

Increasing Treatment Certainty While Controlling Remediation Cost

Case Studies using Hydraulic Fracturing to Deliver Amendments at Low-Permeability Sites

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- » 20 years industry experience
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- » 20 years industry experience
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Increasing Treatment Certainty While Controlling Remediation Cost



- Hydraulic Fracturing Principles & Applications
- Q&A Part 1
- Case Studies Illustrating Use of Fractures for ISCO & ISCR
- Reagent Dosing & Field Productivity
- Hydraulic Fracturing Project Costs
- Q&A Part 2

In-Situ Access to Contaminants

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POLL QUESTION 1



In-Situ Access to Contaminants

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Poll Question 1

- What types of amendment delivery methods have you used on your remediation projects (select all that apply)?
 - » Conventional injection wells
 - » Horizontal injection wells
 - » Direct-push injection
 - » Hydraulic fracturing
 - » Pneumatic fracturing
 - » Soil mixing

In-Situ Access to Contaminants

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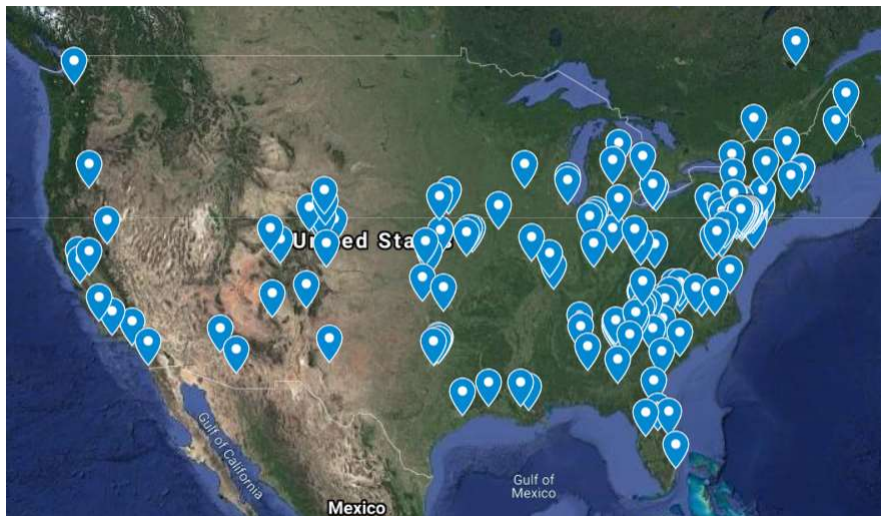
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Hydraulic Fracturing Process



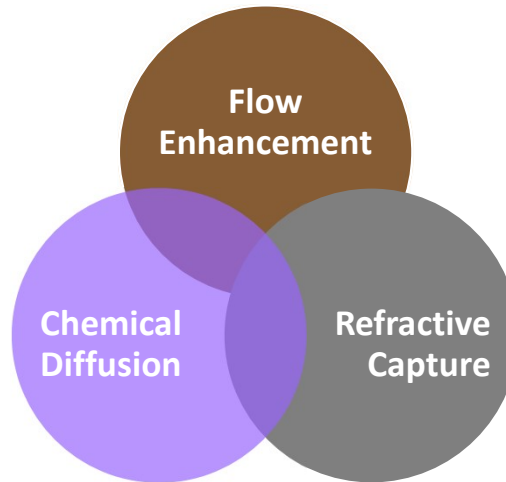
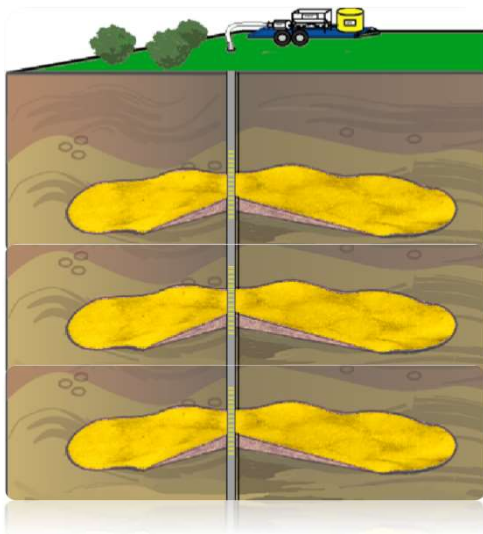
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FRx Project Sites



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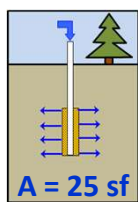
Fractures for Remediation – Treatment Concepts



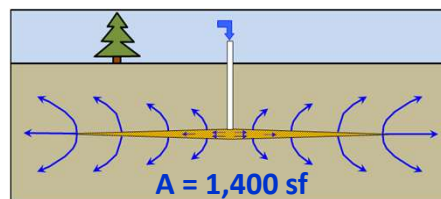
In-Situ Access to Contaminants

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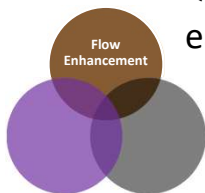
Treatment Concepts – Flow Enhancement DOD Facility in Midwestern US



- 277 gal EVO per well
- 35 weeks
- < 8 gal per week each well



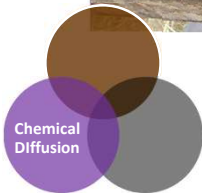
- 556 gal EVO per well
- 2 weeks
- 283 gal per week each well



In-Situ Access to Contaminants

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Treatment Concepts – Chemical Diffusion



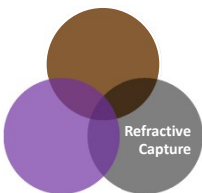
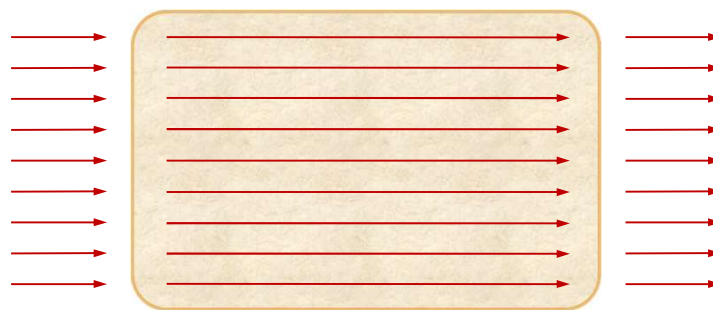
In-Situ Access to Contaminants

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Treatment Concepts – Refractive Capture



**Impacted
Groundwater
Flow**



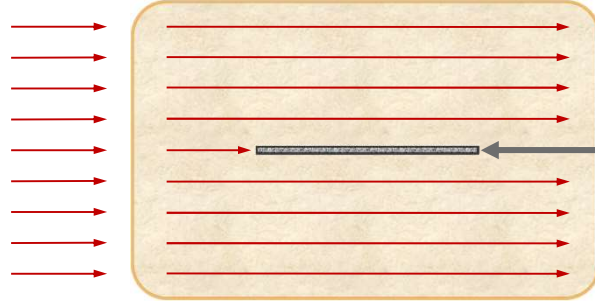
In-Situ Access to Contaminants

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Treatment Concepts – Refractive Capture



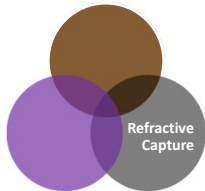
Impacted
Groundwater
Flow



» Oriented parallel to flow

ZVI-filled
fracture
(30-ft diameter)

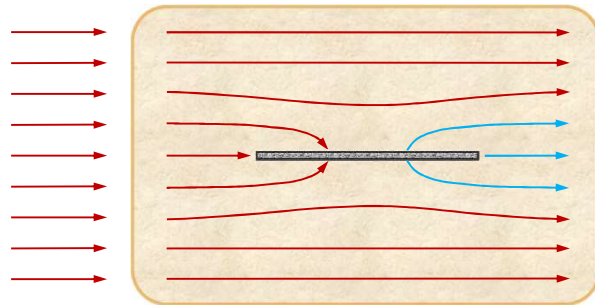
In-Situ Access to Contaminants



Treatment Concepts – Refractive Capture



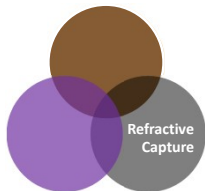
Impacted
Groundwater
Flow



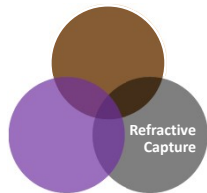
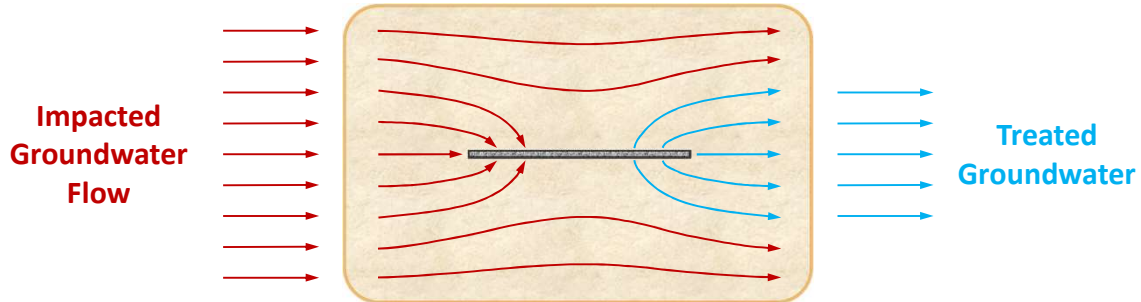
- » Oriented parallel to flow
- » Acts like preferential flow path

Treated
Groundwater

In-Situ Access to Contaminants



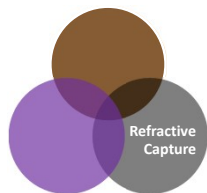
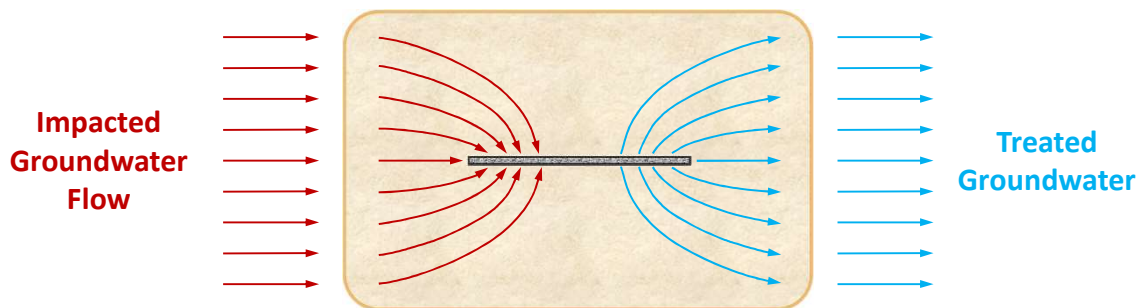
Treatment Concepts – Refractive Capture



- » Oriented parallel to flow
- » Acts like preferential flow path
- » Distorts local groundwater flow

In-Situ Access to Contaminants

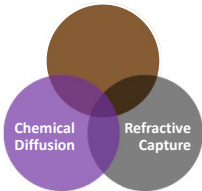
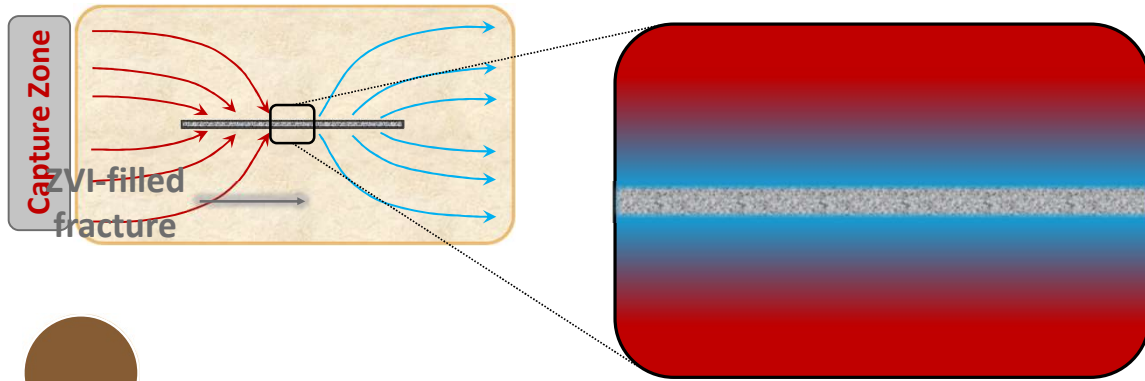
Treatment Concepts – Refractive Capture



- » Oriented parallel to flow
- » Acts like preferential flow path
- » Distorts local groundwater flow
- » $k_{\text{Fracture}} \gg k_{\text{Formation}}$

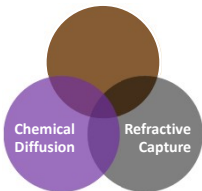
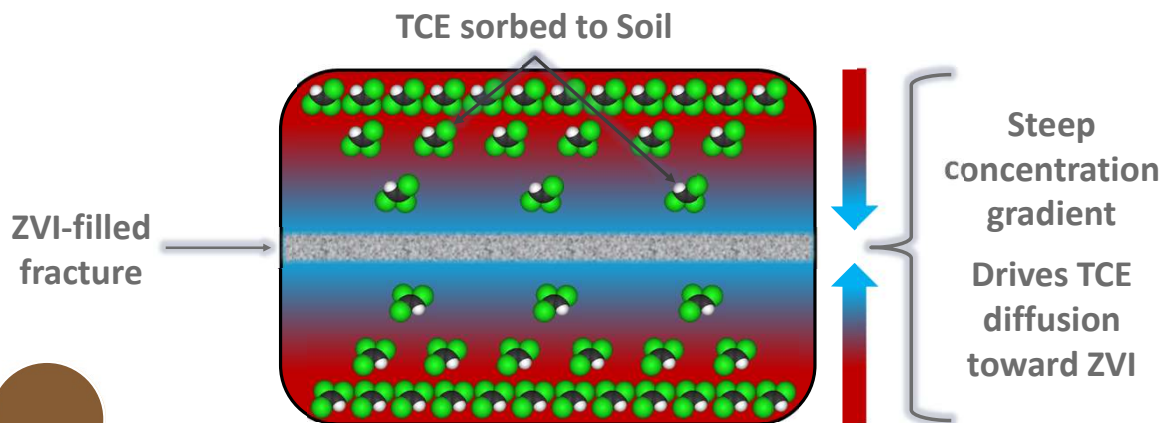
In-Situ Access to Contaminants

Treatment Concepts – Contaminant Diffusion



In-Situ Access to Contaminants

Treatment Concepts – Contaminant Diffusion



In-Situ Access to Contaminants



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POLL QUESTION 2

In-Situ Access to Contaminants

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Poll Question 2

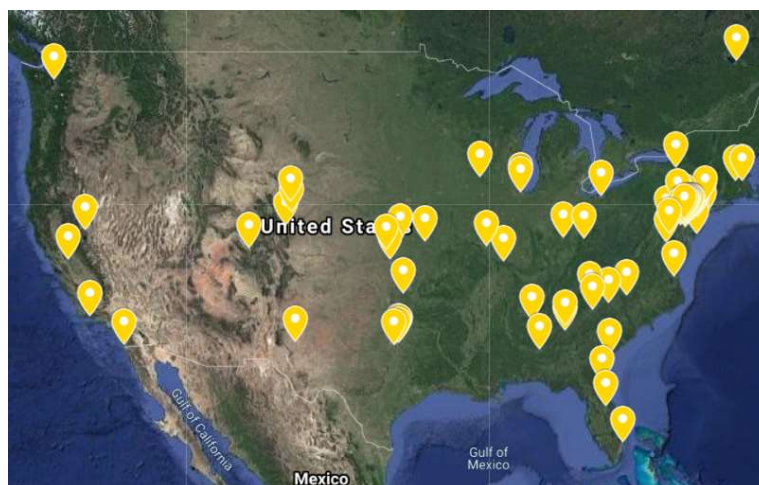
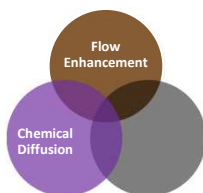
- Which of the following treatment technologies have you utilized in the last 5 years (select all that apply)?
 - » ISCO
 - » ISCR
 - » SVE/MPE
 - » Air Sparging or Biosparging
 - » Enhanced Bioremediation

In-Situ Access to Contaminants

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ISCO Fracturing Experience

95 Projects, >2,000 Fracs

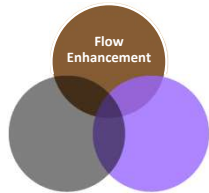


In-Situ Access to Contaminants

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ISCO Flow Enhancement for Source Treatment Former Industrial Site in Colorado

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Geosyntec
consultants

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Case Study Acknowledgements

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Geosyntec
consultants

Ted Kuehster (CO), Garry Stanley (IL), and Emily Stockwell (CO)

In-Situ Access to Contaminants

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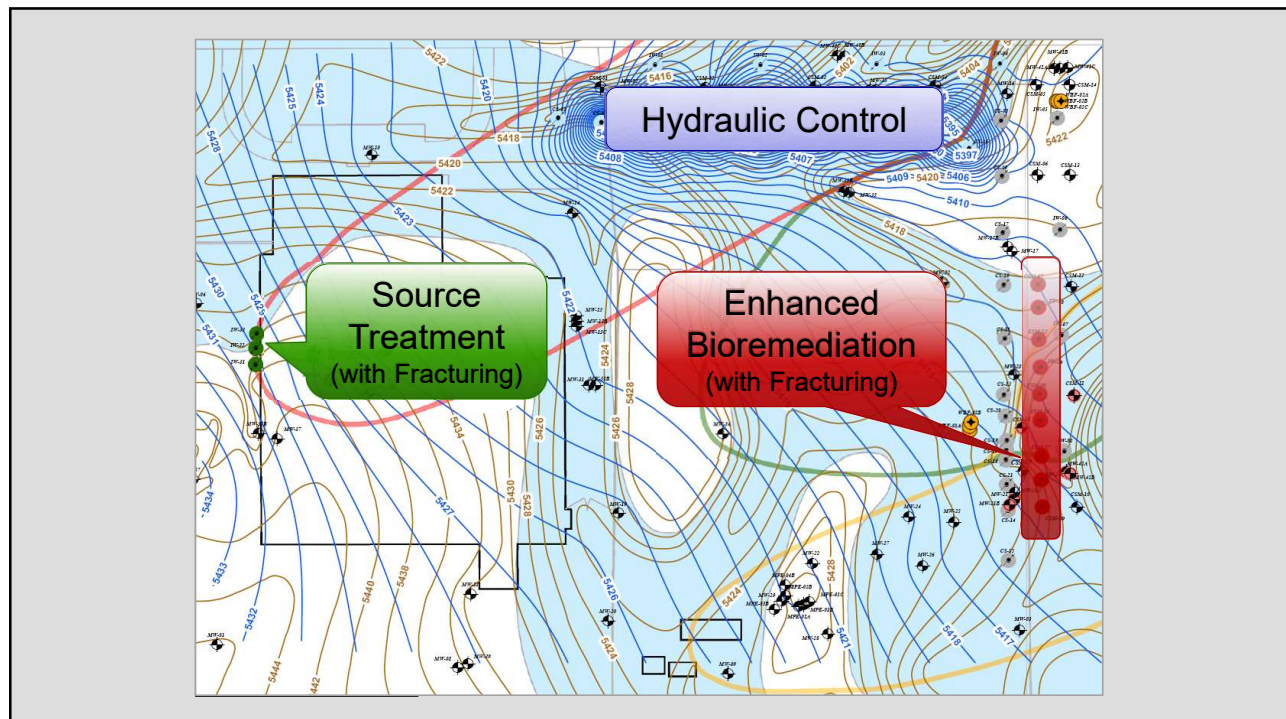
ISCO Flow Enhancement for Source Treatment Former Industrial Site in Colorado



- Vapor degreaser source with 1,1,1-TCA, 1,1-DCE, PCE and TCE
- 1,4-Dioxane identified during subsequent investigations
- Variably weathered alluvial deposits
 - » Claystone and siltstone → variably silty clay
 - » Sandstone → clayey sand
- Groundwater flow through high-k units created a large plume extending offsite

In-Situ Access to Contaminants

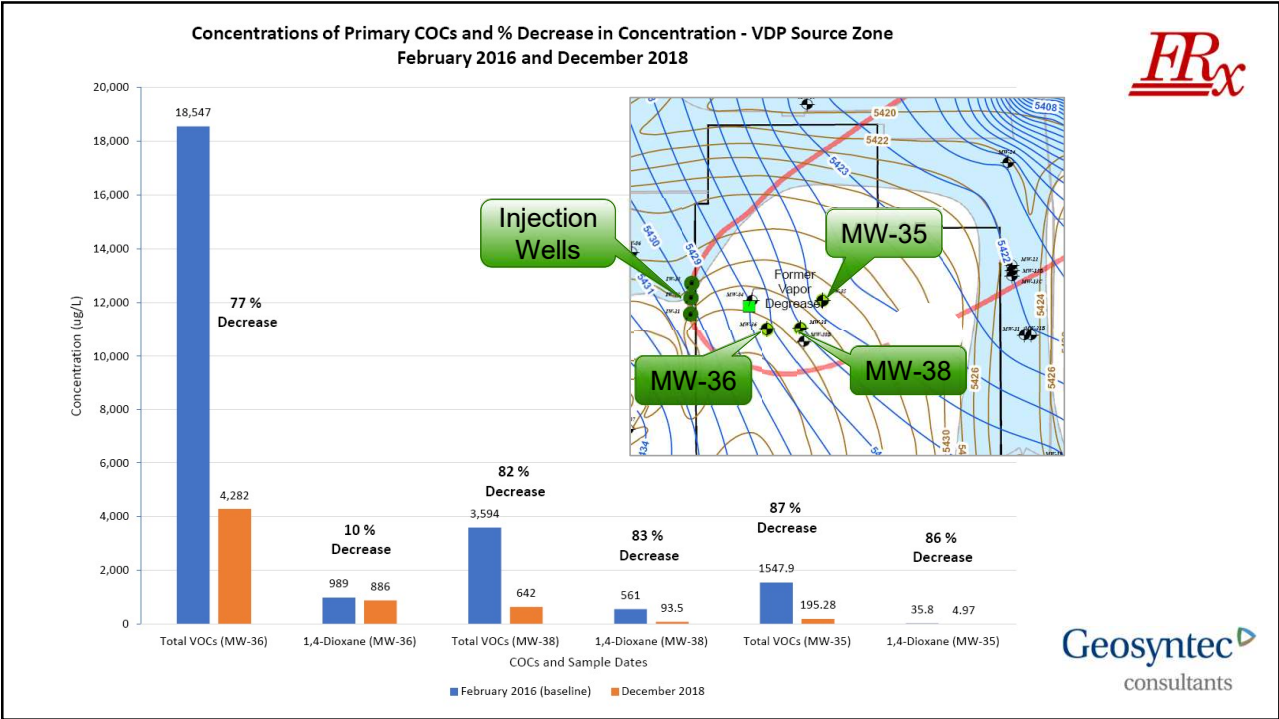
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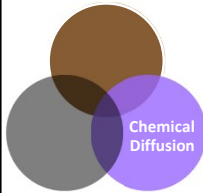
ISCO via Chemical Diffusion K-Persulfate Projects



K-Persulfate Frac



KP Slurry



ISCO via Chemical Diffusion: K-Persulfate Five Projects in Four States

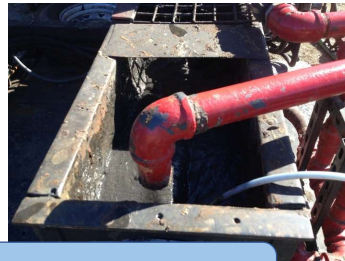


ISCR Fracturing Experience

24 Projects, >1,800 Fracs



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Case Study: New England Site



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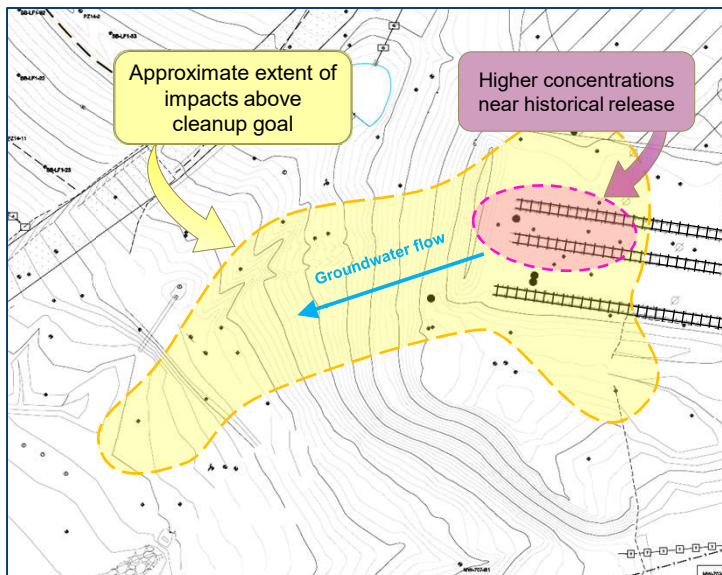
Case Study Acknowledgements



Chris Martin, Rhiannon Scott, and Chris Greene – Massachusetts

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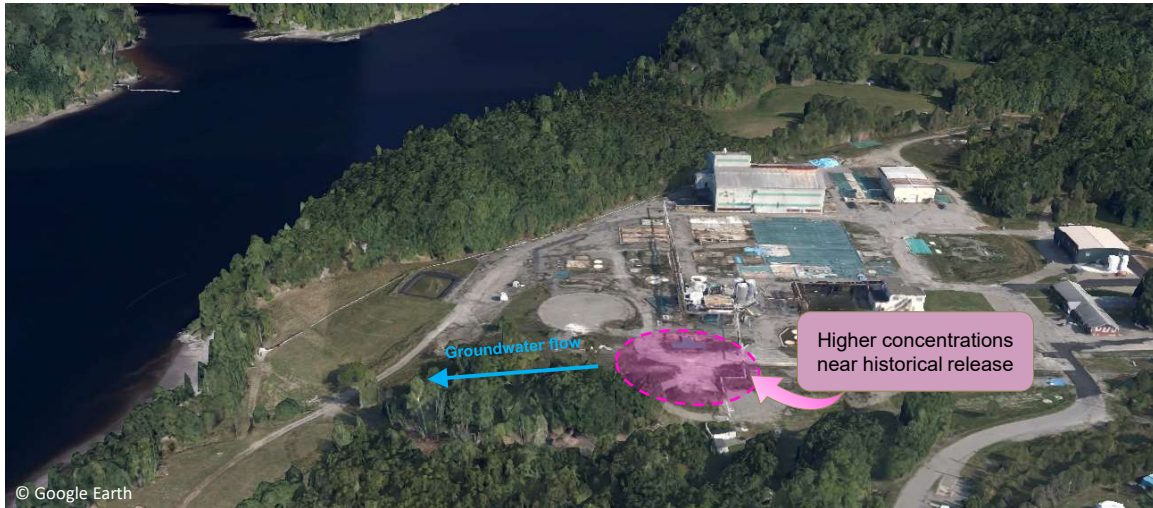
New England Site - Overview



- Remediation of a former chemical manufacturing facility
- Historical releases of chloropicrin in a process handling area led to soil and groundwater impacts
- Excavation of impacted soil was not feasible due to site logistics and health and safety concerns with chloropicrin air emissions

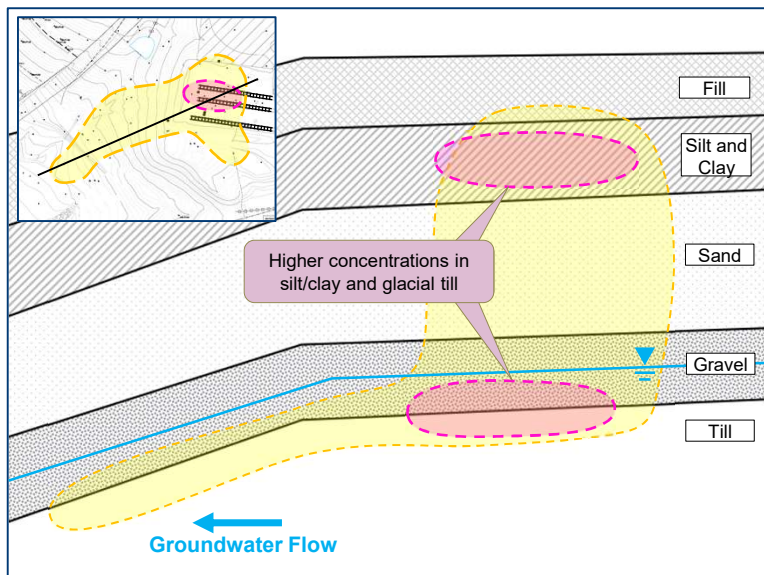
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New England Site - Overview



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New England Site – Conceptual Site Model

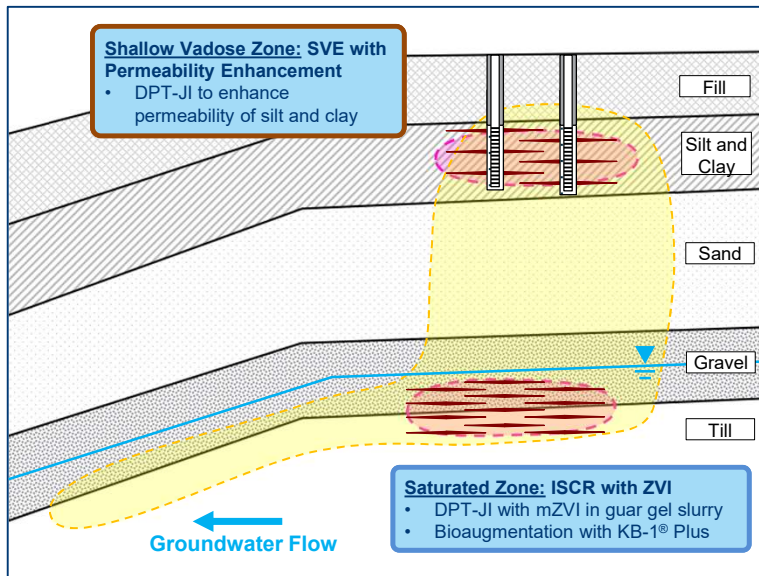


CSM Summary

- Complex glacial geology
- Target treatment zone includes several distinct strata with a wide range in permeability, above and below water table
- Higher concentrations of chloropicrin identified in low-permeability soils

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New England Site – Treatment Design - Phase 1

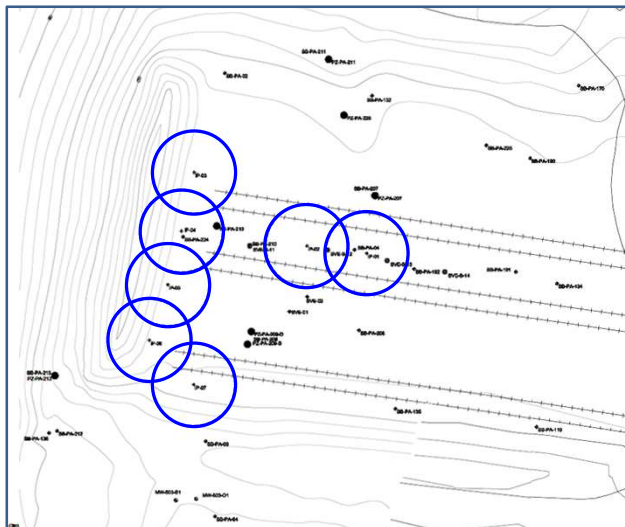


Phase 1 Combined Remedy:

- Evaluate feasibility of DPT-JI to enhance SVE in vadose zone and treat saturated zone with mZVI
- Begin focused treatment in core of plume to accelerate progress towards cleanup goals
- Mitigate downgradient migration of chloropicrin in groundwater

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New England Site – ISCR – Phase 1

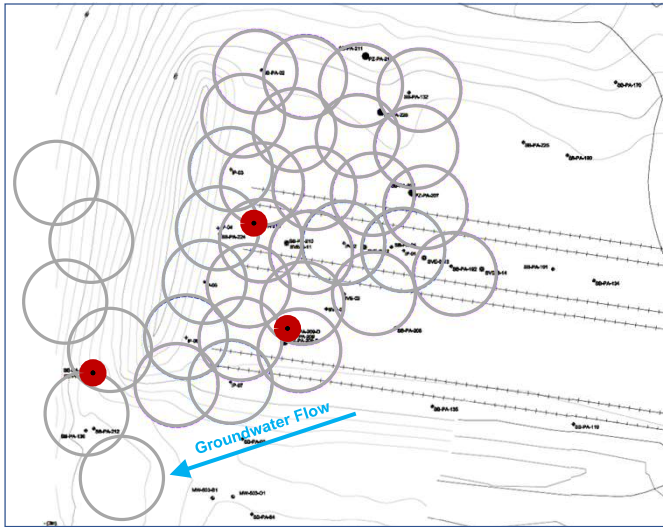


Saturated Zone ISCR – Pilot Test

- 2,800 sq ft treatment area
- 6 ft treatment thickness
- 12 ft design ROI
- 7 locations with 24 individual injections
- 37,100 lbs micro-scale ZVI (mZVI)
- 42 L KB-1® Plus

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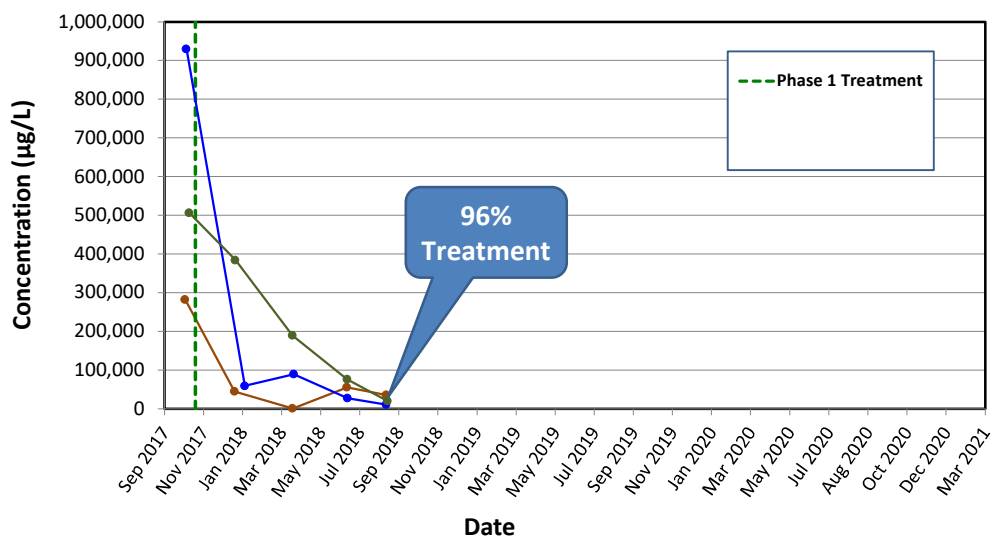
New England Site – Groundwater Monitoring Locations



- Quarterly groundwater monitoring at 5 wells in target treatment area and downgradient

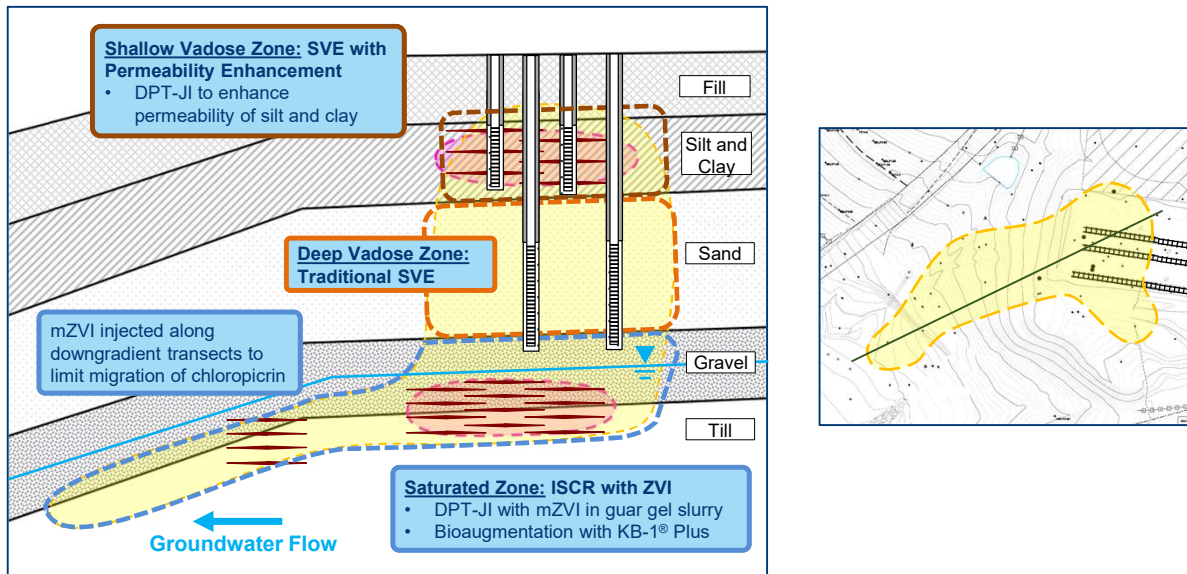
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New England Site – Groundwater Monitoring Results – Phase 1



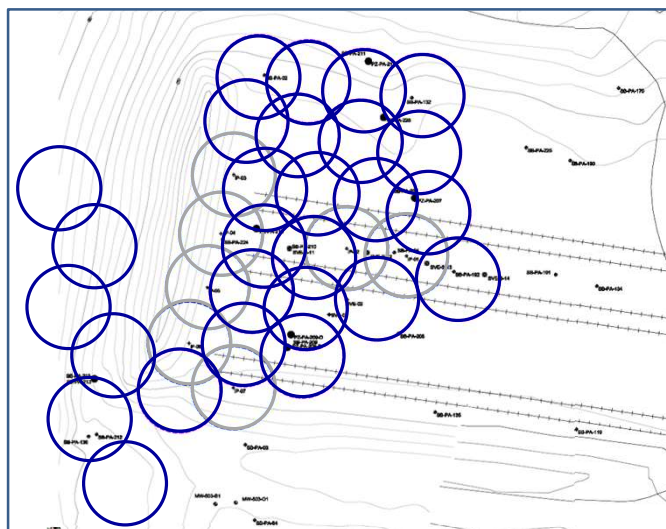
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New England Site – Treatment Design - Phase 2



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New England Site – ISCR – Phase 1 and 2

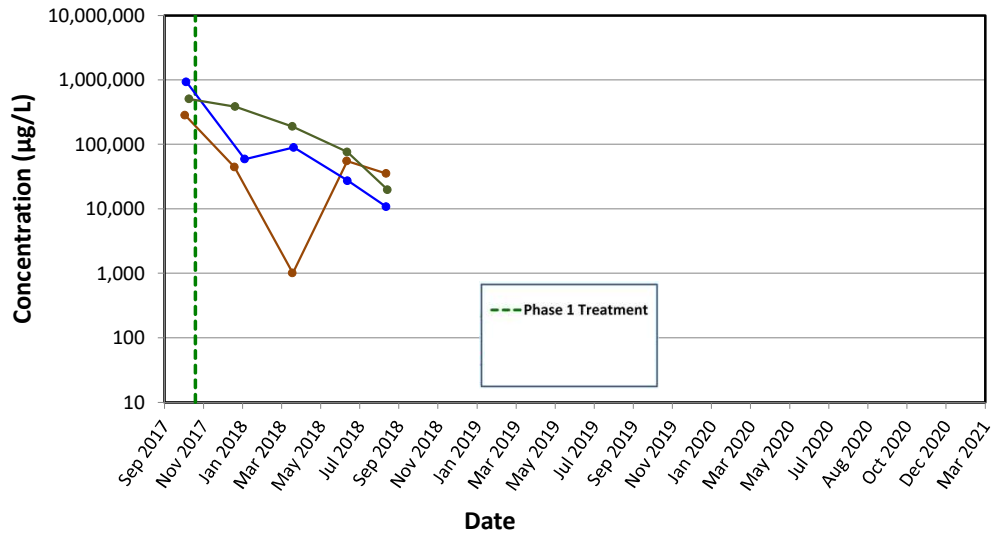


Saturated Zone ISCR – Full Scale

- 9,500 sq ft treatment area
- 6 ft treatment thickness – source
- 12 ft treatment thickness - PRB
- 12 ft design ROI
- 27 locations with 76 individual injections
- 163,600 lbs micro-scale ZVI (mZVI)
- 180 L KB-1® Plus

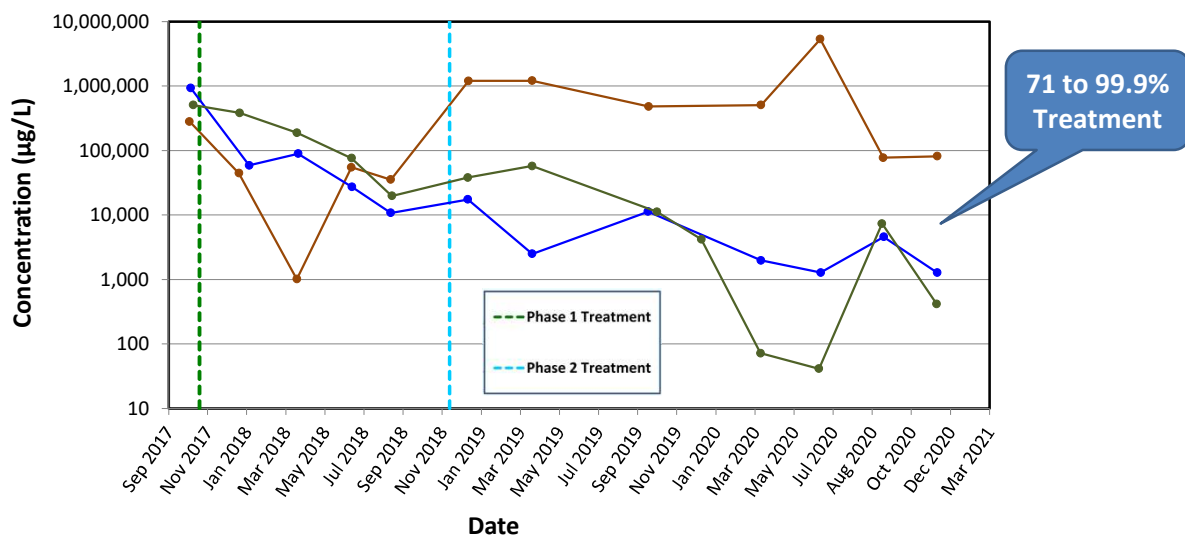
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New England Site – Groundwater Monitoring Results – Phase 1



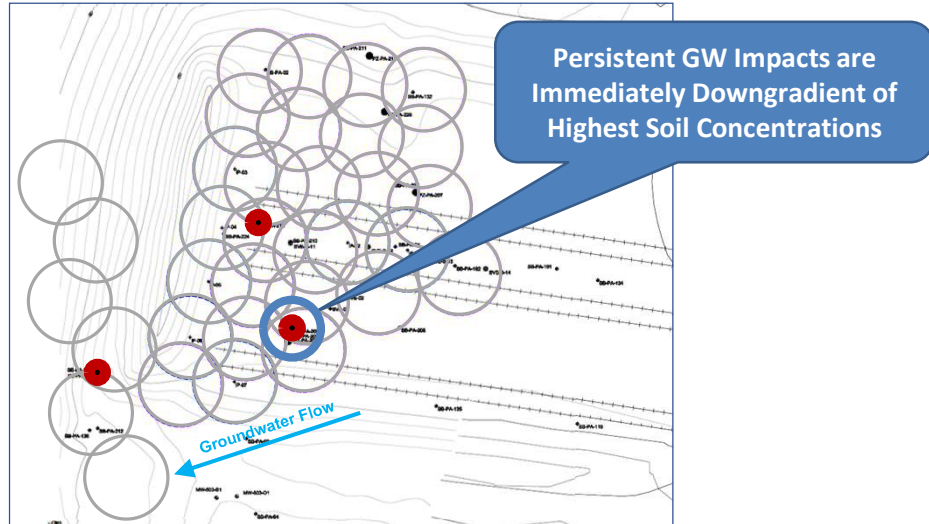
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New England Site – Groundwater Monitoring Results – Phase 2



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New England Site – Groundwater Monitoring Locations



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Case Study: New England Site – Conclusions



- Phase 1 treatment was successful and led to Phase 2 implementation.
- Fracture-enhanced SVE wells facilitated treatment of shallow clay interval with perched water, removing 340 kg of chloropicrin.
- ZVI has been successful at treating high concentrations of chloropicrin in the source and cutting off impacts to downgradient plume. Groundwater monitoring results continue to show improvements.

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POLL QUESTION 3

In-Situ Access to Contaminants

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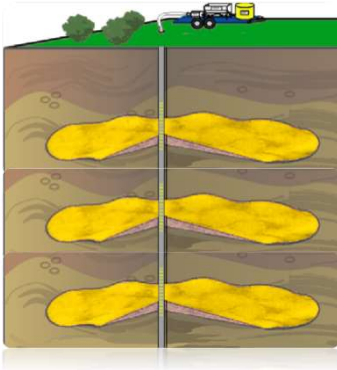
Poll Question 3

- In your experience, what is a typical unit cost (\$/cu yard) for treatment of low-permeability sites?
 - » <\$50
 - » \$50-100
 - » \$100-150
 - » >\$150

In-Situ Access to Contaminants

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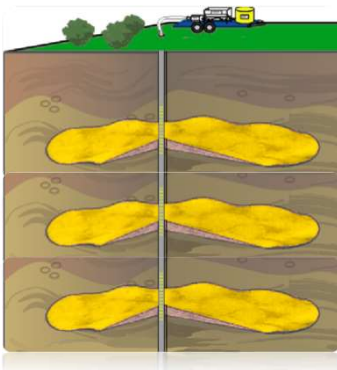
Reagent Dosing & Field Productivity



	K-Permanganate	K-Persulfate (± Activators)	Zero-Valent Iron
Dosing Range			
Pounds/Fracture (typ)			
Pounds/Day (avg)			

In-Situ Access to Contaminants

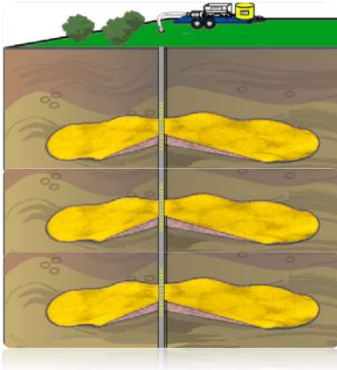
Reagent Dosing & Field Productivity



	K-Permanganate	K-Persulfate (± Activators)	Zero-Valent Iron
Dosing Range	10-15 lbs/cy		
Pounds/Fracture (typ)	1,000 - 1,500		
Pounds/Day (avg)	2002 TX - 4,300 2015 CO - 7,230 2020 NC - 8,750		

In-Situ Access to Contaminants

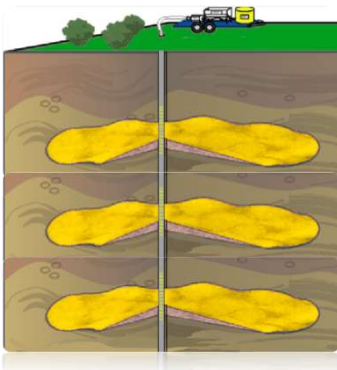
Reagent Dosing & Field Productivity



	K-Permanganate	K-Persulfate (± Activators)	Zero-Valent Iron
Dosing Range	10-15 lbs/cy	6-9 lbs/cy	
Pounds/Fracture (typ)	1,000 - 1,500	500 - 1,000	
Pounds/Day (avg)	2002 TX - 4,300 2015 CO - 7,230 2020 NC - 8,750	2017 CO - 3,000 2017 NM - 5,450 2019 FL - 5,100	

In-Situ Access to Contaminants

Reagent Dosing & Field Productivity



	K-Permanganate	K-Persulfate (± Activators)	Zero-Valent Iron
Dosing Range	10-15 lbs/cy	6-9 lbs/cy	0.25 – 2.8 wt% of soil in TTZ
Pounds/Fracture (typ)	1,000 - 1,500	500 - 1,000	1,500 - 4,000+
Pounds/Day (avg)	2002 TX - 4,300 2015 CO - 7,230 2020 NC - 8,750	2017 CO - 3,000 2017 NM - 5,450 2019 FL - 5,100	2014 SC - 12,100 2018 ME - 15,700 2020 TN - 12,300

In-Situ Access to Contaminants

Hydraulic Fracturing Project Costs - ISCO



Project	Amendments	Amendment Mass (lbs)	Treatment Volume (cubic yards)	Treatment Unit Cost (\$/cy)
ISCO				
Alabama	K-Persulfate Hydrated Lime	18,900	2,300	\$48
New Mexico	K-Persulfate Na-Persulfate Fe-EDTA	39,660	4,850	\$76
Pennsylvania	K-Permanganate	42,000	2,770	\$140

In-Situ Access to Contaminants

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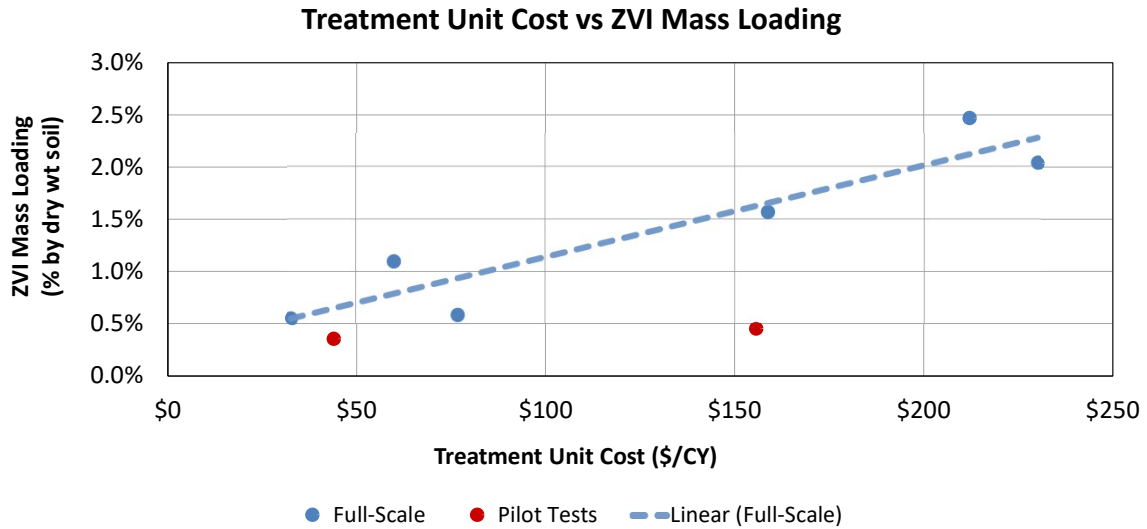
Hydraulic Fracturing Project Costs - ISCR



Project	Amendments	mZVI Mass (lbs)	Treatment Volume (cubic yards)	Treatment Unit Cost (\$/cy)
ISCR				
Louisiana - Source Treatment - Pilot	mZVI, KB-1® Plus, sand	6,000	444	\$156
New England - Source Treatment - Phase 1	mZVI, KB-1® Plus	37,100	613	\$230
New England - PRB	mZVI, KB-1® Plus	49,392	1,061	\$159
New England - Source Treatment - Phase 2	mZVI, KB-1® Plus	113,585	1,548	\$212
New Jersey - Source Treatment - Pilot	mZVI, KB-1® Plus	17,637	1,667	\$44
Texas - Source Treatment - Phase 1	mZVI, KB-1®, sand	31,200	1,785	\$77
Texas - Source Treatment - Phase 2	mZVI, KB-1®, sand	132,300	4,056	\$60
North Carolina - Source Treatment - Full-Scale	mZVI, KB-1®, sand	182,982	11,111	\$33

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Hydraulic Fracturing Project Costs - ISCR



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How to Work with Us



- Call Drew (864) 546-9449
dbaird@frx-inc.com
- Call Chapman (617) 821-0686
cross@frx-inc.com
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Important Site Info

- Drilling technique
- Target zone size
- TTZ characteristics
- Remedial approach
- Site location

In-Situ Access to Contaminants

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**Q&A
Part 2**

