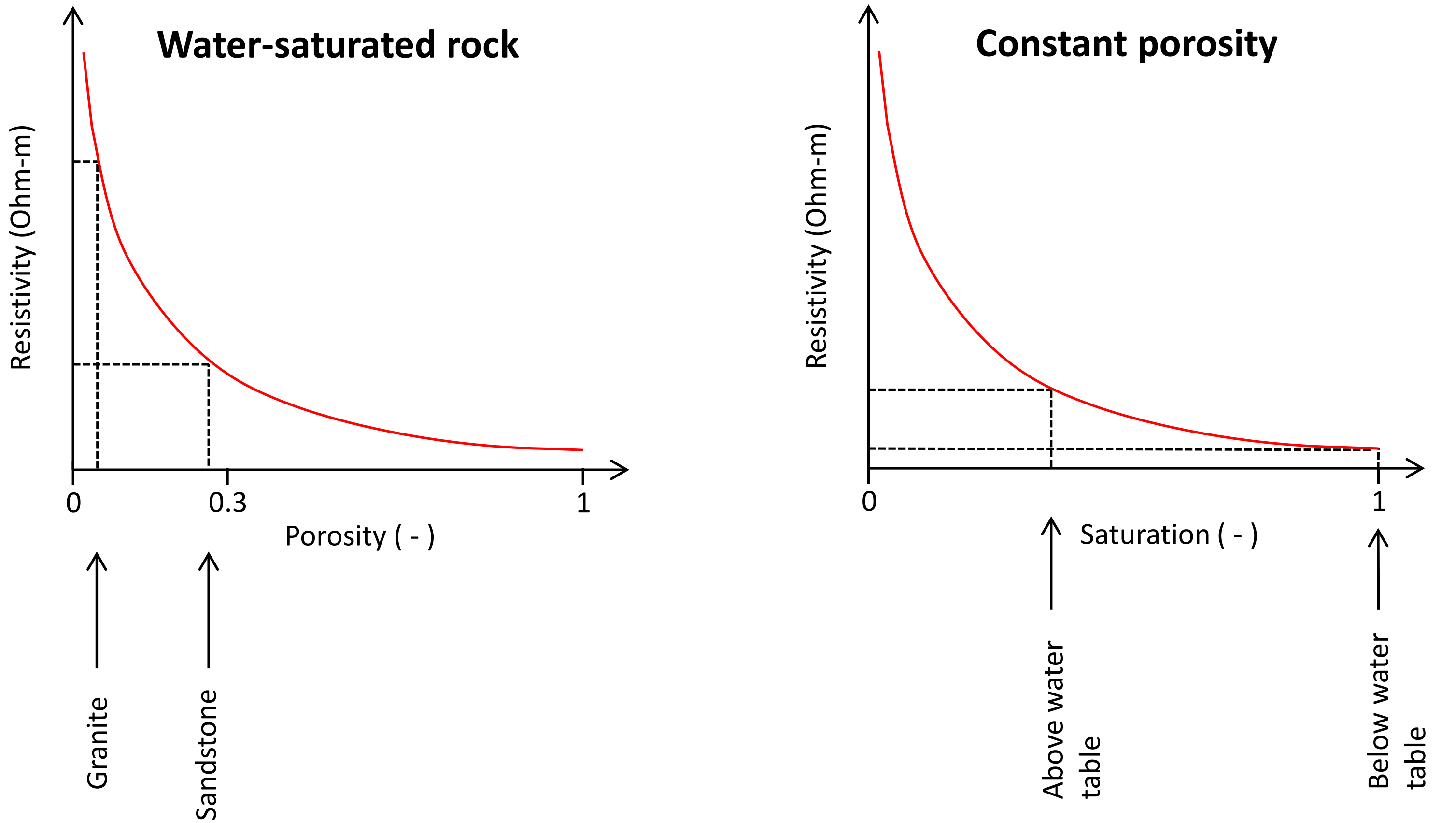
Resistivity low enough for ERH/ET-DSP?



Palacky, G.V. (1987), **Resistivity characteristics of geologic targets**, in Electromagnetic Methods in Applied Geophysics, Vol 1, Theory, 1351

- Required soil resitivity: idealy ~<500 Ω*m
- Shales, sandstone, weathered rocks: 2-2,000 Ω*m
- Igneous, metamorphic, dolomite, limestone: 1,000-100,000 Ω*m
- Solid bedrock in itself cannot be heated using ERH – it is <u>too resistive</u>
- More porous rock needs to be wet

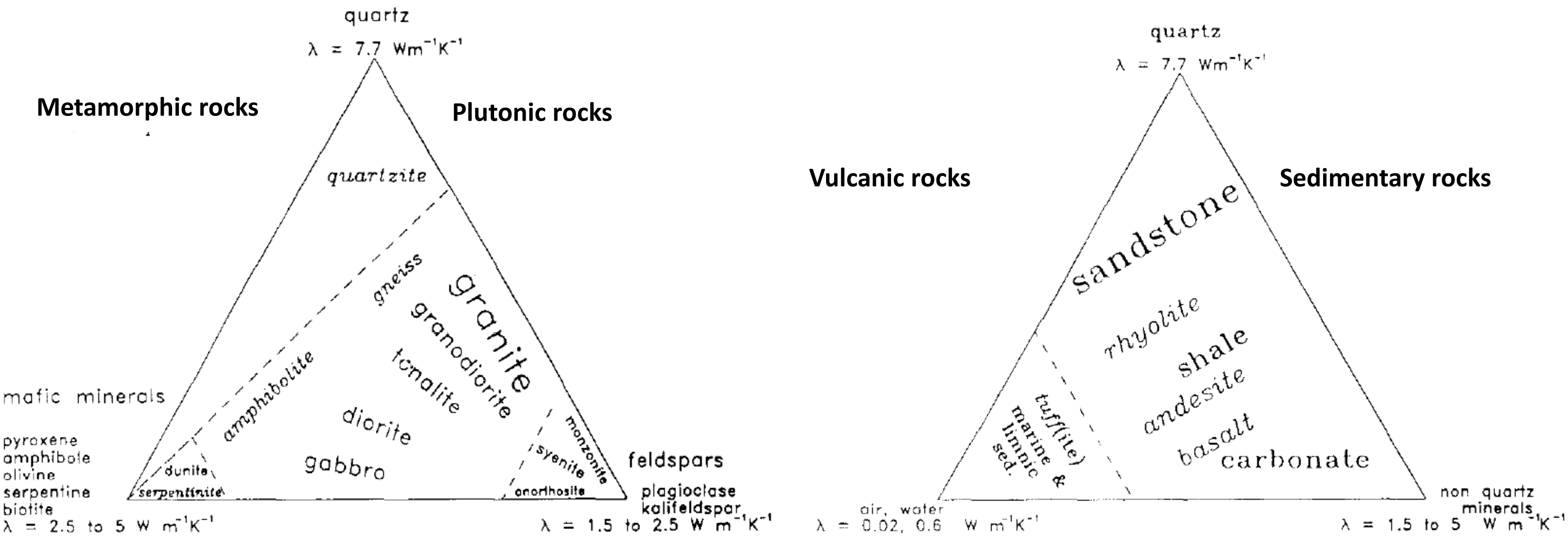
Archie's law: $ER = C^{x}(sat)^{-m}$



ERH:

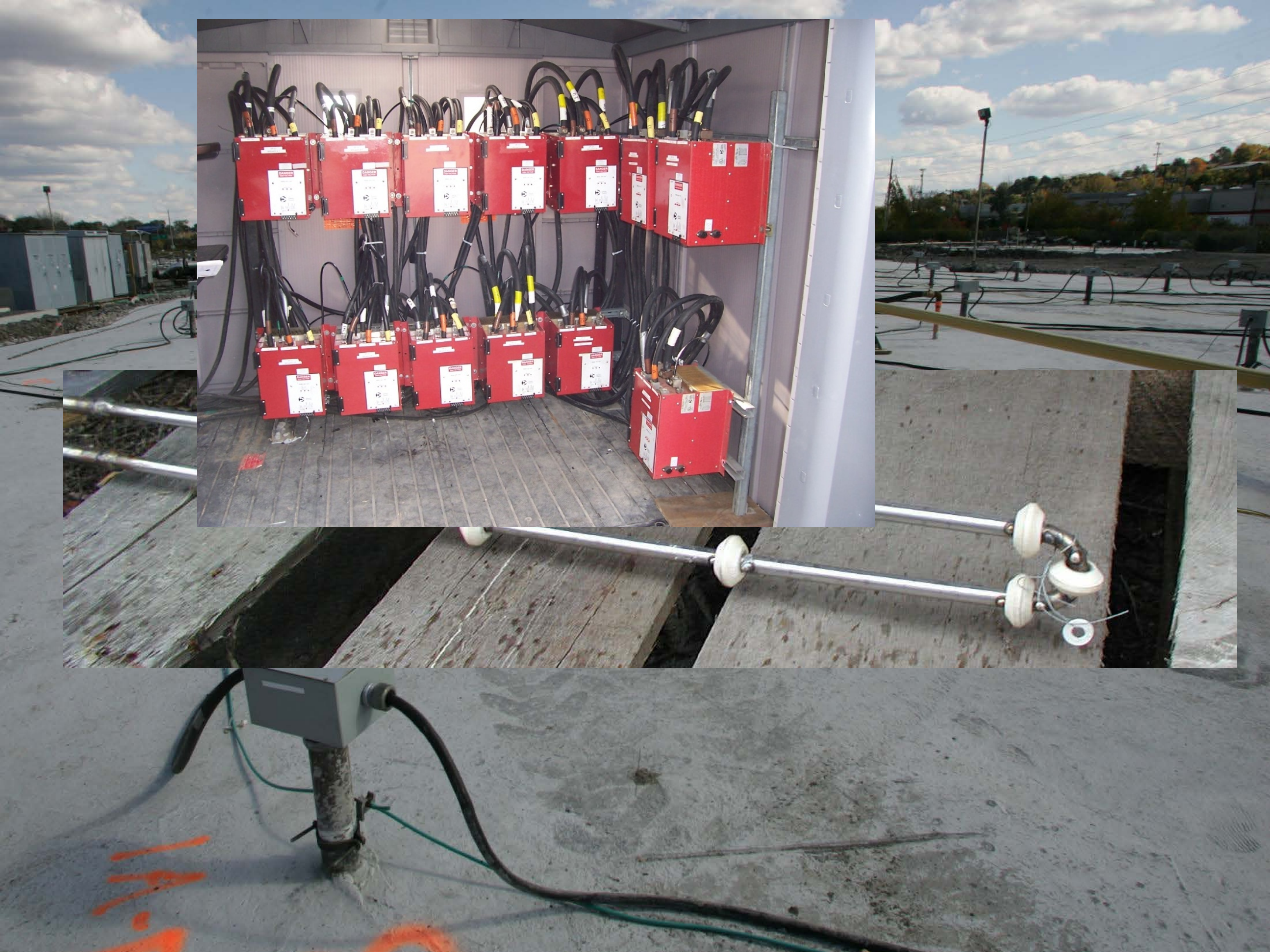
- Low-porosity rock cannot be heated
- Dry rock problematic

Why TCH is a Great Fit

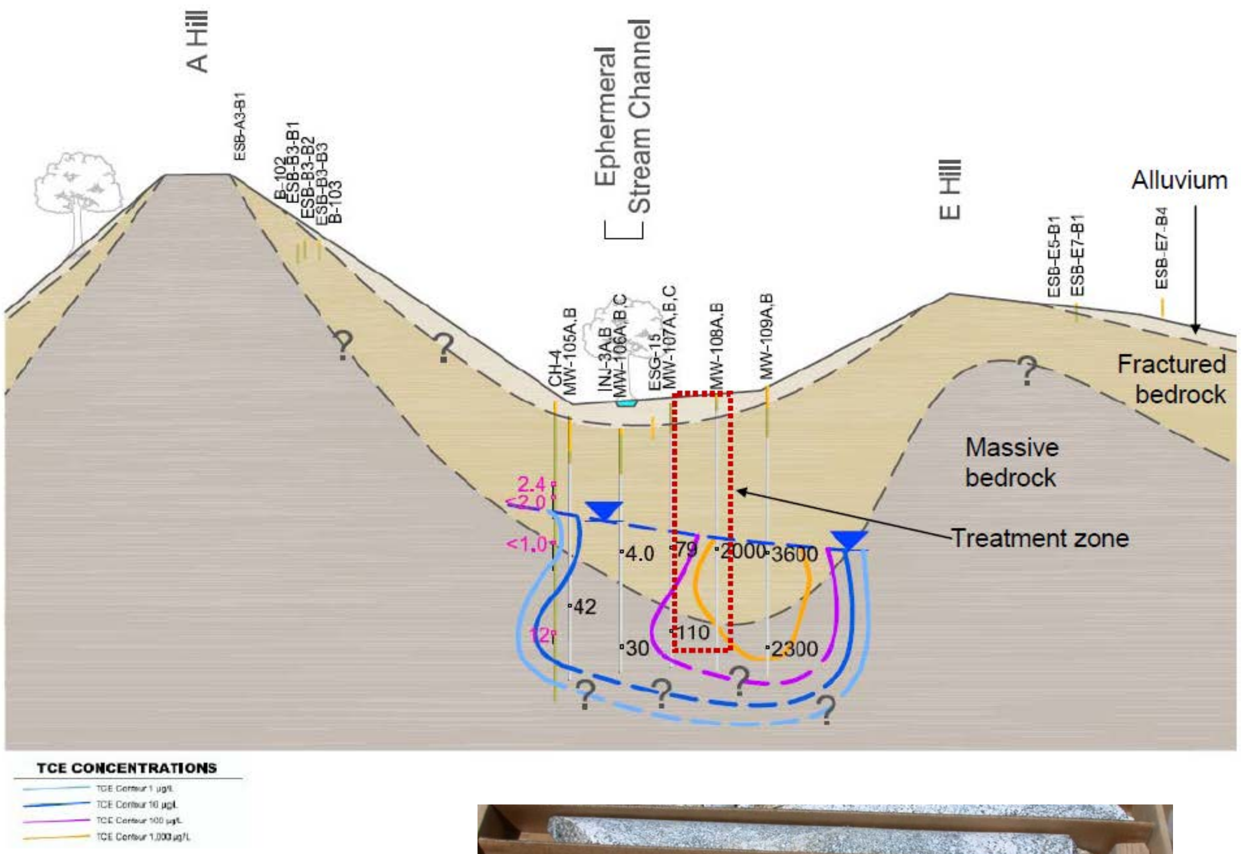


[From Clauser and Huenges]

- Varies based on mineral content, porosity, pore fluid, anisotropy.
- Generally between 1.5 to 7 W/(m*K)
- Variation generally within a factor of 5



The Challenge



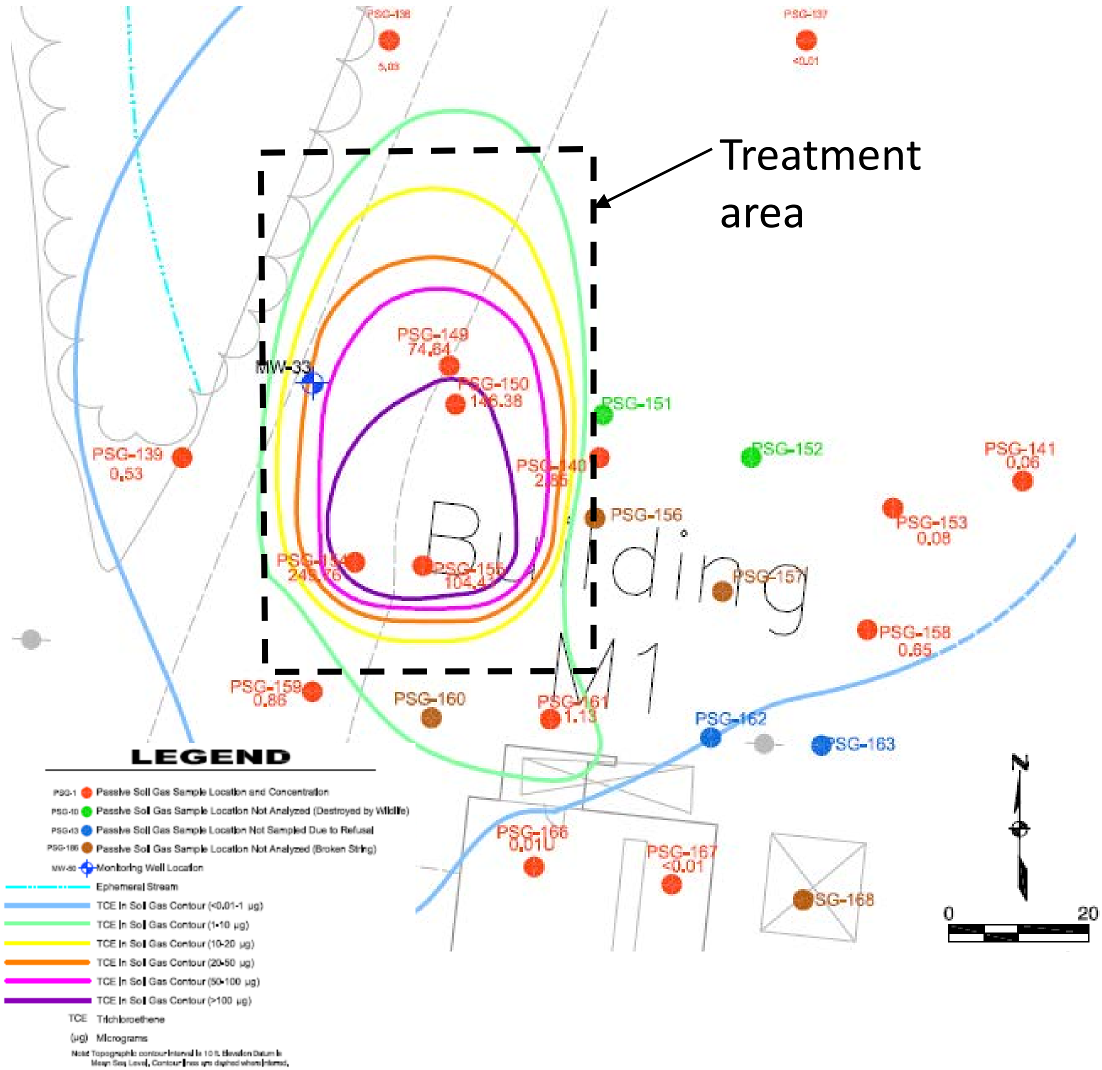
How deep?

Foot-print?

Duration?

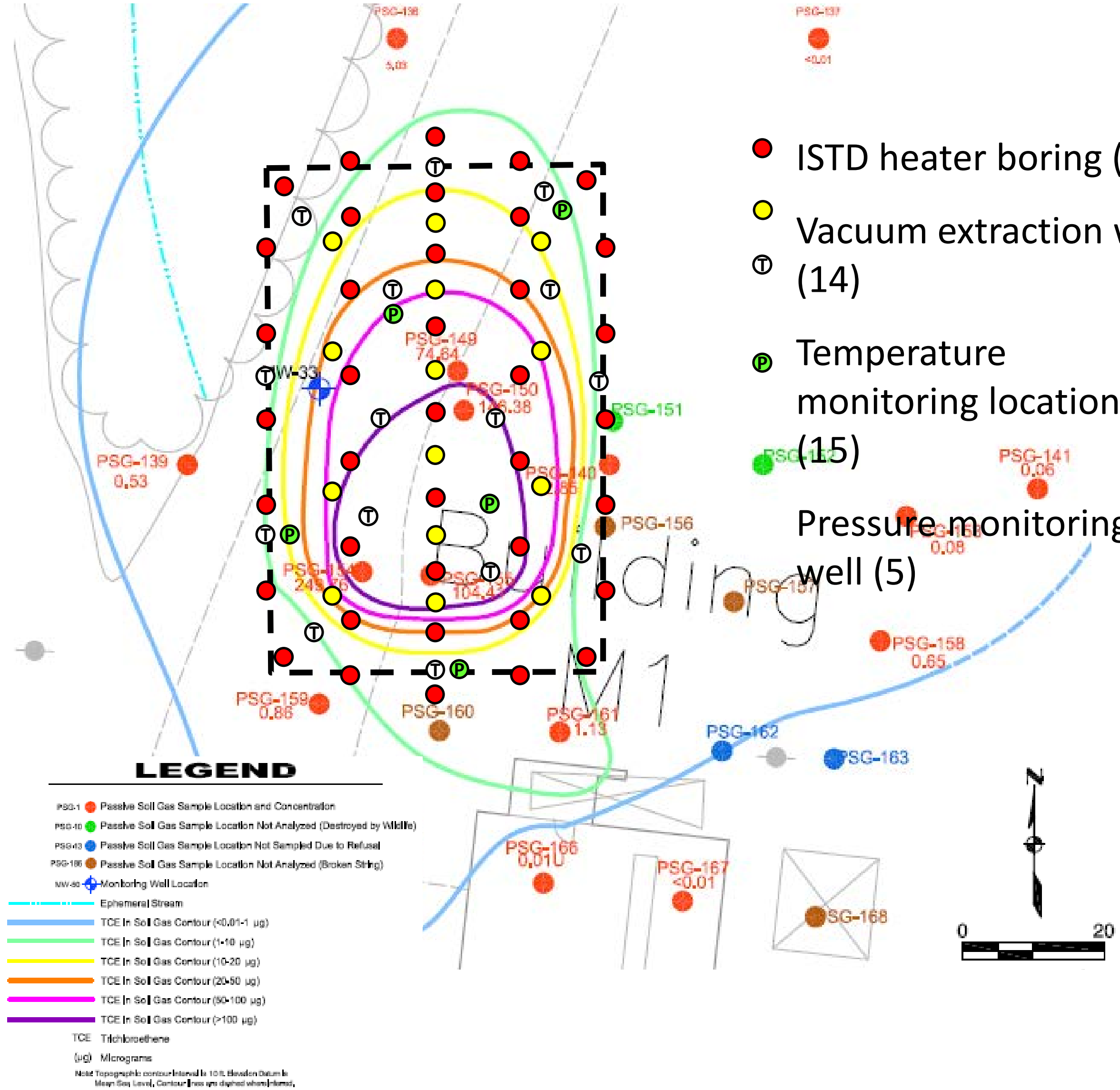
Does it work?

Learn As You Drill !



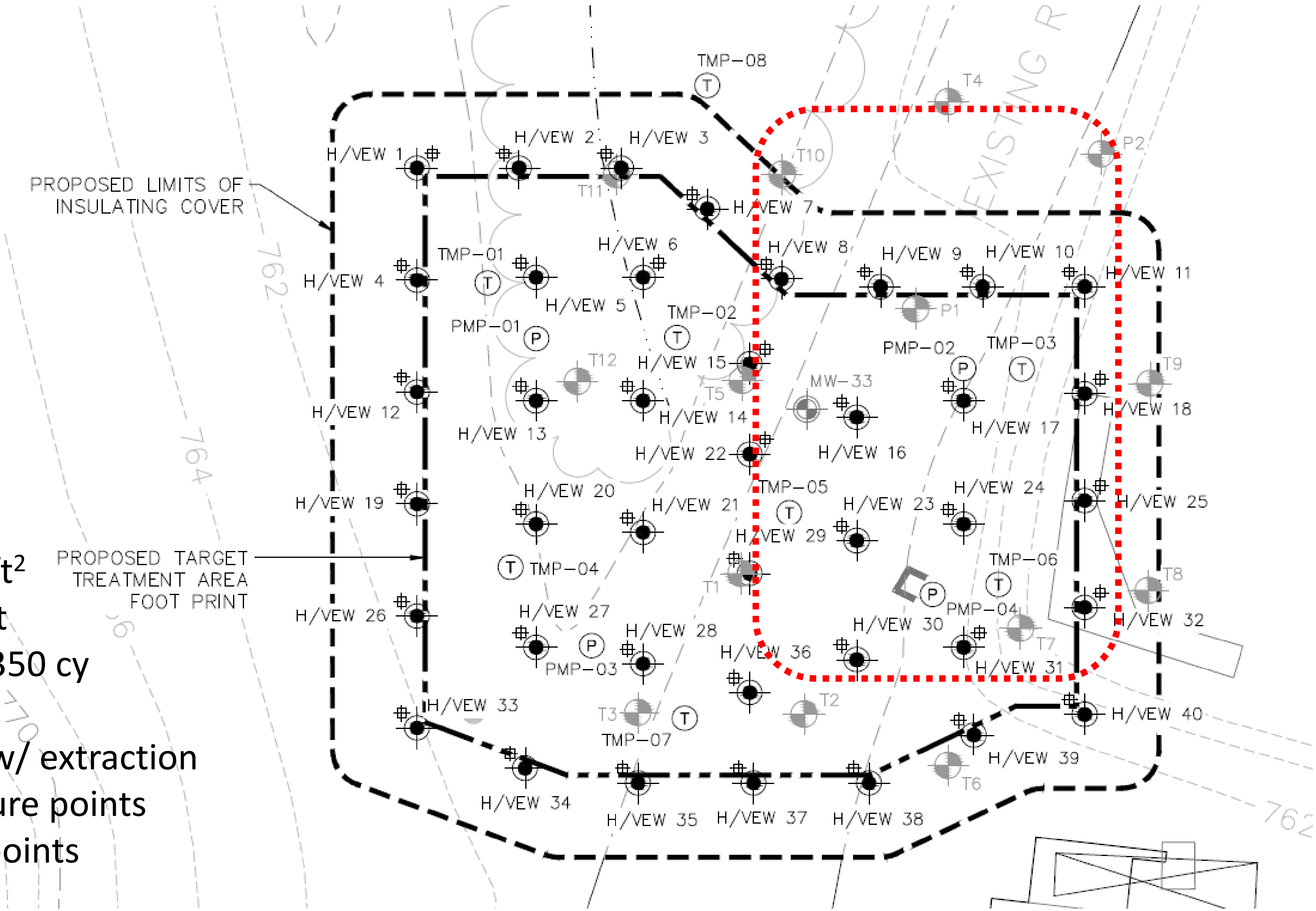
Initial Concept

Flexible implementation concept improves project performance.



- ISTD heater boring (39)
- Vacuum extraction well (14)
- Temperature monitoring location (15)
- Pressure monitoring well (5)

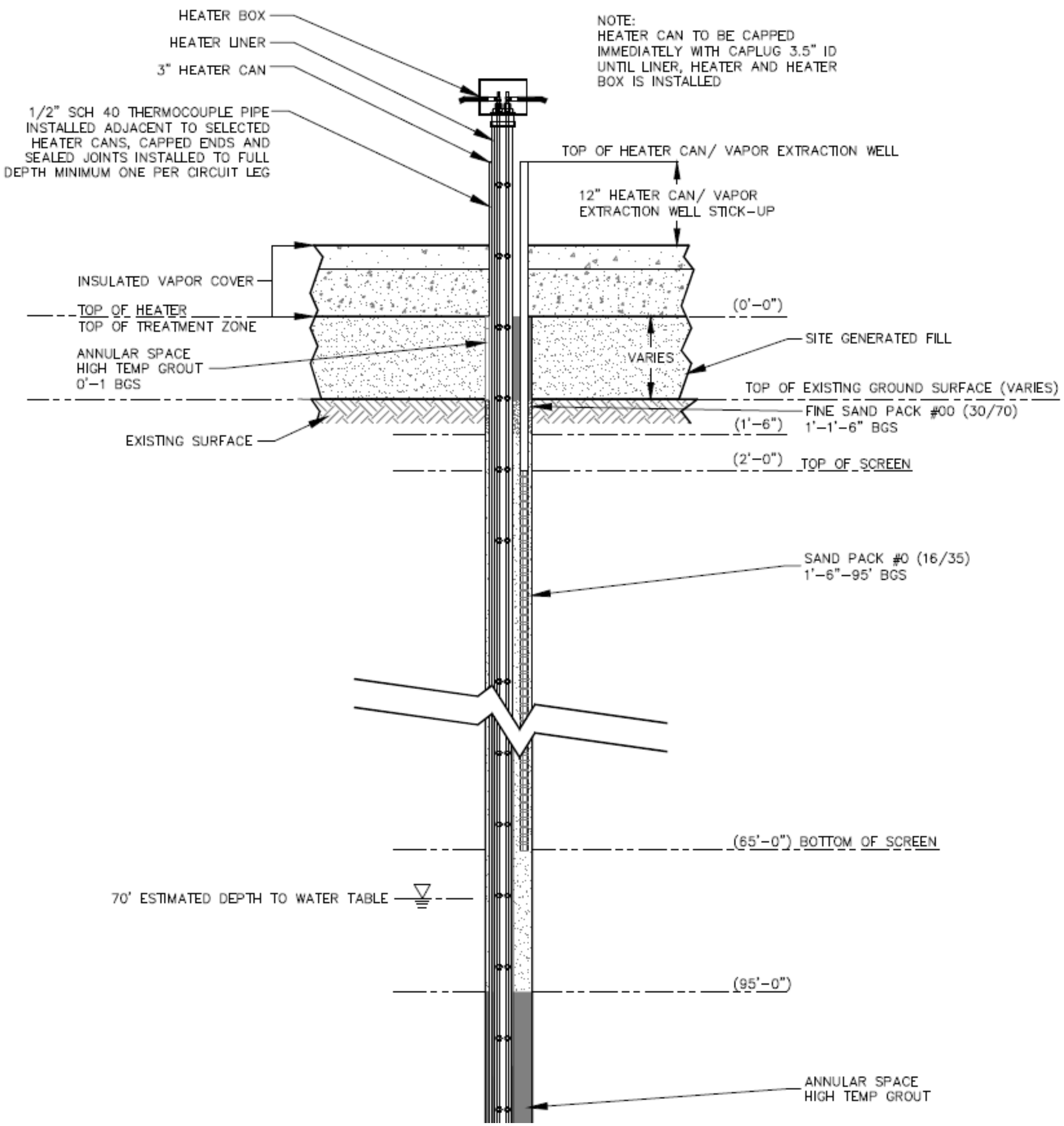
Site Layout – Final Concept



Area 4,950 ft^2
Depth 100 ft
Volume 18,350 cy

40 Heaters w/ extraction
8 Temperature points
4 Pressure points

Vapor Extraction in Each Heater Boring



You don't know where the steam will flow

Co-located SVE Wells on the Heaters

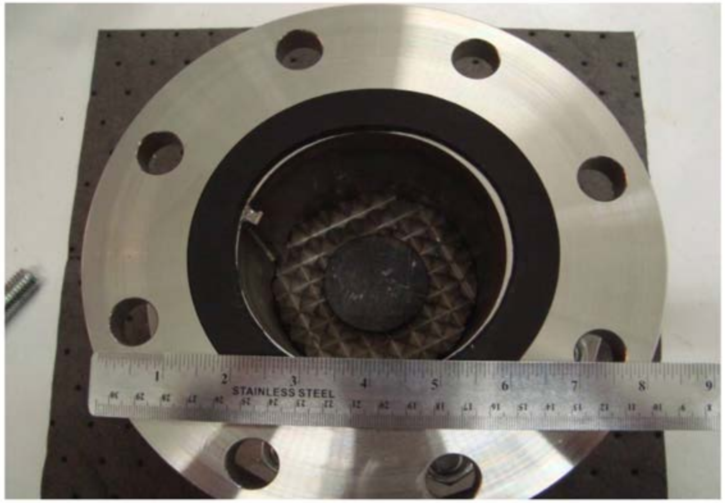
Performance Metrix - Dilemma

- Rock concentrations not easy to obtain

Metrics used instead:

- Temperatures and energy balance
- Mass removal rate and total
- Groundwater sampling
- Vapor concentrations in co-located SVE wells

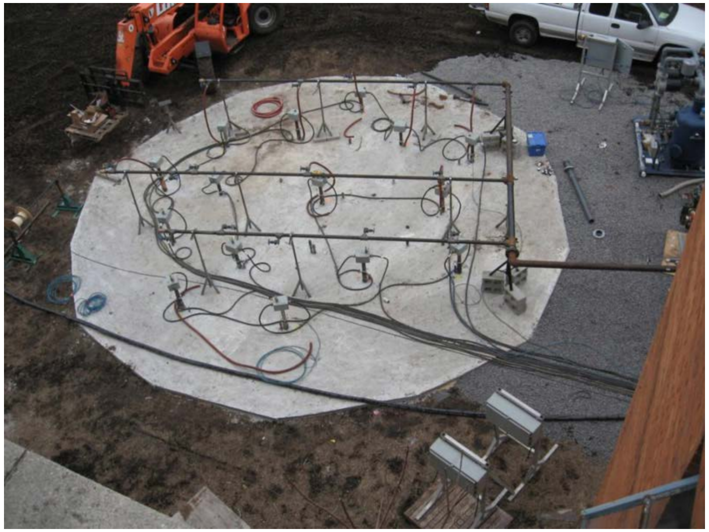
NOT FEASIBLE AT THIS SITE



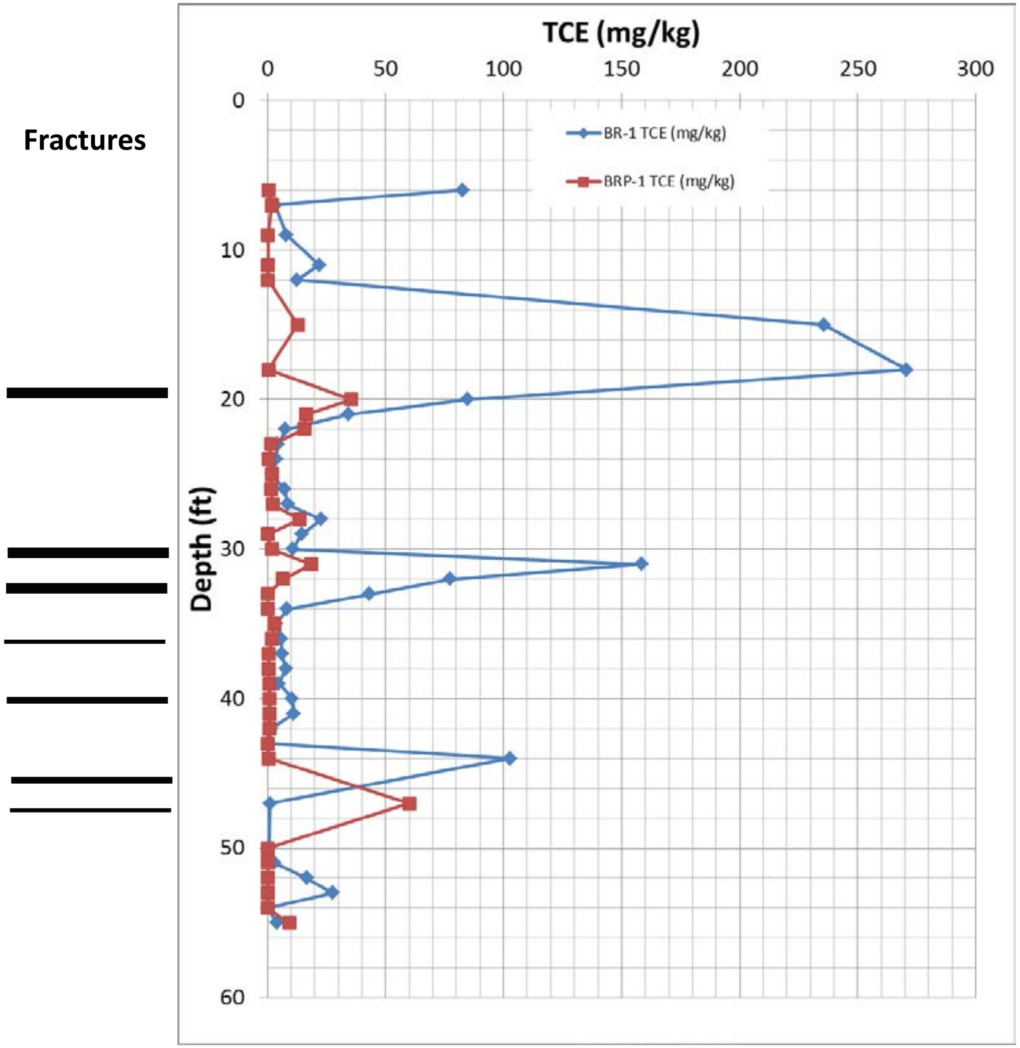
Rock Chips Extracted in Methanol - Case

NJ ESTCP site:

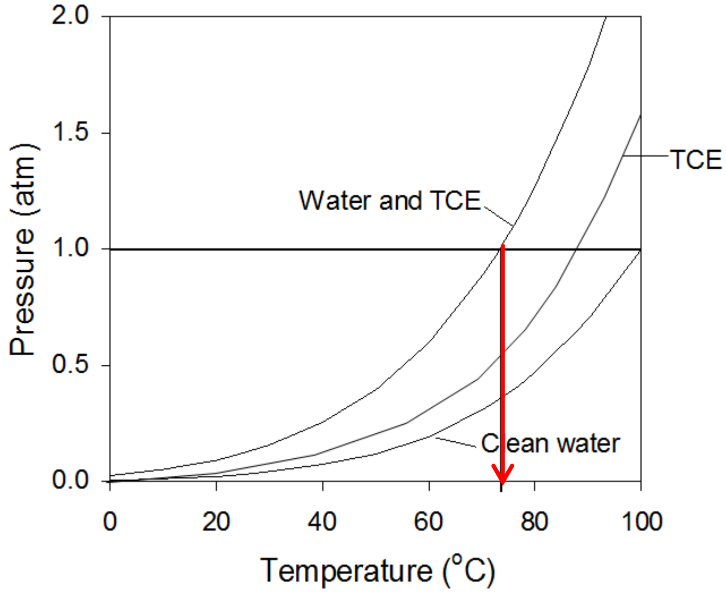
- Matrix COC reduction relatively easy
- TCE levels highest near fractures

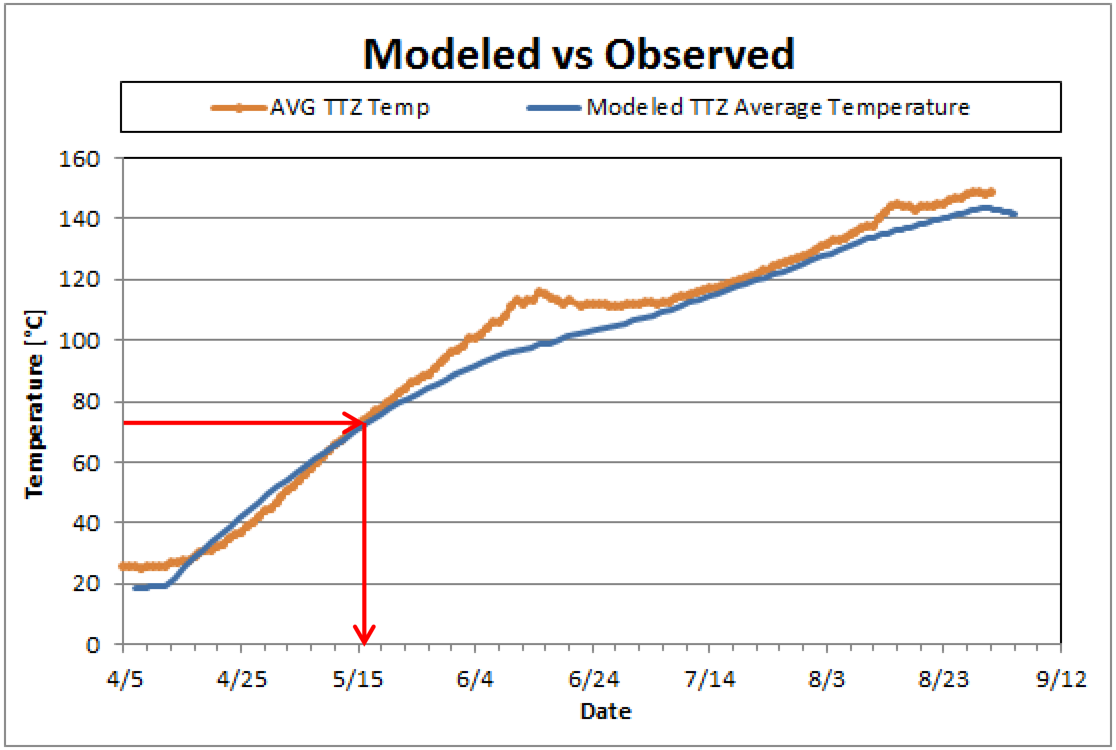


ESTCP Project # ER0715



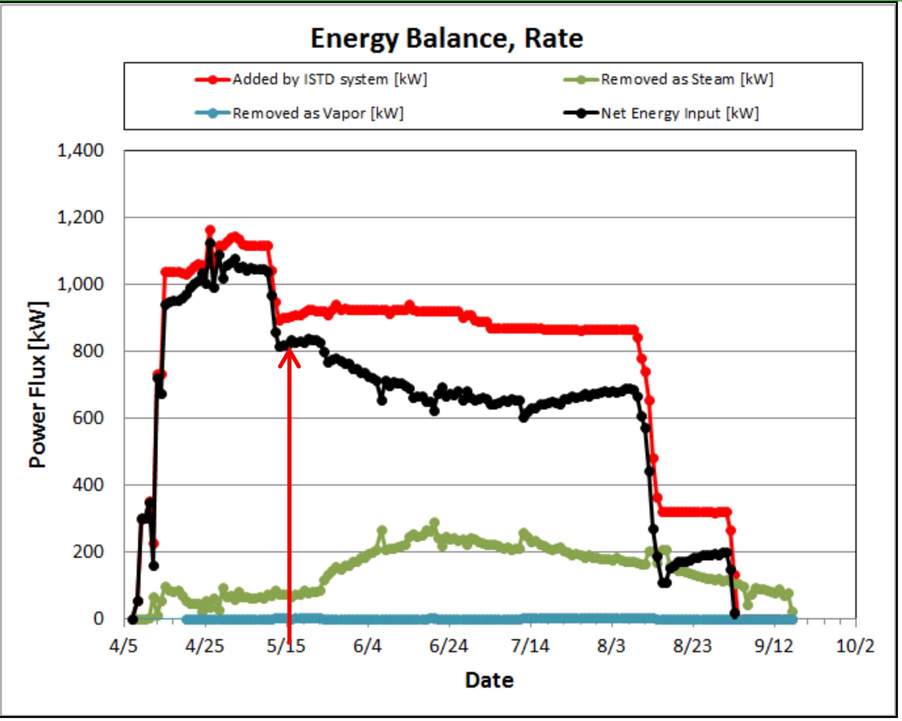
Average Temperature and TCE Behavior





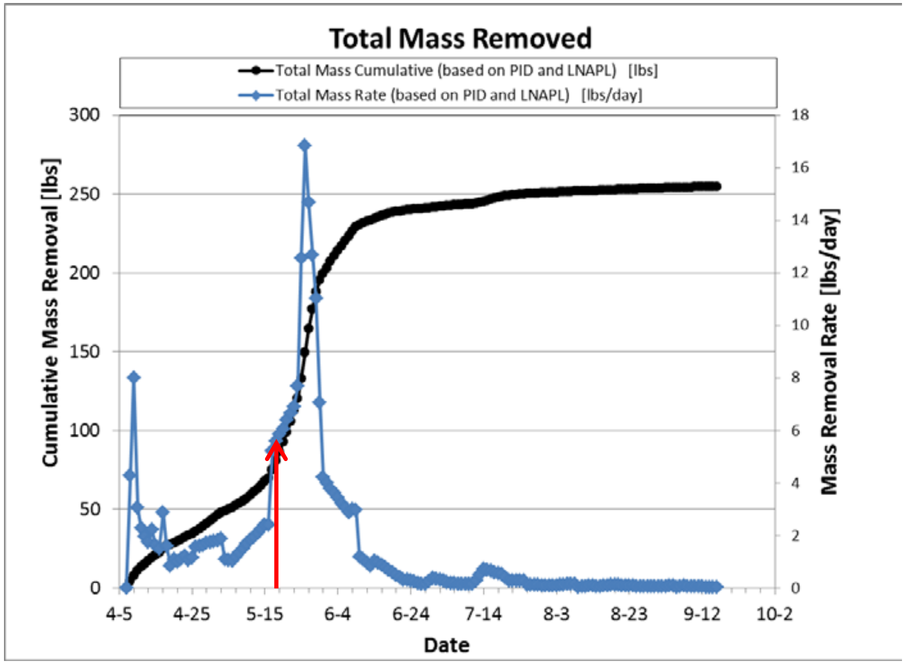
Exceed the boiling point of water-DNAPL and then heat to the boiling point of water

Energy Balance and Mass Removal



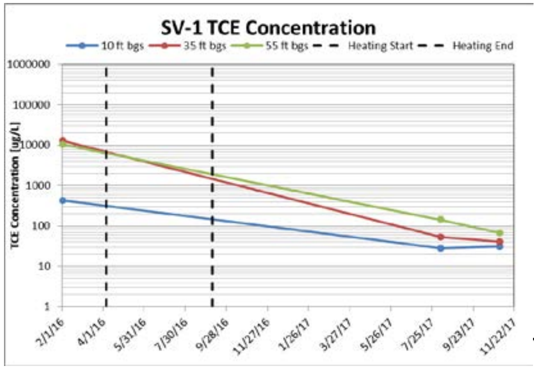
Energy used: 159 kWh/cy

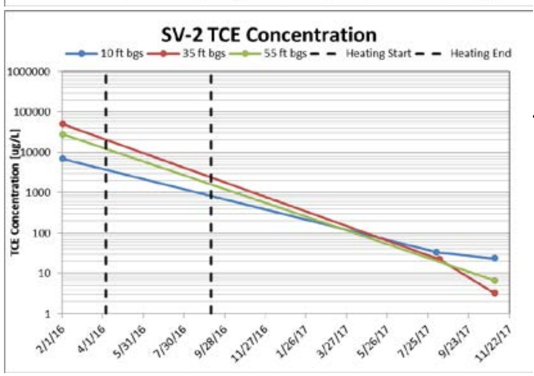
Mass removed: 254 lbs

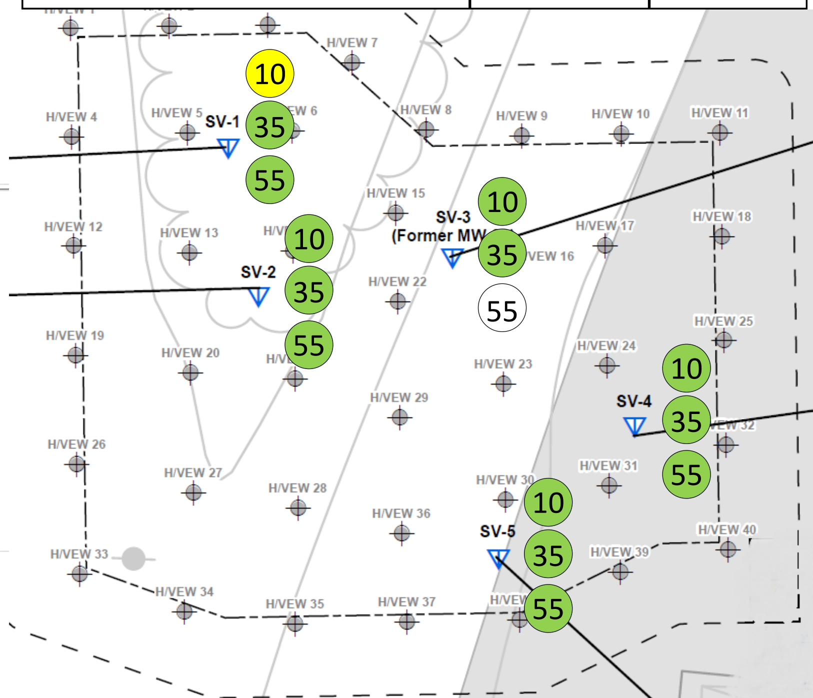


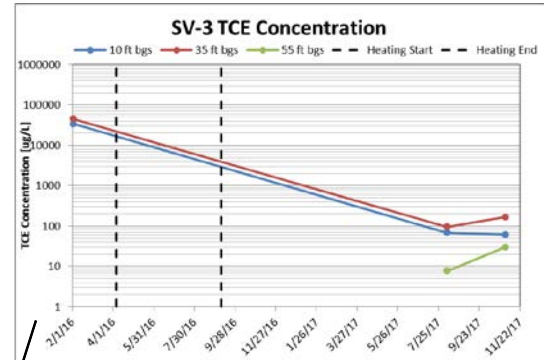
Nested Soil Vapor Probes

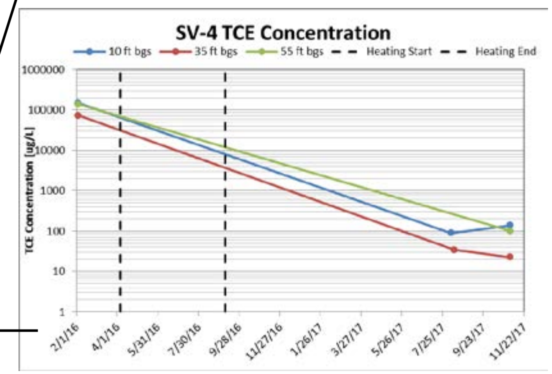
Average TCE Concentration and Removal		
Pre-ISTR Treatment	61,942	µg/L
Post-ISTR Treatment (14 months after shutdown)	61	µg/L
Removal Efficiency	99.90	%

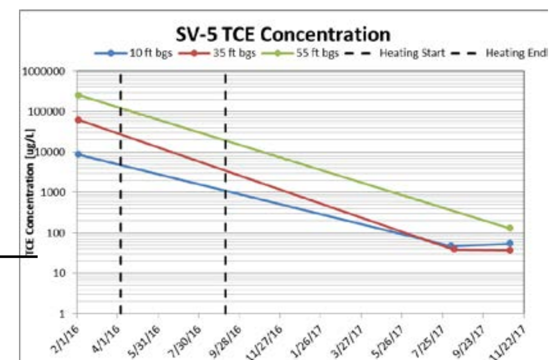












≥99% reduction

≥90% reduction

>70% reduction

≥80% reduction

Not Available

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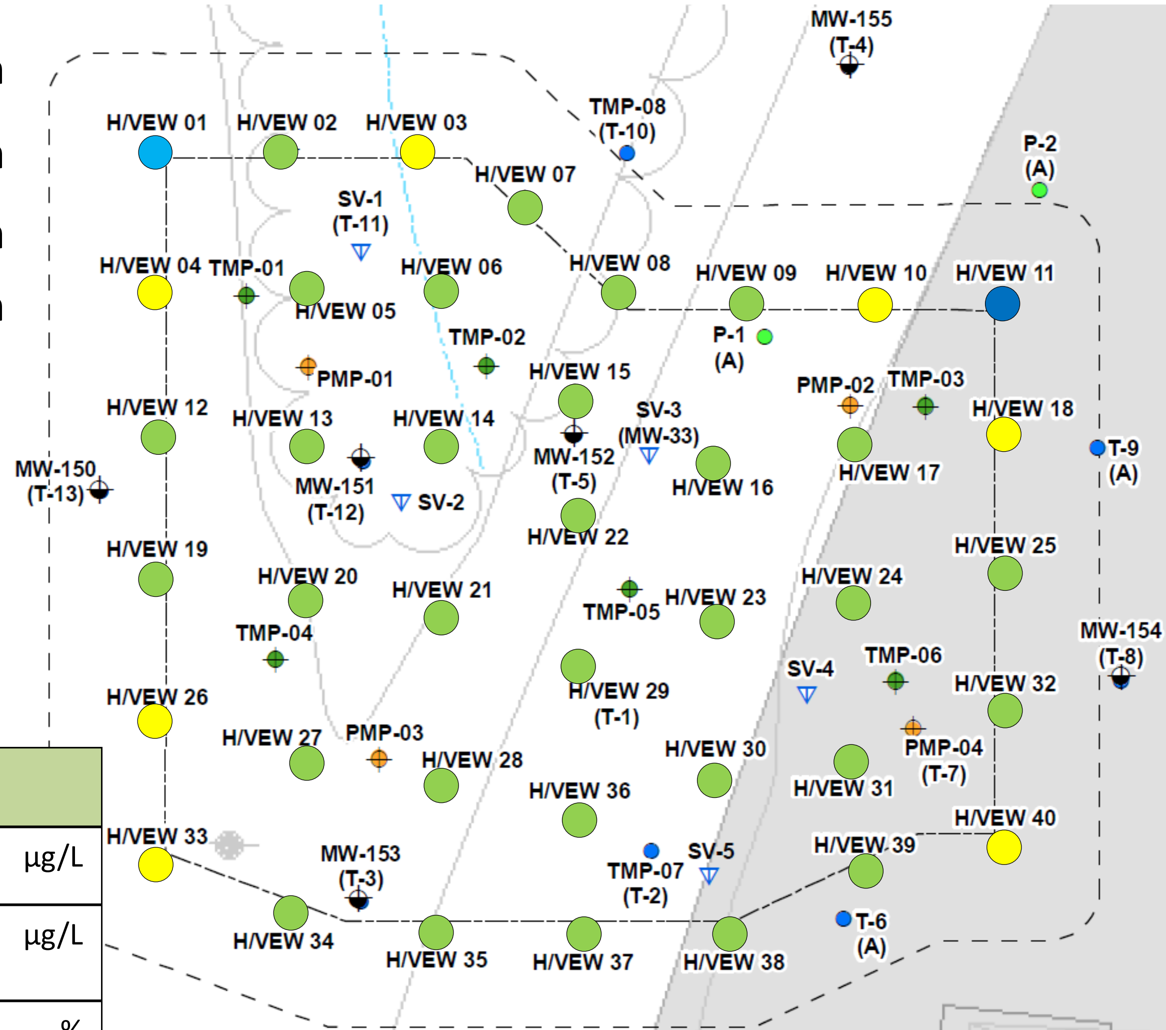
Vapor Samples from Heater Borings

≥99% reduction

≥90% reduction

≥80% reduction

>70% reduction



Average TCE Concentration and Removal		
Pre-ISTR Treatment	10,334	µg/L
Post-ISTR Treatment (2 weeks after shutdown)	1,7	µg/L
Removal Efficiency	99.98	%

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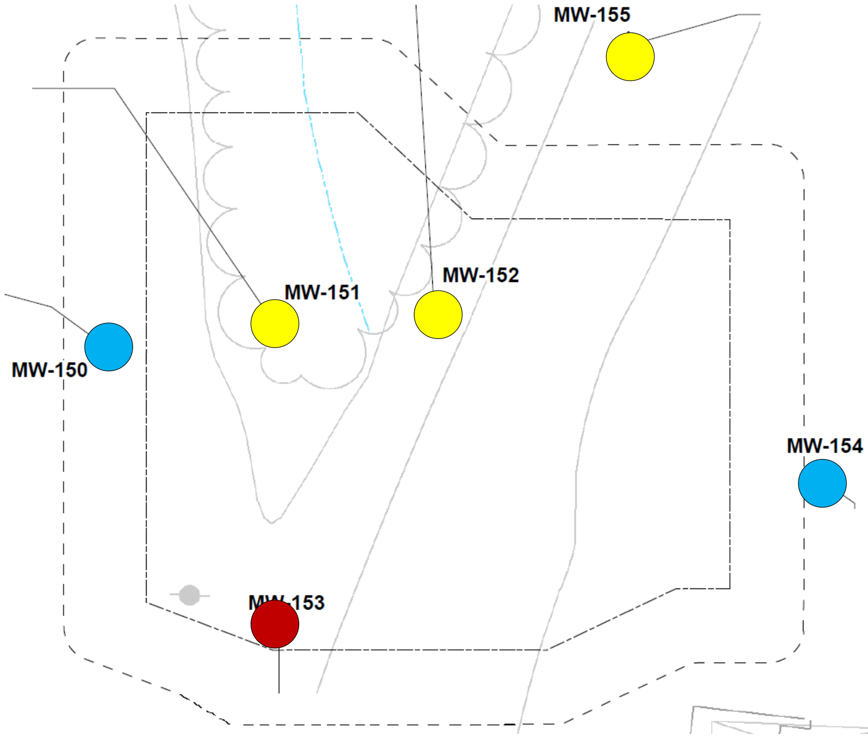
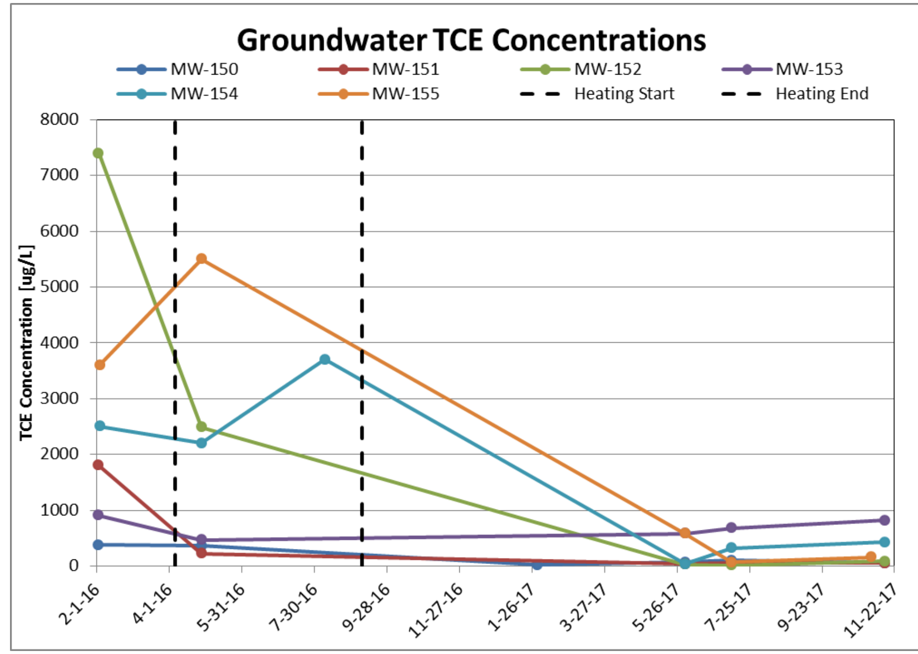
Liquid samples (ug/L)





Average TCE Concentration and Removal		
Pre-ISTR Treatment	2,765	µg/L
Post-ISTR Treatment (14 months after shutdown)	267	µg/L
Removal Efficiency	90.3	%

≥99% reduction
≥80% reduction
≥90% reduction
>70% reduction
<70% reduction

Conclusions

- Proper technology selection
- Learn as you drill!
- Extract from all the heater wells
- Use smart monitoring to know when you are done
- Proper communications with regulators and an open dialogue ensures that remediation expectations are aligned