CASCADE
DRILLING | TECHNICAL SERVICES

Technologies, Methodologies, and Best Practices For Distribution of Liquid and Solid Amendments for Chlorinated Solvent Remediation

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In Situ Remediation End Game

Everyone agrees that contact of the right amendments with contaminants, for a long enough period of time for complete destruction, is the key to remediation success.

Cascade's In Situ Remediation Matrix

- Cascade has developed a matrix of site characteristics for solvents, hydrocarbons, and metals to help select technology and associated delivery approaches.

- Best practices and lesson's learned from thousands of sites have been condensed into this matrix.

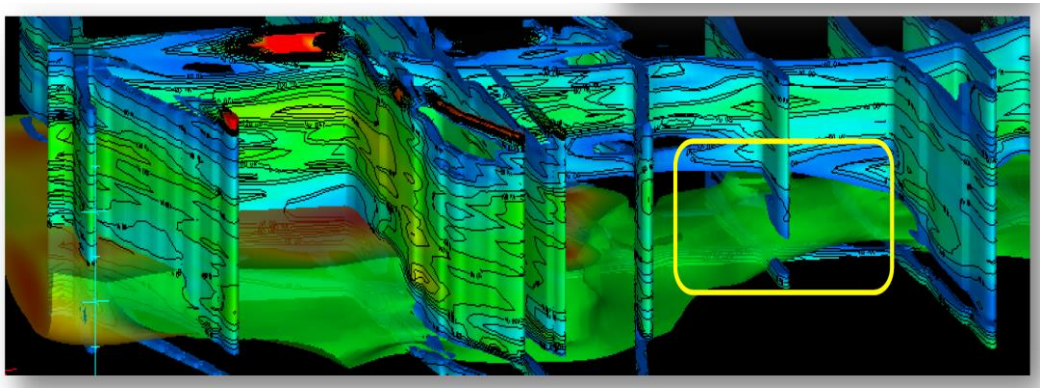
Cascade Matrix - Solvents

	DNAPL and soil metrics		Soil or groundwater metrics		Groundwater metrics		Groundwater metrics	
Technologies	Source		Transition		Plume		Receptors	
	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand
Objective	Mass Reduction		Mass Reduction		MNA		MCLS	
DNAPL	Thermal Thermal/ISCO, Thermal/Bio Thermal/ISCR	EZVI, Surfactants, ISCO	NA	NA	NA	NA	NA	NA
PPM < 1% DNAPL Solubility	NA	NA	ISCR, ISCR/Bio, Activated Carbon Based	ISCO, Bio	NA	NA	NA	NA
< PPM	NA	NA	NA	NA	NA	Bio, PRB ZVI, PRB, ZVI/Bio, PRB Bio, PRB Activated Carbon Based	NA	PRB ZVI, PRB ZVI/Bio. PRB Bio, PRB Activated Carbon Based PRB ISCO Solid
Delivery	Source		Transition		Plume		Receptors	
	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand
DNAPL	ThermalWells	Injection, Emplacement, Fluidization, Recirculation	NA	NA		NA	NA	NA
PPM < 1% DNAPL Solubility	NA	NA	Soil Mixing, Emplacement	Injection, Recirculation	NA	Emplacement, Injection, fluidization	NA	NA
< PPM	NA	NA	NA	NA	NA	Emplacement, Injection, fluidization		Emplacement, Injection, Fluidization
HRSC	Source		Transition		Plume		Receptors	
	Clay	Sand	Clay	Sand	Clay	Sand	Clay	Sand
Objective	Mass, Lithology, K, Flux		Mass, Lithology, K / Flux		Flux		MCLs	
DNAPL	MiHPT, Soil/Mobile Lab, Dye-LIF, FLUTe	MiHPT, Soil/Mobile Lab, Waterloo/Mobile Lab, Dye-LIF	NA	NA	NA	NA	NA	NA
PPM < 1% DNAPL Solubility	NA	NA	MiHPT, Soil/Mobile Lab	MiHPT, Soil/Mobile Lab, Waterloo/Mobile Lab	NA	Waterloo/Mobile Lab	NA	NA
< PPM	NA	NA	NA	NA	NA	Waterloo/Mobile Lab	NA	Waterloo/Mobile Lab

A Closer Look – Source & Transition Zones

	Soil or groundwater metrics	
Technologies	Transition	
	Clay	Sand
Objective	Mass Reduction	
DNAPL	NA	NA
PPM < 1% DNAPL Solubility	ISCR, ISCR/Bio, Activated Carbon Based	ISCO, Bio
< PPM	NA	NA
Delivery	Transition	
	Clay	Sand
DNAPL	NA	NA
PPM < 1% DNAPL Solubility	Soil Mixing, Emplacement	Injection, Recirculation
< PPM	NA	NA

HRSC	Transition	
	Clay	Sand
Objective	Mass, Lithology, K / Flux	
DNAPL	NA	NA
PPM < 1% DNAPL Solubility	MiHPT, Soil/Mobile Lab	MiHPT, Soil/Mobile Lab, Waterloo/Mobile Lab
< PPM	NA	NA



Digging Deeper Into Matrix - Heterogeneity

	DNAPL and soil metrics			
Technologies	Source			
	Clay	Hetrogenenous		Sand
Objective	Mass Reduction			
DNAPL	Thermal	Thermal/ISCO, Thermal/Bio Thermal/ISCR	EZVI, ISCO	EZVI, Surfactants, ISCO
PPM < 1% DNAPL Solubility	NA			NA
< PPM	NA			NA

Digging Deeper Into Matrix - Delivery Technologies

	Drilling Approach	Delivery Tooling
Direct-Push Hydraulic Injection	Direct-Push	Custom top-down & bottom up injection screens or tips
Sonic Hydraulic Injection	Sonic	Custom top-down & bottom up injection screens or tips
Pneumatic Enhanced Fluidization	Sonic, Auger,	Custom nozzle between inflatable packers in open borehole
Pneumatic Emplacement	8040 Casing, Sonic Casing, Auger,	Custom nozzle between inflatable packers in open borehole
Direct-Push Hydraulic Emplacement	Direct-Push	Custom top-down & bottom up injection screens or tips
Hydraulic Emplacement	8040, Sonic, Auger	Custom nozzle between inflatable packers in open borehole

Digging Deeper Into Matrix – Delivery Technology Considerations

DPT	Wells	Emplacement
Top Down / Bottom Up	Diameter	Top Down / Bottom Up
Screened or targeting tools	Screen Size	DPT Vs Straddle Packers in Open or Cased Boreholes
Screen length	Sand Size	
Tool Diameter	Construction Pressure Considerations	
Inner Screens	Packers	
Inner Hose to Maintain Pressures	Nesting	
	Horizontal vs Vertical	

Digging Deeper Into Matrix – Injection, Fluidization, Emplacement

CONSIDERATIONS	EMPLACEMENT METHOD	
	HYDRAULIC	PNEUMATIC (Nitrogen)
Emplacement Pattern	• Larger lateral	• Micro network
Emplacement Tendency	• Creates new	• Dilate and propagate interstitial paths in **bedding planes**
Lithology	• **Silts, clays & weathered bedrock**	• **Well-suited to "self-propping" lithologies, e.g. fractured rock**

Digging Deeper Into Matrix - Delivery Design Considerations

Design Parameter	Considerations
Radius of Influence or Spacing	Soil and Groundwater Volume Around Delivery Location that is Treated
% Pore Volume Injected	Controlled Distribution Via Injection or Emplacement Vs Advection through Seepage Velocity or Diffusion
Flow Rates	Fracturing, Mounding, Day Lighting
Down Hole Pressure	Fracturing, Day Lighting
Heterogeneity	Target Transmissive, Low Perm, or Both
Sequencing	Outside In, Skipping Locations To Minimize Mounding or Day Lighting, Offsetting Locations For Future Events

ROI Design Best Practice

< Fracture Pressure (~ *0.5 to 2 PSI/ft Overburden*)

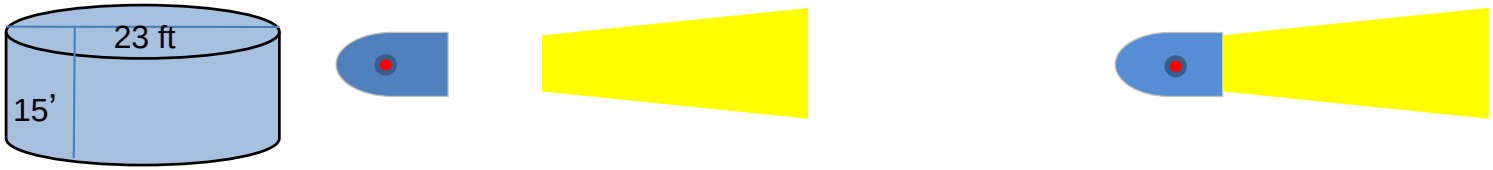
Distribution Through Injection		
Reagent Per Location	Injection Volume as a % of Effective Pore Volume	Distribution ROI
1675 gals	**20%**	**3.5 feet**

+

Distribution through Advection	
Additional ROI from Advection (Feet) **0.5 foot/day Seepage Velocity**	**Time Frame To Achieve Advection ROI (Days)**
8 feet	**Days**

=

ROI
11.5 feet



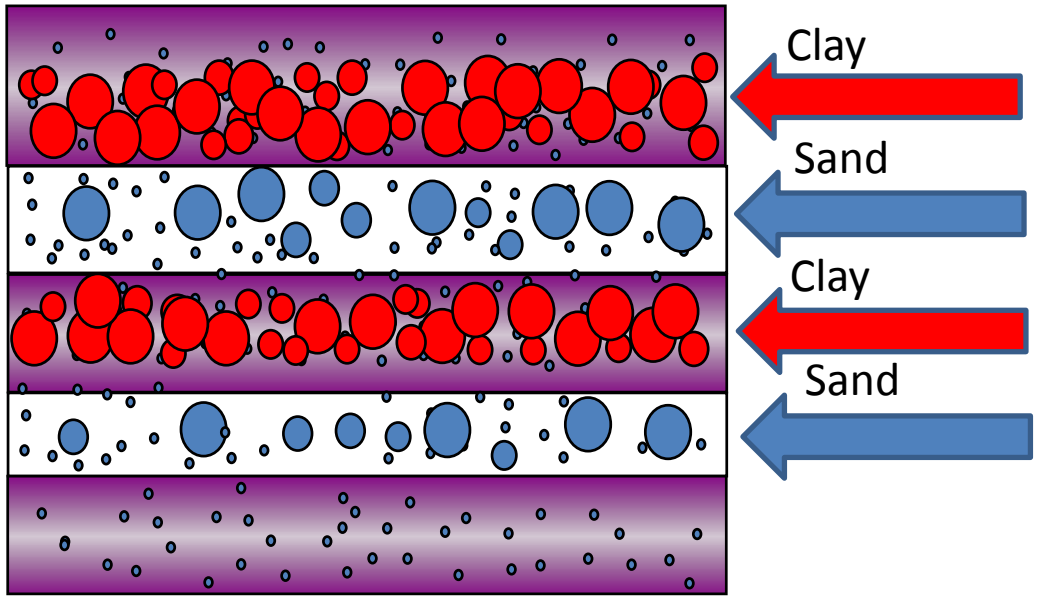
11.5 feet = 3.5 feet + 8 feet @ 16 days

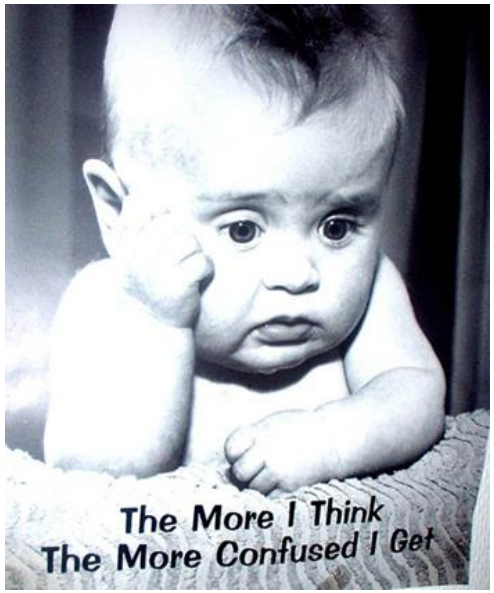
Make Sure Reagent Residence Time Within ROI Volume Will Result in Destruction Considering Kinetics

Delivery Conundrums - ROI

- Low Seepage Velocity, Higher Residence Time But a High Pore Volume For Contact
- High Seepage Velocity, Lower Pore Volume for Contact, but Lower Residence Time

Delivery Conundrums - Heterogeneity





Delivery Optimization with HRSC

HRSC Data	Contaminant Mass	Geo/Hydro	Resolution
Mass Vs Electrical Conductivity (msm)	Source to Plume	Clay to Sands	Continuous logging
Mass Vs Relative K (ft/day)	Source to Plume	Seepage Velocity	Continuous Logging

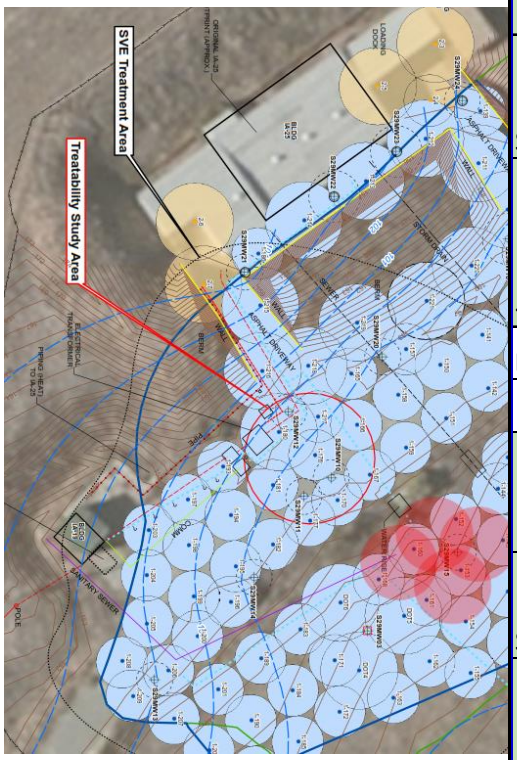
HRSC	Source	
	Clay	Sand
Objective	Mass, Lithology, K, Flux	
DNAPL	MiHPT, Soil, Mobile Lab, Dye/LIF, FLUTe	MiHPT, Soil, Waterloo, Mobile Lab Dye/LIF
PPM < DNAPL Solubility	MIHPT, Soil, Mobile Lab	MIHPT, Soil, Waterloo, Mobile Lab
< PPM	NA	NA

The more vertical resolution, the higher probability the delivery approach will result in contact with adequate residence time required for destruction

Matrix Example – Concord NAWS

Legend

- Phase I Performance Monitoring Well
- Phase II Performance Monitoring Well
- Sentinel Well
- Plume Monitoring Well
- Design Optimization Monitoring Well



	Soil or groundwater metrics		Groundwater metrics	
Technologies	Transition		Plume	
	Heterogeneous	Sand	Heterogeneous	Sand
Objective	Mass Reduction		MNA	
DNAPL	NA	NA	NA	NA
PPM < DNAPL Solubility	ISCR, **ISCR/Bio,** Activated Carbon Based	ISCO, Bio	NA	NA
< PPM	NA	NA	NA	Bio, PRB ZVI, PRB, ZVI/Bio, PRB Bio, PRB Activated Carbon Based
Delivery	Transition		Plume	
	Heterogeneous	Sand	Heterogeneous	Sand
DNAPL	NA	NA		NA
PPM < DNAPL Solubility	Soil Mixing, **Emplacement**	Injection	NA	Emplacement, Injection, fluidization
< PPM	NA	NA	NA	Emplacement, Injection, fluidization

Project Overview

Site Data

- TCE treatment is >700 feet long and extends up to 95 feet bgs
- Aquifer consists of interbedded silts, sands and clays.
- Max TCE concentration 6 mg/L. Very little 1,2-DCE. No VC
- Aquifer is highly aerobic (~ 4 to 7 mg/L DO)
- Dhc not present

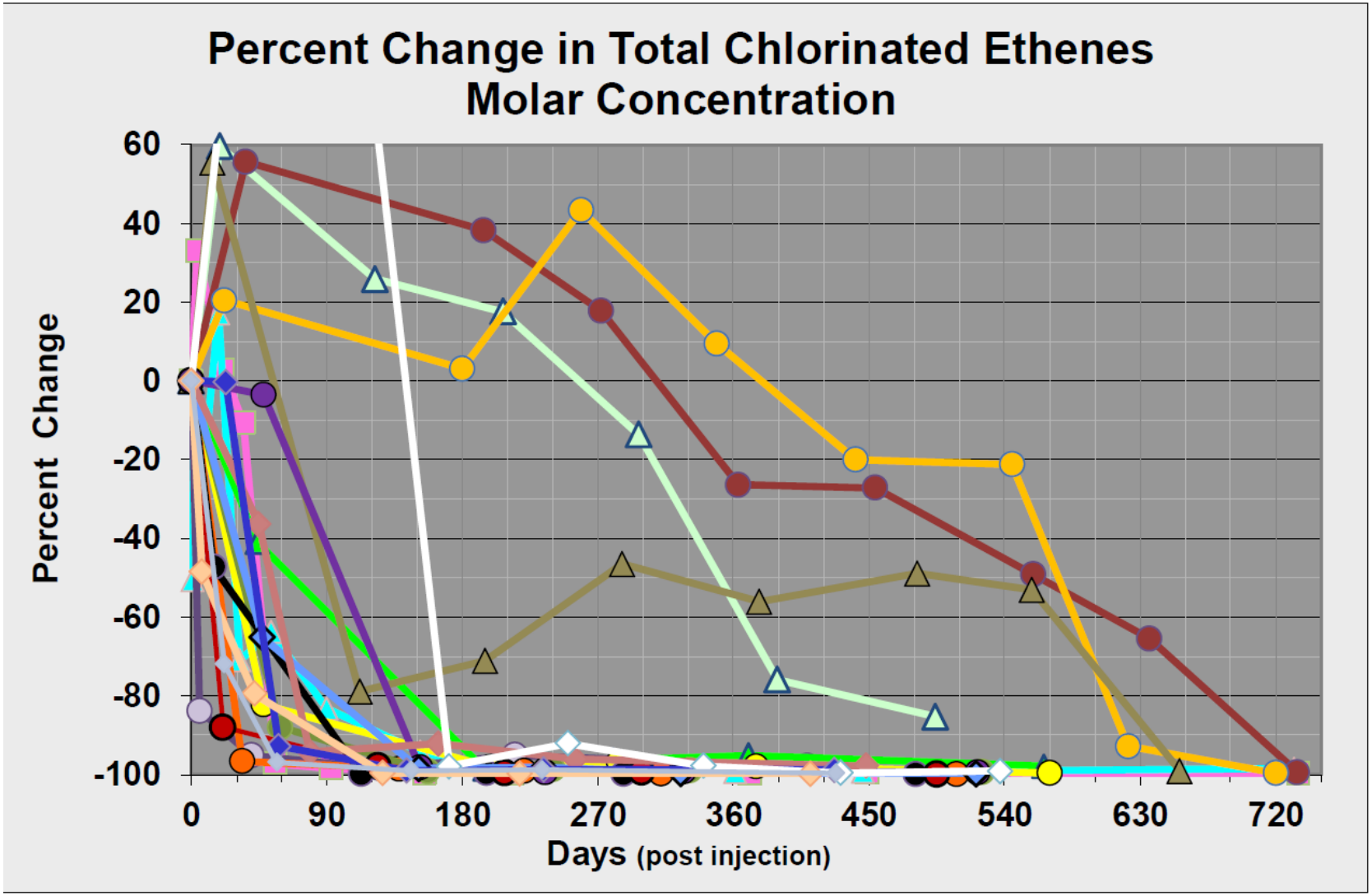
Delivery Approach

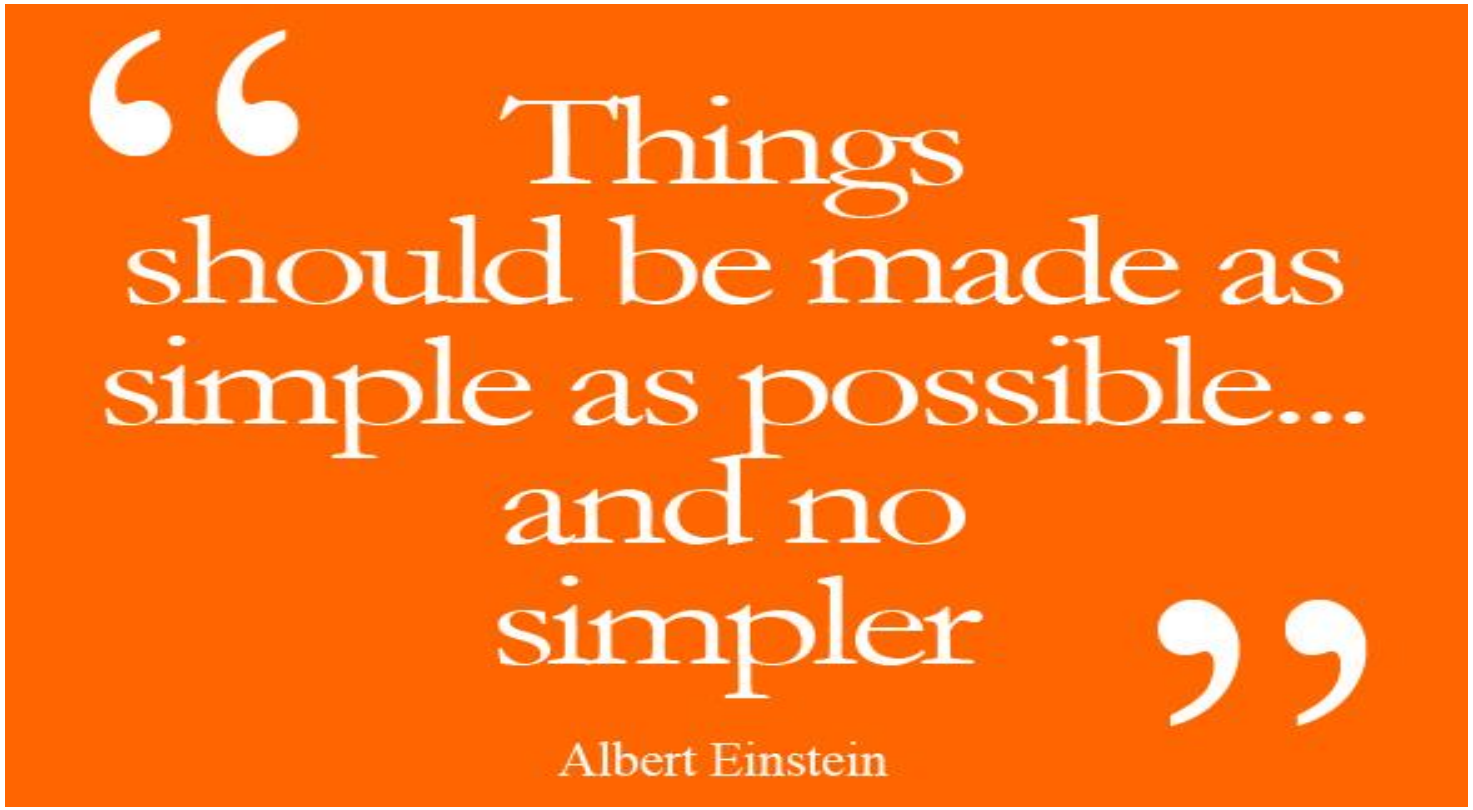
- Hydraulic Emplacement
- DPT Delivery

Amendments

- Injection water preconditioned with sodium lactate
- Emulsified Lecithin Substrate (ELS)
- Bioaugmentation (SDC-9™)
- Zero Valent Iron (ZVI) suspended in guar

Results


Percent Change in Total Chlorinated Ethenes
Molar Concentration
Percent Change
60
40
20
0
-20
-40
-60
-80
-100
0
90
180
270
360
450
540
630
720
Days (post injection)


“ Things should be made as simple as possible... and no simpler ”
Albert Einstein