Answering the Challenges of Low Permeability Formations

GeoTactical Remediation

Battelle 2024
Session: C7. Low-Permeability Zone Treatment Approaches, Permeability Enhancements, and Case Studies

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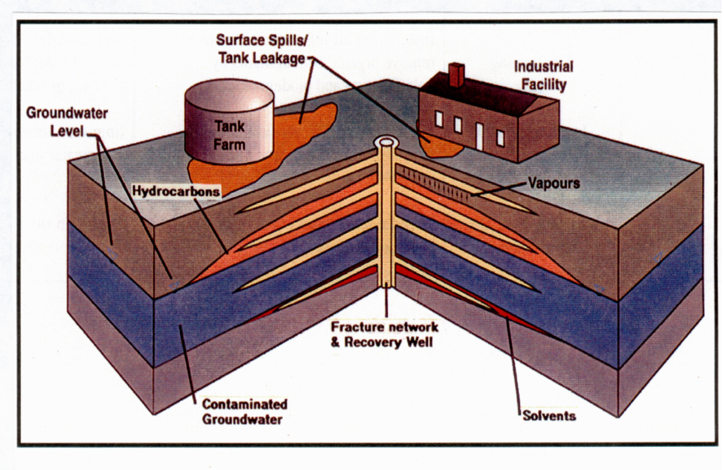
Principal

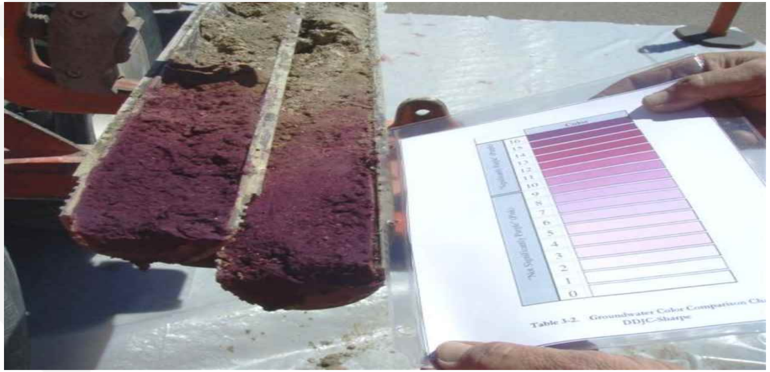
Fracture Injection

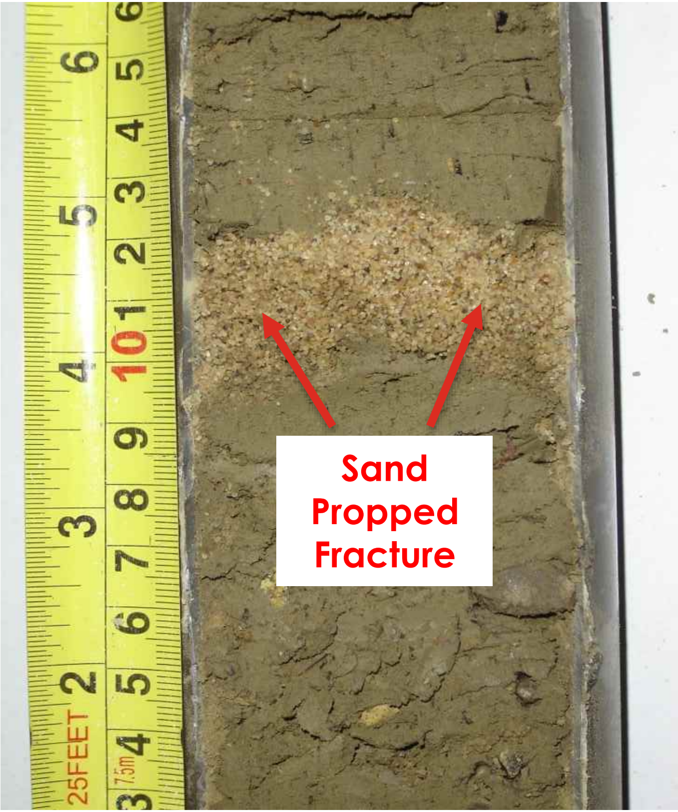
- *Fracture Injection* is a process in which a fluid is applied to a soil or rock mass until failure of the soil or rock occurs, which results in a tensile parting (i.e. fracture)

- Used for:
  - Increasing bulk permeability
  - Greater treatment area per well
  - Better contact with contaminants in matrices with secondary porosity
  - Solid phase amendments



Fractures Exposed





Site 1 – Multiphase Extraction System Enhancement

Criteria	Site Information
Depth	26 to 39 ft bgs
Matrix	Fine grained clays and silts
Contaminant	Condensate
Location	Onsite and offsite migrating towards a lake and underneath highway
Site	Current MPE system at the site

MPE Enhancement Program
Sand Proppant & Surfactant

Program Plan

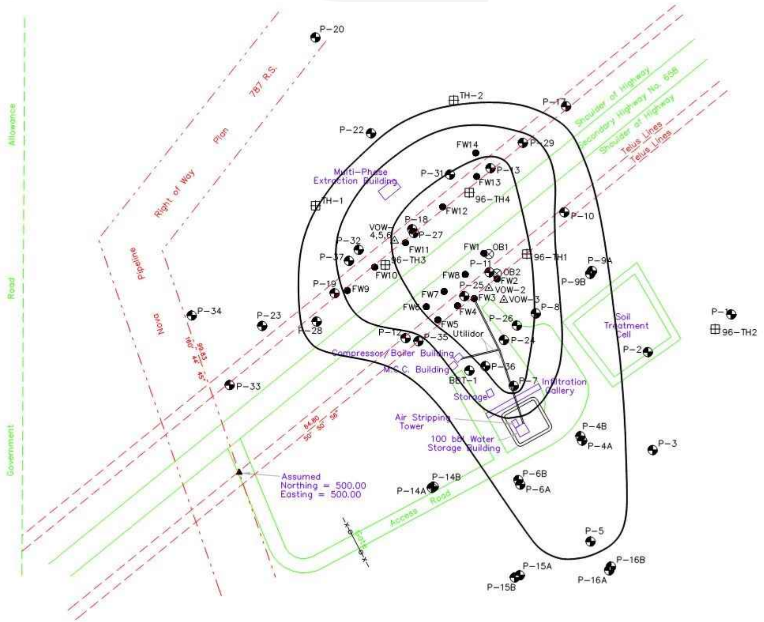
- Sand fractures emplaced with surfactant
- Fracture depths 26 to 39 ft bgs
- 14 borehole locations completed in two phases
- Complete the fracture boreholes as recovery wells

Field Program Adjustments

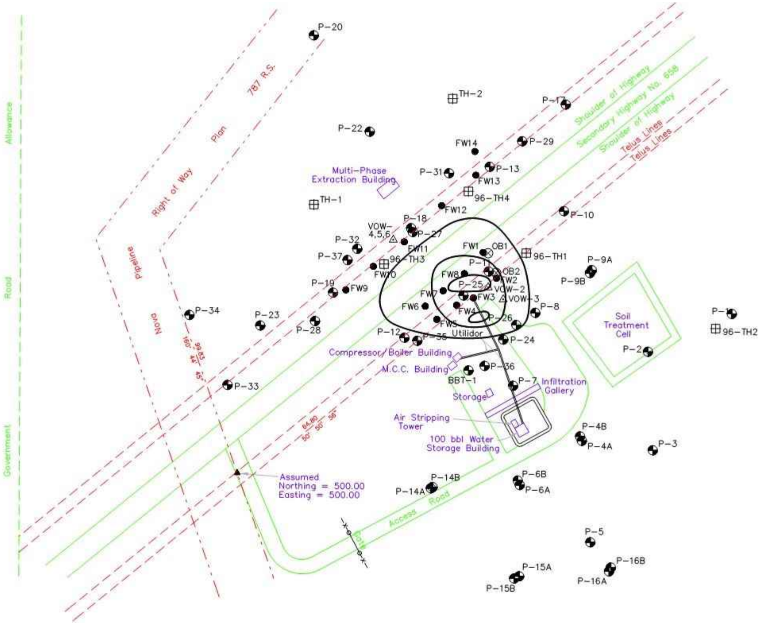
- No significant adjustments

MPE Enhancement Program – Plume Reduction

Prior to Sand Fracturing



4 Years After Sand Fracturing



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MPE Enhancement Program
Sand Proppant & Surfactant – Discussion

Results

Parameter	Baseline Recovery Well	Fractured Recovery Well
Hydraulic Conductivity (m/s)	3×10^{-8}	4×10^{-6}
Flow Rate – Total (gal/day)	35	125
Flow Rate – Condensate (gal/day)	6.4	96
Liquid Composition - % condensate	18%	77%
Radius of Influence (ft)	5 to 6	16 to 19

- Sand fracturing reduced the number of wells required for plume capture, from 50 to 17 (includes three conventional recovery wells)

Lessons Learned

- Increase groundwater condensate recovery by using a surfactant
- Recovery of residual condensate would be more effective with multiple applications of surfactants.

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Site 2 – Injection Enhancement

- Former Whittaker Bermite Facility, Santa Clarita, California
  - Former munitions and explosives manufacturing
- Approach
  - Permeability enhancement by sand propped fracturing
  - Emplaced pathways to be used for future permeation injections
- Pilot program to determine if 25 ft ROI achievable
- Full scale program

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Geology and Contaminants

- Geology: Two lithological units
  - Quaternary alluvium- sand, gravel and boulders
  - Saugus Formation- semi-indurated conglomerate, coarse sandstone, and siltstone
- GW flow direction to NW
- Saugus Formation Hydraulic Conductivity – 10^{-4} to 10^{-6}m/s
- Both units are contaminated
  - Perchlorates
  - VOCs – tetrachloroethene and trichloroethene
- Depth – 55-70 ft bgs

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Permeability Enhancement Program

- Pilot: Permeability enhancement feasibility for the site
  - Permeability Enhancement:
    - Fracture injection of sand proppant into the Saugus Formation
  - Collect data:
    - Enhancement activities, collect tiltmeter (geophysical) analysis of enhanced pathways
  - Tracer solution:
    - In conjunction with tiltmeter to confirm ROI (if 25ft ROI achieved then full scale)
- Full Scale – Emplace sand proppant in 6 additional BHs

Challenges

- Sloughing encountered at some locations/depths
  - Cased to deeper depths
  - Change to top down method with single packer
  - Inflated packer in bottom of casing
- High leak off into formation during injection
  - Indicates that formation is much more permeable than expected
  - Permeability enhancement not required in zone

Project Plan and Adjustments

Parameter	Pilot		Full	
	Plan	Adjustment	Plan	Adjustment
Emplacement Borehole (EB)	1		6	5
Emplacement Pathways (EP)/ Interval	4	6	5	1 - 4
Sand emplaced (lbs)	20,100	17,000	120,600	66,270
Slurry Volume Pumped (gal)	3,000	2,450	21,600	9,325
Confirmation	Tiltmeter and tracer dye		Tiltmeter	

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Overall Project Summary

Parameter	Pilot	Full	Overall
Emplacement Borehole (EB)	1	5	6
Emplacement Pathways (EP)	6	12	18
Injected Interval	57 - 69 ft bgs	59 - 71 ft bgs	57 - 71 ft bgs
Slurry Volume Pumped	2,450 gal	9,325 gal	11,775 gal
Sand Mass Emplaced	~17,000 lbs	~66,250 lbs	~83,000 lbs
EP initiation pressure	208 - 321 psi	197 - 697 psi	197 - 697 psi
Injection Flow rate	17-105 gal/min	105 - 112 gal/min	17 - 112 gal/min

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Pilot Program Confirmation Results

- Results of 3D tiltmeter mapping
  - 2 of 6 EPs strong enough signal to be modelled
  - Extended up to 25 ft NE, E, SE, and S directions from borehole
- Results of fluorescein tracer
  - At least 25 ft ROI
  - 3,040 gal tracer solution into sand EPs, concentration ~2,000 ppb fluorescein, injected at 8 gal/min
  - Dye observed at monitoring well 75ft from injection borehole
  - No surfacing during injection

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Full Scale Program Confirmation Results

- Results of 3D tiltmeter mapping
  - 8 of 12 EPs strong enough signal to be modelled
  - Fracture areas ranged from 850 ft^2 to 7,500 ft^2
  - Average area 2,700 ft^2
  - Aspect ratio ranged from 1.2 to 6.5
  - Dip angles ranged from 3 deg to 69 deg

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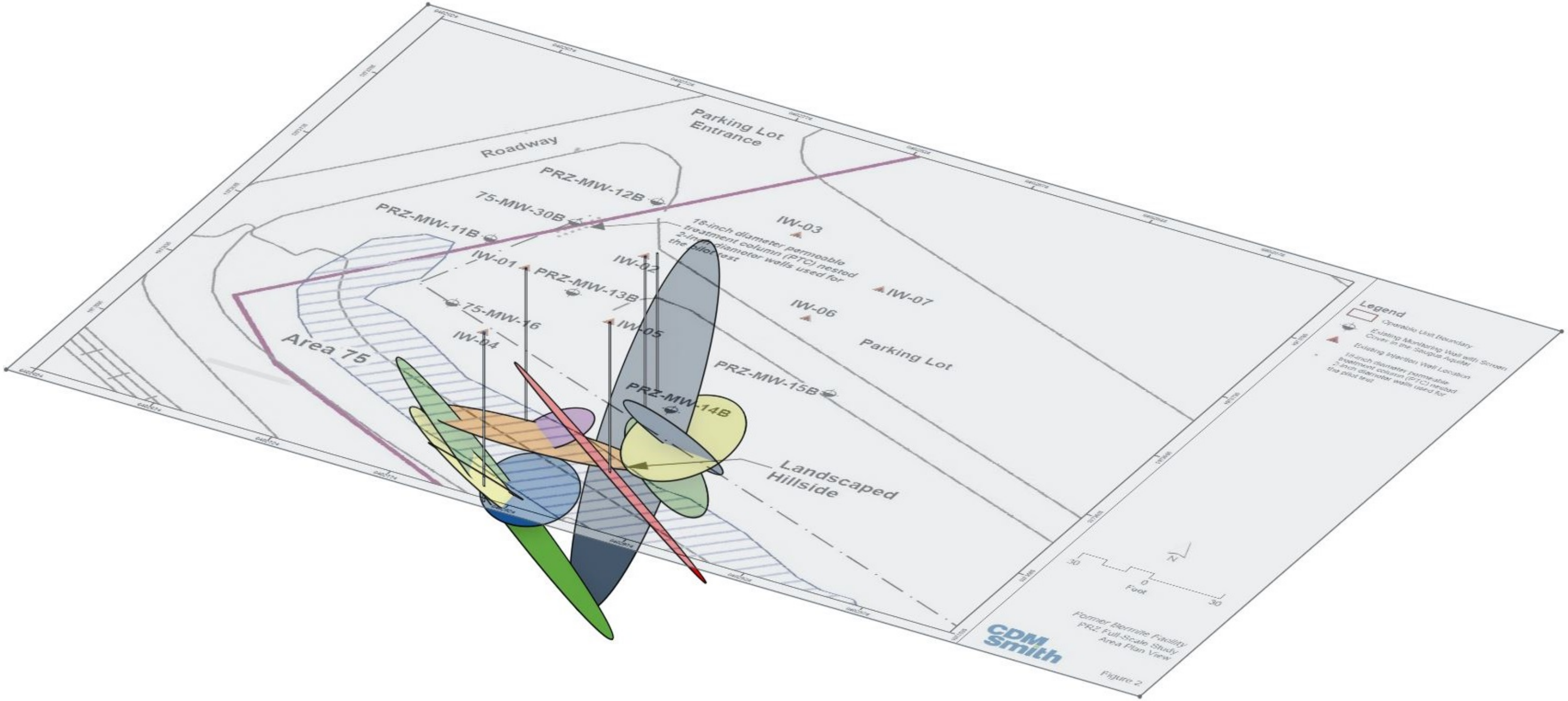
Fracture Network



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Injectable Particle Size

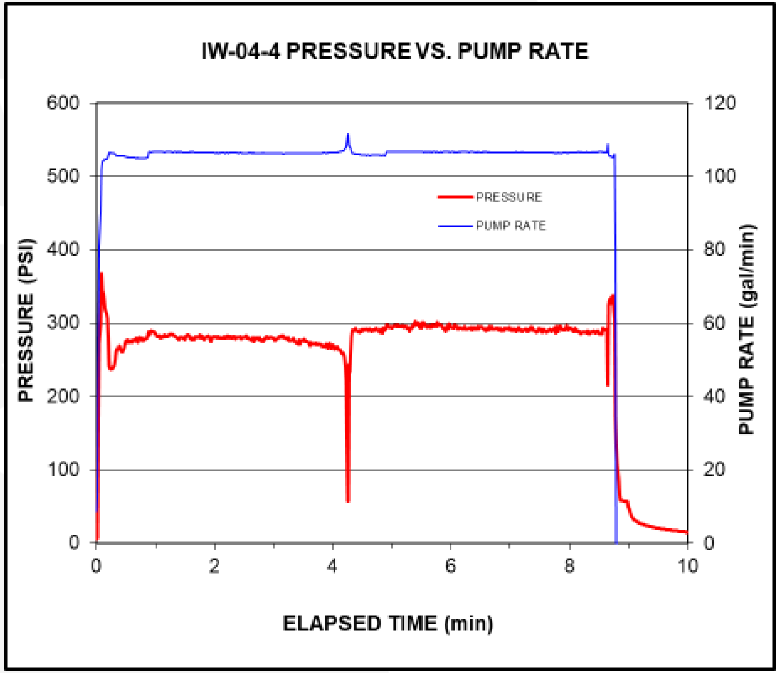
To determine maximum injectable particle size,

$$Ps < \sqrt{(K * 1.04 * 10^8)/7}$$

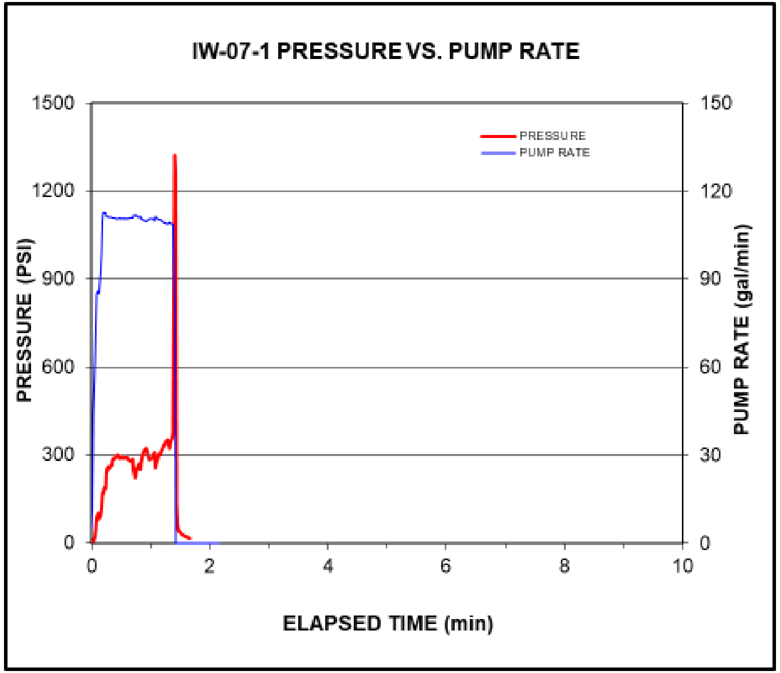
Ps: microns K: m/sec (after Harris and Odom, 1982)

K (m/s)	Soil Type	Injectable Particle Size (microns)	Injectable Amendments
$1x10^{-3}$ – $1x10^{-2}$	Clean Sand, Gravel few fines	122 – 385	Calcium peroxide, Potassium persulfate
$1x10^{-4}$ – $1x10^{-3}$	Alluvial Sand and Gravel	39 – 122	Calcium peroxide, Potassium persulfate - limited
$1x10^{-5}$ – $1x10^{-4}$	Fine to Medium sand	12 – 39	Calcium peroxide – very limited
$1x10^{-6}$ – $1x10^{-5}$	Silty Sand, Clayey Sand	4 – 12	Solutions, Nano Scale
$1x10^{-7}$ – $1x10^{-6}$	Silty Sand, Silt, Clayey Sand, Clay	1.2 – 3.9	Solutions, True Nano Scale
$1x10^{-8}$ – $1x10^{-7}$	Silt, Clayey Sand, Silty Clay, Clay	0.4 – 1.2	Solutions, True Nano Scale

Pressure and Flow vs Time Plots



Fracture Emplacement



Permeation then Screen Out

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Conclusion

- Permeability enhancement
  - Effective means of increasing hydraulic conductivity in low permeability formations
  - Effective for increasing area of contact
- Confirmation methods
  - 3D Tiltmeter mapping to confirm pathway network
  - Tracer dye to confirm network interconnectivity and ROI
- It is important to observe, assess and adjust throughout an injection program, particularly when things are not going as planned

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References

- CDM Smith (2017). *Final Permeability Reactive Zone Pilot Study Report for Northern Alluvium Area of Operable Unit 7, Former Whittaker Bermite Facility, 22116 Soledad Canyon Road, Santa Clarita, California.*
- ESTCP Project ER-201430
  - *A Rigorous Demonstration of Permeability Enhancement Technology for In Situ Remediation of Low Permeability Media*

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Service backed by Science

THANK YOU!

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