

CREATIVE THINKING
EXCEPTIONAL SOLUTIONS

Full Scale Application of ISCO and S-ISCO® for Treatment of NAPL Pharmaceutical Waste Mixture

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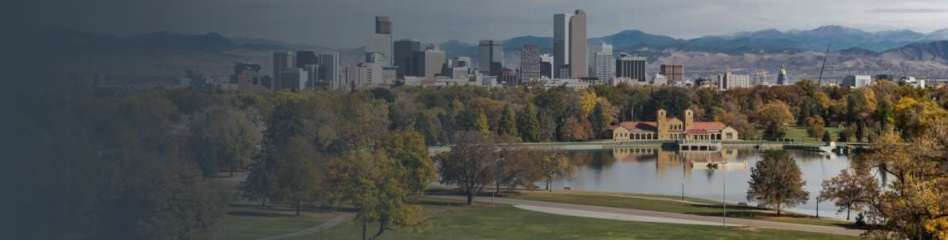




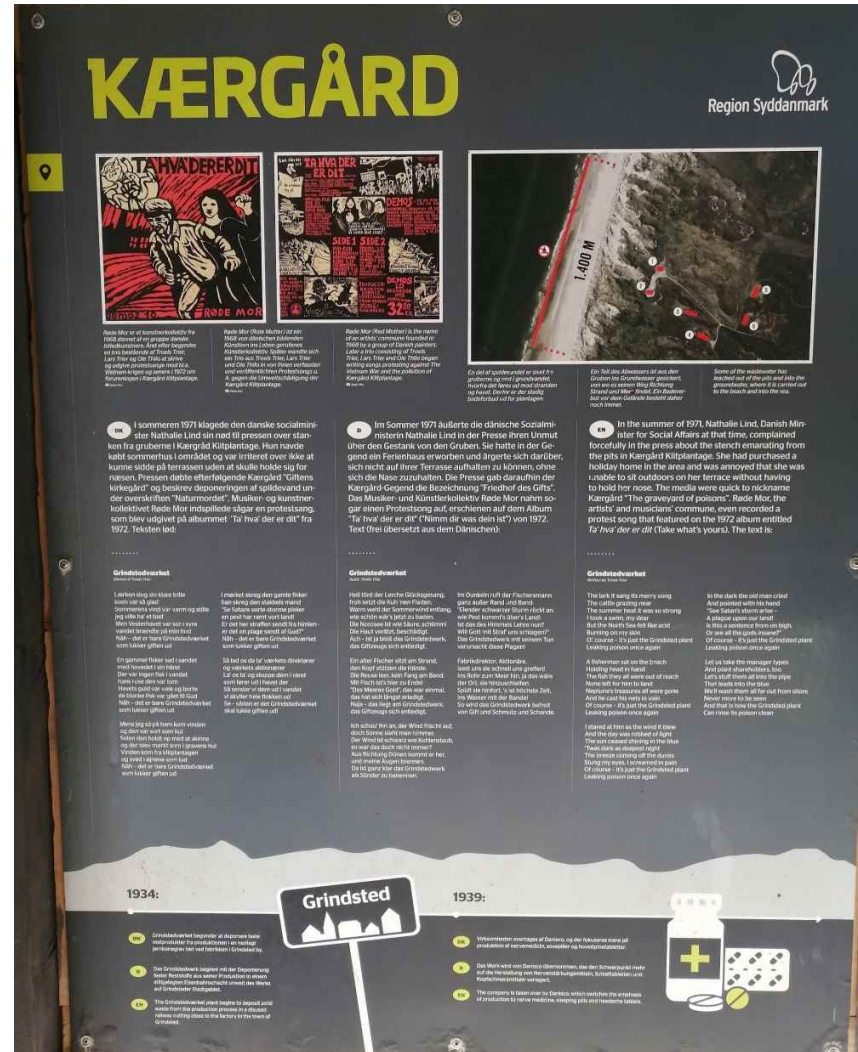
Nature



History



Music



KÆRGÅRD PLANTAGE – WASTE RELEASED

286,000 m³ of wastewater legally released into 6 waste pits

60,000 metric tons of salts and organics

Complex mixture of contaminants in soil and groundwater, including residual NAPL

Goal:

Reduce risk to ecological and human receptors from groundwater discharging into the beach and North Sea, by reducing contaminant mass flux from waste pits



Site contaminants: sulfonamides, barbiturates, aniline, pyridine, chlorinated solvents, fuel hydrocarbons, mercury, cyanide, lithium and other compounds.

CONCEPTUAL SITE MODEL

Core Pit 3 – Layer 2



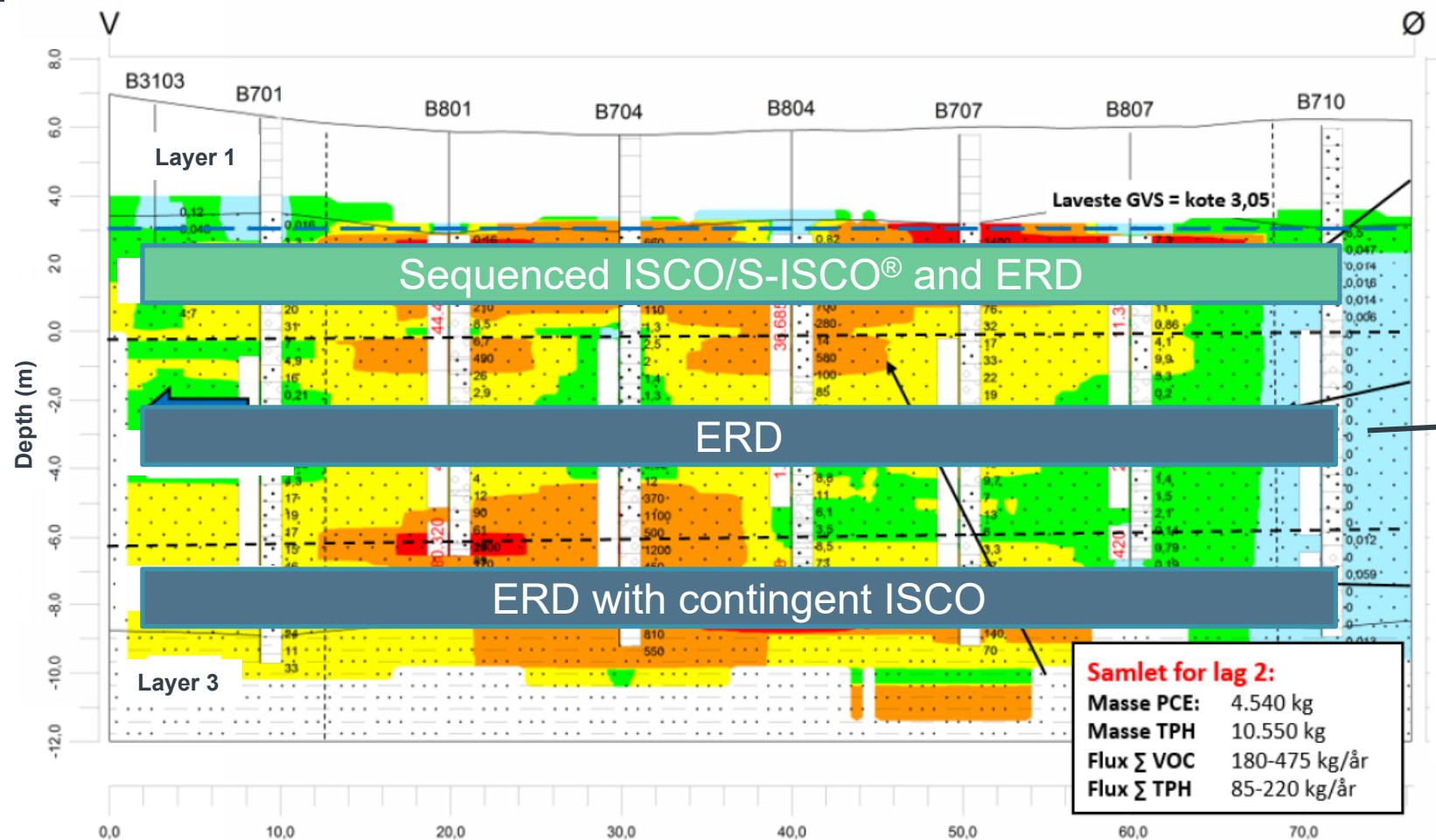


STAGED APPROACH

1. CSM update
2. Laboratory tests (Aalborg University, SiREM and COWI)
 - a. Batch and column tests – Surfactant, ISCO and S-ISCO^{®1}
3. Field pilot tests
 - a. Pull-push-pull test (PPPT) – tracer, surfactant and S-ISCO[®]
4. Full-scale field demonstration (Pit 3)
5. Full-scale (Pits 1, 2 and 4)

1 - S-ISCO, E-Mulse 3 and 145 are proprietary, patented technologies owned by Ethical Solutions, LLC (dba EthicalChem)

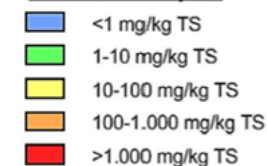
CSM UPDATE AND REMEDY STRATEGY – PIT 3



Pit 3 Treatment Zone

- Layer 2 Volume: 11,615 m³
- Layer 2.1 Volume: 3,030 m³
- PCE Mass: ~ 4.1 ton
- TPH Mass: ~ 11 ton
- VOC Flux: 180-475 kg/yr
- TPH Flux: 85-220 kg/yr

PCE Concentration in Soil



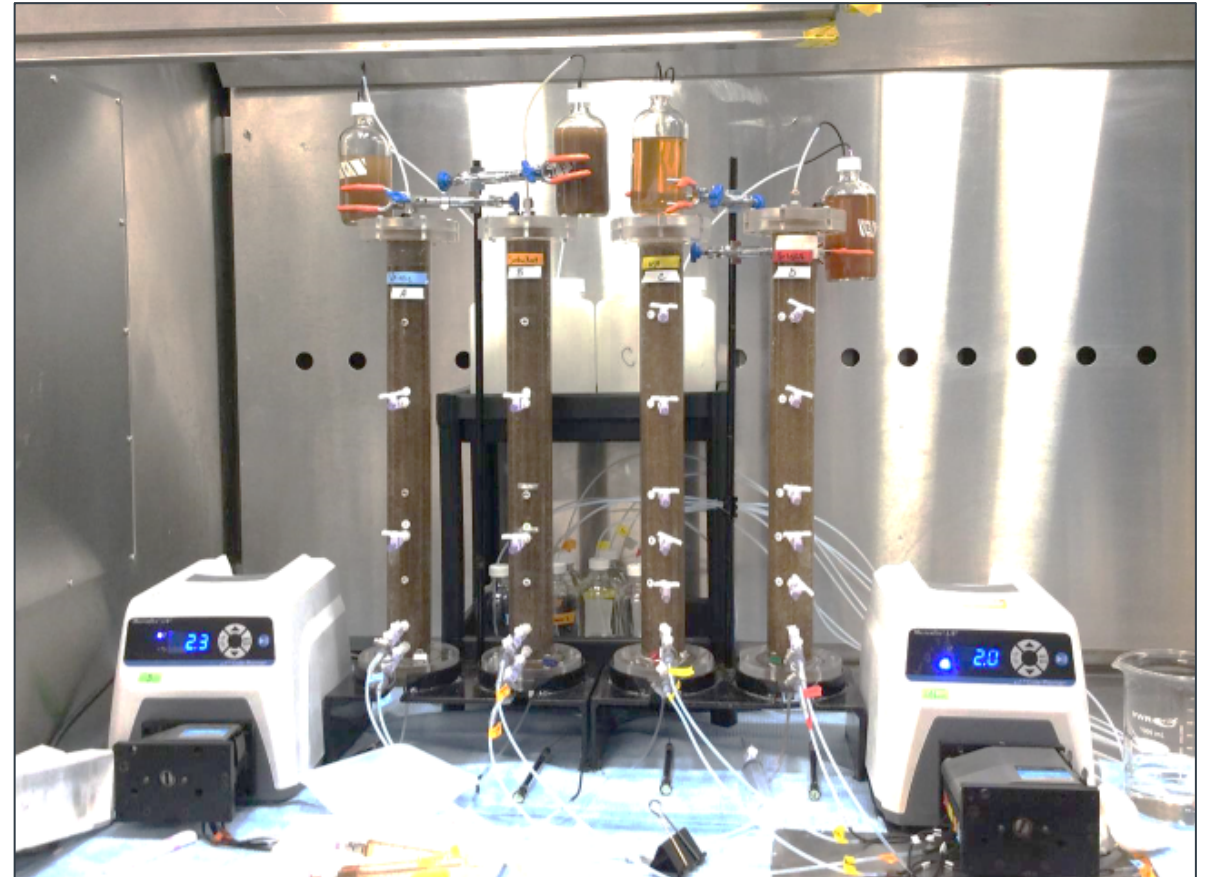
LABORATORY TEST

Aalborg University – batch tests

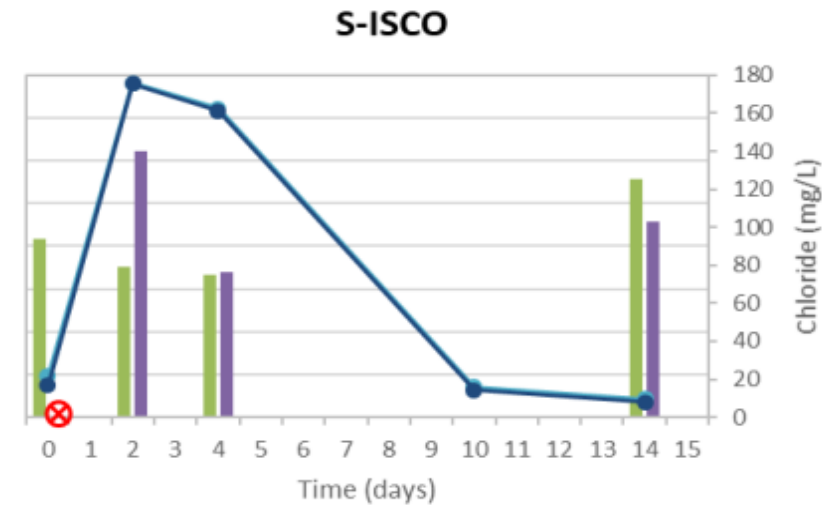
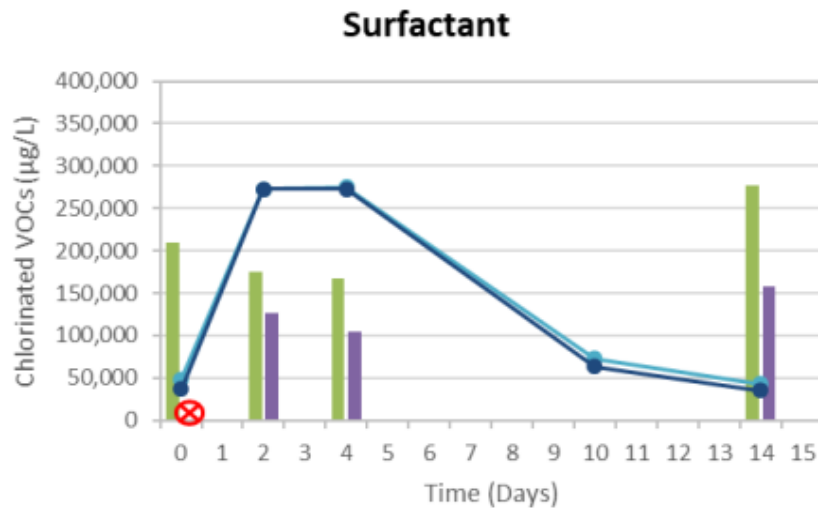
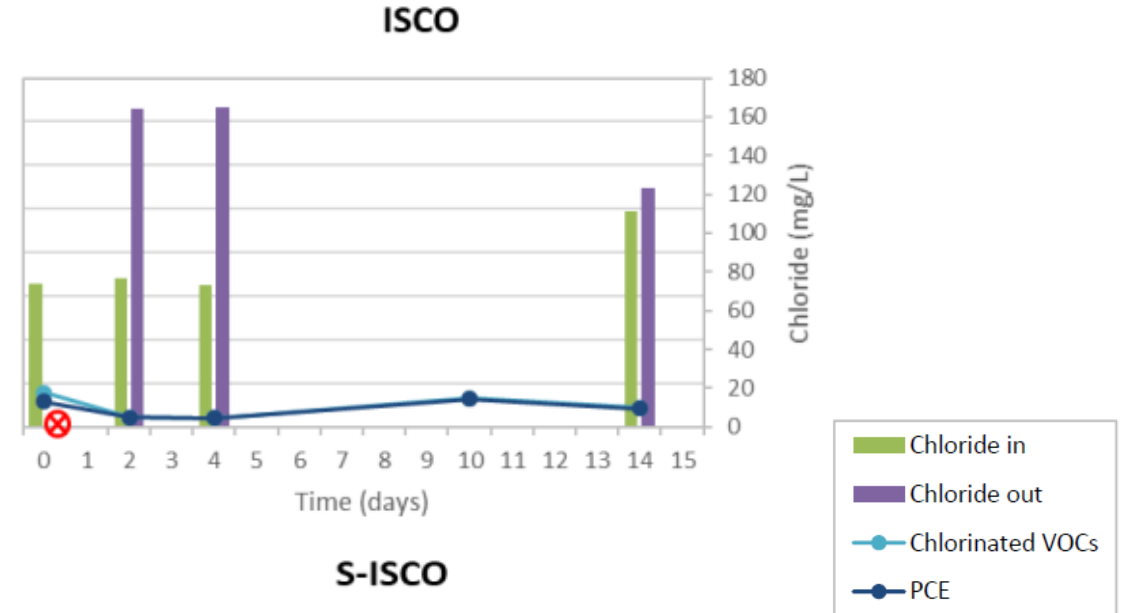
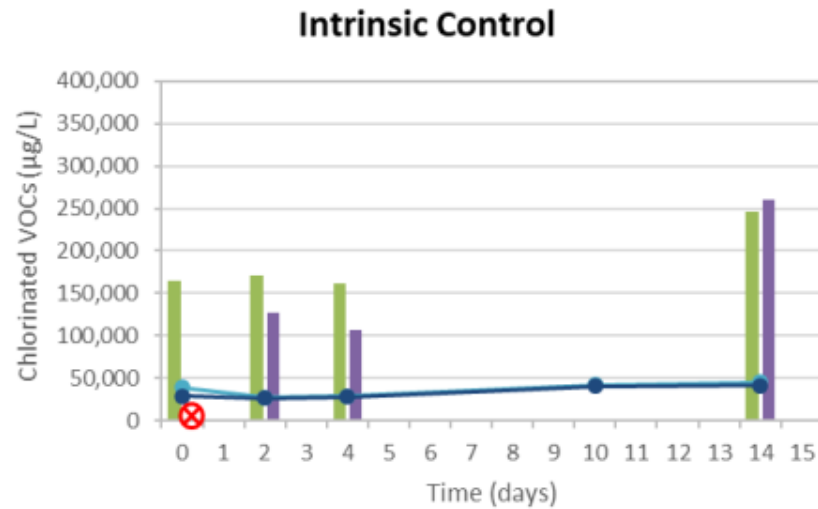
- Surfactant stability, PCE solubility, oxidant consumption and PCE degradation

SiREM – batch and columns tests

- Surfactant observations, surfactant-oxidant interactions, treatment of PCE and TPHs NAPL under stagnant and flowing conditions



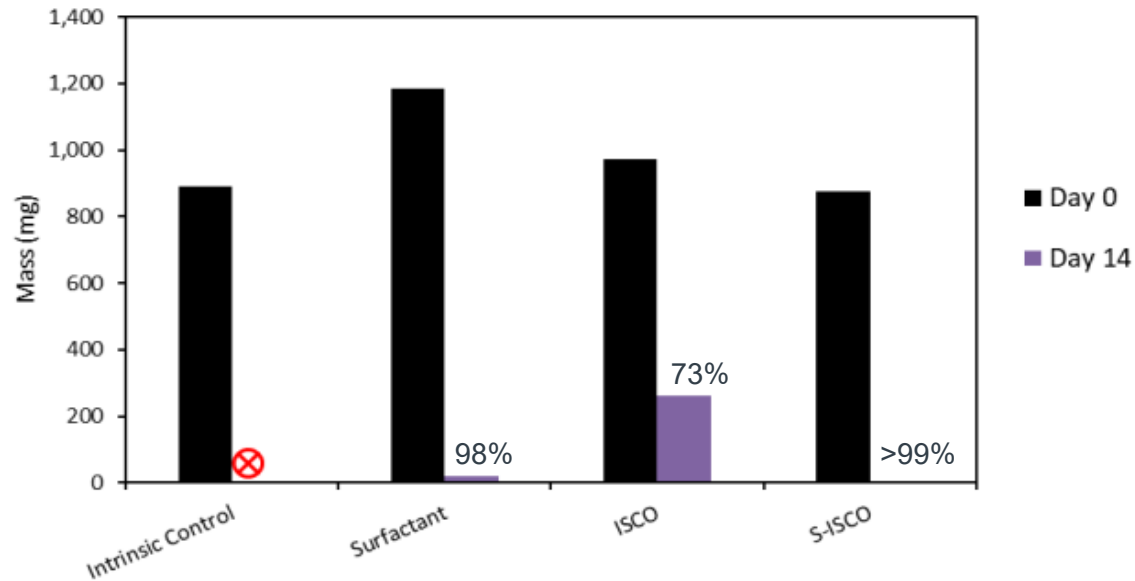
COLUMN TREATABILITY STUDY – PCE EFFLUENT SAMPLES



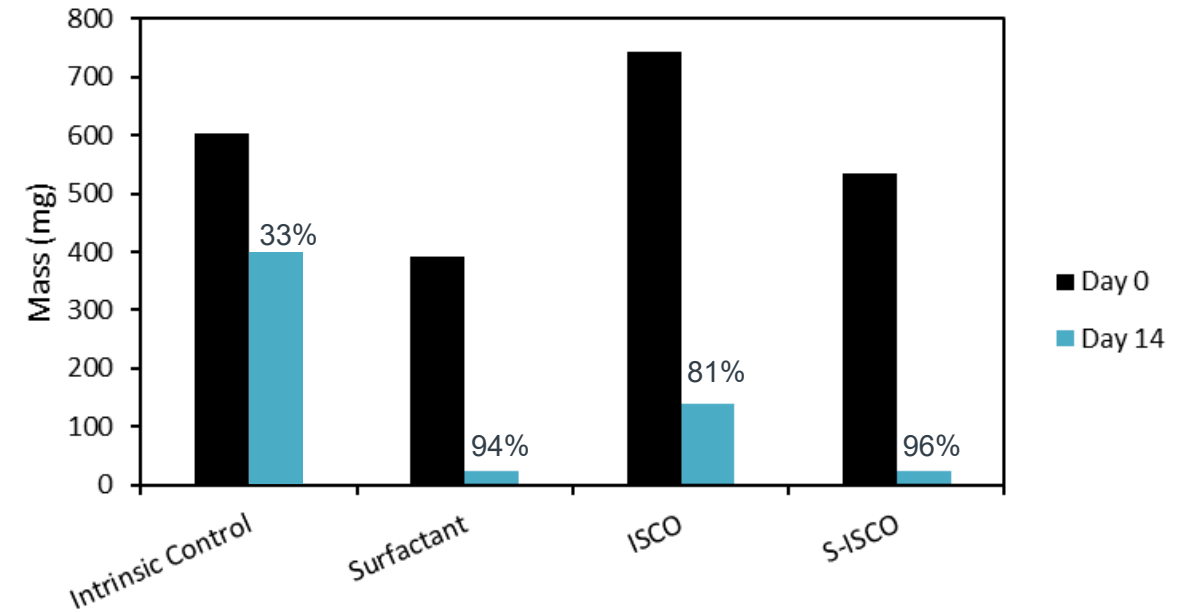
⊗ Not sampled

COLUMN TREATABILITY STUDY – PCE AND TPHs AQUIFER MATERIALS

TPH



PCE

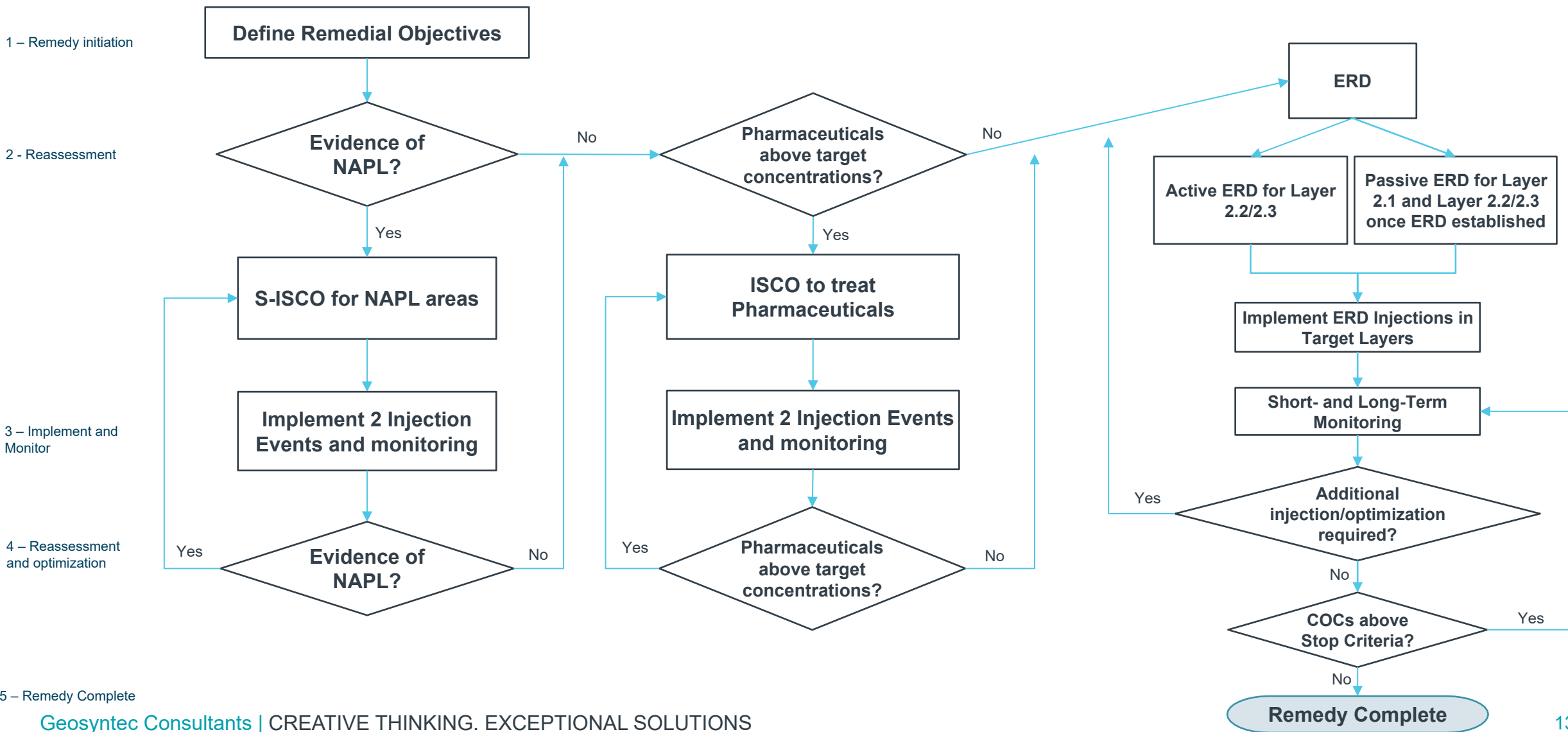


XX% - Mass removed from aquifer material
⊗ - Not sampled

S-ISCO® column flushed with 20 g/L persulfate activated by peroxide at 1:1 molar ratio and 15 g/L (1.5%) surfactant. Total of 14 pore volumes flushed through the columns.

S-ISCO, E-Mulse 3 and 145 are proprietary, patented technologies owned by Ethical Solutions, LLC (dba EthicalChem)

Full Scale Approach



FULL-SCALE FIELD DEMONSTRATION – PIT 3

Pit 3
~250 wells



FULL-SCALE FIELD DEMONSTRATION – PIT 3

2018 to 2020 - ISCO injections: 6 events

2021 - S-ISCO® injections: 3 events

Each ISCO/S-ISCO® injection typically involved:

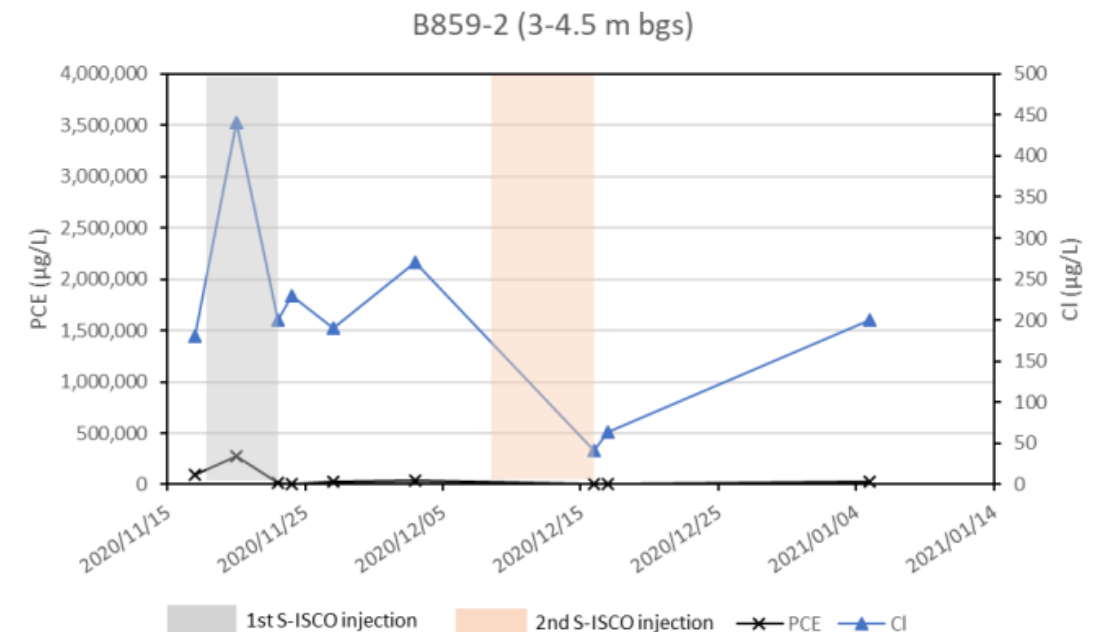
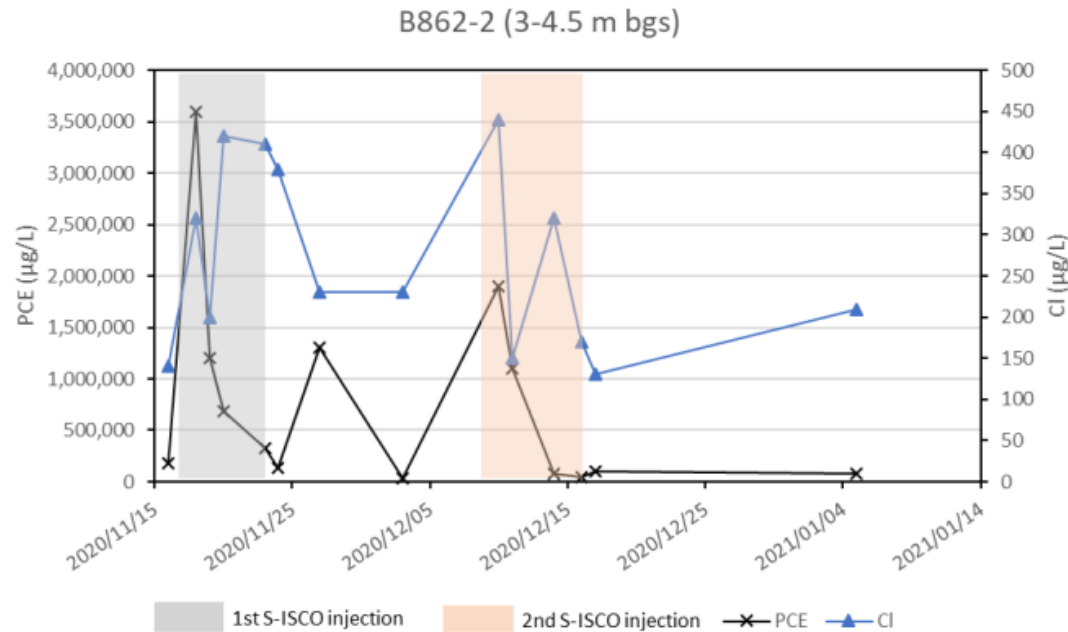
- 20 tons of PS (70 to 120 g/L)
- 20 m³ of 35% hydrogen peroxide (catalyst and stabilizer)
- 5 tons E-Mulse 145 (2%), where applicable
- 800 to 1,600 L per injection point (252 injection points)

2022 Enhanced Reductive Dechlorination (ERD) initiated



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S-ISCO® RESULTS - FULL-SCALE FIELD DEMONSTRATION PIT 3



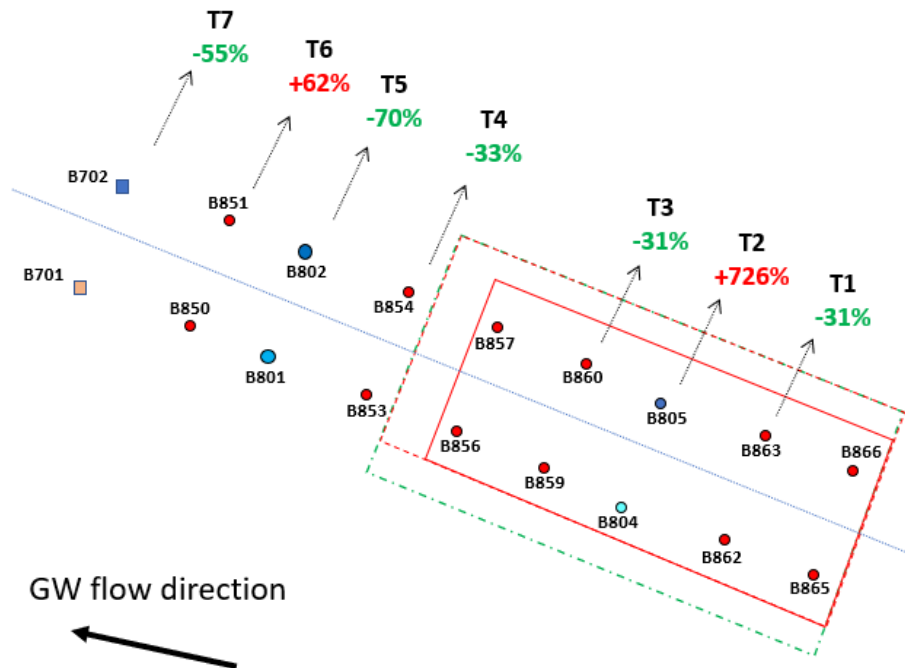
TPHs and PCE mobilization by surfactant combined with chloride production by oxidant destroying mass

TPHs and PCE mobilization in second event was lower in most locations, suggesting less mass present

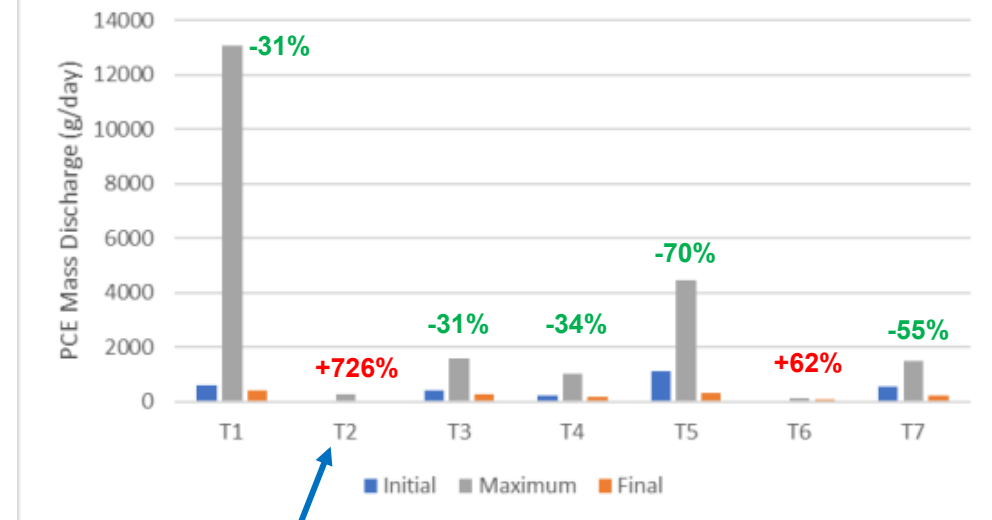
Chloride increase not observed in all locations, but substantial increase in TPHs and PCE above pre-remedy levels not observed, confirming mobilized mass was largely treated

S-ISCO® RESULTS - FULL-SCALE FIELD DEMONSTRATION PIT 3

Changes in PCE Mass Discharge along the Flow Path

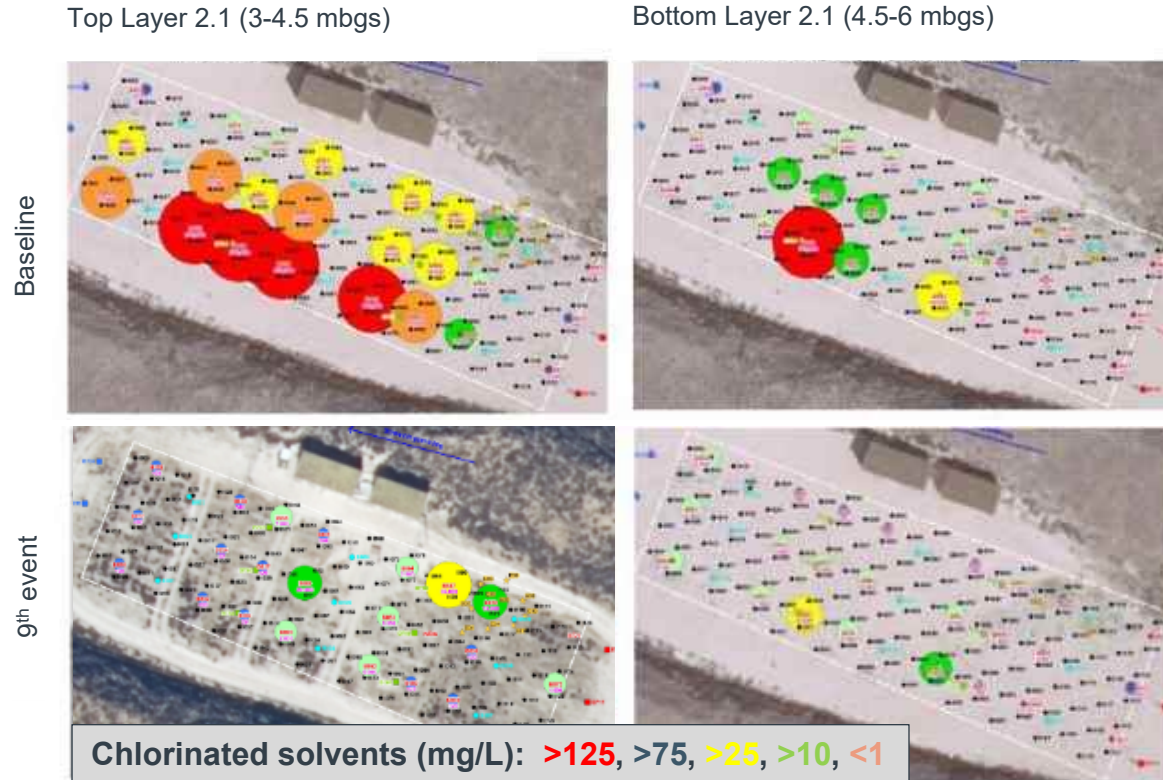


Changes in PCE Mass Discharge - Upper Range



Note the concentrations at T2 and T6 were relatively small, so while discharge increased it was a very small magnitude relative to areas with DNAPL

ISCO/S-ISCO® RESULTS - FULL-SCALE FIELD DEMONSTRATION PIT 3



- Significant decrease in TPH and PCE aqueous concentrations
- ISCO alone not effective where significant NAPL is present

S-ISCO® RESULTS - FULL-SCALE FIELD DEMONSTRATION PIT 3



TPHs and PCE concentrations increased from solubility up to 1,600,000 and 3,600,000 $\mu\text{g/L}$, respectively, but subsequently decreased to below baseline

S-ISCO® solution transported with GW and provide treatment to downgradient areas

Higher chloride concentrations observed in S-ISCO® area than ISCO areas, demonstrating destruction

Mass mobilization not observed in downgradient portion or outside the Pit

STATUS PITS 1, 2 AND 4



Pit 1: 11 injection events ISCO/S-ISCO®

Pit 2: 8 injection events ISCO/S-ISCO®

Pit 4: 9 injection events ISCO/S-ISCO®

Pit 4 - transitioning to ERD

Pits 1 and 2 – additional S-ISCO injection (partial footprint)



CONCLUSIONS

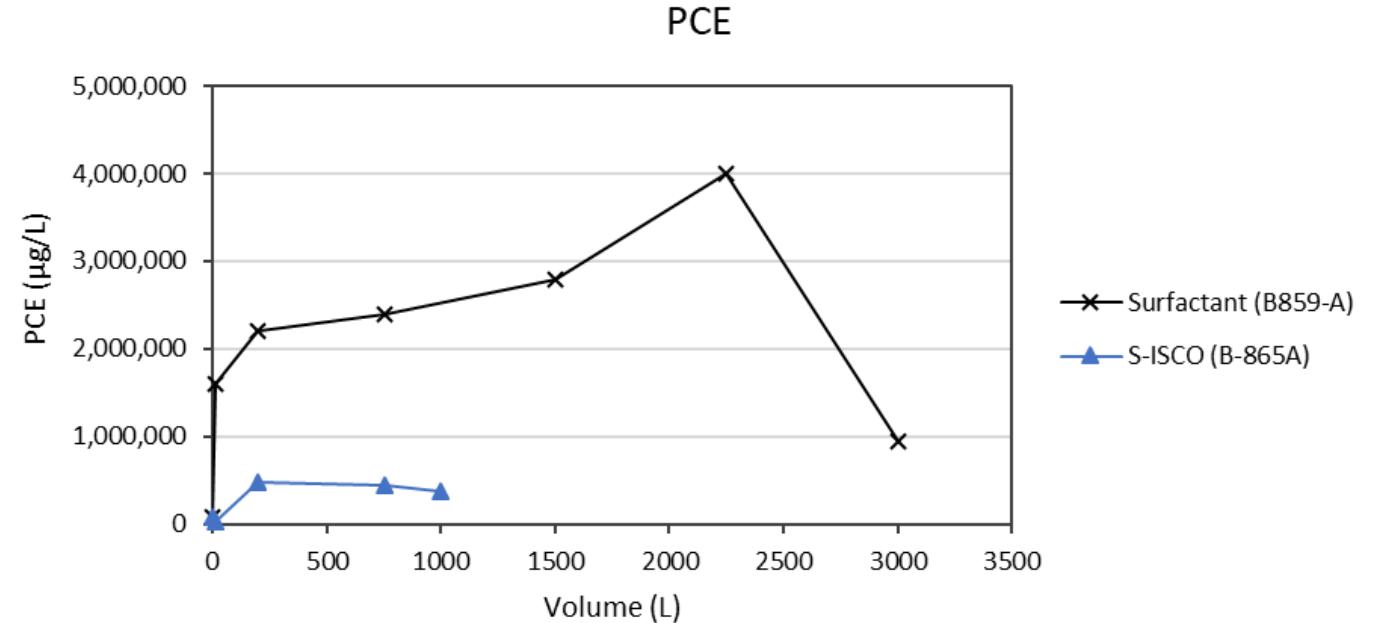
- Importance of staged approach and flexibility
- Oxidant distribution can be a challenge even with large number of IPs (geology and density)
- ISCO effective in dissolved phase and limited when substantial NAPL is present
- S-ISCO® significantly enhanced COC solubilization
- S-ISCO® proved to be cost-effective in areas with significant mass (e.g.: >1,000 mgPCE/kg)
- ISCO and S-ISCO® are effective for pharmaceutical compounds
- The demonstration project has provided important input for the final design of the full-scale remediation in the other Pits
- After reconditioning aquifer to increase pH and reduce residual sulfate ERD has been initiated for polishing

A wide-angle photograph of a city skyline at sunset. The sun is low on the horizon, creating a bright lens flare and casting a warm, golden glow over the scene. The sky is filled with soft, wispy clouds. The city features a variety of skyscrapers and buildings, some of which are illuminated with lights. The foreground is dark and out of focus, showing some greenery and structures.

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FIELD PILOT TEST – PULL-PUSH-PULL TEST



Areas with potential presence of NAPL

Step 1 - Tracer test (NaCl: 100 g/L)

Step 2a: Surfactant test: E-Mulse 145 (5%) + tracer (LiCl: 5 mg/L)

- 78% LiCl recovered, approximately 9.4 kg PCE mass mobilized

Step 2b: S-ISCO® test: persulfate+peroxide (70 g/L, 1:1 ratio) + E-Mulse 145 (5%) + tracer (LiCl: 5 mg/L)

- 36% LiCl recovered, approximately 1.5 kg PCE mass mobilized/oxidized, high concentrations of chloride showing mass destruction

S-ISCO® APPROACH - FULL-SCALE FIELD DEMONSTRATION

Challenges	Solutions
Uncertain NAPL mass	Additional monitoring, adjust reagents volume and concentrations
Oxidant distribution and NAPL at water table	New IPs (reduce well spacing), adjust IPs depth, injection volume, injection/extraction simultaneously, add S-ISCO® for NAPL removal/treatment
Density effect	Adjust IPs depth, change reagent concentrations, inject on top intervals only
Daylighting	Rare – adjusting flows and volume of reagents
S-ISCO® solution preparation / Foaming	Mixing time and speed



Example of delineation of target areas - for Pit 4

Several improvements implemented in Pits 1, 2 and 4 to optimize remedy

S-ISCO® RESULTS - FULL-SCALE FIELD DEMONSTRATION PIT 3

