OBTAINING HIGH-RESOLUTION DATA TO DEMONSTRATE BOS 100® PERFORMANCE IN A LARGE TCE PLUME WITH EXTENSIVE DNAPL PRESENT

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COLORADO BROWNFIELDS CONFERENCE

RIDING THE WAVE OF REDEVELOPMENT

CDPHE

COLORADO
Department of Public Health & Environment

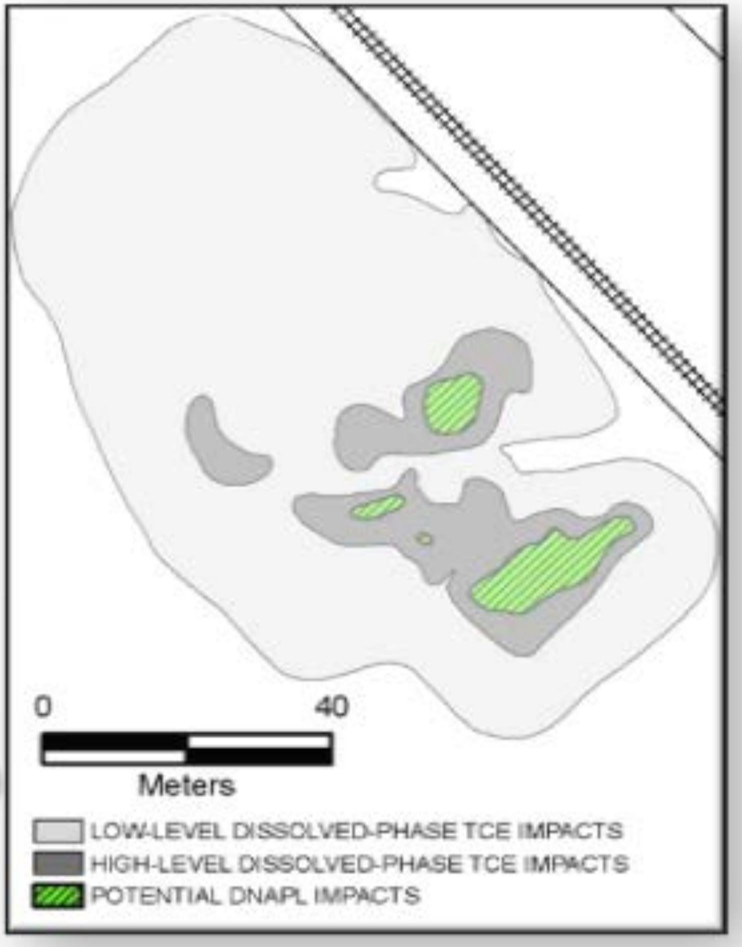
Presented by ***LT Environmental, Inc.***

Agenda

- Background
- Conceptual Site Model
  - Delineation of Nature & Extent of Impacts
  - Mass Flux & Mass Discharge
  - Challenges
- Remedial Technology (BOS 100®)
  - The Trap
  - The Treatment
  - Design
- Remedy Implementation
- Performance Monitoring
- Final Results
- Desired Outcome - Site Closure

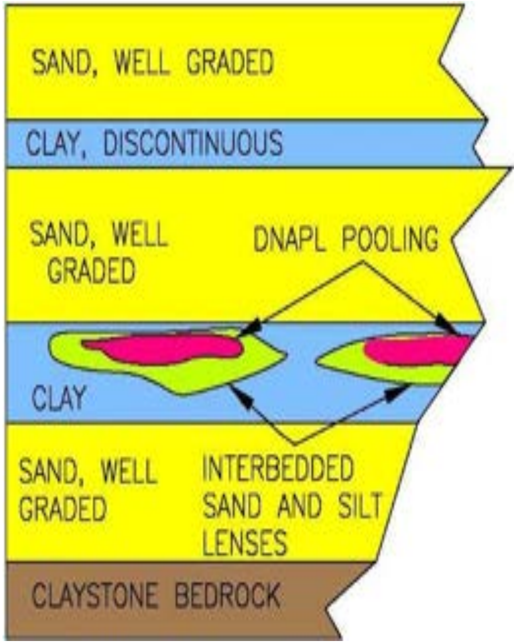
Background

- Former manufacturing facility in a major metropolitan area
- Decades of TCE tankage spills and line releases resulted in 2,500 ft^2 DNAPL plume and 67,000 ft^2 dissolved-phase plume
- TCE in soil up to 54,450,000 µg/kg
- TCE in groundwater up to 1,280,000 µg/l



Background

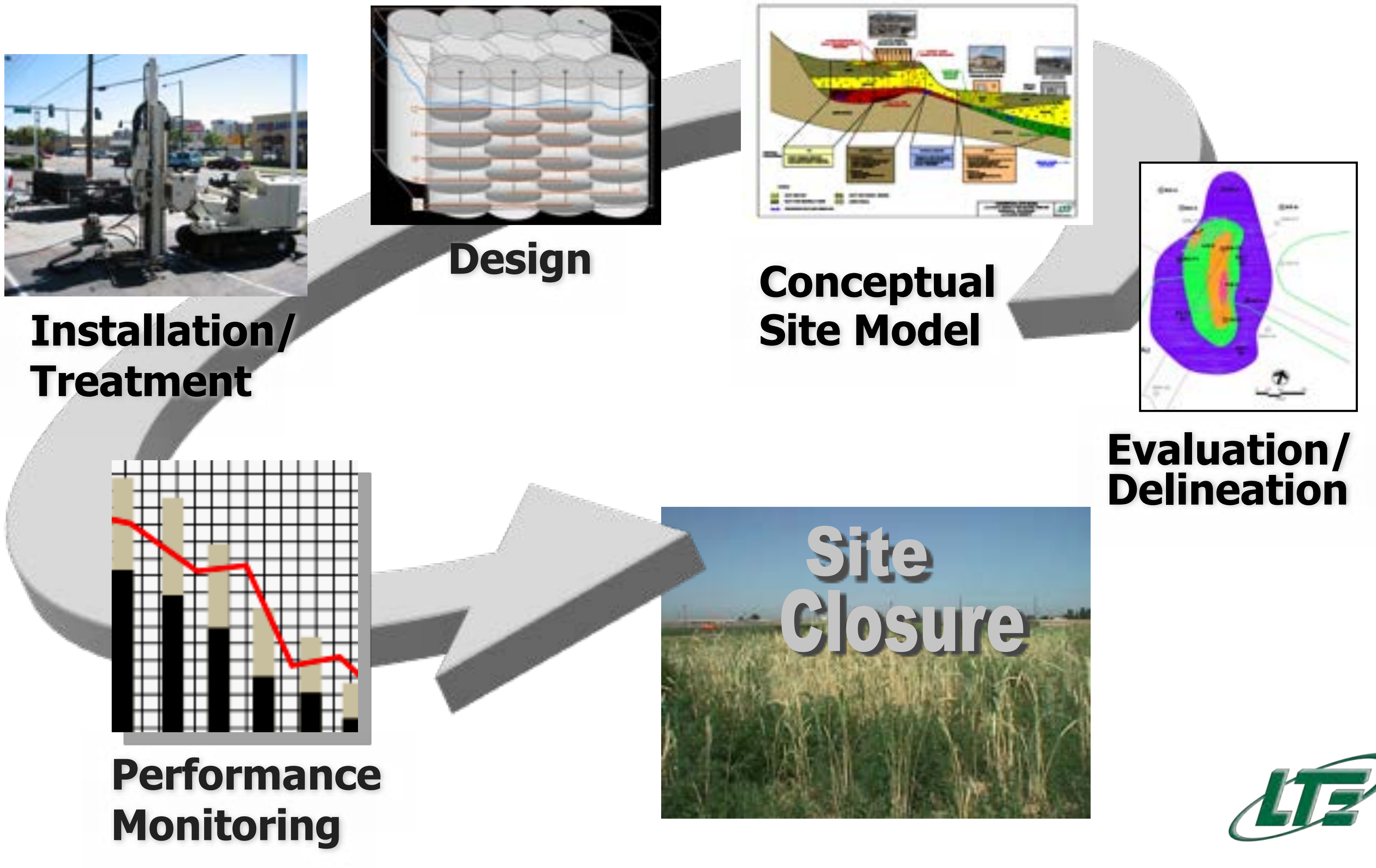
- Site underlain by ~56 ft of alluvium overlying bedrock
- ~ 15 ft aquitard (Si, CL) within alluvium beneath source area
- Impacts did not extend into underlying Claystone



IMPACTFUL AQUIFER CHARACTERISTICS

- Anisotropy and heterogeneity due to variance in matrix density and grain size
- Very small gradient caused solute distribution and flow direction to be unpredictable

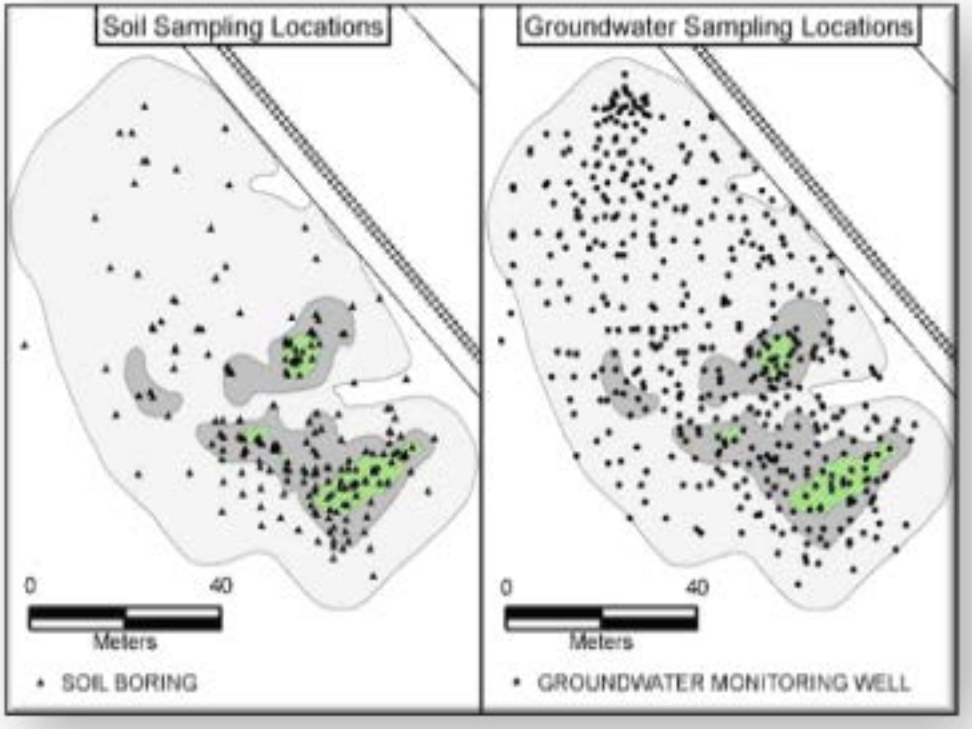
Conceptual Site Model



Conceptual Site Model

Delineation

- A rapid closure strategy requires high-resolution data to fully characterize nature and extent of impact
- DPT used to complete 186 soil borings and 1,349 monitoring wells



- In DNAPL areas, soil data used to characterize sorbed and dissolved-phase impacts to saturated samples
- GW data used to characterize extent of desorptive partitioning

Conceptual Site Model

Delineation

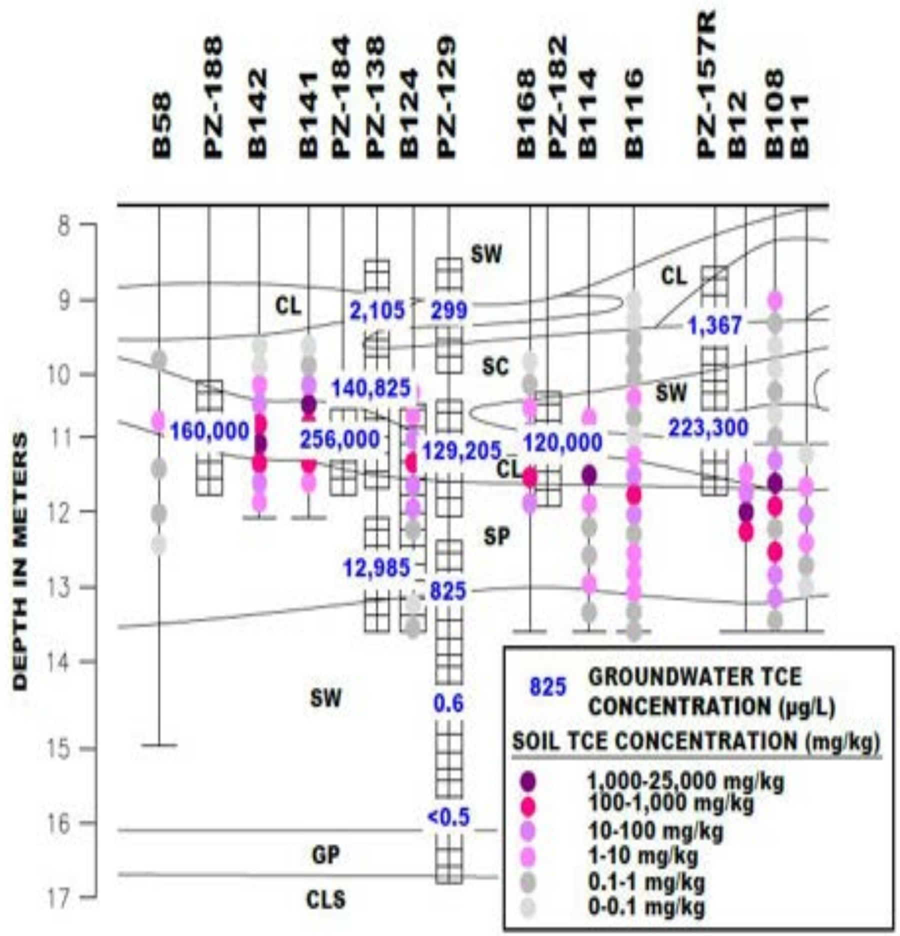
- 1,291 continuous soil samples analyzed to generate vertical profiles of pre-treatment solute distribution and post-treatment BOS 100®
- 5,515 GW samples used to evaluate plume strength and solute distribution by advective & dispersive transport
- TCE concentrations varied 5 orders of magnitude within 5-6 inches through preferential pathways that steered solute circuitously through the matrices, but with apparent precision

Boring ID: B108	
Depth (meters)	TCE Results (µg/kg)
9.26-9.32	8,067
9.57-9.63	115
9.87-9.93	55
10.18-10.24	93
10.6-10.63	512
10.78-10.85	97
11.09-11.15	428
11.43-11.49	53,760
11.55-11.61	25,477,000
11.67-11.73	915,300
12-12.07	193
12.31-12.37	180,190
12.55-12.61	42,367
12.92-12.98	23,210
13.35-13.47	428

Conceptual Site Model

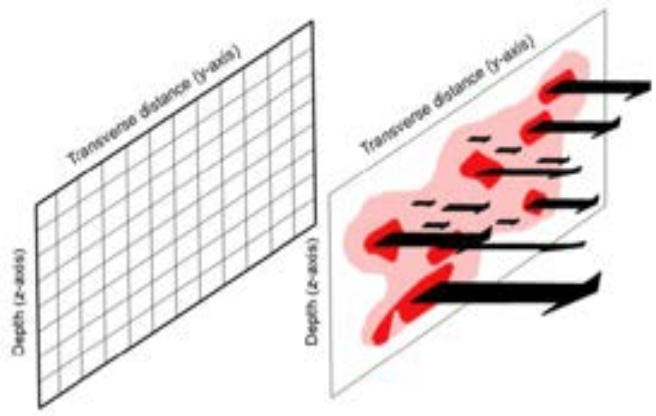
Delineation

- Many wells were nested to evaluate vertical distributions and vertical flow characteristics
- Detailed cross-sections initially used to identify data gaps
- Then orthogonal cross-sections used as transects to quantify source-zone & plume strength
- Plume stability of less concern because of site-wide treatment



Conceptual Site Model

Mass Flux & Mass Discharge



- Mass flux used to identify variability in solute conc's and the transmissive zones transporting bulk of mass
- Mass discharge measurements used to ensure target levels maintained at downgradient property boundary
- Evaluate plume architecture (solute distribution dictated by heterogeneity)
- Evaluate plume strength (contaminant mass moving per unit time)

Conceptual Site Model

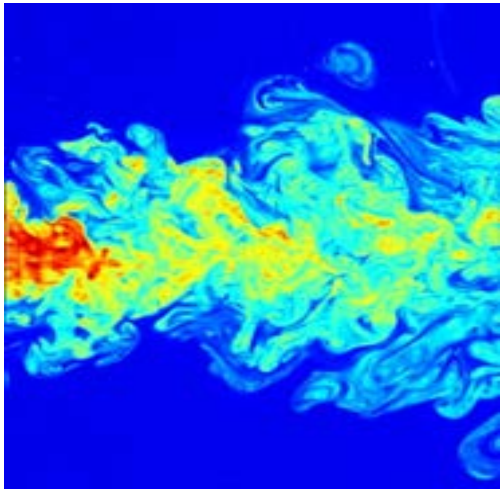
Mass Flux & Mass Discharge

Average Seepage Velocity (v) of Fine-Grained Alluvium	2.35E-07 cm/sec
Average Seepage Velocity (v) of Coarse-Grained Alluvium	2.19E-06 cm/sec
Average Hydraulic Gradient	0.0035 (unitless)
Average Mass Flux From Source Area (Pre-Treatment)	682,185 mg/m^2/year
TCE Mass Discharge From Source Area (Pre-Treatment)	138 kg/year
Average Mass Flux From Source Area (Post-Treatment)	31,984 mg/m^2/year
TCE Mass Discharge From Source Area (Post-Treatment)	6 kg/year
Mass Flux Percent Reduction	95.31 %

- Transect method used for J and M_d in and just downgradient of source and along plume to evaluate remedy performance
- Seepage velocity at individual wells using equilibrium flow-rates from low-flow sampling and associated TCE analytical results
- J spatial and temporal variations can be significant due to variations in conc's and GW flow magnitude and direction
- M_d can only vary over time since only a single value for entire transect

Conceptual Site Model

Challenges

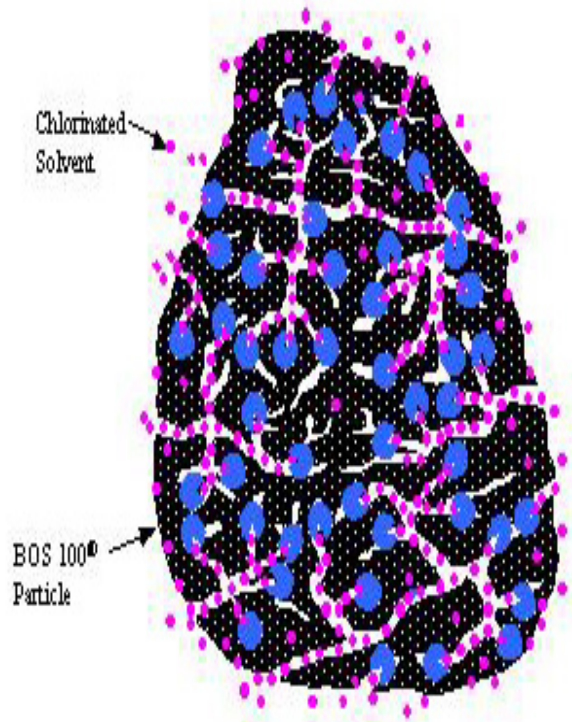


- Treatment unsuccessful due to data gaps from using standard methods. Inaccurate CSM overcome by obtaining high-resolution data
- Shifted focus to saturated soil impacts and didn't base injection loadings on GW conc's only
- Well-graded granular matrix strained out solid BOS 100® (not a miscible fluid)
- Overcame problem using high-pressure (2,050 psi), high-flow rate (250 gpm) pump to jet the slurry
- Mechanical mixing by "fluidizing" the sand matrix

Remedial Technology

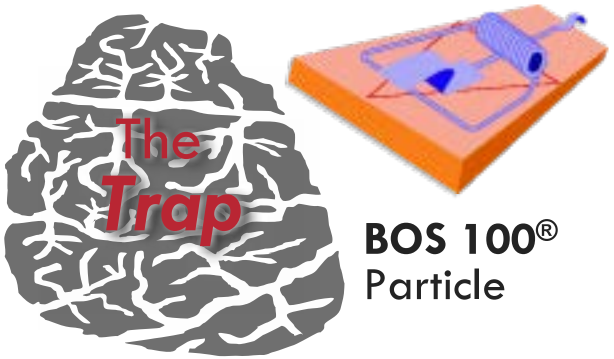
BOS 100® is granular activated carbon impregnated with nano-scale, reactive iron

- Indiscriminate - activated carbon removes virtually all organics, whether in vapor, solid, or aqueous phase
- Efficient destruction of chlorinated solvents via reductive dechlorination
- Effective in the saturated and unsaturated zones
- Works in multiple site conditions - dispite pH, dissolved O_2 levels, microbial or substrate deficiencies



BOS 100® - The Trap

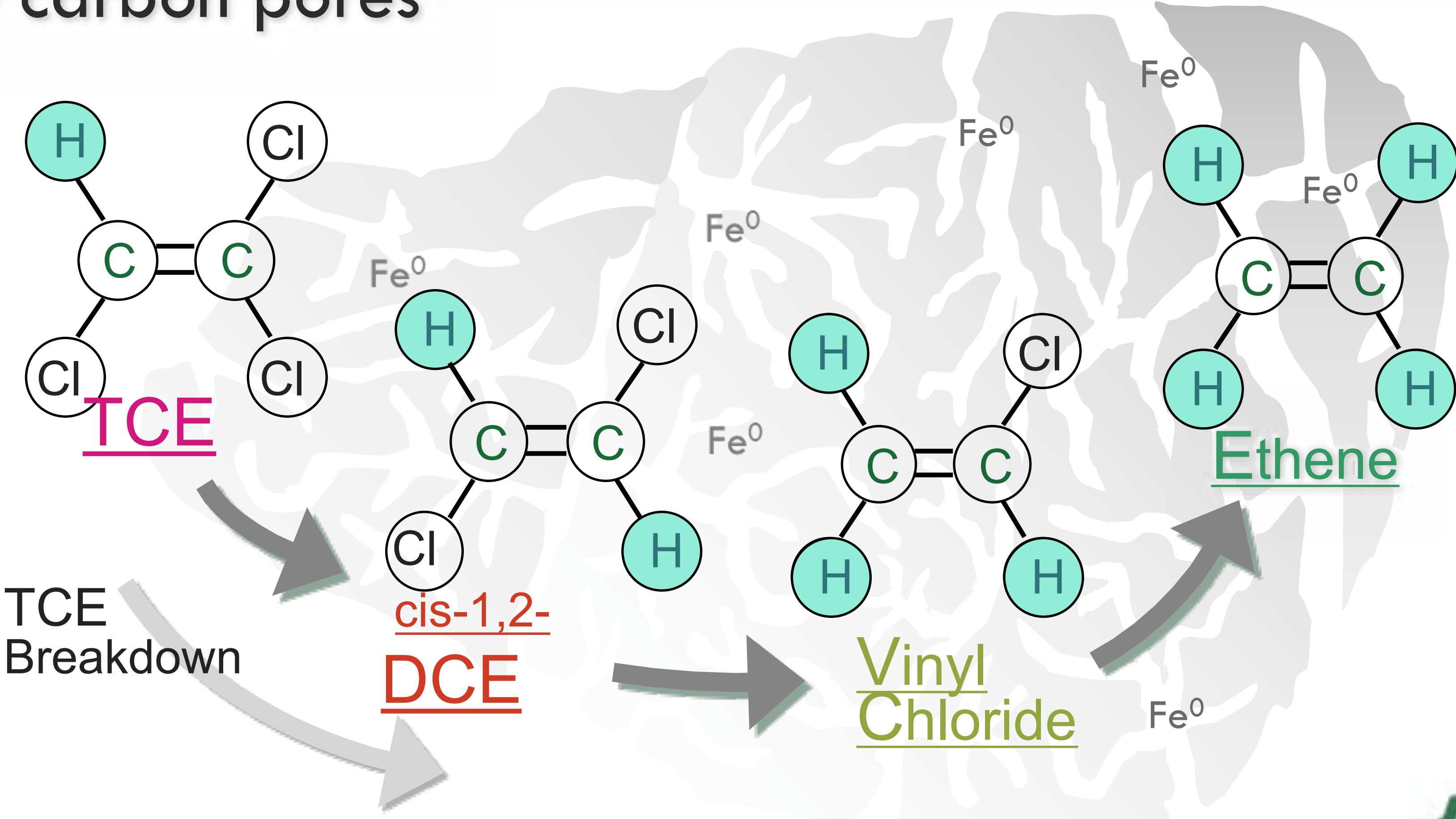
Activated Carbon



- History of use dates back over 2,000 years
- "Laws of nature" make it work every time, with immediate results in vapor, soil, and water
- Inert, non-toxic material that does not degrade
- 1 lb. of carbon = 5.5 million ft^2 of surface area
- Co-locates contaminants with reactive iron for more effective and faster treatment

BOS 100® - The Treatment

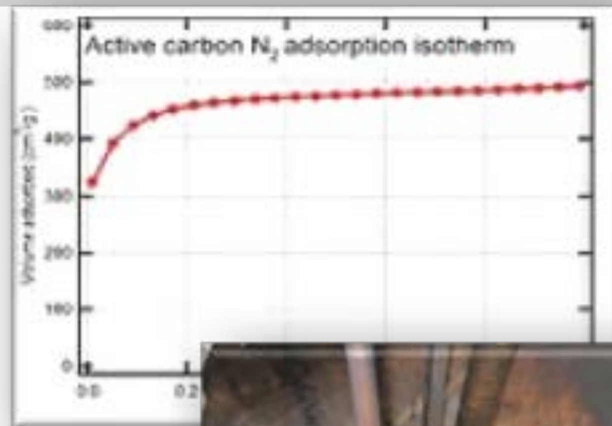
Dechlorination via a **surface chemical reaction** within the carbon pores

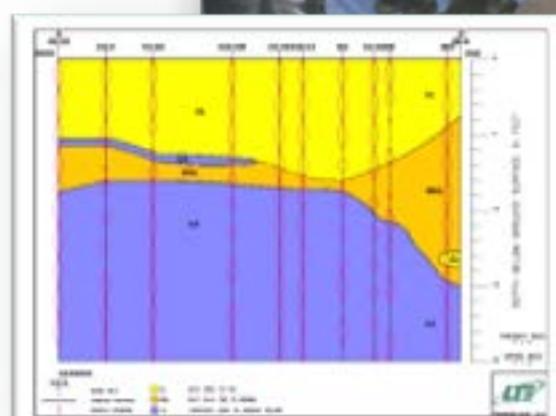


BOS 100® - How To Do It

Design

- Based on carbon adsorption (Freundlich Isotherm) and iron demand of the VOCs
- Slurry loading is a volumetric calculation based on grid dimension and solute concentration
- Detailed cross-sections and high-resolution soil and GW data used to select target injection locations

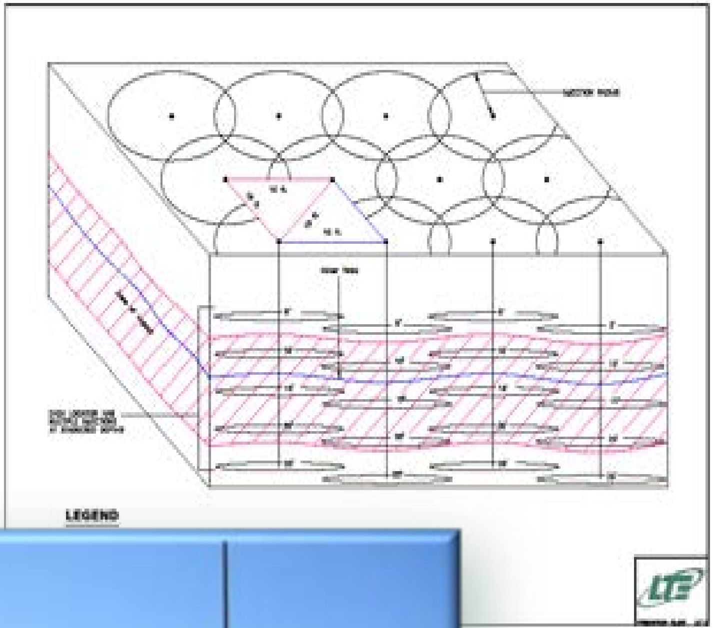




Remedy Implementation

Injection Grids

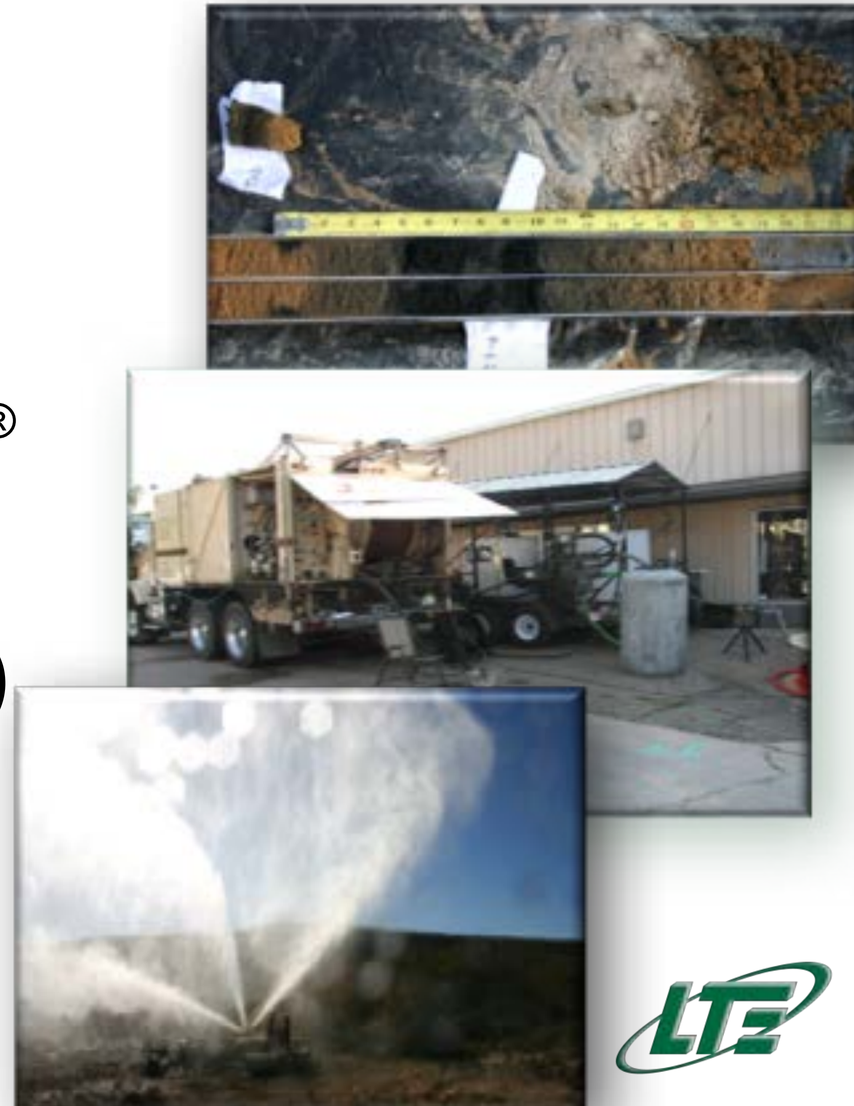
- Cartesian grids with offset rows or radial grids when solute distribution was unpredictable due to shallow gradient (1.6 E 10^{-3} ft/ft)
- Staggered vertical intervals
- Results in "lace-like" distribution with **remedy delivered throughout the plume**
- Pin-point design with surgical implementation or matrix vagaries & nuances cause persistence and project failure



Remedy Implementation

Multiple Phases

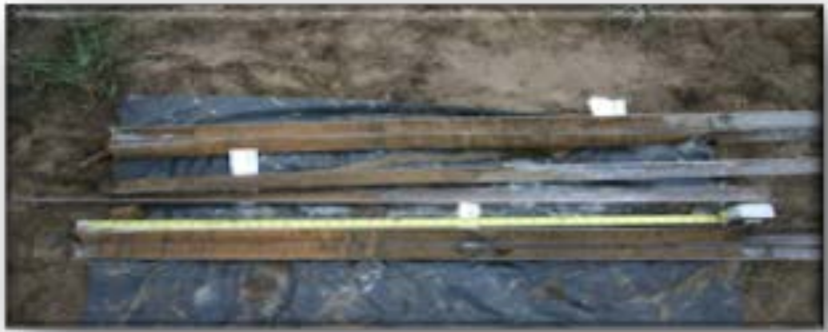
- High-resolution data needed because of complex system of preferential pathways
- High-resolution data allowed for precision placement of BOS 100®
- Where high loadings required, guar was added to increase slurry density (could put 2X more)
- Other distribution challenges overcome by HP/HF pump and variety of injection tips with velocities of 200 – 350 ft/s



Performance Monitoring

Methodologies

- GW sampling before, during, and after injection to monitor remedy performance
- Next-day results allowed for "nimble" design revisions
- M_d calculated periodically to monitor mass reduction (diminished plume strength over time) ensuring property-boundary compliance
- Continuous confirmatory soil borings to document solute mass reduction (especially in DNAPL areas)
- Forensic drilling to observe if BOS 100® seams present



Performance Monitoring

ASSESSMENT SOIL BORING

PID Reading (ppm)	TCE Analytical Result (ug/kg)	Depth (meters)	Sample Run	Recovery	Soil/Rock Type
1	512				CL
ND	97	11.0			ML
1	---				
333	428	11.3			CL
9	---			60"	
9,999+	**25,477,000**	11.6			
390	**915,300**				ML
124	---	11.9			CL
4	193				
9	---	12.2			ML
109	180,190				SP
110	---	12.5			
761	42,367				
455	---	12.8			
57	23,210			60"	
22	---	13.1			
13	---				
40	428	13.4			ML
13	---				
2	---	13.7			

INJECTION INTERVALS

Depth (meters)	BOS-100® Injectate Loading (kg)
10.85	18.2
11.00	18.2
11.15	18.2
11.30	25
11.45	181.8
11.60	**181.8**
11.75	**181.8**
11.90	36.4
12.05	18.2
12.20	25
12.35	36.4
12.50	18.2
12.65	---
12.80	---
12.95	18.2
13.10	18.2
13.25	18.2
13.40	---
13.55	---
13.70	18.2

POST-INJECTION BORING

Depth (meters)	BOS-100® Observations
10.85	BOS-100® Observed
11.00	BOS-100® Observed
11.15	---
11.30	BOS-100® Observed
11.45	BOS-100® Observed
11.60	BOS-100® Observed
11.75	BOS-100® Observed
11.90	BOS-100® Observed
12.05	BOS-100® Observed
12.20	---
12.35	---
12.50	BOS-100® Observed
12.65	---
12.80	---
12.95	---
13.10	BOS-100® Observed
13.25	BOS-100® Observed
13.40	---
13.55	---
13.70	BOS-100® Observed

Final Results

Once the Dust Settled

- TCE concentrations in the dissolved-phase plume were below the target level of 100 µg/l
- Former DNAPL area relegated to dissolved-phase. Three quarters of sustained concentrations below the maximum contaminant levels (MCLs)

Well ID	Historical Maximum TCE Result (µg/L)	Recent TCE Result (µg/L)	Percent Reduction
PZ-039	10,100	10	99.90
PZ-040	52,244	98	99.81
PZ-052	106,250	6	99.99
PZ-055	1,280,000	4	100.00
PZ-125R	30,695	55	99.82
PZ-127	149,260	84	99.94
PZ-138	140,825	39	99.97
PZ-154	589,870	78	99.99
PZ-156R	594,125	6	100.00
PZ-157R2	210,000	62	99.97
PZ-165R	27,000	14	99.95
PZ-175	59,520	40	99.93
PZ-182	120,000	58	99.95
PZ-184	256,000	27	99.99

- TCE concentrations at the property boundaries were also below the MCLs

Desired Outcome

Site Closure

- Closure requirements have been met and include institutional controls (deed restriction for future use of groundwater) and engineering controls (vapor mitigation system required for all new construction)
- Following a year-and-a-half of closure monitoring (6 quarterly events), the State has granted a "No Action Determination" for the site

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