Remediation of BTEX in Shallow, Silty Clay Soil – Successes and Insights

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What We Want to Learn?

Complexities of Nature

Treatment Train Options

Real Solutions

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Background

- Fuel release discovered in May 1998 during soil probe investigation for property transfer.
- Three on-site storage tanks contained unleaded gasoline.

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Background (continued)

- Active facility [fueling station]
- Small site, 0.3 acres [300 ft x 400 ft]
- Shallow groundwater [5 to 8 ft bgs]
- Silty clay soil [0 to 20 ft bgs]
- BTEX and MTBE are chemicals of concern

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Factors Affection Strategy Selection

- Ownership: Responsible Party not current owner; facility closure/demolition not an option.
- Minimize community concerns: noise, odors, aesthetics, safety.
- Minimize waste generation: soil, wastewater, and air emissions.
- Minimize cost: State-funded site sought lower-cost, non-innovative options.

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A 20-Year Subsurface Remediation Treatment Train

Typical Treatment Options

- Free Product Recovery
- Soil Excavation and Off-Site Disposal
- Pump & Treat Groundwater
- In-Situ Chemical Oxidation (ISCO)
- Air Sparging/Soil Vapor Extraction (AS/SVE)
- In-Situ Chemical Reduction (ISCR)
- Vacuum Enhanced Recovery (VER)
- Monitored Natural Attenuation (MNA)

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Free Product Recovery

- The Engine: Free product recovery
- Two inches of free product measured at one well (MW-4) in 1999.
- Free product recovered using passive and active bailing methods due to limited free product depth and soil type.
- Regulation required free product recovery before further active remediation.

Free Product Recovery - Results

- 0.55 gallons free product recovered
  - 0.5 gallons recovered at first event in November 1999.
  - 0.05 gallons recovered after that through September 2000; none afterwards.
- Free product recovery officially ceased October 2002.

Excavation Soil and Off-Site Disposal

- Too disruptive at active facility.
- Existing small business would be adversely affected.
- Not viable: Release this car.

Pump & Treat Groundwater

- Technology proven historically to be ineffective for removing BTEX in silty clay soil to achieve risk-based criteria.
- Local city wastewater utility not willing to accept groundwater discharge.
- Trucking to more distant discharge too expensive.
- Not viable: Release this car.

In-Situ Chemical Oxidation – H_2O_2

- **Car 1**: Solar-powered system installed August 11-14, 2003 injected dilute (4-8%) hydrogen peroxide.
- 30 wells installed to 1.5 ft; 6 wells to 7 ft.
- No significant wastewater, waste soil, or air emissions.

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ISCO Hydrogen Peroxide - Results

- BTEX risk-based concentrations in vadose achieved.
- BTEX concentrations reduced in groundwater.
- Silty clay soil beneath 1.5-ft injection depth not significantly affected.
- System discontinued November 2011 after 8 years of operation.
- Newly required confirmation sampling in 2012 established soil as long-term risk driver.

Benzene in Soil (mg/kg) - 2013

Air Sparging / Soil Vapor Extraction

- Car 2: ART system evaluated May 29, 2014 – March 11, 2015.
- Soil venting and in-well air sparging and groundwater recirculation to add oxygen to subsurface vadose and saturated soil.
- One 6-inch well installed to 15 feet bgs.
- No significant wastewater or waste soil for disposal or air emissions.

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AS/SVE Pilot Study - Results

- Effective at reducing soil and groundwater concentrations of BTEX.
- Radius of influence limited to 15 to 20 ft.
- Drilling equipment for large-diameter AS/SVE wells cannot fit under fueling canopy where significant BTEX in soil remained.
- The 15-well operation required for full-scale operation would be too expensive compared to other options.

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ISCO/Anaerobic Biodegradation

- **Car 3**: Two injections of Carus Oxygen BioChem (OBC™) with Geoprobe™ (13,700 lb total).
  - July 27-August 6, 2015: 57 points
  - August 23-August 29, 2016: 36 points
- Injection pressures 25 to 225 psig.
- Injection depths 5 to 12 ft bgs.
- Bottom-up approach.

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First OBC Injection Event

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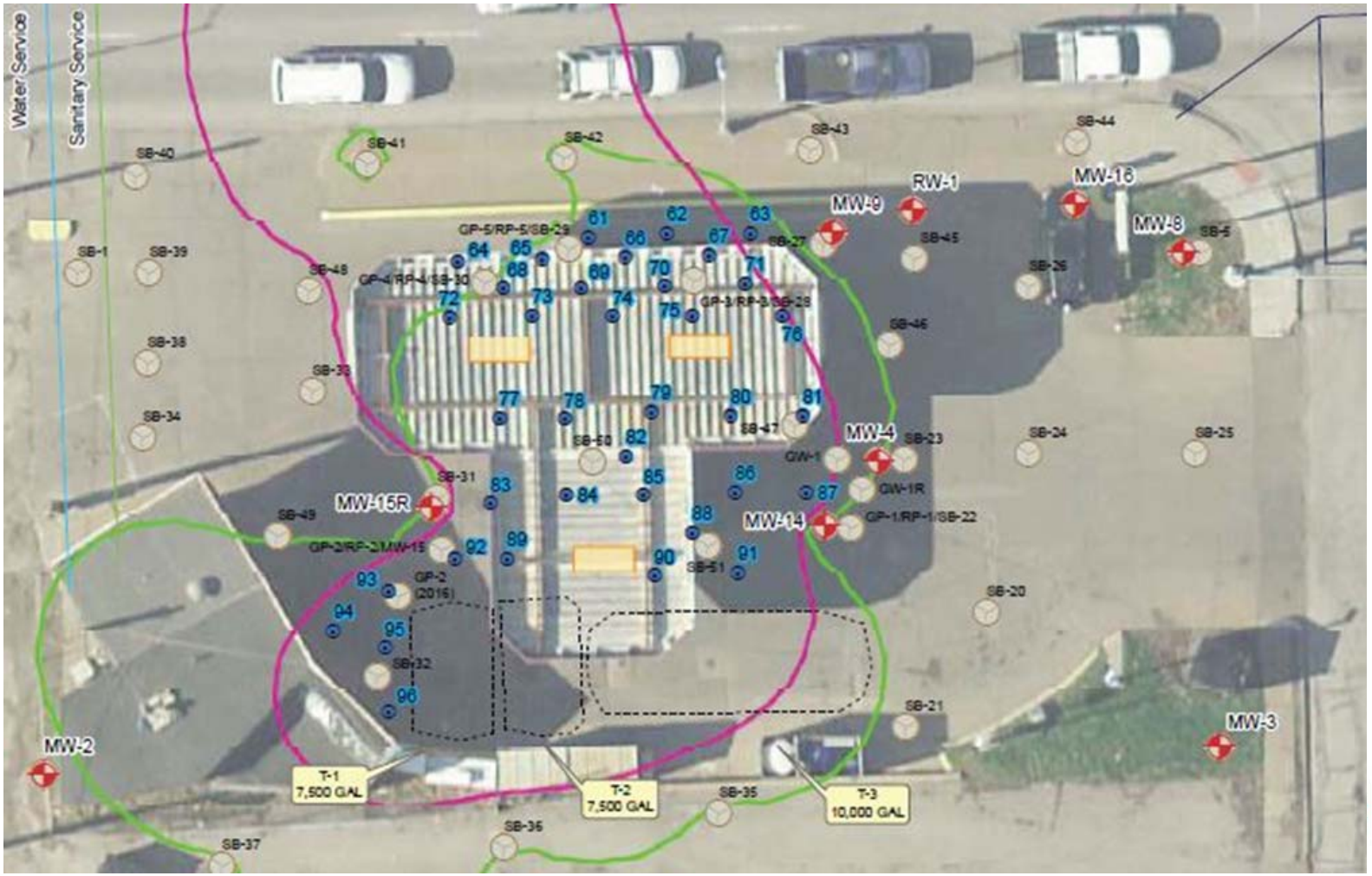
Second OBC Injection Event



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Treatment Results – MW-4

Well ID	Sample Timeframe	Sample Date	Benzene (ug/L)	Xylenes (ug/L)	Dissolved Oxygen (mg/L)	Sulfate (mg/L)
MW-4	Lowest High Risk SSTL		6,514	N/A	N/A	N/A
	Lowest Low Risk SSTL		1,540	N/A	N/A	N/A
	Pre-Pilot	5/30/2012	2,820	11,900	---	---
		9/20/2013	1,360	10,200	---	---
		4/24/2014	1,990	15,800	---	---
	AS/SVE Pilot Study	8/14/2014	920	9,440	---	---
		10/22/2014	859	9,060	1.22	---
		1/22/2015	781	8,430	1.67	---
	Pre-Injection (1st Event)	4/28/2015	856	8,210	1.33	---
		7/27/2015	765	3,780	0.22	<1
	Post-Injection (1st Event)	1/29/2016	711	2,560	1.33	658
		7/11/2016	697	2,700	0.50	1,950
	Post-Injection (2nd Event)	10/11/2016	634	1,830	0.09	2,330
		10/12/2017	331	1,610	0.00	780

Treatment Results – MW-14

Well ID	Sample Timeframe	Sample Date	Benzene (ug/L)	Xylenes (ug/L)	Dissolved Oxygen (mg/L)	Sulfate (mg/L)
MW-14	Lowest High Risk SSTL		4,116	N/A	N/A	N/A
	Lowest Low Risk SSTL		1,540	N/A	N/A	N/A
	Pre-Pilot	5/30/2012	2,380	4,790	---	---
		11/19/2012	2,110	3,010	---	---
		4/25/2013	1,350	6,210	---	---
	AS/SVE Pilot Study	8/14/2014	878	2,270	---	---
		10/22/2014	1,280	4,950	1.88	---
		1/22/2015	1,410	3,830	2.28	---
	Pre-Injection (1st Event)	4/28/2015	1,180	2,110	1.49	---
		7/27/2015	531	8,740	0.20	<1
	Post-Injection (1st Event)	10/6/2015	1,180	1,280	1.16	288
		7/11/2016	505	744	0.04	2,370
	Post-Injection (2nd Event)	10/11/2016	414	562	0.09	1,570
		10/12/2017	553	1,060	0.00	1,420

Treatment Results – MW-15R

Well ID	Sample Timeframe	Sample Date	Benzene (ug/L)	Xylenes (ug/L)	Dissolved Oxygen (mg/L)	Sulfate (mg/L)
MW-15R	Lowest High Risk SSTL		6,529	N/A	N/A	N/A
	Lowest Low Risk SSTL		1,540	N/A	N/A	N/A
	Pre-Pilot	6/4/2012	4,370	10,500	---	---
		11/19/2012	5,830	7,960	---	---
		4/25/2013	5,040	13,900	---	---
	AS/SVE Pilot Study	8/14/2014	2,890	8,360	---	---
		10/22/2014	3,200	8,070	3.11	---
		1/22/2015	2,560	6,200	0.89	---
	Pre-Injection (1st Event)	4/28/2015	2,570	7,430	1.17	---
		7/27/2015	2,600	8,820	0.26	<1
	Post-Injection (1st Event)	10/6/2015	2,500	3,890	1.36	129
		7/11/2016	1,650	2,810	0.03	106
	Post-Injection (2nd Event)	10/11/2016	1,710	1,750	0.07	254
		10/12/2017	1,060	877	0.06	1,080

Treatment Results – MW-9

Well ID	Sample Timeframe	Sample Date	Benzene (ug/L)	Xylenes (ug/L)	Dissolved Oxygen (mg/L)	Sulfate (mg/L)
MW-9	Lowest High Risk SSTL		5,416	N/A	N/A	N/A
	Lowest Low Risk SSTL		1,540	N/A	N/A	N/A
	Pre-Pilot	5/30/2012	9,750	8,240	---	---
		4/25/2013	15,800	9,280	---	---
		4/24/2014	13,000	15,600	---	---
	AS/SVE Pilot Study	8/14/2014	5,530	8,370	---	---
		10/22/2014	2,840	3,620	3.34	---
		1/22/2015	7,590	7,900	0.85	---
	Pre-Injection (1st Event)	4/28/2015	5,510	8,220	1.15	---
		7/27/2015	4,380	10,200	0.26	198
	Post-Injection (1st Event)	10/6/2015	3,190	4,920	1.32	792
		7/11/2016	2,190	2,480	0.08	1,450
	Post-Injection (2nd Event)	10/11/2016	1,410	2,520	0.03	658
		10/12/2017	2,050	2,770	0.00	917

ISCO/ISCR - Results

- BTEX concentrations at monitoring wells decreased.
- Some rebound was observed at some wells.
- Fluctuating BTEX concentrations in groundwater partly due to seasonal water level changes.
- Residual sulfate remained elevated and maintained anaerobic conditions.
- Anaerobic bio slower than aerobic bio.

VER - Description

- **Car 4**: Two one-day events of VER.
  - October 23, 2017
  - November 13, 2017
- MW-4, MW-14, MW-15R, MW-9, MW-17, RW-1.
- Extraction vacuum -18 to -25 psig.
- Extraction depths 5 to 15 ft bgs.
- Q=0.18 to 1.8 cfm; VOCs=376 to 1630 ppmV.

VER – Results

- VER results demonstrated low natural hydraulic conductivity indicative of silty clay soil.
  - Low liquid recovery [450 gallons total groundwater recovered].
  - Low air flow [Q=0.18 to 1.8 cfm].
  - Limited vacuum influence [Less than 20 ft].
  - High noise level.
- No natural fractures or other heterogeneity to enhance recovery.

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Hydraulic Conductivity Estimated

- The most significant site parameter is hydraulic conductivity
- Historic Slug Test Data (typical of sandy silt)
  - MW-4……..1.16 x 10^{-5} cm/sec
  - MW-10……2.19 x 10^{-4} cm/sec (off-site)
  - MW-11……4.06 x 10^{-4} cm/sec (off-site)
- Recent VER Recovery Data (typical of silty clay)
  - MW-14……9.71 x 10^{-7} cm/sec
  - MW-15R…….9.94 x 10^{-7} cm/sec

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The Caboose on this Treatment Train is....

Monitored Natural Attenuation

- Continue bioremediation through anaerobic reductive de-chlorination.
- Utilize semi-annual groundwater sampling and post-event monitoring data to evaluate when the OBC/sulfate concentrations are spent.
- Re-evaluate site risk-parameters including hydraulic conductivity to show potential current and future risks are minimal.

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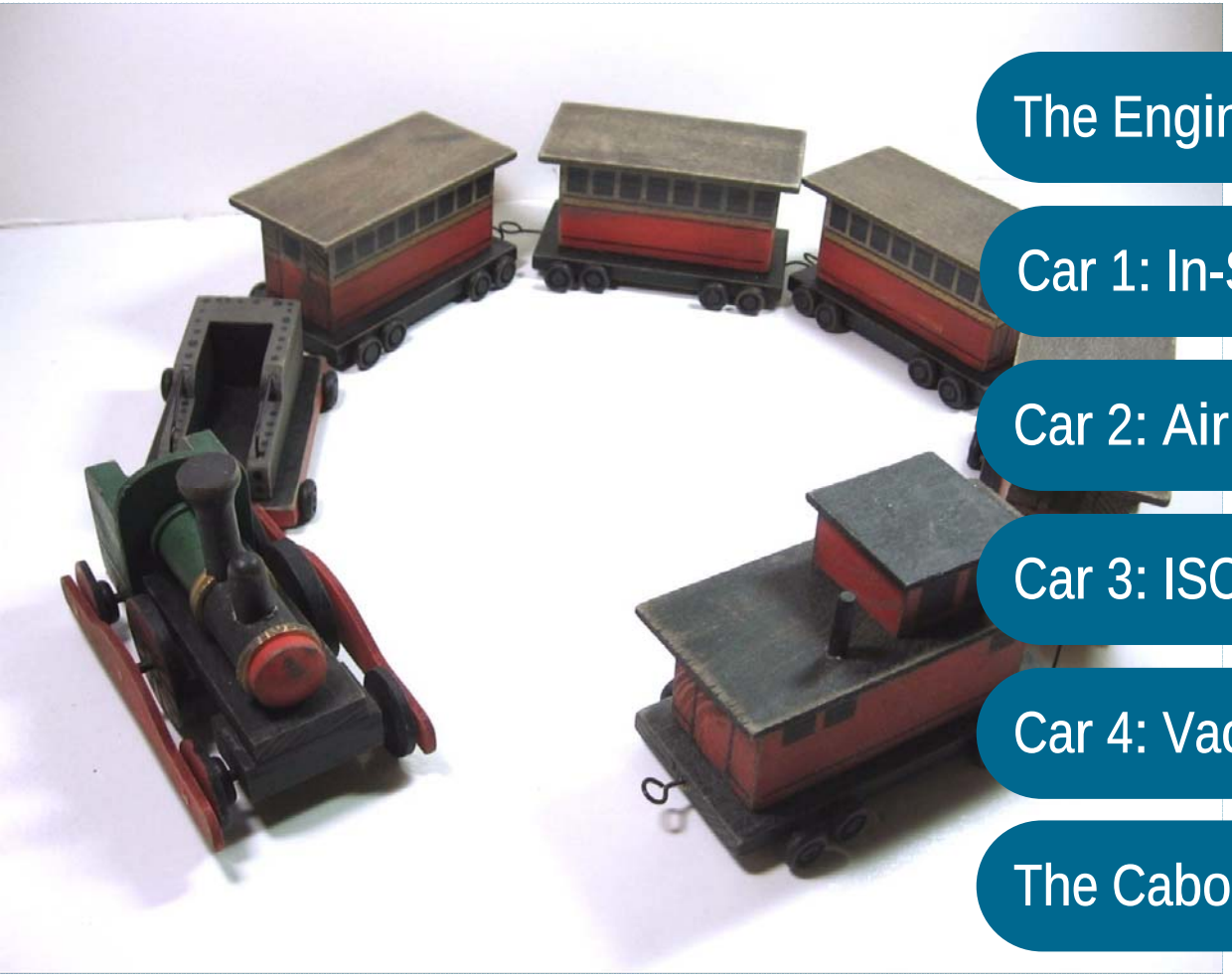
Remediation Treatment Train



- The Engine: Free Product Recovery
- Car 1: In-Situ Chemical Oxidation
- Car 2: Air Sparge/Soil Vapor Extraction
- Car 3: ISCO/Anaerobic Biodegradation
- Car 4: Vacuum-Enhanced Extraction
- The Caboose: MNA

Real Solutions

- **Real solutions** for shallow, silty clay soil **will take time** if access for excavation or active mixing is limited.
- **Real solutions** must determine and incorporate **site-specific considerations.**
- **Real solutions** require frequent re-evaluation of progress to **allow system modification.**
- **Real solutions** often require more than one technology to be applied – the **Treatment Train.**

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